FINAL REPORT

Anaerobic Membrane Bioreactor (AnMBR) for Sustainable Wastewater Treatment

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The primary objective of this pilot-scale project was to demonstrate and validate AnMBR technology for domestic wastewater treatment. Specific objectives associated with this project include: 1) demonstrate the effectiveness of AnMBR at treating screened domestic wastewater at temperatures above 10°C to produce high-quality, re-usable water; 2) demonstrate that AnMBR technology for domestic wastewater treatment can be operated in an energy-neutral manner; 3) compare cost and performance of gas-sparged and GAC-fluidized AnMBRs to conventional aerobic wastewater treatment systems; and 4) conduct a simplified lifecycle assessment of the technology in comparison to conventional technologies.

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FINAL REPORT
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TABLE OF CONTENTS

Page

EXECUTIVE SUMMARY ES-1
1.0 INTRODUCTION 1
1.1 BACKGROUND 1
1.2 OBJECTIVE OF THE DEMONSTRATION 2
1.3 REGULATORY DRIVERS 3
2.0 TECHNOLOGY 5
2.1 TECHNOLOGY DESCRIPTION 5
2.1.1 AnMBR Technology Overview 5
2.1.2 Gas-Sparged AnMBR Pilot System Overview 5
2.1.3 GAC-Fluidized AnMBR Pilot System 9
2.2 TECHNOLOGY DEVELOPMENT 10
2.2.1 AnMBR 10
2.2.2 Methane Recovery and Energy Neutrality 13
2.2.3 Sulfide and Nutrient Removal 14
2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY 16
2.3.1 AnMBR Advantages 16
2.3.2 AnMBR Limitations 16
3.0 PERFORMANCE OBJECTIVES 17
3.1 SUMMARY OF PERFORMANCE OBJECTIVES AND RESULTS 17
3.2 QUANTITATIVE PERFORMANCE OBJECTIVES 17
3.2.1 Effectiveness 17
3.2.2 Net Energy Production Efficiency 24
3.2.3 Implementability 25
3.3 QUALITATIVE PERFORMANCE OBJECTIVES 29
4.0 SITE DESCRIPTION 31
4.1 GAS-SPARGED ANMBR PILOT SYSTEM SITE 31
4.2 GAC-FLUIDIZED ANMBR PILOT SYSTEM SITE 33
4.3 HISTORICAL DATA FOR BOTH SITES 35
5.0 TEST DESIGN 37
5.1 CONCEPTUAL EXPERIMENTAL DESIGN 37
5.2 BASELINE CHARACTERIZATION 38
5.3 TREATABILITY OR LABORATORY STUDY RESULTS 38
5.4 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS 38
5.4.1 Design Criteria 38
5.4.2 Gas-Sparged AnMBR Pilot System 42

TABLE OF CONTENTS (Continued)

Page

5.4.3 GAC-Fluidized AnMBR Pilot System 46
5.5 FIELD TESTING 48
5.5.1 Commissioning and Startup 48
5.5.2 Continuous Optimization Phase 49
5.6 SAMPLING METHODS AND ANALYSIS 55
5.6.1 Volatile Fatty Acids 60
5.6.2 Gas and Dissolved Methane Analysis 60
5.6.3 UF Membrane Analyses 60
5.6.4 Dewaterability Testing 60
5.6.5 Microbial Ecology Analyses for the Gas-Sparged AnMBR 61
5.6.6 Microbial Ecology Analyses for the GAC-Fluidized AnMBR 63
5.6.7 Data Analysis 65
5.7 SAMPLING RESULTS 66
5.7.1 Gas-Sparged AnMBR Bioreactor Operating Conditions 66
5.7.2 GAC-Fluidized AnMBR Bioreactor Operating Conditions 69
5.7.3 Gas-Sparged AnMBR Organics Destruction 71
5.7.4 GAC-Fluidized AnMBR Organics Destruction 74
5.7.5 Comparison of Gas-Sparged and GAC-Fluidized AnMBR Organics Destruction 77
5.7.6 Solids Generation 82
5.7.7 Gas-Sparged AnMBR Biogas Production 84
5.7.8 GAC-Fluidized AnMBR Biogas Production 86
5.7.9 Gas-Sparged AnMBR COD Balance and Methane Yield 88
5.7.10 GAC-Fluidized AnMBR COD Balance and Methane Yield 89
5.7.11 Dissolved Methane Removal 91
5.7.12 Gas-Sparged AnMBR UF Membrane Performance 94
5.7.13 GAC-Fluidized AnMBR UF Membrane Performance 104
5.7.14 Comparison of Gas-Sparged and GAC-Fluidized AnMBR UF Membrane Performance 108
5.7.15 Gas-Sparged AnMBR Sulfide and Phosphorus Removal 117
5.7.16 GAC-Fluidized AnMBR Sulfide and Phosphorus Removal 120
5.7.17 Gas-Sparged AnMBR Ammonia Removal 120
5.7.18 Gas-Sparged and GAC-Fluidized AnMBR Treated Water Quality 123
5.7.19 Gas-Sparged AnMBR Residuals Characterization 126
5.7.20 Gas-Sparged and GAC-Fluidized AnMBR Biogas Characterization 129
5.7.21 Gas-Sparged AnMBR Microbial Ecology 130
5.7.22 GAC-Fluidized AnMBR Microbial Ecology 137
5.7.23 Gas-Sparged AnMBR Energy Efficiency 147
5.7.24 GAC-Fluidized AnMBR Energy Efficiency 151
6.0 PERFORMANCE ASSESSMENT 157
6.1 QUANTITATIVE PERFORMANCE OBJECTIVES 157
6.1.1 Effectiveness 157

TABLE OF CONTENTS (Continued)

Page

6.1.2 Net Energy Production Efficiency 158
6.1.3 Implementability 159
6.2 QUALITATIVE PERFORMANCE OBJECTIVES 162
6.2.1 Compare Gas-Sparged and GAC-Fluidized AnMBRs 162
6.2.2 Assess System Performance with Respect to Temperature 164
6.2.3 Characterize Gas Composition 165
6.2.4 Characterize Process Residuals 165
6.2.5 Characterize Ammonia Sorbent Performance 166
6.2.6 Characterize Membrane Performance 166
6.2.7 Conduct a Broad Lifecycle Assessment (LCA) 167
6.2.8 Characterize Treated Water with Respect to Various Water Reuse Alternatives 167
6.2.9 Characterize Chlorine Demand 167
6.2.10 Characterize Microbial Ecology 167
7.0 COST AND LIFECYCLE ASSESSMENT 169
7.1 COST MODEL 169
7.2 COST DRIVERS 170
7.3 COST ANALYSIS 171
7.3.1 Basis of Design 172
7.3.2 Cost Estimate 189
7.3.3 Cost Estimate Discussion 196
7.4 LIFECYCLE ASSESSMENT 203
7.4.1 Methodology 203
7.4.2 Results: Individual Treatment Process Comparisons 206
7.4.3 Results: Flux and Temperature Scenario Technology Comparisons 215
7.4.4 Sensitivity Analysis of Phosphorus and Sulfide Removal 217
7.4.5 Discussion: Comparison to Other Studies 220
7.4.6 Discussion: Study Conclusions 221
8.0 IMPLEMENTATION ISSUES 223
8.1 PROCESS CONFIGURATION 223
8.2 END-USER CONSIDERATIONS 225
8.3 PROCUREMENT CONSIDERATIONS 226
8.4 POTENTIAL REGULATIONS 227
9.0 REFERENCES 229
APPENDIX A. Points of Contact A-1
APPENDIX B. Gas-Sparged AnMBR Operations and Maintenance Manual and Design Drawings B-1
APPENDIX C. Technical Data Sheets for Chemicals C-1
APPENDIX D. Quality Assurance D-1
APPENDIX E. AWC Laboratory Reports E-1
APPENDIX F. Dewatering Test Report F-1

TABLE OF CONTENTS (Continued)

Page

APPENDIX G. Cost Evaluation Supporting Data G-1
APPENDIX H. Lifecycle Assessment Supporting Data H-1

LIST OF TABLES

Page

Table 2.1 Electrical Energy Requirements and Potential Production from Laboratory Study of GAC-fluidized AnMBR. 14
Table 5.1 Design basis for the gas-sparged and GAC-fluidized AnMBR systems. 39
Table 5.2 Primary process variables used for continuous process optimization. 50
Table 5.3 AnMBR Continuous Optimization Decision Matrix. 50
Table 5.4 Maintenance Cleaning Procedure. 52
Table 5.5 Recovery cleaning procedure. 53
Table 5.6 Performance Monitoring Schedule Indicating Total Number of Analyses Conducted for the Gas-sparged and GAC-fluidized AnMBRs. 56
Table 5.7 Analytical Methods for Sample Analysis. 58
Table 5.8 Summary of Key AnMBR Operation Parameters During Biomass Sampling 62
Table 5.9 Comparison of Three Different DNA Extraction Kit Results Using the Same Sample. 62
Table 5.10 Reactor Conditions at the Three Sampling Time Points. 64
Table 5.11 Average GAC-fluidized AnMBR Permeate COD and BOD_5 Concentrations for 5°C Temperature Ranges and Associated Statistical Levels of Significance for the Differences. 80
Table 5.12 Gas-sparged AnMBR and GAC-fluidized AnMBR Solids Generation and Destruction. 83
Table 5.13 Screening Estimates for COD and TSS Removal. 84
Table 5.14 Gas-sparged AnMBR COD Balance. 88
Table 5.15 GAC-fluidized AnMBR COD Balance. 90
Table 5.16 Ultrafiltration Membrane Autopsy Summary Based on Reports from AWC. 113
Table 5.17 Ultrafiltration Membrane Atomic Ratios. 117
Table 5.18 Gas-sparged AnMBR Coagulation-flocculation-sedimentation Effectiveness for Period of Elevated Iron Dose from 362 to 479 Days. 120
Table 5.19 Jar Testing Results for GAC-fluidized AnMBR Pemeate. 120
Table 5.20 Gas-sparged and GAC-Fluidized AnMBR Treated Water Quality. 124
Table 5.21 Gas-sparged AnMBR Bioreactor Solids Characteristics. 127
Table 5.22 Gas-sparged AnMBR Coagulation-Flocculation-Sedimentation Sludge Elemental Analysis and Calculated Recovery for Period of Elevated Iron Dose from Days 361 to 479. 128
Table 5.23 Dewatering Results for Gas-sparged AnMBR Bioreactor Sludge and Coagulation-Flocculation-Sedimentation Sludge. 129
Table 5.24 Biogas, Gas-sparged and GAC-fluidized AnMBR Biogas Composition. 129
Table 5.25 Comparison of Pilot- and Full-scale Fluidized-bed Reactor Energy Requirements. 153
Table 7.1 Cost Model for Direct and Indirect Capital Costs. 169
Table 7.2 Cost Model for Operating Costs Exclusive of Labor. 170

LIST OF TABLES

Page

Table 7.3 Average Characteristics for Medium Strength Municipal Wastewater..... 172
Table 7.4 Effluent Quality Requirements..... 172
Table 7.5 Main Process Units Included in Each Scenario..... 174
Table 7.6 Preliminary Treatment Basis of Design. 176
Table 7.7 Primary Clarification Design Criteria. 177
Table 7.8 Primary Effluent Loads and Primary Sludge Quantities. 177
Table 7.9 Anaerobic Treatment Overall Basis of Design..... 178
Table 7.10 Anaerobic Bioreactor Basis of Design. 179
Table 7.11 Membrane Bioreactor Basis of Design. 180
Table 7.12 Conventional activated sludge basis of design..... 181
Table 7.13 Membrane Contactors for Dissolved Methane Removal Basis of Design. 182
Table 7.14 Vacuum Flash Tank for Dissolved Methane Removal Basis of Design. 182
Table 7.15 Phosphorus and Sulfide Removal Basis of Design. 183
Table 7.16 Disinfection System Basis of Design. 184
Table 7.17 Primary and Secondary Sludge Thickening, Dewatering, and Stabilization Design Criteria..... 185
Table 7.18 Tertiary Sludge Management Design Criteria..... 186
Table 7.19 Biogas Characteristics. 187
Table 7.20 Biogas treatment and Cogeneration for Scenarios 1 Through 8. 188
Table 7.21 Direct Capital Costs..... 190

LIST OF FIGURES

Page

Figure ES.1 Gas-sparged AnMBR Schematic. ES-3
Figure ES.2 Gas-sparged AnMBR Pilot System Process Flow Diagram. ES-4
Figure ES.3 GAC-fluidized AnMBR Pilot System. ES-4
Figure 2.1 Gas-sparged AnMBR Schematic. 6
Figure 2.2 Photo of ZeeWeed Membrane Module and Schematic of Ultrafiltration Fiber. 7
Figure 2.3 Gas-sparged AnMBR Pilot System Process Flow Diagram. 7
Figure 2.4 Schematic of the Hollow-fiber Gas Transfer Membrane. 8
Figure 2.5 Schematic of Low-energy Ammonia Removal Process. 9
Figure 2.6 GAC-fluidized AnMBR Pilot System. 9
Figure 2.7 Gas-sparged AnMBR Performance. 11
Figure 2.8 Pilot-scale Results for the GAC-fluidized AnMBR. 12
Figure 2.9 Predicted 8×20 Industrial Liqui-Cel gas-liquid Hollow-fiber Membrane Contactor Performance for Removal of 12 mg/L Dissolved Methane. 13
Figure 2.10 Ferric Chloride Coagulation of AnMBR Effluent Demonstrating Phosphorus and Sulfide Removal. 15
Figure 2.11 Clinoptilolite Ammonia Breakthrough Curves Determined in Previous Studies (Guy et al. 2016). 15
Figure 4.1 Ft. Riley Site Vicinity Map. 32
Figure 4.2 Ft. Riley Site Location Map 32
Figure 4.3 GAC-fluidized AnMBR Site Vicinity Map (South Korea). 33
Figure 4.4 GAC-fluidized AnMBR Site Location Map (South Korea). 34
Figure 4.5 Bucheon Wastewater Treatment Plant (South Korea). 34
Figure 4.6 Wastewater Temperature Distributions for Ft. Riley (Camp Funston) Wastewater (left) and Bucheon (right). 35
Figure 4.7 Wastewater Composition for Ft. Riley (Camp Funston) Raw Wastewater (left) and Bucheon Primary Effluent (right). 35
Figure 5.1 Photograph of the Installed Gas-sparged AnMBR at Ft. Riley. 42
Figure 5.2 Feed Pump and Strainer for the Gas-sparged AnMBR. 43
Figure 5.3 Gas-sparged AnMBR Bioreactor, UF Membrane Tank, and Dissolved Methane Removal Contactor. 43
Figure 5.4 Process and Instrumentation Diagram for the Bioreactor and UF Systems. 44
Figure 5.5 Process and Instrumentation Diagram for the Permeate Pump and Dissolved Methane Removal System. 45
Figure 5.6 Gas-sparged AnMBR Coagulation-flocculation, Sedimentation, and Ammonia Removal Processes. 45
Figure 5.7 Process and Instrumentation Diagram for the Coagulation-flocculation-Sedimentation and Ammonia Removal Processes. 46

LIST OF FIGURES

Page

Figure 5.8 Photograph of the First-stage (AFBR - left) and Second-stage (AFMBR - right) GAC-fluidized AnMBR Systems. 47

Figure 5.9 Process Flow Diagram of the GAC-fluidized AnMBR Showing the First-stage Anaerobic Fluidized Bioreactor (AFBR) and Second Stage Anaerobic Fluidized Membrane Bioreactor (AFMBR). 48

Figure 5.10 Gannt Chart for the Demonstration. 49

Figure 5.11 Gas-sparged AnMBR Volume and Flow Rate (a) and Calculated Hydraulic Residence Time and Organic Loading Rate (b). 67

Figure 5.12 Gas-sparged AnMBR Solids Wasting Rate and Rsidence Time. 68

Figure 5.13 Gas-sparged AnMBR TSS and VSS Concentrations (a) and Mass (b) in the Bioreactor and Membrane Tank. 68

Figure 5.14 GAC-fluidized AnMBR Volume and Flow Rate (a), Hydraulic Residence Time, Volumetric Organic Loading Rate (b), and Organic Loading Rate per ass GAC (c). 69

Figure 5.15 GAC-fluidized AnMBR Solids Wasting Rate and Suspended Solids Residence Time. 70

Figure 5.16 GAC-fluidized AnMBR TSS and VSS oncentrations. 71

Figure 5.17 Gas-sparged AnMBR COD (a), BOD_5 (b), and Removals (c) by the Bioreactor and UF Systems. 73

Figure 5.18 Gas-sparged AnMBR Permeate COD and VFAs Expressed as COD in Response to Bioreactor Sludge Wasting Event (a) and VFA Composition (b). 74

Figure 5.19 GAC-fluidized AnMBR COD (a), BOD_5 (b), and Removals (c) by the Bioreactor and UF Systems. 76

Figure 5.20 Comparison of Gas-sparged and GAC-fluidized AnMBR Performance at Different Temperatures for COD (a) and BOD_5 (b) Removal. 78

Figure 5.21 Comparison of Gas-sparged and GAC-fluidized AnMBR Influent Concentrations at Different Temperatures for COD (a) and BOD_5 (b). 79

Figure 5.22 Comparison of Gas-sparged and GAC-fluidized AnMBR Permeate Concentrations at Different Temperatures for COD (a) and BOD_5 (b). 81

Figure 5.23 Comparison of Gas-sparged and GAC-fluidized AnMBR Permeate Concentrations at Different Temperature Ranges for COD and BOD_5. 82

Figure 5.24 Gas-sparged AnMBR Daily Average Biogas and Gaseous Methane Flow Rates and Methane Composition. 85

Figure 5.25 Gas-sparged AnMBR Daily Average Gaseous, Dissolved, and Total Methane Mass Rates Compared to Temperature. 85

Figure 5.26 Gas-sparged AnMBR Daily Average Total Methane Mass Rate Compared to Organic Loading Rate and Feed Flow Rate. 86

Figure 5.27 GAC-sparged AnMBR Daily Average Biogas and Gaseous Methane Flow Rates and Methane Composition without COD Supplementation. 86

Figure 5.28 GAC-sparged AnMBR Gaseous, Dissolved, and Total Methane Mass Rates without COD Supplementation Compared to Temperature. 87

LIST OF FIGURES

Page

Figure 5.29 GAC-sparged AnMBR Total Methane Mass Rate without COD Supplementation Compared to Organic Loading Rate and Feed Flow Rate. 87
Figure 5.30 Gas-sparged AnMBR Methane Yield in Relationship to Temperature. 89
Figure 5.31 GAC-fluidized AnMBR Methane Yield without COD Supplementation in Relationship to emperature. 91
Figure 5.32 Dependence of Dissolved Methane Removal on Absolute Gas Pressure and Liquid Flow Rate in Comparison to 3M Model Results. 92
Figure 5.33 Relationship of Sulfide (a) and Dissolved Inorganic Carbon (b) Removal to Absolute Gas Pressure and Liquid Flow Rate. 93
Figure 5.34 Comparison of Membrane Methane Flux to Performance Objective at Different Absolute Gas Pressures and Liquid Flow Rates. 93
Figure 5.35 Gas-sparged AnMBR Net Ultrafiltration Flux Compared to Performance Objective, Transmembrane Pressure, and Permeability. Permeability is corrected to 20°C. 94
Figure 5.36 Gas-sparged AnMBR Ultrafiltration Performance from Days 0 to 60. Permeability is Corrected to 20°C. 95
Figure 5.37 Gas-sparged AnMBR Ultrafiltration Performance from Days 50 to 100. 96
Figure 5.38 Gas-sparged AnMBR Ultrafiltration Performance from ays 90 to 150. 96
Figure 5.39 Gas-sparged AnMBR Ultrafiltration Performance from Days 130 to 200. 97
Figure 5.40 Gas-sparged AnMBR Ultrafiltration Performance from Days 190 to 250. 98
Figure 5.41 Gas-sparged AnMBR Ultrafiltration Performance from Days 250 to 300. 98
Figure 5.42 Gas-sparged AnMBR Ultrafiltration Performance from Days 280 to 350. 99
Figure 5.43 Gas-sparged AnMBR Ultrafiltration Performance in Relationship to Total Solids and Filtered COD Fractions in the Bioreactor Prior to and After the Major Wasting Event. 100
Figure 5.44 Gas-sparged AnMBR Ultrafiltration Performance from Days 350 to 400. 100
Figure 5.45 Gas-sparged AnMBR Ultrafiltration Performance from Days 400 to 500. 101
Figure 5.46 Gas-sparged AnMBR Ultrafiltration Summary. 102
Figure 5.47 Gas-sparged AnMBR Ultrafiltration Membrane Modules Prior to (a) and After (b) the Demonstration. 103
Figure 5.48 GAC-fluidized AnMBR Ultrafiltration Flux Compared to Performance Objective, Transmembrane Pressure, and Permeability. 104
Figure 5.49 GAC-fluidized AnMBR Ultrafiltration Performance from Days 0 to 250. 105
Figure 5.50 GAC-fluidized AnMBR Ultrafiltration Performance from Days 0 to 250. 105
Figure 5.51 GAC-fluidized AnMBR Ultrafiltration Performance in Relationship to Total Suspended Solids and Filtered (1.2 μm) COD. 106
Figure 5.52 GAC-fluidized AnMBR Ultrafiltration Performance from Days 350 to 536. 107
Figure 5.53 GAC-fluidized AnMBR Ultrafiltration Summary. 108
Figure 5.54 GAC-fluidized AnMBR Ultrafiltration Membrane Modules Prior to (a) and After (b) the Demonstration. Close-up Photos of the Top (c), Middle (d), and Bottom (e,f) of the Fibers After (d,f,h) the Demonstration. 109

LIST OF FIGURES

Page

Figure 5.55 Comparison of Gas-sparged and GAC-fluidized AnMBR Ultrafiltration Permeability in Relation to Net Gas Sparge Rate (a), Total Solids Concentration (b) and 1.2-µm Filtered COD Concentration (c). 110

Figure 5.56 Comparison of Gas-sparged and GAC-fluidized AnMBR Ultrafiltration Permeability for Different Time Periods. 111

Figure 5.57 Electron Photomicrographs of Cleaned Gas-sparged (a) and GAC-fluidized (b) UF Fibers..... 113

Figure 5.58 GAC-fluidized AnMBR Ultrafiltration Membrane Scanning Electron Photomicrographs of UF Membranes Including an Intact Membrane (Shin et al. 2016a) (a), and Samples from the Top (b), Middle (c) and Bottom (d) of the GAC-fluidized AnMBR in this Study. 114

Figure 5.59 Energy Dispersive Spectroscopic Elemental Analysis of UF Fiber Sections for gas-sparged (a,c) and GAC-fluidized (b,d) Reporting All Detected Elements (a,b) and Excluding Carbon and Oxygen (c,d). 116

Figure 5.60 Surface Plots Demonstrating the Results of the Matrix of Jar Tests Conducted by Varying Ferric Chloride and ACH Concentrations, While Holding Polymer Dosing to a Consistent 1 mg/L to Determine Optimal Dosages for Reduction of Sulfide Residual Concentrations (a) and Turbidity (b). 117

Figure 5.61 (a) Sulfide Residuals in Response to Varying Concentrations of Ferric Chloride (a) and Removal of Phosphorus and Sulfide in Response to Varying Concentrations of ACH (b). 118

Figure 5.62 Gas-sparged AnMBR Coagulation-flocculation Chemical Doses and Resultant pH Values (a) Along with Associated Removals of Sulfide (b) and Total Phosphorus (c). 119

Figure 5.63 Gas-sparged AnMBR Ammonia Breakthrough Curves for Two Runs with New Clinoptilolite Media. 121

Figure 5.64 Gas-sparged AnMBR Ammonia Concentrations Over Time, Clinoptilolite Effluent Concentrations Prior to Breakthrough, and Percent Removal Compared to Performance Objective..... 122

Figure 5.65 Gas-sparged AnMBR Clinoptilolite Loading per Run (a), Overall Reduction in Loading After Each Regeneration Cycle (b), and Dissolved Iron Concentrations in the Column Influent (c)..... 123

Figure 5.66 Gas-sparged AnMBR Total Phosphorus Concentrations Through the Entire Process. 125

Figure 5.67 Phylum Level Relative Abundance of Bacteria with ≥ 1% Relative Abundance for at Least One Sample Date..... 130

Figure 5.68 Family Level Relative Abundance of Bacteria with ≥ 1% Relative Abundance for at Least One Sample Date..... 132

Figure 5.69 Genus Level Relative Abundance of Bacteria with ≥ 1% Relative Abundance for at Least One Sample Date..... 133

Figure 5.70 Relative Abundance of Archaea Compared to Bacteria. 134

LIST OF FIGURES

Page

Figure 5.71 Relative Abundance of Key Methanogen Orders (a – top) and Genera (b – bottom) Compared to the Total Abundance of the Set. 135
Figure 5.72 Diagram of Hypothesized Relationships of Key Microbes. 136
Figure 5.73 Dendrogram of Cluster Analysis Based on the Bray-Curtis Dissimilarity for Bacterial Community at Days 342, 436 and 555. 138
Figure 5.74 Dendrogram of Cluster Analysis Based on the Bray-Curtis Dissimilarity for Archaeal Community at Days 342, 436 and 555. 139
Figure 5.75 Overview of GAC, Bulk, and Influent Sewage Bacterial Community Compositions Sampled at Days 342, 436 and 555. 142
Figure 5.76 Composition of Dominant Syntroph Genera in GAC, Bulk, and Influent Sewage Samples Obtained on Days 342, 436 and 555. 143
Figure 5.77 Composition of Dominant Exoelectrogen Genera Composition in GAC, Bulk, and Influent Sewage Samples Obtained on Days 342, 436 and 555. 144
Figure 5.78 Overview of GAC, Bulk, and Influent Sewage Archaeal Community Compositions Sampled at Days 342, 436 and 555. 145
Figure 5.79 Methanogen Composition in GAC, Bulk, and Influent Sewage Samples Obtained on Days 342, 436 and 555. 146
Figure 5.80 Gas-sparged AnMBR Energy Consumption Associated with Different Processes at Biogas Sparging Flow Rates of 25 (a), 50 (b), and 100 std. L/min (c). 148
Figure 5.81 Gas-sparged AnMBR Total Energy Consumption for Different Permeate Flux and Biogas Sparging Flow Rates. 149
Figure 5.82 Gas-sparged AnMBR Ratio of Energy Production to Consumption (a) and Net Energy Consumption (b) for Different Operating Conditions and Temperatures. 151
Figure 5.83 GAC-fluidized AnMBR Energy Consumption Associated with Permeate Pumping and Mixing as Tested (a) and with Dissolved Methane Removal Energy for the Gas-sparged AnMBR (b). 152
Figure 5.84 GAC-fluidized AnMBR Ratio of Energy Production to Consumption (a) and Net Energy Consumption (b) for Different Operating Conditions and Temperatures and Not Including Dissolved Methane Recovery. 154
Figure 5.85 GAC-fluidized AnMBR Ratio of Energy Production to Consumption (a) and Net Energy Consumption (b) for Different Operating Conditions and Temperatures and Including Dissolved Methane Recovery Based on Gas-sparged AnMBR Results. 155
Figure 7.1 Direct Capital Costs for Conventional Treatment and Different AnMBR Process Configurations at Net Fluxes of 7.5 LMH (a), 15 LMH (b) and 30 LMH (c). P Denotes Primary Treatment. 191
Figure 7.2 Annual Operating Costs Excluding Labor Maintenance at Temperatures > 25°C for Conventional Treatment and Different AnMBR Process Configurations at Net Fluxes of 7.5 LMH (a), 15 LMH (b), and 30 LMH (c). 193

LIST OF FIGURES

Page

Figure 7.3 Annual Operating Costs Excluding Labor and Maintenance at Temperatures < 20°C for Conventional Treatment and Different AnMBR Process Configurations at Net Fluxes of 7.5 LMH (a), 15 LMH (b), and 30 LMH (c)..... 194

Figure 7.4 20-Year Lifecycle Costs Excluding Labor and Maintenance at Temperatures > 25°C for Conventional Treatment and Different AnMBR Process Configurations at Net Fluxes of 7.5 LMH (a), 15 LMH (b) and 30 LMH (c)..... 195

Figure 7.5 20-Year Lifecycle Costs Excluding Labor and Maintenance at Temperatures < 20°C for Conventional Treatment and Different AnMBR Process Configurations at Net Fluxes of 7.5 LMH (a), 15 LMH (b) and 30 LMH (c)..... 196

Figure 7.6 Net Energy Consumption for Different AnMBR Scenarios Compared to Conventional Treatment..... 197

Figure 7.7 Total Chemical Use Per Unit Volume of Water Treatment for Different AnMBR Scenarios at 15 LMH Using Ferric Chloride and ACH (a) or Alum (b) for Phosphorus and Sulfide Removal in Comparison to Conventional Treatment. . 198

Figure 7.8 Total Solid Residuals Produced per Unit Volume of Water Treatment for Different AnMBR Scenarios at 15 LMH Using Ferric Chloride and ACH (a) or Alum (b) for Phosphorus and Sulfide Removal in Comparison to Conventional Treatment. . 199

Figure 7.9 Comparison of Total Annual Chemical Costs Associated with Different Approaches for Phosphorus and Sulfide Removal at 15 LMH..... 200

Figure 7.10 Comparison of Lifecycle Costs Associated with Different Approaches for Phosphorus and Sulfide Removal at 15 LMH and > 25°C. 200

Figure 7.11 Total Capital Cost Including Direct and Indirect Costs Per Gallon-per-day Design Capacity. 201

Figure 7.12 Operating Cost Per 1000-gallons for AnMBR Scenarios at 7.5 LMH (a,d), 15 LMH (b,e), and 30 LMH (c,f) and Conventional Treatment at Different Temperatures Compared to Chemical Cost (i.e., Membrane Cleaning, Sulfide and Phosphorus Removal, Sludge Management, Disinfection, and GAC Replacement) Based on Use of Ferric Chloride and ACH (a,b,c) or Alum (d,e,f). Maintenance and Labor Costs Are Not Included..... 202

Figure 7.13 LCA Boundary..... 204

Figure 7.14 Relative Impact Assessment for Scenario 1 – Gas-sparged AnMBR Without Primary Treatment. 207

Figure 7.15 TRACI Normalized Impact Assessment for Scenario 3 – hybrid AnMBR..... 208

Figure 7.16 Impact Assessment Normalized to Conventional Treatment Method for Scenario 3 – hybrid AnMBR. 209

Figure 7.17 Carcinogenics (CTUh) Impact Assessment Normalized to Conventional Treatment Method. 211

Figure 7.18 Ecotoxicity (CTUe) Impact Assessment Normalized to Conventional Treatment Method. 212

Figure 7.19 Global Warming (kg CO2 eq) Impact Assessment Normalized to Conventional Treatment Method..... 213

LIST OF FIGURES

Page

Figure 7.20 Ecotoxicity (CTUe) Characterization Impact Assessment Method. 214
Figure 7.21 Characterization Impact Assessment of the AnMBR and Conventional Process Scenarios. 216
Figure 7.22 Relative Impacts of Scenarios without Sulfide and Phosphorus Removal at 15 LMH (F2) and >25°C (T1). 218
Figure 7.23 Characterization Impact Sensitivity with Respect to Sulfide and Phosphorus Removal Using Alum for Treatment Processes with 15 LMH (F2) and >25°C (T1). 219
Figure 7.24 Costs Borne by Society (CO_2eq) for Conventional Treatment and AnMBR Scenarios at 15 LMH and >25°C. 221

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ACRONYMS AND ABBREVIATIONS

$\#/m^2$	number of membranes per square meter
acfm	actual cubic feet per minute
ACH	aluminum chlorohydrate
AFBR	anaerobic fluidized bioreactor
AFMBR	anaerobic fluidized membrane bioreactor
AltCH4	alternative dissolved methane removal process
AnMBR	anaerobic membrane bioreactor
ANSI	American National Standards Institute
ASHRAE	Am. Society of Heating, Refrigeration, and Air Conditioning Engineers
ASTM	American Society for Testing and Materials
atm m^3 mol^{-1}	atmosphere cubic meter per mole
AWC	American Water Chemicals
BOD_5	five-day biochemical oxygen demand
bp	base pairs
°C	degrees centigrade
$C^{in}{}_i$	influent concentration of component *i*
$C^{out}{}_i$	outlet concentration of component *i*
$C^{out}{}_{TSS}$	outlet total suspended solids concentration
$C^{solids}{}_i$	solids concentration of component *i*
CERL	Construction Engineering Research Laboratory
cm	centimeter
cm^2	square centimeter
COD	chemical oxygen demand
CONUS	Continental United States
CST	capillary suction time
CTUe	comparative toxic units for ecosystems
CTUh	comparative toxic units for humans
d	day
d^{-1}	reciprocal day
DNA	deoxyribonucleic acid
DoD	Department of Defense
E	head loss in meters
$\hat{E}_{adiabatic}$	unit adiabatic compression energy per unit volume of permeate
$\hat{E}_{generation}$	unit energy produced as electricity unit volume of permeate
$\hat{E}_{pumping}$	unit pumping energy consumed per unit volume of permeate
EDS	energy dispersive spectroscopy
EMOU	El Monte Operable Unit
EO	Executive Order
EPA	U.S. Environmental Protection Agency
eq	equivalents

ER	Environmental Restoration
ERDC	Engineering Research and Development Center
ESTCP	Environmental Security Technology Certification Program
EXWC	Engineering and Expeditionary Warfare Center
F1	7.5 LMH flux
F2	15 LMH flux
F3	30 LMH flux
FBR	fluidized bed reactor or fluidized bioreactor
FOG	fats, oil and grease
FS	fixed solids
FSS	fixed suspended solids
ft	feet
$FW_{methane}$	formula weight of methane
g	gravitation constant or gram
g	gravitational constant
g/g	gram per gram
g-VS/g-COD	gram volatile solids per gram COD
g VSS/g COD	gram volatile suspended solids per gram COD
g L^{-1} d^{-1}	gram per liter per day
g m^{-2} d^{-1}	gram per square meter per day
gfd/psi	gallon per square foot per day per pound per square inch
GAC	granular activated carbon
gal	gallon
GC	gas chromatograph
gpd	gallons per day
gpd/sf	gallons per day per square foot
gpm	gallons per minute
h	hour
H	head
hp or HP	horsepower
HPLC	high performance liquid chromatography
HRT	hydraulic residence time
ICP-OES	inductively coupled plasma optical emission spectrometry
I&C	instrumentation and control
IX	ion exchange
k	heat capacity ratio
kg	kilogram
kg CFC-11 eq	kilograms of chlorofluorocarbon-11 equivalent
kg CO2 eq	kilograms of carbon dioxide equivalent
kg-COD m^{-3} d^{-1}	kilogram COD per cubic meter per day
kg N eq	kilograms of nitrogen equivalent
kg O3 eq	kilograms of ozone equivalent

kPa	kilopascal
kg PM2.5 eq	kilograms of fine particulate matter equivalent
kg SO2 eq	kilograms of sulfur dioxide equivalent
kg/tonne	kilogram per metric ton
kg-TSS/kg-COD	kilogram total suspended solids per kilogram COD
kJ/mol	kilojoule per mole
kW	kilowatt
kW/m^3	kilowatt per cubic meter
kWh/m^3	kilowatt-hour per cubic meter
kWh/MG	kilowatt-hour per million gallons
kWh/mol	kilowatt-hour per mole
kWh/yr	kilowatt-hours per year
KSU	Kansas State University
L	liter
L/d	liter per day
lb/d	pounds per day
LCA	lifecycle assessment
LCFA	long-chain fatty acid
LCIA	lifecycle impact assessment
LEED	Leadership in Energy and Environmental Design
LMH	liter per square meter per hour
LMH/bar	LMH per bar
LMH bar^{-1} d^{-1}	LMH per bar per day
LSI	Langelier saturation index
µm	micrometer
m^2	square meter
m^2/m^2	square meter/square meter
m^3	cubic meter
m^3/d	cubic meter per day
MGD	million gallons per day
mg/L	milligram per liter
mg-N/L	milligram nitrogen per liter
mg-P/L	milligram phosphorus per liter
mg L^{-1} d^{-1}	milligram per liter per day
mg/m^3	milligram per cubic meter
m/h	meter per hour
MILCON	military construction
min	minute
MJ Surplus	megajoule surplus
mL/min	milliliter per minute
mm	millimeter
mm Hg	millimeter mercury
MPN	most probable number
MPN/100 mL	MPN per 100 milliliters
mV	millivolt

η	pump efficiency
N	normal
NA	not applicable or not analyzed
NF	normalization factor
ng/µL	nanogram per micrometer
nm	nanometer
NPK	nitrogen-phosphorus-potassium
NR	nutrient removal
NSF	National Sanitation Foundation International
NTU	nephelometric turbidity unit
OLR	organic loading rate
OPCC	opinion of probable construction cost
OSHA	Occupational Safety and Health Administration or Act
OTU	operational taxonomic unit
p or P	probability or primary
PACl	polyaluminum chloride
P_{in}	inlet absolute gas pressure
P_{out}	outlet absolute gas pressure
psi	pounds per square inch
PN	project number
ppbV	parts per billion by volume
PVC	polyvinyl chloride
PVDF	polyvinylidene chloride
Q	flow rate
Q_{in}	actual inlet volumetric flow rate
Q_{LHV}	lower heating value of methane
qPCR	quantitative polymeric chain reaction
Q_{pump}	pump flow rate
$Q_{permeate}$	permeate flow rate
R	Pearson correlation coefficient
RCRA	Resource Conservation and Recovery Act
rpm	revolutions per minute
rRNA	ribosomal ribonucleic acid
RSK	U.S. EPA R. S. Kerr Laboratory
s^{-1}	reciprocal seconds
sec	second
SAF-MBR	staged anaerobic fluidized membrane bioreactor
SCFA	short-chain fatty acid
scfm	standard cubic feet per minute
SEM	scanning electron microscopy

SERDP	Strategic Environmental Research and Development Program
SM	Standard Methods
SOP	standard operating procedure
SRB	sulfate-reducing bacteria
SRT	solids residence time
SS	suspended solids
sSRT	suspended solids residence time
std.	standard
T	temperature
T1	> 25°C
T2	< 20°C
TCLP	toxicity characteristic leaching procedure
TDS	total dissolved solids
TKN	total Kjeldahl nitrogen
TMP	transmembrane pressure
TRACI	Tool for the Reduction and Assessment of Chemical and other Environmental Impacts
TS	total solids
TSS	total suspended solids
UF	ultrafiltration
U.S.	United States
USGS	US Geological Survey
V	volt
VFA	volatile fatty acid
VS	volatile solids
VSS	volatile suspended solids
$W_{methane}$	methane mass flow rate
WRIR	Water Resources Investigation Report
wt	weight

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ABSTRACT

OBJECTIVES

The primary objective of this pilot-scale project was to demonstrate and validate AnMBR technology for domestic wastewater treatment. Specific objectives associated with this project include: 1) demonstrate the effectiveness of AnMBR at treating screened domestic wastewater at temperatures above 10°C to produce high-quality, re-usable water; 2) demonstrate that AnMBR technology for domestic wastewater treatment can be operated in an energy-neutral manner; 3) compare cost and performance of gas-sparged and GAC-fluidized AnMBRs to conventional aerobic wastewater treatment systems; and 4) conduct a simplified lifecycle assessment of the technology in comparison to conventional technologies.

TECHNOLOGY DESCRIPTION

AnMBR technology is the marriage of anaerobic biological treatment and physical membrane separation. There are several different configurations of the AnMBR system. The main elements of the AnMBR system are a primary anaerobic bioreactor and a secondary membrane bioreactor. The primary anaerobic bioreactor contains microorganisms that convert organic carbon and associated five-day biochemical oxygen demand (BOD_5) in wastewater into an energy-rich, biogas-containing methane and carbon dioxide. The biogas produced in the primary anaerobic bioreactor can be used to generate electricity, heat, or fuel for vehicles. The secondary membrane bioreactor contains ultrafiltration (UF) membranes that separate the microorganisms and other suspended solids from the treated effluent (permeate). The pilot systems included in this demonstration used different methods of UF membrane flux maintenance. One pilot system used gas-sparging (gas-sparged AnMBR), and the other pilot system used GAC-fluidization (GAC-fluidized AnMBR). The primary bioreactor in the gas-sparged AnMBR was a suspended growth system. The primary bioreactor in the GAC-fluidized AnMBR was a GAC-fluidized bed reactor. Downstream processes were also evaluated including dissolved methane removal, sulfide and phosphorus removal, and ammonia removal.

DEMONSTRATION RESULTS

Performance of the AnMBR systems was evaluated with respect to effectiveness, net energy production efficiency, and implementability. The effectiveness of the AnMBR technology was assessed with respect to treated water quality. Both AnMBR systems met or exceeded EPA secondary treatment objectives but the GAC-fluidized AnMBR achieved better effluent quality at lower hydraulic residence times. Ammonia, total phosphorus, sulfide, and dissolved methane were also removed to varying extents. Energy consumption and production were calculated for a matrix of operating scenarios that included various net permeate fluxes and temperatures for the gas-sparged and GAC-fluidized AnMBRs. In general, energy-neutral or -positive operation was more likely at greater flux, temperature, and influent COD concentration. The AnMBR process has the potential to be cost-competitive with conventional treatment. The application of a hybrid process involving a GAC-fluidized bioreactor followed by a gas-sparged UF membrane process and a low-cost process for dissolved methane removal appears to be promising.

Alternative methods for sulfide removal such as biological oxidation should be evaluated because chemical coagulation is likely to be cost-prohibitive. In general, conventional treatment had the lowest overall environmental impact, followed by primary sedimentation in combination with a hybrid AnMBR comprised of a GAC-fluidized bioreactor, a gas-sparged UF membrane, a vacuum degasser for dissolved methane removal, and chemical coagulation for sulfide and phosphorus removal. Chemical consumption during sulfide and phosphorous removal are the primary environmental impact drivers. Considering that sulfide is probably more of a driver of chemical use than phosphorus (and that phosphorus removal may not always be necessary), alternative methods such as biological sulfide oxidation should be explored. Integration of alternative methods for sulfide removal alongside bioenergy recovery is necessary for developing an AnMBR treatment process that is more sustainable than a conventional treatment approach.

IMPLEMENTATION ISSUES

The results of this demonstration and economic analysis support use of primary sedimentation followed by a bioreactor and a gas-sparged UF membrane system. Inclusion of primary sedimentation in the process is projected to provide a greater potential for energy-neutral or energy-positive operation. Based on the results of this demonstration, the recommendation is to use a hybrid AnMBR comprised of a GAC-fluidized bioreactor followed by gas-sparged UF membranes. Dissolved methane removal using vacuum-operated membrane contactors was determined to have potential of removing 90% dissolved methane, but the pressure loss through the contactors will result in high energy consumption. Therefore, alternative dissolved methane removal technologies, such as vacuum degassers warrant evaluation. They have the potential for low-cost and low-energy consumption. Sulfide must be removed prior to discharge or reuse. Coagulation-flocculation-sedimentation is a standard process and was demonstrated to be capable of sulfide and total phosphorus removal. Chemical cost and environmental impact associated with sulfide removal were determined to be high. Alternative sulfide removal technologies, such as biological sulfide oxidation, may also be effective and less expensive. Further research into cost-effective and sustainable technologies for sulfide and phosphorus removal is recommended. Nitrogen removal requires further evaluation. Clinoptilolite was capable of removing ammonia in this demonstration, but the brine was not capable of being regenerated. Use of regenerable clinoptilolite downstream of an AnMBR is being evaluated further in ESTCP project ER-201728. Other options for nitrogen removal have also been evaluated and should be considered.

EXECUTIVE SUMMARY

INTRODUCTION

The Anaerobic Membrane Bioreactor (AnMBR) for Sustainable Wastewater Treatment project was conducted to demonstrate and validate the use of AnMBR technology for treatment of domestic wastewater. As part of the project, two pilot-scale AnMBR treatment systems were tested for over one year. These included a gas-sparged AnMBR and a granular activated carbon (GAC)-fluidized AnMBR.

The Department of Defense (DoD) currently uses aerobic treatment processes, such as activated sludge and oxidation ponds, to treat domestic wastewater generated at DoD facilities. Some undesirable characteristics of these aerobic treatment processes are:

- Aerobic treatment processes have a high energy demand because they require aeration to oxidize organic material in the wastewater.
- Aerobic treatment processes generate a significant amount of sludge.
- Aerobic treatment processes do not recover the inherent energy contained in the wastewater.

An alternative to conventional aerobic treatment processes is anaerobic treatment, which has the following benefits:

- Anaerobic treatment processes do not require aeration to oxidize organic material in the wastewater, so they have a lower energy demand versus aerobic processes.
- Anaerobic treatment processes produce less sludge than aerobic processes.
- Anaerobic treatment processes produce methane-rich biogas that can be used to generate electricity, heat, or vehicle fuel. The energy content of the biogas can potentially offset the energy used by the treatment process, making the process energy-neutral or energy-positive (i.e., does not require a net input of energy).

One type of anaerobic treatment process that is of particular interest for implementation at DoD facilities is the AnMBR treatment process. In addition to the benefits described above, this process produces an effluent that can meet reuse standards, such as American National Standards Institute (ANSI)/National Sanitation Foundation (NSF) 350 for five-day biochemical oxygen demand (BOD_5) and total suspended solids (TSS). Therefore, implementation of this treatment technology could increase the amount of water recycled at DoD facilities while also decreasing the operational costs of wastewater treatment at DoD facilities.

However, there are certain unknowns regarding the ability of the AnMBR treatment technology to reliably treat domestic sewage for various reuse applications in an energy-neutral manner. Also, AnMBR technology has not been tested at any DoD installations. Therefore, this demonstration was conducted to determine whether AnMBR technology can meet DoD requirements and can operate successfully on a domestic wastewater application.

OBJECTIVES

The primary objective of this pilot-scale project was to demonstrate and validate AnMBR technology for domestic wastewater treatment. Specific objectives associated with this project include:

- Demonstrate the effectiveness of AnMBR at treating screened domestic wastewater at temperatures above 10°C to produce high-quality, re-usable water.
- Determine a lower applicable temperature limit for AnMBR technology that can be used to identify appropriate implementation sites.
- Demonstrate that AnMBR technology for domestic wastewater treatment can be operated in an energy-neutral manner.
- Demonstrate use of the technology in a treatment train that can effectively remove nitrogen and phosphorus nutrients and sulfide (when necessary) in tandem with carbonaceous BOD_5 and TSS.
- Demonstrate that hollow-fiber gas transfer membrane technology can effectively recover dissolved methane from AnMBR permeate.
- Demonstrate that the AnMBR minimizes sludge production and determine whether the sludge that is produced can be used beneficially as biosolids.
- Demonstrate that the AnMBR is a safe technology that is implementable at DoD installations and public utilities.
- Compare cost and performance of a gas-sparged AnMBR to a GAC-fluidized AnMBR.
- Compare cost and performance of gas-sparged and GAC-fluidized AnMBRs to conventional aerobic wastewater treatment systems.
- Conduct a simplified lifecycle assessment of the technology in comparison to conventional technologies.

TECHNOLOGY DESCRIPTION

AnMBR technology is the marriage of anaerobic biological treatment and physical membrane separation. There are several different configurations of the AnMBR system. The various configurations differ in regard to the location of the membranes and the method of membrane flux maintenance. The membranes can be located in either the primary bioreactor or in a secondary and separate membrane bioreactor. Both pilot systems included in this demonstration had an external secondary membrane bioreactor. The main elements of the AnMBR system are a primary anaerobic bioreactor and a secondary membrane bioreactor.

The primary anaerobic bioreactor contains microorganisms that convert organic carbon and associated BOD_5 in wastewater into an energy-rich biogas containing methane and carbon dioxide. This conversion involves multiple steps, including disintegration, hydrolysis, fermentation, and methanogenesis. The biogas produced in the primary anaerobic bioreactor can be used to generate electricity, heat, or fuel for vehicles.

The secondary membrane bioreactor contains ultrafiltration (UF) membranes that separate the microorganisms and other suspended solids from the treated effluent (permeate). This physical separation process serves to 1) maintain a high mixed liquor of volatile suspended solids (VSS) concentration in the bioreactor, and 2) produce a suspended solids-free permeate.

The pilot systems included in this demonstration used different methods of UF membrane flux maintenance. One pilot system used gas-sparging, and the other pilot system used GAC-fluidization. The configurations of the two pilot systems are described in more detail below.

Gas-Sparged AnMBR Pilot System

The pilot system that was demonstrated consisted of four main process units, including:

- Gas-sparged AnMBR for removal of dissolved organics and suspended solids.
- Hollow-fiber gas transfer membrane for removal of dissolved methane.
- A coagulation-flocculation-sedimentation system for removal of sulfide and phosphorus.
- Ion exchange (IX) system for removal of ammonia.

A schematic of the gas-sparged AnMBR unit operation is shown in Figure ES.1. The process consisted of a primary anaerobic bioreactor and a secondary membrane bioreactor. Wastewater was pumped into the primary anaerobic bioreactor, which contained microorganisms that convert organic carbon into biogas. The contents of the primary bioreactor were circulated continuously through the secondary membrane bioreactor, which contained hollow-fiber UF membrane modules. The membranes were used to separate microorganisms and other suspended material from the treated effluent (permeate), which was pulled through the membrane by means of a permeate pump. The biogas produced in the bioreactor was either exhausted from the system or blown into the bottom of the secondary membrane bioreactor, where it bubbled up past the membranes to the top of the tank. This process, called sparging, helped keep suspended solids that in part cause membrane fouling from building up on the membranes. Biogas that was exhausted from the system could be used to generate electricity, heat, or fuel for vehicles. The permeate from the secondary membrane bioreactor was conveyed downstream for further treatment by additional processes (Figure ES.2) that included removal of dissolved methane, sulfide, phosphate, and ammonia.

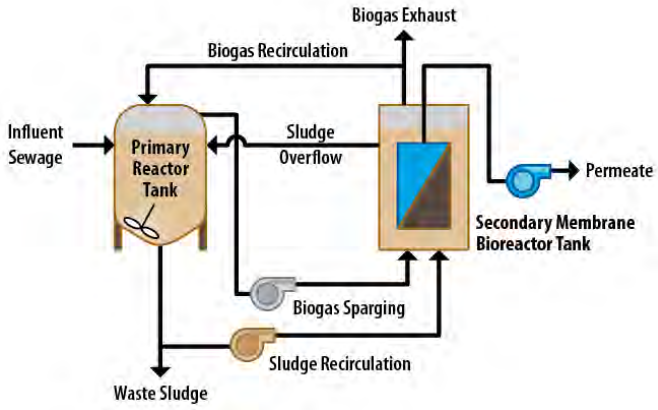

Figure ES.1 Gas-sparged AnMBR Schematic.

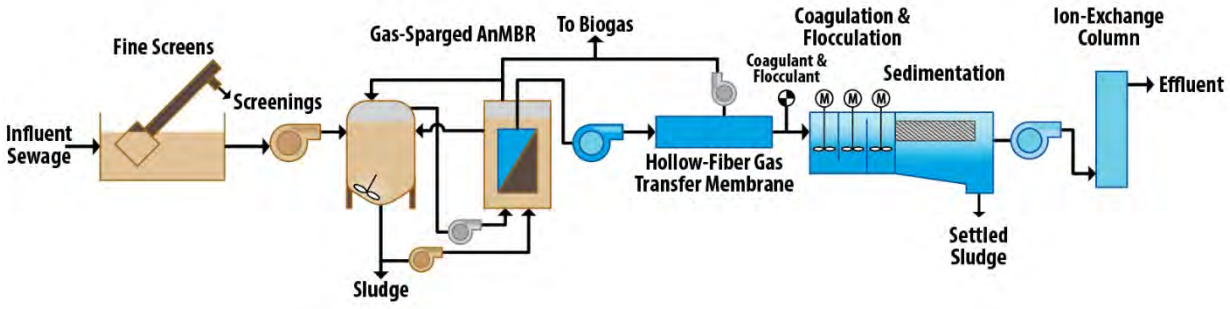

Figure ES.2 Gas-sparged AnMBR Pilot System Process Flow Diagram.

GAC-Fluidized AnMBR Pilot System

A process flow diagram of the GAC-fluidized AnMBR system is shown in Figure ES.3. This system consisted of two bioreactors. The first is an anaerobic fluidized-bed reactor (AFBR), which is followed by an anaerobic fluidized-bed membrane bioreactor (AFMBR). The two bioreactors are collectively referred to as the staged anaerobic fluidized membrane bioreactor (SAF-MBR).

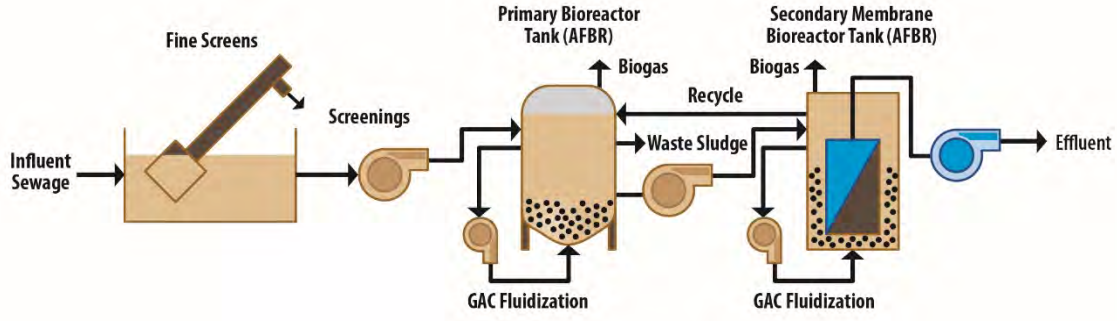

Figure ES.3 GAC-fluidized AnMBR Pilot System.

Wastewater was pumped into the AFBR, which contained active microorganisms and GAC media, the latter serving as a support media for the microorganisms. The AFBR was also equipped with a recirculation pump to keep the GAC fluidized. The AFBR provided partial treatment of the wastewater, converting the organic carbon into biogas. After treatment in the AFBR, the partially treated wastewater was pumped to the AFMBR, which contained active microorganisms, GAC particles that serve as a support media for the microorganisms, and ultrafiltration membranes. Inside the AFMBR, the wastewater was further treated, and the membranes separated the treated effluent from the microorganisms and other suspended materials in the wastewater. Recirculation between the two reactors was also conducted to promote better solids hydrolysis.

As in the AFBR, the liquid contents of the AFMBR were recirculated continuously from the top of the reactor to the bottom. But here, the fluidized GAC particles came into contact with the membranes. The physical movement of the GAC particles against the membranes helped to keep the membranes clean and reduce membrane fouling. Thus, the GAC-fluidized AnMBR is a unique membrane bioreactor system that employs a novel, energy-efficient approach for control of membrane fouling.

PERFORMANCE ASSESSMENT

Performance of the AnMBR systems was evaluated with respect to effectiveness, net energy production efficiency, and implementability. The effectiveness of the AnMBR technology was assessed with respect to treated water quality. The success was assessed through a comparison of water quality parameters to U.S. Environmental Protection Agency (EPA) secondary treatment standards, published criteria for water reuse, and other applicable metrics. Primary performance objectives are discussed here. Additional objectives are discussed in the main report.

Effectiveness

COD and BOD5

The average effluent chemical oxygen demand (COD) concentration in the gas-sparged AnMBR was 58±27 mg/L, which is about equal to the performance objective of 60 mg/L. The average COD removal was 90±4%. The average effluent COD concentration in the GAC-fluidized AnMBR was 29±9 mg/L, which is less than the performance objective. The average COD removal was 86±3%.

The average effluent BOD_5 concentration in the gas-sparged AnMBR was 25±12 mg/L, which is less than the performance objective of 30 mg/L but greater than the reuse objective of 10 mg/L. The average BOD_5 removal was 89±5%. The average effluent BOD_5 concentrations in the GAC-fluidized AnMBR was 15±9 mg/L, which is less than the performance objective of 30 mg/L and greater than the re-use objective of 10 mg/L. The average BOD_5 removal was 85±7%.

Fine screening was the only form of primary treatment used in this demonstration. Primary sedimentation may have resulted in even lower effluent concentrations and potentially less than 10 mg/L BOD_5.

Ammonia

The ammonia removal by the clinoptilolite column prior to breakthrough was 99.9±0.1%, which is greater than the performance objective of 90%. The influent and effluent ammonia concentrations were 37±4 and 0.05±0.05 milligrams of nitrogen per liter (mg-N/L), respectively.

Total Phosphorus

Total phosphorus was reduced from 7.0±2.9 mg/L in the screened gas-sparged AnMBR influent to 0.43±0.29 mg/L in the clinoptilolite effluent for an overall removal of 94±3%, which was greater than the performance objective of 90%.

Total Sulfide

Sulfide was reduced from 27±5 to 0.7±1.7 mg/L by chemical coagulation. The median and minimum effluent concentrations were 0.10 and 0.04 mg/L, respectively. Overall sulfide removal, including the elevated values, was 99±2%. While the median sulfide concentration met the performance objective of 0.1 mg/L, the average concentration did not. Further optimization of the coagulation system would likely have improved the performance leading to attainment of the performance objective. The performance objective may be too stringent for certain applications in which the performance would then be deemed to be acceptable.

Dissolved Methane

The average dissolved methane removal by a gas-liquid membrane contactor under optimized conditions was 79±2%, which was not greater than the performance objective of 90%. The influent dissolved methane concentration for these tests was 13±2 mg/L.

Net Energy Production Efficiency

Energy consumption and production were calculated for a matrix of operating scenarios that included various net permeate fluxes and temperatures for the gas-sparged and GAC-fluidized AnMBRs. Temperature was an important factor because the total methane yield was observed to be greater at elevated temperatures. Energy-neutral or -positive operation was estimated for some but not all of these scenarios. In general, energy-neutral or -positive operation was more likely at greater flux, temperature, and influent COD concentration. At the average observed flux for the gas-sparged AnMBR (7.6 liters per square meter per hour [LMH or L m^{-2} h^{-1}]), the ratio of energy produced: energy consumed was 60% for T < 20°C and 84% for T > 25°C (COD = 620 mg/L). At the maximum flux (14 LMH), the ratio was 100% for T < 20°C and 140% for T > 25°C. At the average flux for the GAC-fluidized AnMBR (7.9 LMH) and without supplemental COD (COD = 210 mg/L), the ratio was 55% for T < 20°C and 90% for T > 25°C. If the influent COD was greater (390 mg/L), the ratio at an average flux would be 77% for T < 20°C and 130% for T > 25°C. Therefore, the performance objective of energy neutrality was met by both systems under certain conditions.

While energy neutrality may not be possible under all conditions, decreasing the net energy consumption relative to conventional activated sludge can more likely be achieved. Gas-sparged AnMBR operating conditions at high flux and low sparge rates were more likely to result in net energy consumption less than 0.3 to 0.6 kWh/m^3, which is typical for conventional wastewater treatment plants. All GAC-fluidized AnMBR operating conditions resulted in net energy consumption less than that for conventional wastewater treatment plants. These results suggest the prospect of energy reduction using AnMBR processes in place of conventional activated sludge technologies is promising.

Implementability

Organic Loading Rate

The average organic loading rate in the gas-sparged AnMBR was 1.3±0.5 kg-COD m^{-3} d^{-1}, which is greater than the performance objective of 0.6 kg-COD m^{-3} d^{-1}. The average organic loading rate in the GAC-fluidized AnMBR without COD supplementation was 1.4±0.5 kg-COD m^{-3} d^{-1}, which is greater than the performance and similar to the rate for the gas-sparged AnMBR. The organic loading rates of both AnMBRs were similar because both the hydraulic residence time and the influent COD for the gas-sparged AnMBR were greater than for the GAC-fluidized AnMBR.

Hydraulic Residence Time

The average hydraulic residence time (HRT) for the gas-sparged AnMBR was 11±3 hours (h), which is less than the performance objective of 20 h. The average HRT for the GAC-fluidized AnMBR was 3.9±1.0 h, which is less than the performance objective of 20 h and 65% less than the average hydraulic residence time for the gas-sparged AnMBR.

Biosolids Production

The volatile solids (VS) generation per unit mass loaded COD for each AnMBR system was calculated and compared to the performance objective of 0.2 grams volatile solids per gram COD loaded (g-VS/g-COD_{loaded}). The results were 0.074 and 0.13 g-VS/g-COD_{loaded} for the gas-sparged and GAC-fluidized AnMBR. Both of these values met the performance objective. The value for the gas-sparged AnMBR may be underestimated in part because of solids settling in the bioreactor and incomplete recovery. On the other hand, the greater solids residence time (60±27 days [d] versus 11±5 d calculated for suspended/non-biofilm solids only) in the gas-sparged AnMBR could have led to greater hydrolysis and a lower value.

Membrane Flux

The average net flux of the gas-sparged AnMBR for the entire demonstration, excluding periods of mechanical shutdown and COD overloading, was 7.6±1.6 LMH. This flux was greater than the goal of 6 LMH. The maximum net flux was 14 LMH. The average net flux of the GAC-fluidized AnMBR for the entire demonstration, excluding periods of mechanical shutdown, reactor upsets, and COD supplementation, was 7.9±2.2 LMH. This flux was greater than the goal of 6 LMH. The maximum net flux was 12 LMH.

Overall, the gas-sparged AnMBR ultrafiltration process demonstrated greater resilience in response to elevated concentrations of solids and colloidal organics. However, both systems demonstrated instability (i.e., variable permeability over time), which was attributable not only to varying operational conditions and mechanical upsets but also to differences in membrane performance caused by the different methods of fouling management (i.e., variable biogas sparging versus constant GAC fluidization). Inconsistent and insufficient maintenance cleaning also likely contributed to these instabilities.

Wastewater Temperature

The intent of this performance objective was to demonstrate attainment of effectiveness at temperatures ≥ 10°C. The COD and BOD_5 removals in the gas-sparged AnMBR did not decrease with decreasing temperatures between 15 and 30°C. The performance with respect to COD and BOD_5 removal below 15°C could not be evaluated because ambient wastewater temperatures did not go that low. COD and BOD_5 permeate concentrations did not increase as temperatures decreased between 15 and 30°C. In the GAC-fluidized AnMBR, COD and BOD_5 removals did not decrease and the permeate concentrations did not increase as temperatures decreased between 15 and 30°C. The period of time when temperatures were between 10 and 15°C was concurrent with a process upset resulting from an inadvertent pump reversal. When non-upset data are evaluated, only three data points between 14.0 and 14.8°C exist, and they do not indicate a trend of changing performance with temperature. Therefore, insufficient data exist to evaluate performance of the GAC-fluidized AnMBR at temperatures < 15°C.

Dissolved Methane Removal Rate

This performance objective is important with respect to the capital cost and replacement cost of gas-liquid membrane contactors for dissolved methane removal. The performance objective for methane flux was 0.5 grams per square meter per day (g m^{-2} d^{-1}) and the observed flux was 6.5±1.8 g m^{-2} d^{-1}. If two contactors had been installed in series, thereby doubling the membrane area to achieve the 90% removal objective, the performance objective for flux would still have been met.

Clinoptilolite Robustness

Robustness was quantified with respect to the variation on ammonia loading over multiple regeneration cycles. No decrease in the ammonia loading over multiple sorption/regeneration cycles would indicate good robustness. Two regeneration cycles were conducted, and the loading decreased by 21 to 50% compared to the performance objective of 10%. The second regeneration did not result in further decreases in ammonia loading suggesting robustness after the initial sorption/regeneration cycle, but additional loading/regeneration cycles would be required to validate this hypothesis. Therefore, the conclusion is that the performance objective for robustness was not met, but this conclusion is based on limited testing.

Membrane Performance

Primary conclusions based on membrane performance and post-demonstration analyses are:

- Permeability of both sets of membranes started high and then decreased by about ten-fold over the period of over one year of operation. However, permeability of the gas-sparged membranes was similar or greater than of the GAC-fluidized membranes even though concentrations of suspended solids and colloidal organics were much greater in the gas-sparged AnMBR.
- Maintenance cleaning in both systems was insufficient and contributed to the decreases in permeability.
- Increasing the biogas sparge rate in the gas-sparged AnMBR resulted in increased permeability, though at an increased energy cost. Such modification of permeability is not possible in the GAC-fluidized AnMBR system.
- Membrane foulants on the membranes included both organics (e.g., biofilm) and inorganics (clay-like materials likely associated with the wastewater influent). Primary sedimentation could reduce the amount of inorganic fouling of the membranes. In addition, the GAC-fluidized AnMBR membranes were coated with elemental carbon. The carbon may have deposited through the demonstration or following the upset condition, when GAC was ground in the recirculation pumps.
- Membrane abrasion was much greater in the GAC-fluidized AnMBR compared to gas-sparged AnMBR. The membrane lifetime in the gas-sparged AnMBR is estimated to be on the order of ten years or more based on historical operation of aerobic membrane bioreactors with the same membranes. The GAC-fluidized AnMBR membranes are likely to have a much shorter lifetime.
- These results suggest membrane performance in the gas-sparged AnMBR was more robust and flexible than in the GAC-fluidized AnMBR, though energy requirements for gas-sparging are greater than those for GAC-fluidization.

Treated Water Quality with Respect to Various Water Reuse Alternatives

Water quality data suggest the treated water is potentially suitable for surface water discharge, depending on local regulatory requirements and a variety of re-use opportunities, including toilet flushing, irrigation, dust suppression, etc. The treated water would require additional treatment for indirect potable reuse, such as ozone-biofiltration or full-advanced treatment using reverse osmosis.

Process Residuals

Biosolids and coagulation-flocculation-sedimentation sludge from the gas-sparged AnMBR process were characterized and compared to regulatory requirements for land application of biosolids. The biosolids met criteria for class B biosolids with respect to fecal coliforms and class A biosolids with respect to metals. It did not meet class A criteria with respect to concentrations of enteric viruses and *Salmonella*. Therefore, the biosolids meet class B requirements with respect to pathogens. Class A could be met if primary sedimentation and anaerobic digestion were added to the process. Coagulation sludge contained phosphorus that has potential use as a fertilizer and contained appreciable phosphorus, sulfur, iron and aluminum. Further studies would be necessary to determine whether the phosphorus and sulfur are agriculturally available, considering it was coagulated with iron and aluminum coagulants. Dewatering of both residuals was evaluated. The biosolids required more polymer for dewatering than the chemical sludge but was still capable of attaining a solids content of 16%.

COST AND LIFE CYCLE ASSESSMENT

Cost

The AnMBR process has the potential to be cost-competitive with conventional treatment considering the possibility of energy-positive operation. The application of a hybrid process involving a GAC-fluidized bioreactor followed by a gas-sparged UF membrane process and a low-cost process for dissolved methane removal appears to be promising. Alternative methods for sulfide removal such as biological oxidation should be evaluated because chemical coagulation is likely to be cost-prohibitive. Membrane replacement costs and chemical costs for membrane cleaning also must be considered. The actual lifetime of UF membranes in an AnMBR is unknown; however, gas-sparged UF membrane lifetime is expected to be ten years or more based on experience with aerobic membrane bioreactors using the same membranes. Chemical use for membrane maintenance and recovery cleaning should be considered and optimized. Implementation of the AnMBR process in warmer climates and on relatively strong wastewater streams would increase the potential for even more energy-positive operation and overall cost reduction. Finally, the AnMBR is a new process that has not had years of operational experience like conventional treatment processes. Therefore, it is not unexpected that estimated AnMBR costs are greater than conventional treatment costs. Nevertheless, the potential for cost reduction exists and can be realized through process modification and implementation. Full-scale implementation on smaller distributed systems is a logical first step.

Lifecycle Assessment

In general, conventional treatment had the lowest overall environmental impact, followed by primary sedimentation in combination with a hybrid AnMBR comprised of a GAC-fluidized bioreactor, a gas-sparged UF membrane, a vacuum degasser for dissolved methane removal, and chemical coagulation for sulfide and phosphorus removal. The CO2eq offsets from electricity and heat generated had a strong influence on overall environmental impact contributions from the AnMBR process; however, the chemical use associated with sulfide and phosphorus removal process resulted in greater environmental impact than did conventional treatment.

The sensitivity analysis indicated that the sulfide and phosphorous removal component of the AnMBR treatment processes contributes at least 70% to overall environmental impact contributions, compared to at least 24% as a component of conventional treatment. Chemical consumption during sulfide and phosphorous removal are the primary environmental impact drivers. Considering that sulfide is probably more of a driver of chemical use than phosphorus (and that phosphorus removal may not always be necessary), alternative methods such as biological sulfide oxidation should be explored. Integration of alternative methods for sulfide removal alongside bioenergy recovery is necessary for developing an AnMBR treatment process that is more sustainable than a conventional treatment approach.

IMPLEMENTATION ISSUES

Process Configuration

The results of this demonstration and economic analysis support use of primary sedimentation followed by a bioreactor and a gas-sparged UF membrane system. Inclusion of primary sedimentation in the process is projected to provide a greater potential for energy-neutral or energy-positive operation. In addition, the potential for membrane fouling – particularly by fats, oil and grease (FOG) – will be reduced.

The bioreactor may be either a suspended growth bioreactor or a GAC-fluidized bioreactor. However, the first-stage GAC-fluidized bioreactor was demonstrated to require a shorter HRT and produce better effluent quality than the first-stage suspended growth bioreactor. The GAC-fluidized bioreactor – being a fixed film system – will also be more resilient to process upsets based on previous research and experience comparing fixed film and suspended growth wastewater treatment systems.

Based on the results of this demonstration, the recommendation is to use a hybrid AnMBR comprised of a GAC-fluidized bioreactor followed by gas-sparged UF membranes. GAC-fluidized membrane integrity was demonstrated in this and previous studies to be severely compromised by GAC-abrasion and the lifetime of these membranes would be much shorter than that of gas-sparged UF membranes. Additionally, the GAC-fluidized UF membranes require lower packing density than gas-sparged UF membranes, are not commercially available, and are likely to be more expensive.

Dissolved methane removal using vacuum-operated membrane contactors was determined to have potential of removing 90% dissolved methane, but the pressure loss through the contactors will result in high energy consumption. Therefore, alternative dissolved methane removal technologies, such as vacuum degassers, warrant evaluation. They have the potential for low-cost and low-energy consumption.

Sulfide must be removed prior to discharge or reuse. If it is not removed, it can lead to several problems including: 1) oxidization to sulfur and fouling of process piping, 2) contribution to oxygen demand and generation of turbidity (from the generated elemental sulfur) upon discharge to surface water, and 3) toxicity and noxious odors precluding many reuse opportunities. Phosphorus may need to be removed in the case of surface water discharge depending on local regulatory requirements.

Coagulation-flocculation-sedimentation is a standard process and was demonstrated to be capable of sulfide and total phosphorus removal. Use of the sedimentation solids as a fertilizer is possible but requires further study to determine plant uptake. Chemical cost and environmental impact associated with sulfide removal were determined to be high. Alternative sulfide removal technologies, such as biological sulfide oxidation, may also be effective and less expensive. Further research into cost-effective and sustainable technologies for sulfide and phosphorus removal is recommended.

Nitrogen removal requires further evaluation. Clinoptilolite was capable of removing ammonia in this demonstration, but the brine was not capable of being regenerated. Use of regenerable clinoptilolite downstream of an AnMBR is being evaluated further in ESTCP project ER-201728. Other options for nitrogen removal have also been evaluated and should be considered.

Water reuse is an option and may require additional treatment depending on the specific end use.

Operability

Operability includes various aspects including plant reliability, permit compliance, and operator skill level and certification requirements. The plant must be reliable and capable of consistently meeting discharge requirements to remain in compliance with permits. AnMBRs have clearly not been in existence as long as oxidation ditch and activated sludge technologies. Therefore, a track record is not available to assess reliability. This demonstration indicated that upset conditions can occur, but this is the case at conventional treatment plants as well. Further demonstrations of AnMBRs are necessary to provide such a track record of reliability.

Operator skill level and certification requirements associated with a plant's permit may be increased compared to a conventional plant. This has been the case when conventional plants have been upgraded to *aerobic* MBRs or anaerobic digesters are installed at an existing facility. These requirements are not necessarily impediments but must be considered.

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1.0 INTRODUCTION

The Anaerobic Membrane Bioreactor (AnMBR) for Sustainable Wastewater Treatment project was conducted to demonstrate and validate the use of AnMBR technology for treatment of domestic wastewater. As part of the project, two pilot-scale AnMBR treatment systems were tested for over one year. These included a gas-sparged AnMBR and a granular activated carbon (GAC)-fluidized AnMBR. This report includes:

- Section 1 Introduction – Provides background, general objectives, and regulatory drivers for the technology.
- Section 2 Technology – Presents background on the technology, including its development applications, advantages and limitations.
- Section 3 Performance Objectives – Presents the performance objectives for the technology demonstration and the high-level results.
- Section 4 Site Description – Provides information on the sites where the demonstrations were conducted, along with historical data.
- Section 5 Test Design – Presents the design, methodology, and detailed results for the demonstration tests.
- Section 6 Performance Evaluation – Substantiates the performance objective results in Section 3 with the test results in Section 5.
- Section 7 Cost and Lifecycle Assessment – Presents an economic analysis of the technology, along with a simplified lifecycle assessment.
- Section 8 Implementation Issues – Presents a discussion of considerations for end-users considering technology implementation.
- Section 9 References – Presents literature citations for the report.

1.1 BACKGROUND

The Department of Defense (DoD) currently uses aerobic treatment processes, such as activated sludge and oxidation ditches, to treat domestic wastewater generated at DoD facilities. Some undesirable characteristics of these aerobic treatment processes are:

- Aerobic treatment processes have a high energy demand because they require aeration to oxidize organic material in the wastewater.
- Aerobic treatment processes generate a large amount of sludge.
- Aerobic treatment processes do not recover the inherent energy contained in the wastewater.

An alternative to conventional aerobic treatment processes is anaerobic treatment, which has the following benefits:

- Anaerobic treatment processes do not require aeration to oxidize organic material in the wastewater, so they have a lower energy demand versus aerobic processes.
- Anaerobic treatment processes produce less sludge than aerobic processes.

- Anaerobic treatment processes produce methane-rich biogas that can be used to generate electricity, heat, or vehicle fuel. The energy content of the biogas can potentially offset the energy used by the treatment process, making the process energy neutral or energy positive (i.e., does not require a net input of energy).

One type of anaerobic treatment process that is of particular interest for implementation at DoD installations is the AnMBR treatment process. In addition to the benefits described above, this process has the potential to produce an effluent that can meet reuse standards, such as American National Standards Institute (ANSI)/National Sanitation Foundation [NSF]) 350 for five-day biochemical oxygen demand (BOD_5) and total suspended solids (TSS). Therefore, implementation of this treatment technology could increase the amount of water recycled at DoD facilities while also decreasing the operational costs of wastewater treatment at DoD facilities.

However, there are certain unknowns regarding the ability of the AnMBR treatment technology to reliably treat domestic sewage for various reuse applications in an energy-neutral manner. Also, AnMBR technology has not been tested at any DoD installations. Therefore, this demonstration was conducted to determine whether AnMBR technology can meet DoD requirements and can operate successfully on a domestic wastewater application.

1.2 OBJECTIVE OF THE DEMONSTRATION

The primary objective of this pilot-scale project was to demonstrate and validate AnMBR technology for domestic wastewater treatment. Specific objectives associated with this project include:

- Demonstrate the effectiveness of AnMBR at treating screened domestic wastewater at temperatures above 10°C to produce high quality, re-usable water.
- Determine a lower applicable temperature limit for AnMBR technology that can be used to identify appropriate implementation sites.
- Demonstrate that AnMBR technology for domestic wastewater treatment can be operated in an energy-neutral or energy-positive manner.
- Demonstrate use of the technology in a treatment train that can effectively remove nitrogen and phosphorus nutrients and sulfide in tandem with carbonaceous BOD_5 and TSS.
- Demonstrate that hollow-fiber gas transfer membrane technology can effectively recover dissolved methane from AnMBR permeate.
- Demonstrate that the AnMBR minimizes sludge production and determine whether the sludge that is produced can be used beneficially as biosolids.
- Demonstrate that the AnMBR is a safe technology that is implementable at DoD installations and public utilities.
- Compare cost and performance of a gas-sparged AnMBR to a GAC-fluidized AnMBR.
- Compare cost and performance of gas-sparged and GAC-fluidized AnMBRs to conventional aerobic wastewater treatment systems.
- Conduct a simplified lifecycle assessment of the technology in comparison to conventional treatment.

1.3 REGULATORY DRIVERS

A variety of drivers require reductions in water and energy use on military installations, including:

- Executive Order (EO) 13693 mandates that water efficiency and conservation measures be implemented to achieve at least 36% reduction in water demand by 2025.
- American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) 189.1-2009, Leadership in Energy and Environmental Design (LEED) and various Energy Policy Acts all have required more sustainable use of water.
- The Army has implemented a Net-Zero installations policy seeking to increase and improve sustainability on installations, including Net-Zero Water.
- The U.S. Environmental Protection Agency (EPA) is encouraging sustainable water use through various programs, such as the Green Building Initiative and Green Infrastructure.
- The DoD Strategic Sustainability Performance Plan provides an approach towards meeting these requirements which includes a focus on: 1) reducing energy needs and reliance on fossil fuels, and 2) water resources management.

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2.0 TECHNOLOGY

2.1 TECHNOLOGY DESCRIPTION

Two AnMBR pilot systems were studied as part of this demonstration: 1) a gas-sparged AnMBR pilot system, and 2) a GAC-fluidized AnMBR pilot system. The section provides a description of each system along.

2.1.1 AnMBR Technology Overview

AnMBR technology is the marriage of anaerobic biological treatment and physical membrane separation. There are several different configurations of the AnMBR process. The various configurations differ in regard to the location of the membranes and the method of cleaning the membranes. The membranes can be located either in the primary bioreactor or in a secondary and separate membrane bioreactor. Both pilot systems included in this demonstration had an external secondary membrane bioreactor. The main elements of the AnMBR system are a primary anaerobic bioreactor and a secondary membrane bioreactor.

The primary anaerobic bioreactor contains microorganisms that convert organic carbon and associated BOD_5 in wastewater into an energy-rich biogas containing methane and carbon dioxide. This conversion involves multiple steps, including disintegration, hydrolysis, fermentation, and methanogenesis. The biogas produced in the primary anaerobic bioreactor can be used to generate electricity, heat, or fuel for vehicles.

The secondary membrane bioreactor contains membranes that separate the microorganisms and other suspended solids from the treated effluent (permeate). This physical separation process serves to 1) maintain a high mixed liquor volatile suspended solids (VSS) concentration in the bioreactor, and 2) produce a suspended solids-free permeate.

The pilot systems included in this demonstration used different methods of cleaning the membranes. One pilot system cleaned the membranes using a gas-sparging method, and the other pilot system cleaned the membranes using a GAC scouring method. The configurations of the two pilot systems are described in more detail below.

2.1.2 Gas-Sparged AnMBR Pilot System Overview

The pilot system that was demonstrated consisted of four main process unit, including:

- Gas-sparged AnMBR for removal of BOD_5, COD, and TSS.
- Hollow-fiber gas transfer membrane for removal of dissolved methane.
- A coagulation-flocculation & sedimentation system for removal of sulfide and phosphorus.
- Ion exchange (IX) system for removal of ammonia.

Each of these technologies is described in detail below.

Gas-Sparged AnMBR

A schematic of the gas-sparged AnMBR unit operation is shown in Figure 2.1. The process consisted of a primary anaerobic bioreactor and a secondary membrane bioreactor. Wastewater was pumped into the primary anaerobic bioreactor, which contained microorganisms that converted organic carbon into biogas. The contents of the primary bioreactor were circulated continuously through the secondary membrane bioreactor, which contained hollow-fiber ultrafiltration (UF) membrane modules. The membranes were used to separate microorganisms and other suspended material from the treated effluent (permeate), which was pulled through the membrane by means of a permeate pump.

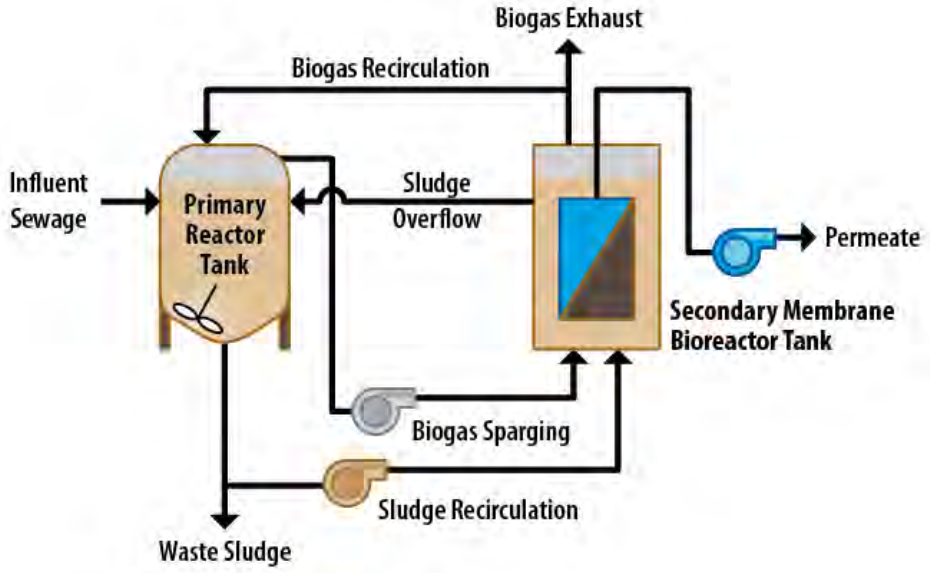

Figure 2.1 Gas-sparged AnMBR Schematic.

The gas-sparged AnMBR pilot system used ZeeWeed TR500d UF membrane modules manufactured by Suez. The membrane bioreactor contained three membrane modules. Figure 2.2 includes a photo of a full-scale ZeeWeed membrane module and a schematic of a single membrane fiber showing how the fiber separates suspended solids from the permeate. These types of membranes exclude solid particles larger than 0.04 micrometers (µm), including most pathogens and large molecular weight organics, resulting in high permeate quality. The biogas produced in the digester was either exhausted from the system or flowed into the bottom of the secondary membrane bioreactor, where it bubbled up past the membranes to the top of the tank. This process, called sparging, helped keep suspended solids that cause membrane fouling from building up on the membranes. Biogas that was exhausted from the system could be used to generate electricity, heat, or fuel for vehicles. During this demonstration, biogas production was quantified and vented. The permeate from the secondary membrane bioreactor was conveyed downstream for further treatment by additional processes (Figure 2.3) that included removal of dissolved methane, sulfide, phosphate, and ammonia, as described in the following sections.

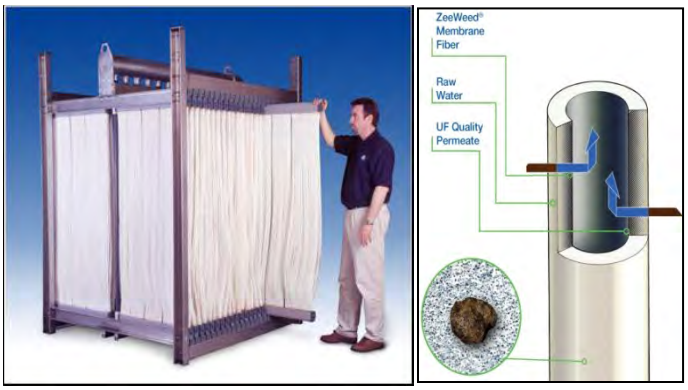

Figure 2.2 Photo of ZeeWeed Membrane Module and Schematic of Ultrafiltration Fiber.

Photo courtesy of Suez.

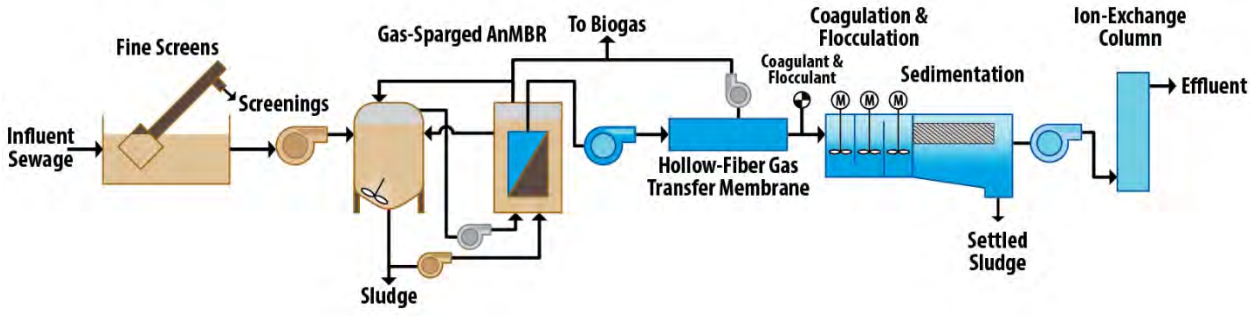

Figure 2.3 Gas-sparged AnMBR Pilot System Process Flow Diagram.

Hollow-Fiber Gas Transfer Membrane

During anaerobic treatment of relatively dilute domestic wastewater at temperatures less than ~20ºC, a significant percentage of the produced methane remains dissolved in the permeate rather than being exhausted from the system as a biogas (Shin et al. 2016c). Recovery and use of this dissolved methane can increase the overall efficiency of the system and help to achieve the goal of energy neutrality.

Hollow-fiber gas-transfer membranes have been used successfully at small scales for recovery of dissolved methane from AnMBR permeate (Crone et al. 2016). This technology has also been used to deoxygenate water and remove carbon dioxide from water at large scales on the order of millions of gallons per day. Therefore, this technology is applicable to methane recovery from AnMBR permeate and was demonstrated as a component of the gas-sparged AnMBR.

A schematic of the hollow-fiber gas-transfer membrane is shown in Figure 2.4. Permeate flowed through the shell-side (i.e., outside the membranes) of the hollow-fiber membrane contactor. Dissolved methane was drawn from the permeate, through the membrane, and into the lumen side (inside the membranes) of the fibers by means of a vacuum pump. The gas that was pulled out of the permeate contained hydrogen sulfide, carbon dioxide, and moisture in addition to methane.

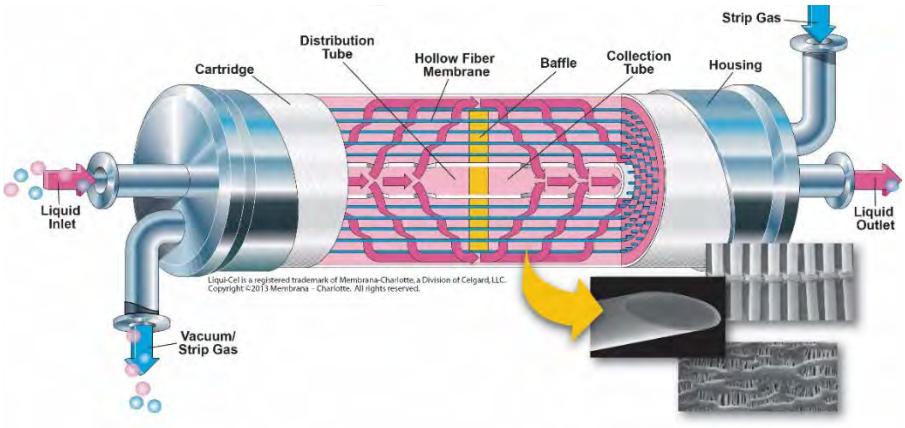

Figure 2.4 Schematic of the Hollow-fiber Gas Transfer Membrane.

Courtesy of 3M Corporation.

Flocculation and Sedimentation System

At times, regulatory requirements impel nutrient removal from treated wastewater before discharging to surface waters. Anaerobic treatment of wastewater alone will remove little nitrogen or phosphorus and will produce sulfide from the reduction of sulfur compounds contained in the wastewater. Phosphorus can be removed by various biological processes, but these processes include aerobic treatment and are energy intensive. One chemical process that removes both phosphorus and sulfide is coagulation-flocculation-sedimentation. Such a process was implemented as part of the gas-sparged AnMBR pilot system to remove sulfide and phosphorus from the AnMBR effluent. The system consisted of a series of coagulation/flocculation basins, followed by a sedimentation basin, and used ferric chloride and aluminum chlorohydrate as coagulants and a cationic emulsion polymer as a flocculant, as shown in Figure 2.3. In certain water-reuse situations, such as irrigation, phosphorus may not need to be removed because it is a useful nutrient.

Ion Exchange System

An additional contaminant of concern in domestic wastewater that is not addressed by conventional AnMBR systems is ammonia. In fact, during anaerobic treatment, organic nitrogen in the raw wastewater is converted to ammonia, thereby increasing concentrations.

Traditional methods of removing ammonia are energy-intensive aeration processes, such as nitrification-denitrification (McCarty 2018). One of the goals of this project is to demonstrate that AnMBR technology can be operated in an energy-neutral configuration while treating domestic wastewater. Therefore, a more energy-efficient and potentially more cost-effective approach for ammonia removal was implemented as part of the gas-sparged AnMBR pilot system. The process that was implemented used clinoptilolite ion-exchange media to remove ammonia from the AnMBR effluent. Other alternatives, such as nitritation or anammox treatment, could also be considered but were outside of the scope of this project.

A schematic of the ion-exchange ammonia removal process and the procedure for regenerating the ion-exchange media is shown in Figure 2.5. and was developed under the DoD Strategic Environmental Research and Development Program (SERDP) (Guy et al. 2016). The AnMBR effluent was pumped through the clinoptilolite ion-exchange media. The ammonium ion in the AnMBR effluent exchanged with sodium ion on the media, thus, reducing the ammonia concentration. Once the clinoptilolite media was saturated with ammonia, the clinoptilolite bed was removed from the system and replaced with new media. The ammonia saturated clinoptilolite media was regenerated by means of a sodium chloride brine or sodium hydroxide. The ammonia brine resulting from the regeneration process was fed into an electrolysis process that generated nitrogen and hydrogen gas. Generated hydrogen can be used to generate electricity by means of a hydrogen fuel cell, and the electricity powered the electrolysis process.

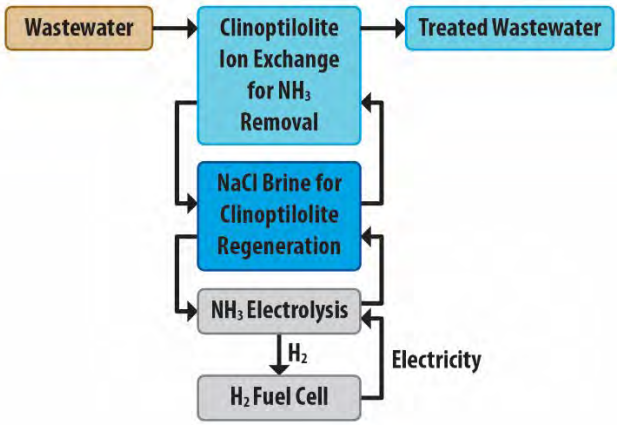

Figure 2.5 Schematic of Low-energy Ammonia Removal Process.

2.1.3 GAC-Fluidized AnMBR Pilot System

A process flow diagram of the GAC-fluidized AnMBR system is shown in Figure 2.6. This system consists of two bioreactors. The first is an anaerobic fluidized-bed reactor (AFBR), which is followed by an anaerobic fluidized-bed membrane bioreactor (AFMBR). The two bioreactors are collectively referred to as the staged anaerobic fluidized membrane bioreactor (SAF-MBR).

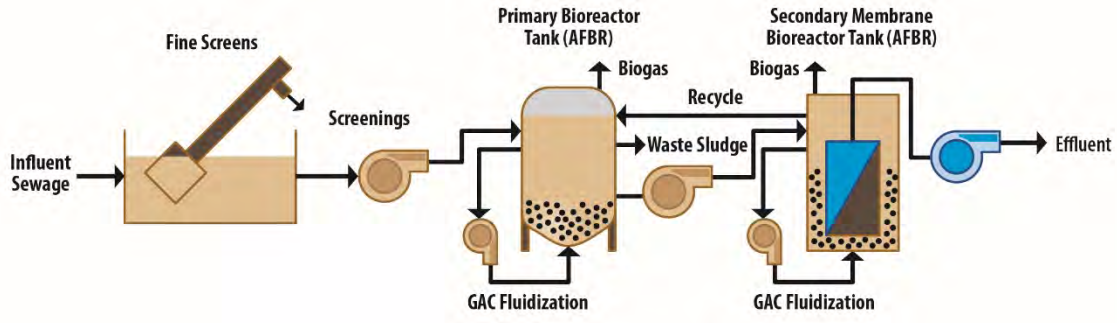

Figure 2.6 GAC-fluidized AnMBR Pilot System.

Wastewater was pumped into the AFBR, which contained active microorganisms and fluidized GAC media, the latter serving as a support media for the microorganisms. The AFBR was also equipped with a recirculation pump to keep the GAC fluidized. The AFBR provided partial treatment of the wastewater, converting the organic carbon into methane-rich biogas. After treatment in the AFBR, the partially treated wastewater was pumped to the AFMBR, which contained active microorganisms, GAC particles that served as a support media for the microorganisms, and ultrafiltration membranes. Inside the AFMBR, the wastewater was further treated, and the membranes separated the treated effluent from the microorganisms and other suspended materials in the wastewater. Recirculation of water but not GAC between the two reactors was also conducted.

The AFMBR pilot system used SM-1015 UF membrane modules manufactured by Lotte Chemical (formerly Samsung). The membrane bioreactor contained four membrane modules. Each module contained a similar type (polyvinylidene fluoride - PVDF) and shape (hollow fiber) membrane to the ZeeWeed membrane module used in the gas-sparged AnMBR.

As in the AFBR, the liquid contents of the AFMBR were continuously recirculated from the top of the reactor to the bottom. But here, the fluidized GAC particles came into contact with the membranes. The physical movement of the GAC particles against the membranes helped keep the membranes clean and reduce membrane fouling. Thus, the GAC-fluidized AnMBR is a unique membrane bioreactor system that employs a novel energy-efficient approach for control of membrane fouling.

Although a relatively new technology, as compared with gas-sparged AnMBRs, the GAC-fluidized AnMBR has been demonstrated at pilot scale to successfully treat settled and screened domestic wastewater at temperatures as low as 8°C (Bae et al. 2013, Shin et al. 2014). Therefore, it is considered a viable technology and comparison to the gas-sparged system was conducted.

2.2 TECHNOLOGY DEVELOPMENT

2.2.1 AnMBR

The AnMBR concept was reported in literature as early as 1978. Since then, the technology has been developed and operated at pilot-scale and full-scale, mostly in industrial and high strength wastewater applications. As of 2016, there were an estimated 22 full-scale installations by various manufacturers. Recently there has been an increasing interest in using AnMBRs for treating municipal wastewater. This technology has also been tested at the lab and pilot scales for relatively low strength domestic wastewater (Berube et al. 2006, Dagnew et al. 2011, Dereli et al. 2012, Dong et al. 2015b, 2016, 2018, Dunaev et al. 2010, Grant et al. 2008, Kanai et al. 2010, Kim et al. 2011, McCarty et al. 2011, Raskin et al. 2012, Smith et al. 2012a, Smith et al. 2013, Smith et al. 2012b). However, there are a limited number of installations for this application due to the issues associated with low ambient temperatures and low organic strength. This section provides an overview of AnMBR technology research and development.

Anaerobic treatment processes, such as anaerobic digestion, are generally thought to be limited to mesophilic (~35ºC) and thermophilic (~55ºC) temperatures. This would appear to be an impediment to treatment of domestic wastewater where temperatures in the U.S. range from

3 to 27ºC and average about 16ºC (Smith et al. 2012b). However, recent research has indicated successful anaerobic treatment of domestic wastewater at temperatures of 15ºC (Smith et al. 2012a, Smith et al. 2013) and even as low as 10ºC (Bae et al. 2013, Yoo et al. 2012, Yoo et al. 2014). Even lower temperatures may be possible (Smith et al. 2015). Thus, the AnMBR can be expected to treat a significant fraction of U.S. wastewater, but not necessarily all wastewater. Anaerobic treatment of wastewater at seasonally varying temperatures is possible with the AnMBR due to high microbial concentrations and community adaptation. High microbial concentrations promote high volumetric BOD_5 removal rates even though specific microbial activities may be lower at relatively low temperatures. The use of membranes in both AnMBR configurations and the use of GAC to support microbial biofilms in the GAC-fluidized AnMBR promote residence and development of high microbial concentrations.

A pilot-scale evaluation of the gas-sparged AnMBR demonstrated that it is feasible to employ the AnMBR for municipal wastewater treatment at ambient temperature (Dagnew et al. 2012, Dagnew et al. 2011). During a steady state period, the organic loading rate (OLR), hydraulic residence time (HRT) and solids residence time (SRT) were 0.58 kg-COD m^{-3} d^{-1}, 7.5 h and 80-100 d, respectively, and the mixed liquor VSS in the anaerobic bioreactor ranged from 9 to 14 grams per liter (g/L). Compared to previous studies of AnMBRs treating similar wastewaters, a good effluent quality of 14 mg/L BOD_5 and stable membrane operation with transmembrane pressure (TMP) of less than 5 kiloPascals (kPa) at a flux of 17 LMH was established using a scalable AnMBR system configuration. The AnMBR technology was capable of meeting and exceeding EPA secondary treatment requirements of 30 mg/L BOD_5 and 30 mg/L TSS (Figure 2.7) (Dagnew et al. 2011).

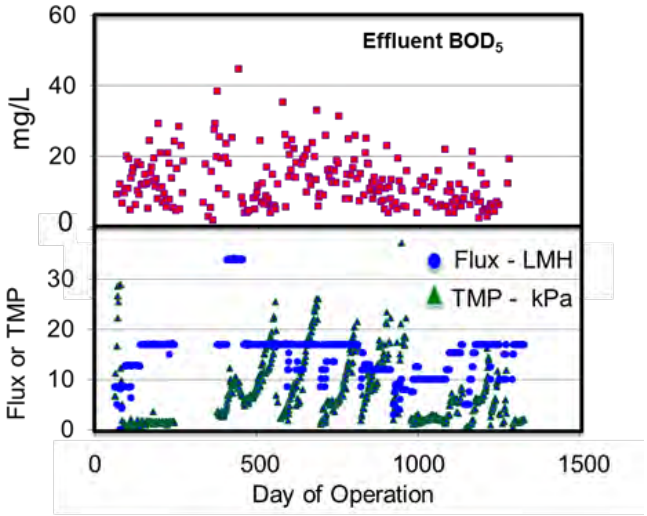

Figure 2.7 Gas-sparged AnMBR Performance.

During this time the pilot was operated under a number of bioreactor and membrane process operating conditions. The reported TMP values reflect the impact of operation over a range of fluxes, solids loadings, cleaning strategies, sparging rates and temperatures. During treatment of this municipal wastewater, most methane remained dissolved in the permeate and was not recovered. Therefore, methane recovery from the permeate is required both to achieve energy recovery and to prevent emission of methane, a powerful greenhouse gas.

A 7- to 12-cubic meter per day (m^3/d) pilot study of the GAC-fluidized AnMBR process was conducted for over a year at the Bucheon wastewater treatment plant near Seoul, South Korea (Figure 2.8). The primary reactor was operated at a 2-h HRT, and the secondary membrane bioreactor was operated at 2.3- to 4.8-h HRT, for a total HRT of 4.3 to 6.8 h. Net membrane flux varied between 4.1 and 7.5 LMH. The membrane system was installed and began operating just as winter was approaching, and hence, full acclimation to meet the resulting wastewater temperatures as low as 8ºC did not occur. Nevertheless, effluent BOD_5 never exceeded 40 mg/L, and over two months with wastewater temperature in the range of 23 to 26ºC, effluent COD was less than 30 mg/L with effluent BOD_5 of 6 mg/L or less. Under subsequent winter conditions, effluent BOD_5 averaged less than 10 mg/L (Shin et al. 2014).

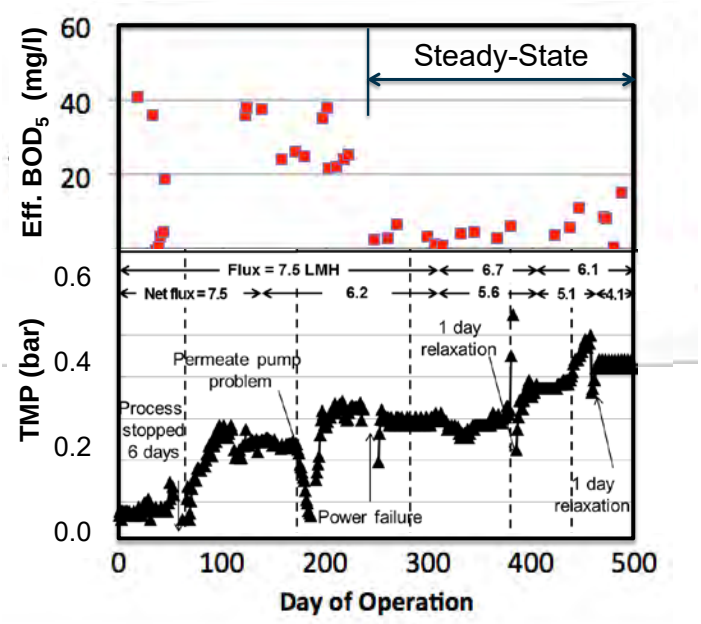

Figure 2.8 Pilot-scale Results for the GAC-fluidized AnMBR.

There have been several laboratory evaluations of the GAC-fluidized AnMBR process with dilute wastewater (Kim et al. 2011, Yoo et al. 2012, Yoo et al. 2014). One publication contains studies on screened settled domestic wastewater obtained from the Bucheon treatment plant at temperatures in 5ºC increments from 10 to 25ºC (Bae et al. 2013). The primary reactor was operated at a 1-h HRT and the secondary membrane bioreactor at a 1.3-h HRT, for a total of 2.3-h HRT. The system had been operating for 200 d before the temperature evaluation was started, so the system was well acclimated. Average influent COD varied from 235 to 300 mg/L. Effluent COD averaged no more than 30 mg/L, effluent BOD_5 averaged no more than 7 mg/L, even at 10ºC, and effluent TSS was less than 1 mg/L. Waste biosolids production was only 0.01 to 0.03 kilograms TSS per kilogram COD (kg-TSS/kg-COD), less than one-tenth that of an aerobic system. Operating at a flux of 9 LMH, no membrane cleaning was required for over 200 d of operation. The energy requirement for system operation was estimated at 0.05 kWh/m^3, which is about one-fourth of the electrical energy that could be obtained from cogeneration with the methane produced. No damage to membranes from GAC scouring was observed after two years of operation.

2.2.2 Methane Recovery and Energy Neutrality

Previous AnMBR research demonstrated that a significant percentage of the produced methane remains dissolved in the permeate rather than being evolved as biogas (Bandara et al. 2012, Bandara et al. 2011, Dagnew et al. 2012, Dagnew et al. 2011, Shin et al. 2016c). Attainment of the goal of energy neutrality requires recovery and use of this dissolved methane. Hollow-fiber gas-transfer membranes have been used successfully at small scales for recovery of dissolved methane from AnMBR permeate (Bandara et al. 2012, Bandara et al. 2011, Cookney et al. 2012, Crone et al. 2016). This technology has also been used to deoxygenate water and remove carbon dioxide from water at large scales on the order of millions of gallons per day. Modeling conducted by 3M Corporation indicates greater than 90% methane removal when operated under conditions of 12°C and 50 millimeters mercury (mm Hg) absolute pressure (Figure 2.9). This approach produces a concentrated biogas stream. It will contain hydrogen sulfide, carbon dioxide, and moisture in addition to methane.

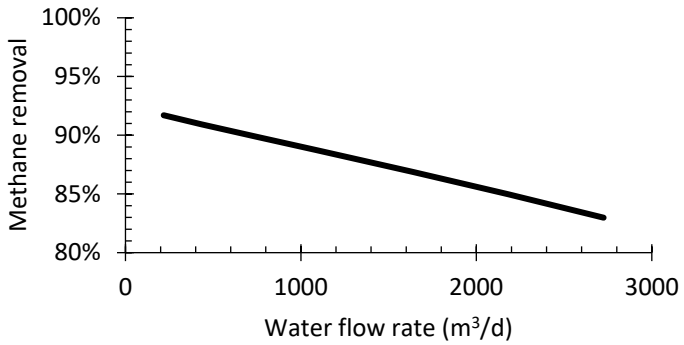

Figure 2.9 Predicted 8×20 Industrial Liqui-Cel gas-liquid Hollow-fiber Membrane Contactor Performance for Removal of 12 mg/L Dissolved Methane.

Energy balances have demonstrated the AnMBR system can be energy neutral or positive (Kim et al. 2011, Yoo et al. 2012). Electrical energy requirements were calculated to be 0.012 and 0.037 kWh/m^3 for the AFBR and AFMBR, respectively, or total electrical energy requirement of 0.049 kWh/m^3 (Table 2.1). The gaseous methane production from both the AFBR and AFMBR was sufficient to generate 0.119 kWh/m^3 of electrical energy, which was 74% more energy than the demand. An additional 0.063 kWh/m^3 could be obtained from effluent dissolved methane. Note these studies were conducted with primary effluent. If the energy content of the primary solids were included, the energy balance would be more positive yet.

Table 2.1 Electrical Energy Requirements and Potential Production from Laboratory Study of GAC-fluidized AnMBR.

	AFBR	AFMBR	System Total
Electrical Energy Required			
Energy for fluidizing GAC			
Reactor head loss, cm H_2O	3.4	3.8	NA
Reactor influent plus recirculation flow rate, L/d	452	1013	NA
Fluidization energy requirement, kW [a]	1.74×10^{-6}	4.37×10^{-6}	NA
Required pumping energy, kWh/m^3 [b]	0.0070	0.0228	0.0298
Energy for permeate extraction			
Average TMP, cm H_2O	NA	23.8	NA
Permeate flow rate, L/d	NA	4.6	NA
Permeate energy requirement, kW [a]	NA	1.24×10^{-7}	NA
Required pumping energy, kWh/m^3 [b]	NA	0.0006	0.0006
Total pumping energy required for system, kWh/m^3	0.0070	0.0234	0.0304
Total electrical energy required for pumps, kWh/m^3 [c]	0.011	0.036	0.047
Electrical Energy Production Potential			
Methane production, mol/m^3 influent			
Gaseous	0.285	0.116	NA
Dissolved	NA	0.707	NA
Total	0.285	0.823	1.108
Methane energy content, kWh/m^3 [d]	0.063	0.183	0.246
Electrical energy production from methane, kWh/m^3 [c]	0.021	0.061	0.082
Electrical energy produced/required	1.91	1.69	1.74

[a] Energy requirement = 9.8QE, where Q (m^3/s) is flow rate and E (m H_2O) is head loss (Kim et al. 2011).
[b] Energy per unit of AFBR and AFMBR influent flow rates.
[c] Assumed energy transfer efficiency of 33% in conversion of methane to electricity and of 65% in conversion of electrical energy to pump energy (Kim et al. 2011).
[d] Energy available from methane combustion is 800 kJ/mol (0.222 kWh/mol) (Kim et al. 2011)

2.2.3 Sulfide and Nutrient Removal

A successful evaluation of coagulation-flocculation-sedimentation for sulfide and phosphorus removal from AnMBR permeate was conducted at the Bucheon wastewater treatment plant during winter months with temperatures between 10 and 15ºC. Ferric chloride (30 mg-Fe/L) consistently reduced effluent sulfide down from 8.7 to 0.1 mg/L and phosphate from 2.8 to 0.3 /,9milligrams phosphorus per liter (mg-P/L) at a pH between 7 and 9 with a water temperature of 11ºC (Figure 2.10).

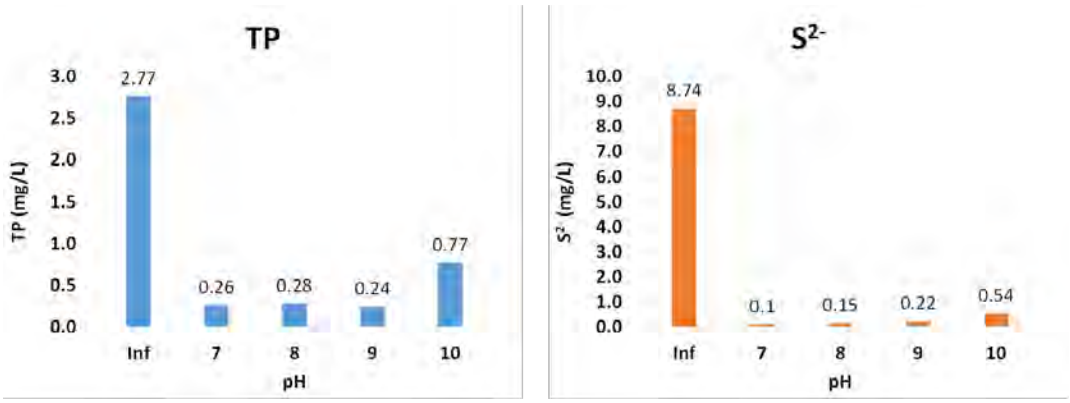

Figure 2.10 Ferric Chloride Coagulation of AnMBR Effluent Demonstrating Phosphorus and Sulfide Removal.

Satisfying ammonia discharge requirements requires alternative approaches to traditional energy intensive aeration-based processes (McCarty 2018). To this end, a novel energy-efficient approach for ammonia removal developed under the SERDP funding (Guy et al. 2016) was further assessed in this project. Ammonia (in the form of ammonium ion) is removed from water by means of clinoptilolite (Figure 2.11). Clinoptilolite is a naturally occurring zeolite that is capable of selectively removing ammonium ions from water via an ion exchange mechanism (Hegger 2010). The relative abundance of clinoptilolite in the U.S., its inexpensive cost, and environmentally friendly nature make it an ideal nitrogen removal technology. Following collection on clinoptilolite, the sequestered ammonia can be used as a fertilizer via spreading of the clinoptilolite on land, or the clinoptilolite can be regenerated with a brine solution and then used for further treatment. Dr. Kathryn Guy at the Construction Engineering Research Laboratory (CERL), Principal Investigator for the SERDP project, has assessed the feasibility of clinoptilolite regeneration and ammonia electrolysis for hydrogen and electricity production (Guy et al. 2016). Traditionally, ammonia brines would be considered a potentially difficult waste to manage for municipal wastewater treatment plant. However, the concentrated ammonia in this form is ideal for feeding into a developing technology such as ammonia electrolysis. Ammonia electrolysis has the benefit of producing hydrogen from the ammonia, potentially offsetting the energy input required for treatment.

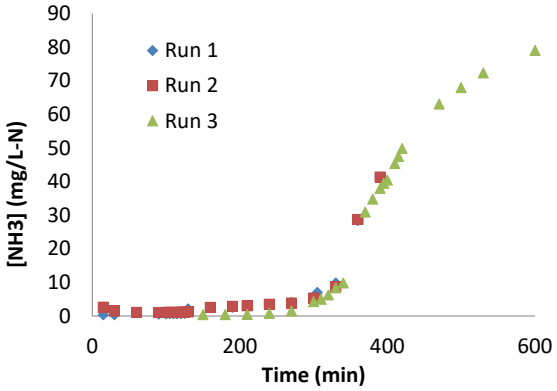

Figure 2.11 Clinoptilolite Ammonia Breakthrough Curves Determined in Previous Studies (Guy et al. 2016).

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

2.3.1 AnMBR Advantages

The general advantage to DoD is a cost-efficient, small-footprint, and scalable technology for treating domestic wastewater. Specific benefits of the AnMBR process include:

- Potentially energy-neutral or energy-positive technology for wastewater treatment.
- Low sludge production.
- Low effluent BOD_5 and TSS concentrations, comparable to highly treated wastewaters acceptable for non-potable reuse.
- Potential applicability to more than 50% of wastewater reclamation facilities in the Continental United States (CONUS) based on temperature of domestic wastewater.

2.3.2 AnMBR Limitations

The limitations associated with using AnMBR technology for treating domestic wastewater will be evaluated during this demonstration. Known and potential limitations are presented below.

- Full-scale demonstration of AnMBR systems for efficient domestic wastewater treatment has not yet been demonstrated.
- The primary technical limitation generally assumed for AnMBR treatment of domestic wastewater is related to the low organic strength of domestic wastewater and low wastewater temperature. For the AnMBR to be applicable to DoD installations in the CONUS, it must be capable of treating a significant fraction of wastewater streams, which vary in temperature.
- Technical limitations are also associated with other water quality parameters. The AnMBR process can treat carbonaceous BOD_5 but requires additional processes for treating nutrients such as nitrogen and byproducts such as sulfide. However, secondary treatment, and not advanced nutrient removal, is generally required for the majority of DoD installations. Additionally, there are many newer processes for nitrogen removal that are particularly appropriate for anaerobically treated wastewaters, such as the one evaluated in this demonstration.
- Methane recovery is a potential limitation. Much of the methane remaining in the AnMBR permeate can be dissolved, but there are many potential processes available to address this issue, such as the use of gas-liquid hollow-fiber mass transfer systems to recover methane, which were evaluated as part of this demonstration.
- Membrane fouling is a potential limitation of all membrane processes. This important area was explored in this study.
- Biosolids quality for some uses is a potential limitation and was explored in this study to build upon previous research (Dong et al. 2015a). The amount of biosolids that is produced by anaerobic processes has been demonstrated to be less than that in aerobic processes and waste heat can be used for drying (Scherson and Criddle 2014).

3.0 PERFORMANCE OBJECTIVES

A summary of the performance objectives and results are presented and described in this section. The performance objectives provided the basis for evaluating the performance and costs of AnMBR technology. A detailed presentation of the results and substantiation of the conclusions is presented in Sections 5 and 6.

3.1 SUMMARY OF PERFORMANCE OBJECTIVES AND RESULTS

The quantitative performance objectives for this project are summarized in Table 3.1. Table 3.1 includes quantitative performance objectives, which have specific quantitative targets. Qualitative performance objectives are summarized in Table 3.2. Qualitative performance objectives were used to determine if enough information was collected for optimizing the evaluated technologies and potentially implementing them at full scale.

3.2 QUANTITATIVE PERFORMANCE OBJECTIVES

3.2.1 Effectiveness

The effectiveness of the AnMBR technology was assessed with respect to treated water quality. The success was assessed by comparing water quality parameters to EPA secondary treatment standards, published criteria for water reuse, and other applicable metrics.

Data Collected

Data requirements are listed in Table 3.1 and include metrics for oxygen demand (i.e., COD and BOD_5), nutrients (i.e., ammonia and total phosphorus), sulfide, total suspended solids, turbidity, pH and dissolved methane. Dissolved methane is included because it is a potent greenhouse gas.

Results and Interpretation

Success was determined by the ability of the processes to treat water that meets EPA secondary standards and/or NSF/ANSI 350 reuse standards. While EPA secondary standards for BOD_5 and total suspended solids are well defined, standards for nutrients are normally based on total maximum daily load calculations and are specific to the point of discharge. Criteria for reuse also vary widely across the nation and depend on the specific reuse scenario. Nutrient removal metrics of 90% are listed as success criteria; however, lower removal percentages may provide water suitable for non-potable reuse applications, such as agricultural or landscape irrigation. Other water quality indicators, such as sulfide and dissolved methane, do not necessarily have regulatory standards but are important with respect to odors and potential for greenhouse gas emissions. Additionally, if not removed, they contribute to BOD_5 and COD.

Table 3.1 Quantitative performance objectives and results. Results (average±standard deviation) are for non-upset conditions as discussed in Section 5.

Performance Objective	Data Requirements	Success Criteria	Gas-Sparged AnMBR Results	GAC-Fluidized AnMBR Results
Effectiveness	• COD	• ≤ 60 mg/L	• Met – Permeate COD was 58±27 mg/L with influent COD of 620±240 mg/L.	• Met – Permeate COD was 29±9 mg/L with influent COD of 210±50 mg/L.
	• BOD_5	• ≤ 30 mg/L[a] ≤ 10 mg/L[b]	• Met 30-mg/L goal – Permeate BOD_5 was 25±12 mg/L with influent BOD_5 of 250±130 mg/L.	• Met 30-mg/L goal – Permeate BOD_5 was 15±9 mg/L with influent BOD_5 of 140±40 mg/L.
	• Ammonia	• ≥ 90% removal	• Met – 99.9±0.1% removal.	• Not evaluated.
	• Total phosphorus	• ≥ 90% removal	• Met – 94±3% removal.	• Not evaluated.
	• Total sulfide	• ≤ 0.1 mg/L (established in the Technology Demonstration Plan, but may be unreasonably low)	• Not Met – 0.67±1.7 mg/L with 99±2% removal. Median was 0.10 mg/L.	• Not evaluated.
	• Total suspended solids	• ≤ 30 mg/L[a] ≤ 10 mg/L[b]	• Met 30-mg/L goal – 25±17.	• Not evaluated.
	• Turbidity	• ≤ 2 NTU[b]	• Not Met – 9.8±8.8 NTU.	• Not Met – 5.3±3.2 NTU.
	• pH	• 6-9[2]	• Met – 8.1±1.1.	• Met – 7.3±0.2.
	• Dissolved methane	• ≥ 90% removal	• Not Met – 79±2% removal. Maximum removal 83%.	• Not evaluated.

Performance Objective	Data Requirements	Success Criteria	Gas-Sparged AnMBR Results	GAC-Fluidized AnMBR Results
Net Energy Production Efficiency	• Liquid flow rates & pressures • Biogas flow rate • Biogas methane content • Gas-liquid membrane contactor flow rates and pressures • Engineering design calculations	• Energy neutrality where ratio of energy produced to energy consumed ≥ 100%	• Met under certain conditions – At average flux, ratio was 60% for T < 20°C and 84% for T > 25°C. At maximum flux ratio was 100% for T < 20°C and 150% for T > 25°C.	• Met under certain conditions – At average flux without supplemental COD, ratio was 55% for T < 20°C and 90% for T > 25°C. At average flux with supplemental COD, ratio was estimated to be 77% for T < 20°C and 130% for T > 25°C.
Implementability	• Organic loading rate	• ≥ 0.6 kg COD m^{-3} d^{-1}	• Met – 1.3±0.5 kg COD m^{-3} d^{-1}	• Met – 1.4±0.5 kg COD m^{-3} d^{-1}
	• Hydraulic residence time	• ≤ 20 h	• Met – 11±3 h	• Met – 3.9±1.0 h
	• Biosolids production	• ≤ 0.2 g VSS/g COD loaded	• Met – 0.074 g-VS/g-COD	• Met – 0.13 g-VSS/g-COD
	• Membrane flux (net)	• ≥ 6 LMH	• Met – 7.6±1.6 LMH	• Met – 7.9±2.2 LMH
	• Maintenance cleaning frequency	• ≤ 3 times per week	• Met – 0.3/week	• Met – 0.5/week
	• Recovery cleaning frequency	• ≤ 6 times per year	• Met – 1.5/year	• Met – 2/year
	• Wastewater temperature	• Effectiveness at ≥ 10 °C	• Inconclusive – only one data point available for 10 to 15 °C. Met for ≥ 15°C	• Inconclusive – only three data points available 10 to 15 °C. Met for ≥ 15°C
	• Dissolved methane removal rate	• ≥ 0.5 g m^{-2} d^{-1} (based on 20 mg/L influent dissolved methane)	• Met – 6.5±1.8 g m^{-2} d^{-1}	• Not evaluated

Performance Objective	Data Requirements	Success Criteria	Gas-Sparged AnMBR Results	GAC-Fluidized AnMBR Results
	• Clinoptilolite robustness	• Ammonia loading decreases by no more than 10% after 10 regeneration cycles	• Not Met – 33±18% decreased after 2 regeneration cycles	• Not evaluated
	• Total phosphorus removal rate	• ≥ 60 mg L^{-1} d^{-1} (based on 4.0 mg-P/L influent)	• Not Met – 53±13 mg L^{-1} d^{-1} (maximum was 68)	• Not evaluated
	• Ammonia removal rate	• ≥ 2 g L^{-1} d^{-1} (based on 29 mg-N/L influent)	• Met – 4.4±0.9 g L^{-1} d^{-}	• Not evaluated
	• Electrolysis	• ≥ 90% ammonia removal	• Not Met – 0% removal	• Not evaluated
	• Safety	• No OSHA-reportable safety incidents	• Met	• Not evaluated
	• Ease of use	• Wastewater treatment plant operator certification requirement	• See text	• See text

[a] EPA secondary treatment standard
[b] NSF/ANSI 350 reuse standard

Table 3.2 Qualitative performance objectives and results.

Performance Objective	Data Requirements	Success Criteria	Results
Compare gas-sparged and GAC-fluidized AnMBRs	• COD • BOD_5 • Total suspended solids • Turbidity • pH • Liquid flow rates and pressures • Biogas flow rate • Biogas methane content • Engineering design calculations • Organic loading rate • Biosolids production • Membrane flux (net) • Maintenance cleaning frequency • Recovery cleaning frequency	• Collect comparable data to allow comparison between the technologies with respect to attainment of quantitative performance objectives	• Section 3.2 • Section 5.7 • Section 6.2.1
Assess system performance with respect to temperature	• Effectiveness data (see quantitative performance objectives) • SRT, HRT, OLR, membrane flux and TMP • VFAs and alkalinity • Temperature	• Develop quantitative relationships between reaction rates, membrane flux/TMP, and wastewater temperature	• Section 5.7.5 • Section 5.7.14 • Section 6.2.2
Characterize gas composition	• Gas composition (CH_4, CO_2, N_2, O_2), siloxanes, H_2S	• Collect sufficient data to determine gas purification requirements for power production	• Section 5.7.20 • Section 6.2.3
Characterize process residuals	• AnMBR sludge production rate and analysis (total solids, total suspended solids, volatile solids, volatile suspended solids, total fixed solids, fixed suspended solids, pathogen indicators, Part 503 biosolids indicators, dewaterability) • Flocculation/settling system sludge production rate and analysis (reactive sulfide, total phosphorus, total iron, RCRA metals, total solids)	• Collect sufficient data to determine residuals handling and disposal requirements as well as potential for beneficial reuse	• Section 5.7.19 • Section 6.2.4

Performance Objective	Data Requirements	Success Criteria	Results
Characterize ammonia sorbent performance	• Ammonia loading and breakthrough time per cycle • Sorbent regenerability	• Collect sufficient data to determine ammonia removal cost and performance	• Section 5.7.17 • Section 6.2.5
Characterize membrane performance	• Membrane analyses • Monitor membrane breakage/failure	• Collect sufficient data to determine membrane fouling and longevity	• Section 5.7.14 • Section 6.2.6
Conduct a broad lifecycle assessment (LCA)	• Power requirements, residuals generation, materials (including chemical usage and unique capital construction materials), power generation, greenhouse gas emissions, water reuse potential	• Collect sufficient data to conduct a simplified LCA and compare lifecycle environmental impacts of a conventional wastewater treatment process	• Section 7.4
Characterize treated water with respect to various water reuse alternatives[1]	• BOD_5, TSS, total nitrogen, ammonia, nitrate, nitrite, total phosphorus, sulfide, turbidity, *E. coli*, total coliforms, pH, specific conductivity	• Collect sufficient data to adequately characterize water quality	• Section 5.7.18 • Section 6.2.8
Characterize chlorine demand[1]	• Chlorine demand	• Collect sufficient data to adequately characterize chlorine demand	• Section 5.7.18 • Section 6.2.9
Characterize microbial ecology	• DNA sequencing, qPCR analysis	• Collect sufficient data to adequately characterize microbial ecology	• Sections 5.7.21 and 5.7.22

COD and BOD_5

The average effluent COD concentration in the gas-sparged AnMBR was 58±27 mg/L (average ± standard deviation) which about equal to the performance objective of 60 mg/L. The average COD removal was 90±4%. The average effluent COD concentration in the GAC-fluidized AnMBR was 29±9 mg/L, which is less than the performance objective ($p < 0.001$). The average COD removal was 86±3%. The influent COD concentrations in the gas-sparged and GAC-fluidized AnMBRs were 620±240 mg/L and 210±50 mg/L, respectively, which may have contributed to the differences in the effluent concentrations.

The average effluent BOD_5 concentration in the gas-sparged AnMBR was 25±12 mg/L, which is less than the performance objective of 30 mg/L ($p=0.004$) but greater than the reuse objective of 10 mg/L. The average BOD_5 removal was 89±5%. The average effluent BOD_5 concentrations in the GAC-fluidized AnMBR was 15±9 mg/L, which is less than the performance objective of 30 mg/L ($p < 0.001$) and greater than the re-use objective of 10 mg/L. The average BOD_5 removal was 85±7%. The influent BOD_5 concentrations in the gas-sparged and GAC-fluidized AnMBRs were 250±130 mg/L and 140±40 mg/L, respectively, which contributed to the differences in the effluent concentrations.

Fine screening was the only form of primary treatment used in this demonstration. Primary sedimentation may have resulted in even lower effluent concentrations and potentially less than 10 mg/L BOD_5 based on previous demonstrated with the GAC-fluidized AnMBR (Dagnew et al. 2011, Dong et al. 2016, Shin et al. 2014).

Ammonia

The ammonia removal by the clinoptilolite column after four hours (12 to 20 empty bed volumes) was 99.9±0.1%, which is greater than the performance objective of 90% ($p < 0.0001$). The influent and effluent ammonia concentrations were 37±4 and 0.05±0.05 milligrams of nitrogen per liter (mg-N/L), respectively. Initial ammonia breakthrough was observed after 50 to 100 empty bed volumes.

Total Phosphorus

Total phosphorus was reduced from 7.0±2.9 mg/L in the screened AnMBR influent to 0.43±0.29 in the clinoptilolite effluent for an overall removal of 94±3%, which was greater than the performance objective of 90% ($p=0.052$). The overall removal for total phosphorus was a result of the individual removals attributable to the AnMBR, chemical coagulation, and clinoptilolite sorption. The coagulation-flocculation-sedimentation process removed most of the phosphorus. Total phosphorus concentrations in the coagulation influent were reduced from 4.2±0.6 mg/L by 83±9% (effluent concentration 0.72±0.36 mg/L).

Total Sulfide

Sulfide was reduced from 27±5 to 0.7±1.7 mg/L. Effluent sulfide was > 1 mg/L on days 382 and 437 for unknown reasons, which contributed to the high standard deviation. The median and minimum effluent concentrations were 0.10 and 0.04 mg/L, respectively. Overall sulfide removal including these elevated values was 99±2%. While the median sulfide concentration met the performance objective, the average concentration did not. Further optimization would likely have improved the performance leading to attainment of the performance objective.

Total Suspended Solids and Turbidity

Total suspended solids in the gas-sparged AnMBR final effluent (i.e., clinoptilolite column effluent) was 25±17 mg/L and less than the EPA secondary treatment standard of 30 mg/L although not at a statistically significant level (p=0.30). Turbidity was elevated in both the gas-sparged and GAC-fluidized AnMBR and greater than the performance objective of 2 nephalometric turbidity units (NTU). The gas-sparged AnMBR sedimentation basin was undersized, which lead to elevated total suspended solids and turbidity. These processes are standard, and final effluent quality could be improved through process design and optimization. The GAC-fluidized AnMBR turbidity was likely associated with precipitation of the anaerobic ultrafiltration permeate following exposure to the atmosphere. Coagulation was not tested downstream of the GAC-fluidized AnMBR.

pH

The pH of the gas-sparged and GAC-fluidized AnMBR permeates were 6.9±0.2 and 7.3±0.2, respectively. The final gas-sparged AnMBR effluent (i.e., after coagulation and ammonia removal) was 8.1±1.1. All pH values met the performance objectives of 6 to 9 ($p \leq 0.017$).

Dissolved Methane

The average dissolved methane removal under optimized conditions was 79±2%, which was not greater than the performance objective of 90%. The influent dissolved methane concentration for these tests was 13±2 mg/L.

3.2.2 Net Energy Production Efficiency

The amount of energy necessary to operate the AnMBR systems was evaluated and compared to potential energy from generated biogas and recovered dissolved methane to determine whether the systems met the goal of energy neutrality.

Data Collected

Data requirements are listed in Table 3.1. Energy consuming processes included pumping between the bioreactor and the membrane tank, mixing, GAC fluidization, biogas sparging, and permeate pumping. The vacuum pump used to operate the gas-liquid contactor was also evaluated for energy consumption. Monitoring of these processes included measurements of flow rates and pressure drops. Other energy consuming processes in the pilot systems, such as liquid metering pumps, may be significant at pilot-scale but would not be significant at full-scale and were not monitored. Engineering design calculations were conducted to estimate full-scale unit energy consumption (e.g., kWh/m^3 water treated) for each energy consuming process. These calculations used data collected during the pilot demonstration. Energy production was based on measured biogas flow rates and methane composition which varied in relation to temperature. Calculations of electricity consumption and generation used standard efficiencies.

Results and Interpretation

Energy consumption and production were calculated for a matrix of operating scenarios that included various net permeate fluxes and temperatures for the gas-sparged and GAC-fluidized AnMBRs. Temperature was an important factor because the total methane yield was observed to be greater at elevated temperatures. Energy neutral or positive operation was estimated for some but not all of these scenarios. In general, energy-neutral or positive operation was more likely at greater flux, temperature, and influent COD concentration. At the average observed flux for the gas-sparged AnMBR (7.6 LMH), the ratio of energy produced:energy consumed was 60% for T < 20°C and 84% for T > 25°C (COD = 620 mg/L). At the maximum flux (14 LMH), the ratio was 100% for T < 20°C and 140% for T > 25°C. At the average flux for the GAC-fluidized AnMBR (7.9 LMH) and without supplemental COD (COD = 210 mg/L), the ratio was 55% for T< 20°C and 90% for T > 25°C. If the influent COD was greater (390 mg/L), the ratio at an average flux would be 77% for T < 20°C and 130% for T > 25°C. Therefore, the performance objective of energy neutrality was met by both systems under certain conditions.

While energy neutrality may not be possible under all conditions, decreasing the net energy consumption relative to conventional activated sludge can more likely be achieved. Gas-sparged AnMBR operating conditions at high flux and low sparge rates were more likely to result in net energy consumption less than 0.3 to 0.6 kWh/m^3, which is typical for conventional wastewater treatment plants (McCarty et al. 2011, Seib et al. 2016, Smith et al. 2012b). All GAC-fluidized AnMBR operating conditions resulted in net energy consumption less than that for conventional wastewater treatment plants. These results suggest the prospect of energy reduction using AnMBR processes in place of conventional activated sludge technologies is promising.

3.2.3 Implementability

The purpose of this performance objective is to demonstrate that the AnMBR technology can be implemented at full scale in a practical manner in terms of capital cost, operating cost, and overall lifecycle cost. The success criteria were established based on typical design criteria used for conventional wastewater treatment and design criteria for previously demonstrated AnMBR systems.

Data Collected

In high-level terms, the capital cost of the AnMBR is driven primarily by the organic loading rate, HRT, and the membrane flux. The operating cost (excluding labor) is primarily driven by energy (e.g., pumping), chemical requirements (e.g., sulfide and phosphorus removal and membrane cleaning chemicals), membrane replacement, and solids generation rates and characteristics (e.g., dewaterability). These and other parameters (Table 3.1) were estimated during the demonstration and used to estimate capital and operating costs as described in Section 7. Downstream processes including dissolved methane removal, coagulation-flocculation-sedimentation and ammonia removal were also evaluated with respect to chemical use and loading rates or fluxes.

Results and Interpretation

The metrics listed in Table 3.1 were established based on previous research and reasonable operating conditions. While success will be evaluated with respect to meeting these criteria, the economic analysis will ultimately determine technology cost-effectiveness and implementability. Nevertheless, each of the implementablity parameters are discussed below.

Organic Loading Rate

The average organic loading rate in the gas-sparged AnMBR was 1.3±0.5 kg-COD m^{-3} d^{-1}, which is greater than the performance objective of 0.6 kg-COD m^{-3} d^{-1} ($p < 0.0001$). The average organic loading rate in the GAC-fluidized AnMBR without COD supplementation was 1.4±0.5 kg-COD m^{-3} d^{-1}, which is greater than the performance objective ($p < 0.0001$) and similar to the rate for the gas-sparged AnMBR. The organic loading rates of both AnMBRs were similar because both the hydraulic residence time and the influent COD for the gas-sparged AnMBR were greater than for the GAC-fluidized AnMBR. Supplemental COD was fed to the GAC-fluidized AnMBR after day 475 to increase the COD concentration. During this time (day 476 to day 535) the organic loading rate increased incrementally but averaged 2.2±0.5 kg-COD m^{-3} d^{-1}. BOD_5, and COD removals decreased during this time, suggesting the organic loading rate with supplemental COD may have been too high.

Hydraulic Residence Time

The average hydraulic residence time for the gas-sparged AnMBR was 11±3 h which is less than the performance objective of 20 h ($p < 0.0001$). The level sensor in the bioreactor tank became fouled with sludge and overestimated the liquid volume through day 283. Thus, the average hydraulic residence time was likely overestimated. The average hydraulic residence time for the GAC-fluidized AnMBR was 3.9±1.0 h, which is less than the performance objective of 20 h ($p < 0.0001$) and 65% less than the average hydraulic residence time for the gas-sparged AnMBR.

Biosolids Production

The volatile solids (VS) generation per unit mass loaded COD for each AnMBR system was calculated and compared to the performance objective of 0.2 g-VS/g-COD_{loaded}. The results were 0.074 and 0.13 g-VS/g-COD_{loaded} for the gas-sparged and GAC-fluidized AnMBR. Both of these values met the performance objective. The value for the gas-sparged AnMBR may be underestimated in part because of solids settling in the bioreactor and incomplete recovery. On the other hand, the greater solids residence time (60±27 d versus 11±5 d calculated for suspended/non-biofilm solids only) in the gas-sparged AnMBR could have led to greater hydrolysis and a lower value. The fixed solids recovery was low for both systems. Part of the low recovery for both systems was low precision of the solids analyses. When values for both systems are corrected based on the fixed solids recovery, the values (0.17 and 0.24 g-VS/g-COD) are similar to the performance objective.

Membrane Flux

Operation of the gas-sparged AnMBR over the duration of the demonstration involved variation of several variables including the HRT, wasting rate, associated bioreactor VSS concentration, UF permeation flux, and biogas blower flow rate and duty (i.e., percent of time the biogas blower was on when cycling). Operation of the GAC-fluidized AnMBR over the duration of the demonstration involved variation of several parameters including the HRT, wasting rate, bioreactor VSS concentration, and UF permeation flux. The purpose of the above variations was to optimize the AnMBR and meet all of the performance objectives.

The average net flux of the gas-sparged AnMBR for the entire demonstration, excluding periods of mechanical shutdown and COD overloading, was 7.6±1.6 LMH. This flux was greater than the goal of 6 LMH ($p < 0.0001$). The maximum net flux was 14 LMH. The average net flux of the GAC-fluidized AnMBR for the entire demonstration, excluding periods of mechanical shutdown, upsets, and COD supplementation, was 7.9±2.2 LMH. This flux was greater than the goal of 6 LMH ($p < 0.0001$). The maximum net flux was 12 LMH.

While not a performance objective, an operational objective was to maintain the transmembrane pressure less than 30 kPa to prevent irreversible fouling of the UF membranes. This operational objective was met most, but not all of the time in the gas-sparged AnMBR. The transmembrane pressure in the GAC-fluidized AnMBR was less than 30 kPa for the first 170 days and then inconsistently less than 30 kPa thereafter.

Permeabilities in both AnMBR systems decreased over the duration of the demonstration. The initial permeabilities (corrected to 20°C) from 1 to 60 days were 280±110 and 200±60 LMH/bar in the gas-sparged and GAC-fluidized AnMBR, respectively. The final permeabilities were 49±25 and 24±13 LMH/bar, respectively. Insufficient membrane maintenance cleaning may have contributed to the reduction in permeability.

Overall, the gas-sparged AnMBR ultrafiltration process demonstrated similar or greater permeability even though concentrations of solids and colloidal organics were greater. However, both systems demonstrated instability (i.e., variable permeability over time), which was attributable not only to varying operational conditions and mechanical upsets but also to differences in membrane performance caused by the different methods of fouling management (i.e., variable biogas sparging versus constant GAC fluidization). Inconsistent and insufficient maintenance cleaning also likely contributed to these instabilities.

Maintenance and Recovery Cleaning Frequency

Maintenance cleaning frequencies for the gas-sparged and GAC-fluidized AnMBRs were 0.31 and 0.45 cleans/week which is much fewer than the performance objective of ≤ 3 cleans/week. While this met the performance objective, inconsistent and insufficiently frequent maintenance cleaning likely contributed to decreased permeability over time in both systems. Recovery cleaning frequencies for the gas-sparged and GAC-fluidized AnMBRs were 1.5 and 2.0 cleans/year which are also fewer than the performance objective. Therefore, an opportunity exists to increase ultrafiltration performance by increasing the cleaning frequency.

Wastewater Temperature

The intent of this performance objective is to demonstrate attainment of effectiveness at temperatures ≥ 10°C. The COD and BOD_5 removals in the gas-sparged AnMBR did not decrease with decreasing temperatures between 15 and 30°C. The performance with respect to COD and BOD_5 removal below 15°C could not be evaluated because ambient wastewater temperatures did not go that low. COD and BOD_5 permeate concentrations did not increase as temperatures decreased between 15 and 30°C. In the GAC-fluidized AnMBR, COD and BOD_5 removals did not decrease and the permeate concentrations did not increase as temperatures decreased between 15 and 30°C.

The period of time when temperatures were between 10 and 15°C was concurrent with a process upset resulting from an inadvertent pump reversal. When non-upset data are evaluated, only three data points between 14.0 to 14.8°C exist, and they do not indicate a trend of changing performance with temperature. Therefore, insufficient data exist to evaluate performance of the GAC-fluidized AnMBR at temperatures < 15°C.

Dissolved Methane Removal Rate

This performance objective is important with respect to the capital cost and replacement cost of gas-liquid membrane contactors for dissolved methane removal. The performance objective for methane flux was 0.5 grams per square meter per day (g m^{-2} d^{-1}), and the observed flux was 6.5±1.8 g m^{-2} d^{-1} ($p < 0.0001$). If two contactors were installed in series, thereby doubling the membrane area to achieve the 90% removal objective, the performance objective for flux would still be met.

Clinoptilolite Robustness

Robustness was quantified with respect to the variation on ammonia loading over multiple regeneration cycles. No decrease in the ammonia loading (i.e., per unit mass of clinoptilolite) over multiple sorption/regeneration cycles would indicate good robustness. Two regeneration cycles were conducted, and the loading decreased by 21 to 50% compared to the performance objective of 10%. The second regeneration did not result in further decreases in ammonia loading suggesting robustness after the initial sorption/regeneration cycle, but additional loading/regeneration cycles would be required to validate this hypothesis. Therefore, the conclusion was that the performance objective for robustness has not been met, but this conclusion is based on limited testing.

Total Phosphorus Removal Rate

The phosphorus removal rate by coagulation-flocculation was 53±12 milligrams per liter per day (mg L^{-1} d^{-1}), which was less than the performance objective of 60 mg L^{-1} d^{-1} ($p=0.052$). This rate is based on the combined volume of the coagulation, flocculation, and sedimentation vessels. Further optimization may have resulted in the performance objective being met.

Ammonia Removal Rate

The ammonia removal rate prior to breakthrough was 4.4±0.9 grams per liter per day (g L^{-1} d^{-1}), which is greater than the performance objective of 2 g L^{-1} d^{-1} ($p=0.00063$). A full-scale system would conceivably be designed in a lead-lag configuration to maximize loading (i.e., the lead bed would be run past breakthrough). In this case, the overall removal rate would be less than the reported value.

Electrolysis

Electrolysis of ammonia-laded regenerant solution was conducted with GreenBox™ technology. Electrolysis was not observed with any of the solutions. It is believed that iron from upstream coagulation processes interfered negatively with the electrodes. Further studies on the linkage of clinoptilolite ion exchange with ammonia electrolysis will require non-iron based coagulants and/or a change in process order.

Safety

No Occupational Safety and Health Administration or Act (OSHA)-reportable safety events were incurred at Ft. Riley, substantiating the ability to safely design and operate an AnMBR system despite potentially hazardous concentrations of methane and hydrogen sulfide.

Ease of Use

The operator certification requirement for a full-scale AnMBR plant will depend on the specific requirements of the treatment plant permitting agency. During the upgrade of the Loch Sheldrake wastewater treatment plant in New York to add *aerobic* membrane bioreactors, the requirement increased from a Grade 3 to a Grade 4A operator license. This plant had conventional activated sludge and anaerobic digestors prior to the upgrade. This is just one example, and it cannot be extrapolated to other facilities.

3.3 QUALITATIVE PERFORMANCE OBJECTIVES

The ten qualitative performance objectives evaluated during the technology demonstration (Table 3.2) are discussed in Section 6. These objectives do not have numeric success criteria. Rather, they involved collection of data to enable completion of detailed analyses described in other sections of this report. Rather than repeat those analyses, Table 3.2 provides references to relevant sections in this report.

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4.0 SITE DESCRIPTION

The gas-sparged AnMBR pilot system was installed and operated at an existing wastewater pump station site at Camp Forsyth in Ft. Riley, Kansas. The GAC-fluidized AnMBR pilot system was installed and operated at the Bucheon wastewater treatment plant in Bucheon, South Korea. Additional information on these two sites is provided in this section.

4.1 GAS-SPARGED ANMBR PILOT SYSTEM SITE

Vicinity and location maps for the Camp Forsyth pump station are provided in Figure 4.1 and Figure 4.2, respectively.

The Camp Forsyth pump station used to be part of a former wastewater treatment plant. The plant was demolished and the pump station was upgraded in 2006 as part of the Advanced Wastewater Treatment Plant and Collection System Pump Station and Force Main Project (PN 45230). The pump station currently receives sewage through an 18-inch diameter gravity line and a 10-inch diameter force main and pumps it to the 'Big Bertha' pump station, which then pumps the sewage to the Custer Hill wastewater treatment plant.

The pump station consists of an electrical building, a chemical storage and metering facility, a screening facility, and a pump building. The chemical storage and metering equipment was used when the site was part of the former treatment plant, but it is not currently used. The equipment may be used in the future to provide odor control in the force main between the pump station and the 'Big-Bertha' pump station. The screening facility was installed in 2012 as part of the Upgrade Pump Station Building 2592 Project and consists of a single drum screen with approximately 1/2-inch diameter openings. Influent sewage passes through the drum screen and flows by gravity into the pump station wet well. The pump building consists of a wet well and a dry-pit, which contains the pumps. The site is surrounded by an existing chain link fence that has a lockable gate in it. The site also has existing overhead lighting, which turns on at night.

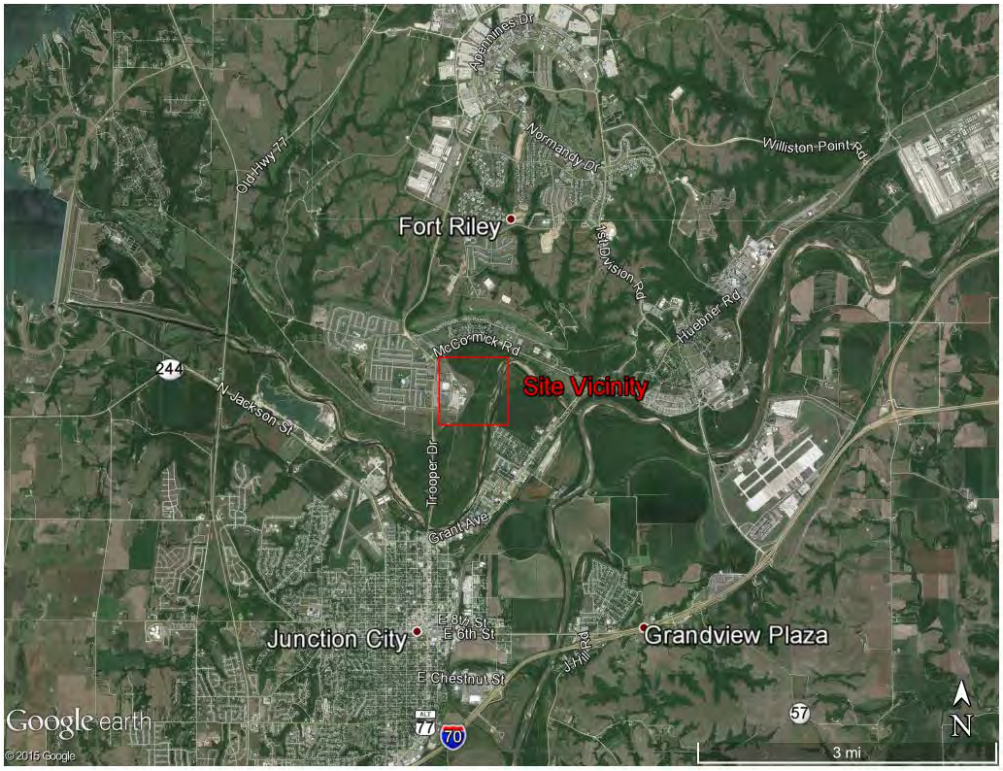

Figure 4.1 Ft. Riley Site Vicinity Map.

Figure 4.2 Ft. Riley Site Location Map

4.2 GAC-FLUIDIZED ANMBR PILOT SYSTEM SITE

The location of Bucheon wastewater treatment plant, South Korea, is indicated in Figure 4.3 (a vicinity map) and Figure 4.4 (a site location map). The general view of the Bucheon plant is also shown in Figure 4.5. The treatment processes of the Bucheon plant include a grit chamber, influent pump station, primary sedimentation tanks, aeration tanks, secondary sedimentation tanks, total phosphorus treatment facilities, sludge thickeners, sludge digesters, and dewatering facilities. The plant was founded in 1991 with a single process of Biodenipho^{TM} (520,000 m^3/d of treatment capacity). Later, a second system (four-stage biological nutrient removal process, 380,000 m^3/d of treatment capacity) was installed in 2002 to meet an increased flow rate of domestic wastewater and rigid effluent quality standards. It contains anoxic, anaerobic, and aerobic section trains.

The GAC-fluidized AnMBR pilot system was installed at the site in 2012 and has been operated for other studies. Since the pilot system is already installed at the site and is in a good location, no other sites were considered for the GAC-fluidized pilot system.

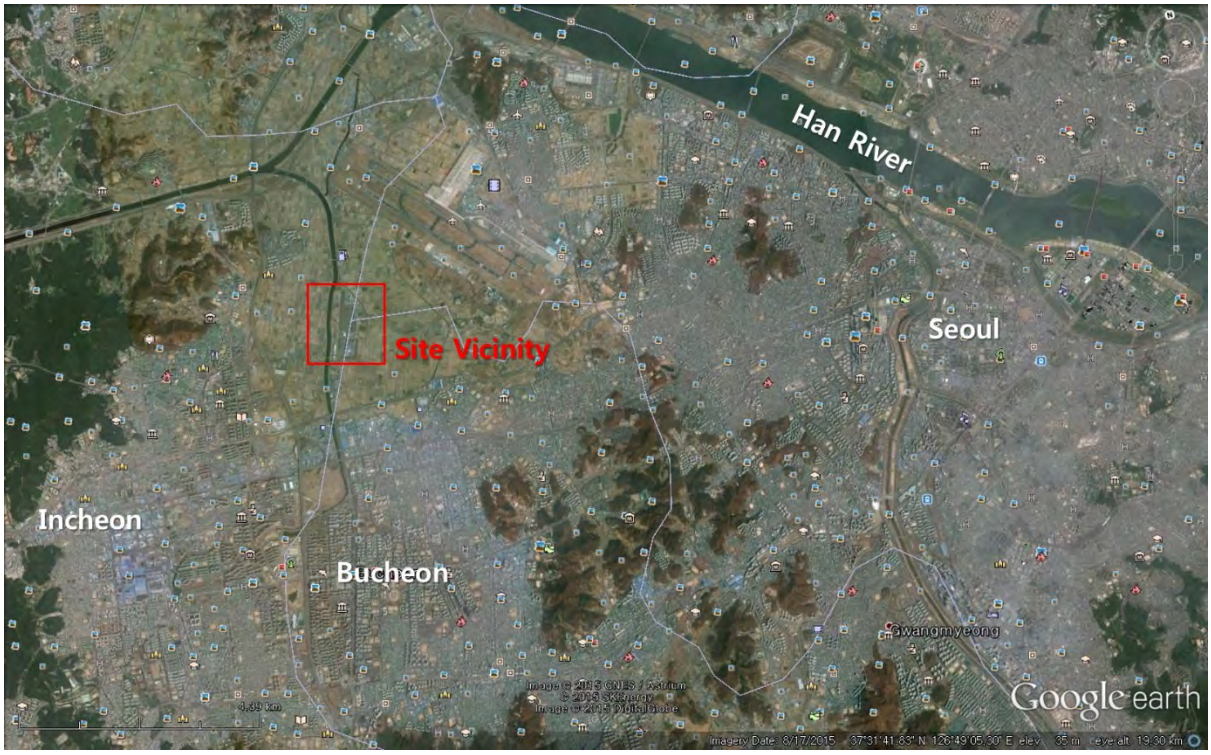

Figure 4.3 GAC-fluidized AnMBR Site Vicinity Map (South Korea).

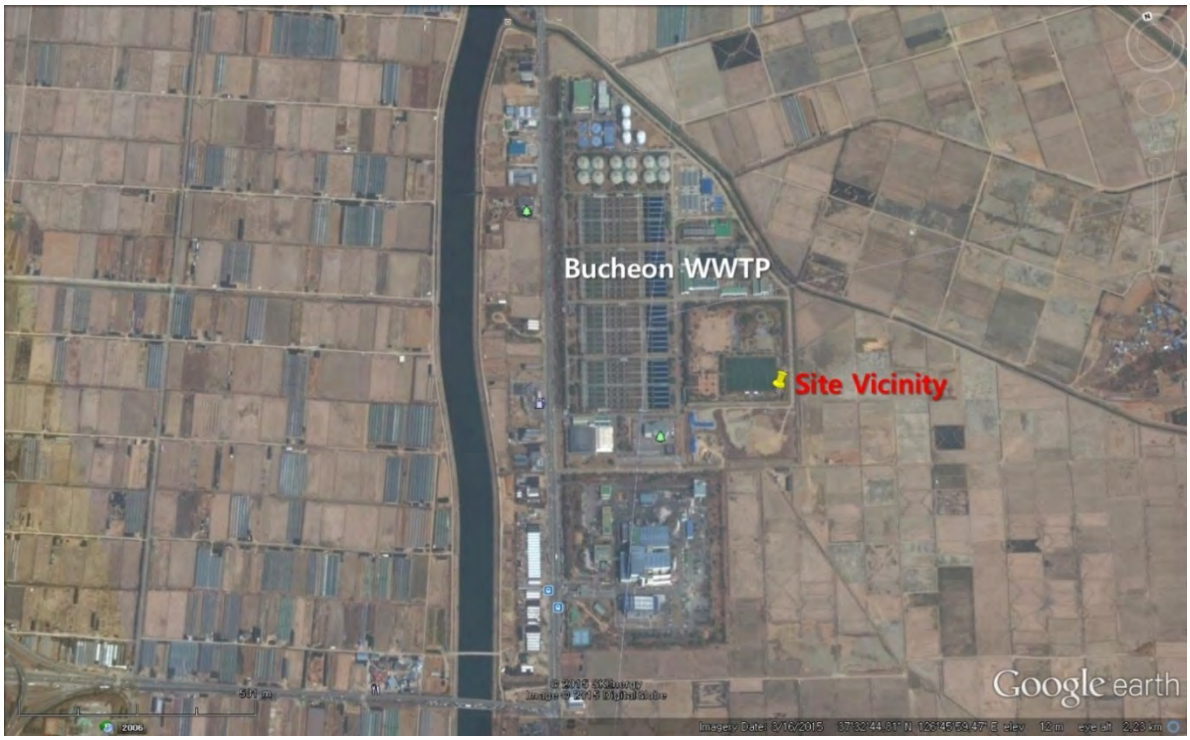

Figure 4.4 GAC-fluidized AnMBR Site Location Map (South Korea).

Figure 4.5 Bucheon Wastewater Treatment Plant (South Korea).

4.3 HISTORICAL DATA FOR BOTH SITES

One of the objectives of the demonstration is to compare the cost and performance of the gas-sparged and GAC-fluidized AnMBRs. Direct comparison was possible but limited because the two AnMBR systems treated different wastewater sources. Two important wastewater characteristics that affected the comparison are temperature and water quality. The data presented in Figure 4.6 illustrate that the wastewater temperature variation at Ft. Riley and Bucheon are similar. The minimum, median, and maximum temperatures for Ft. Riley are 12, 19, 26°C, respectively, compared to 8, 22, and 32°C for Bucheon. Directly comparable wastewater composition data are not available. Nevertheless, Ft. Riley (Camp Funston) raw wastewater and Bucheon primary effluent water quality results are shown in Figure 4.7. The primary effluent of the Bucheon plant is clearly more dilute than the Ft. Riley raw wastewater. If primary treatment is assumed to remove 45% BOD_5 (Tchobanoglous et al. 2014), then the calculated average raw Bucheon wastewater BOD_5 is 282 mg/L, which is similar to the value of 317 mg/L for Ft. Riley. If primary treatment is assumed to remove 60% TSS (Tchobanoglous et al. 2014), then the calculated average raw Bucheon wastewater TSS is 263 mg/L, which is about half of the Ft. Riley value of 506 mg/L. Despite the differences in organic matter, the wastewaters have similar nitrogen and phosphorus concentrations.

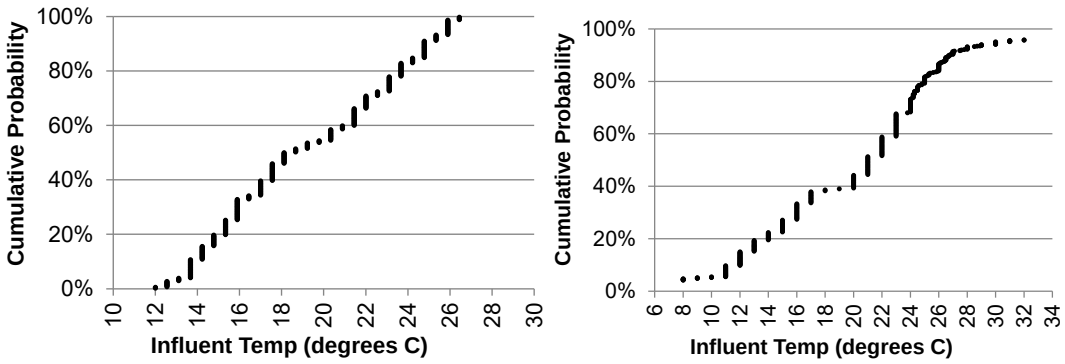

Figure 4.6 Wastewater Temperature Distributions for Ft. Riley (Camp Funston) Wastewater (left) and Bucheon (right).

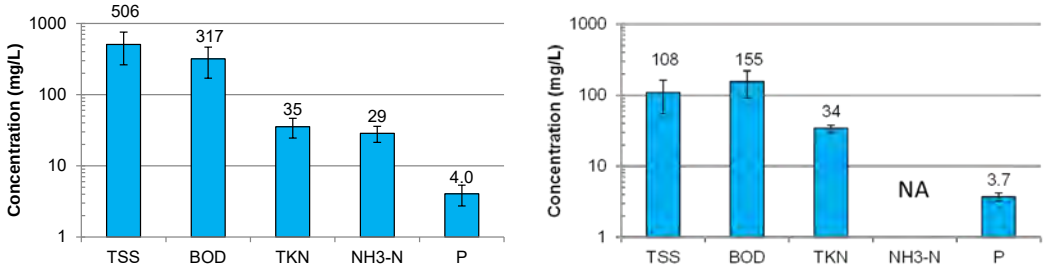

Figure 4.7 Wastewater Composition for Ft. Riley (Camp Funston) Raw Wastewater (left) and Bucheon Primary Effluent (right).

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5.0 TEST DESIGN

This section provides a detailed description of the design of the gas-sparged AnMBR pilot system and the GAC-fluidized pilot system. This section also describes the testing methods and detailed results of the testing conducted to address the performance objectives described in Section 3.

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

The gas-sparged AnMBR pilot system demonstration and the GAC-fluidized pilot system demonstration both consisted of the following phases:

- Setup: During this phase of the demonstration, the major components of the gas-sparged AnMBR pilot system were fabricated and installed in a portable trailer. The trailer was shipped to the Ft. Riley project site and installed. After installation, the pilot system was tested. The GAC-fluidized pilot system was already fabricated and installed at the Bucheon wastewater treatment plant. During this phase of the demonstration, the system was slightly modified to treat raw screened sewage rather than primary effluent.

- Startup: The startup phase for the two AnMBRs was somewhat different, as the GAC-fluidized system had previously been operated, and seeded GAC was already available to begin this demonstration.

  During startup of the gas-sparged system, the anaerobic bioreactor was seeded with mesophilic anaerobic digester sludge, and the influent flow rate was steadily increased while still meeting the effluent water quality criteria listed in Table 3.1. The startup phase for the gas-sparged AnMBR was originally anticipated to take three months but required less than one week.

  The GAC-fluidized AnMBR was already installed at the Bucheon wastewater treatment plant and had been operating from 2012 to 2015 treating settled wastewater (i.e., primary clarifier overflow) (Shin et al. 2014). It was then modified to treat screened sewage initially at an HRT of 12 h. The HRT was then reduced incrementally to 1.5 h.

- Continuous Optimization: After startup was complete and stable operation was achieved, the pilot systems were operated continuously for a period of over one year. During this time, the pilot systems were optimized continuously while the temperature and influent wastewater quality varied naturally. Optimization was achieved through adjustment of influent flow rate, permeate flow rate, sludge wasting rate, and membrane cleaning frequency. For the gas-sparged AnMBR demonstration, gas-liquid contactor conditions for dissolved methane removal, coagulant and polymer doses for sulfide and total phosphorus removal, and ion-exchange operating conditions for ammonia removal were also adjusted to optimize the performance of process units downstream of the AnMBR system.

Additional details are provided in Section 5.5.

5.2 BASELINE CHARACTERIZATION

No baseline characterization was conducted. Sampling and analysis of wastewater influent were conducted throughout the demonstration, as described in Section 5.5.

5.3 TREATABILITY OR LABORATORY STUDY RESULTS

No separate treatability or laboratory studies were conducted.

5.4 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

5.4.1 Design Criteria

The design criteria for the gas-sparged and GAC-fluidized AnMBR systems are summarized in Table 5.1.

Table 5.1 Design basis for the gas-sparged and GAC-fluidized AnMBR systems.

Parameter	Units	Gas-Sparged AnMBR	GAC-Fluidized AnMBR
Influent Screen/Strainer			
Opening size	mm	1.7	2
Primary Bioreactor			
Empty bed bioreactor active volume (used to calculate HRT)	m^3	1.3	0.99
GAC settling volume (i.e., aqueous volume in addition to above, not used to calculated HRT)	m^3	NA	0.62
Flow rate	m^3/d	1.6 - 5.5	7 - 20
HRT	h	6 - 20	1.2 - 3.5
GAC type	-	NA	Calgon Filtrasorb 300 sieved to remove < 0.8 mm
GAC	kg	NA	139
GAC fluidization velocity (empty bed basis)	m/h	NA	27
Recycle flow rate within primary bioreactor	m^3/d	18±4	220
Secondary Membrane Bioreactor			
Empty bed reactor volume (used to calculate HRT)	m^3	0.12	0.77
GAC settling volume (i.e., aqueous volume in addition to above)	m^3	NA	1.4
Membrane make	-	Suez	Lotte Chemical (formerly Samsung)
Membrane model	-	ZeeWeed 500d	SM-1015
Membrane type	-	PVDF on woven polyester	PVDF (PET filament embedded)
Membrane area	m^2	12.9 (three 4.3-m^2 modules)	60 (four 15-m^2 modules)
Pore size	µm	0.04	0.03
Membrane fiber size (OD/ID)	mm	1.9/0.8	2.1/1.1
Exposed fiber length	mm	1099	1827

Parameter	Units	Gas-Sparged AnMBR	GAC-Fluidized AnMBR
Membrane area per unit empty bed reactor volume	m^2/m^3	110	78
Membrane surface area per module footprint area[a]	m^2/m^2	349	375
Number of membranes per module footprint area	$\#/m^2$	64,286	31,500
Instantaneous flux	LMH	7 - 22	6 - 18
Net flux	LMH	5 - 18	5 - 14
Membrane cleaning chemicals	-	500 mg/L NaOCl and 2000 mg/L citric acid	500 mg/L NaOCl and 2000 mg/L citric acid
Reactor HRT	h	0.7 - 2.5	1.0 - 3.0
Combined HRT for both bioreactors	h	6.7 - 23	2.2 - 6.5
Biogas membrane sparge flow rate	L/min	25 - 100	NA
Specific biogas membrane sparge flow rate	$m^3\ m^{-1}\ h^{-1}$	0.11 - 0.46	NA
GAC type	-	NA	Calgon Filtrasorb 300 sieved to remove < 0.8 mm
GAC	kg	NA	264
GAC fluidization velocity	m/h	NA	90
Recirculation flow rate within secondary bioreactor	m^3/d	0	840
Recirculation flow rate between primary and secondary bioreactors	m^3/d	15±3	1.2±0.6
Methane Contactor			
Type	-	Microporous hollow fiber	NA
Make	-	3M Liqui-Cel	
Model	-	2.5 × 8 Industrial Extra-Flow	
Membrane type	-	X40	
Membrane area	m^2	1.5	
Vacuum pump absolute pressure	mm Hg	25	

Parameter	Units	Gas-Sparged AnMBR	GAC-Fluidized AnMBR
Rapid Mix Basin			
Volume	L	5.7	NA
Number of mixers	-	1	
Mixer speed	s^{-1}	400	
Coagulant	-	Ferric chloride and aluminum chlorohydrate	
Flocculation Basin			
Volume, total	L	83	NA
Number of chambers	-	3	
Number of mixers	-	3	
Mixer speed	s^{-1}	10	
Flocculant	-	Cationic emulsion polymer	
Sedimentation Basin			
Volume	L	91	NA
Lamella plate surface area	cm^2	7500	
Surface loading rate	m/h	1.0 – 1.5	
Sludge mechanism	-	Manual scraper	
Settled water basin volume	L	9.8	
Ion-Exchange Column			
Diameter	cm	15	NA
Height	cm	107	
Media type	-	Clinoptilolite	
Media manufacturer/make	-	NFM Pools/Zeobest®	
Surface loading rate	m/h	3.7 – 13	
Empty bed contact time	min	5.1 - 17	

[a] Values are similar because GAC-fluidized AnMBR UF has 50% fewer membranes per unit area, but the membranes are twice as long relative to the gas-sparged AnMBR.

5.4.2 Gas-Sparged AnMBR Pilot System

A set of design drawings for the gas-sparged AnMBR pilot system is included as part of the Operations and Maintenance Manual included in Appendix B. The major design and operational attributes are summarized here.

The gas-sparged AnMBR pilot system consisted of two trailers: 1) a process trailer fabricated by Intuitech of Salt Lake City, Utah, and 2) a rented office/laboratory trailer (Figure 5.1). The process trailer was an 8-feet (ft)-wide, 40-ft-long trailer and contained all the process equipment. The office trailer was an 8-ft-wide, 20-ft-long trailer used for office/storage space. Both trailers were installed on gravel pads behind the existing pump station building at the Camp Forsyth Pump Station site.

Figure 5.1 Photograph of the Installed Gas-sparged AnMBR at Ft. Riley.

A progressive cavity pump (Moyno model C23AC1E) and self-cleaning strainer (Eaton model DCF400) with a 1.7-millimeter (mm) screen was installed inside the existing pump station (Figure 5.2). The pump withdrew sewage from the existing pump station wet well and pumped it through the strainer prior to being conveyed to the bioreactor in the process trailer (see Figure 5.3 and Figure 5.4). The bioreactor was insulated but not heated or cooled. A progressive cavity pump recirculated fluid in the bioreactor. A second progressive cavity pump (Moyno model 33304) recirculated the fluid between the bioreactor and the UF membrane tank. This second pump also discharged sludge at a predetermined rate. A gear permeate pump (Oberdorfer model R10411PB-C1) created suction on the UF membranes and conveyed the permeate to the gas-liquid contactor for dissolved methane removal (Figure 5.5). The effluent from this contactor flowed by gravity to the coagulation-flocculation-sedimentation process (Figure 5.6 and Figure 5.7).

The coagulation-flocculation process included a single rapid-mix vessel and three slow-mix coagulation-flocculation vessels in series. The sedimentation basin contained lamellar plate settlers and a sludge basin that was emptied manually. The clarified effluent was pumped (Moyno model 22002) through the ion-exchange column that contained clinoptilolite media (Figure 5.6 and Figure 5.7) prior to being discharged back to the wet well.

Figure 5.2 Feed Pump and Strainer for the Gas-sparged AnMBR.

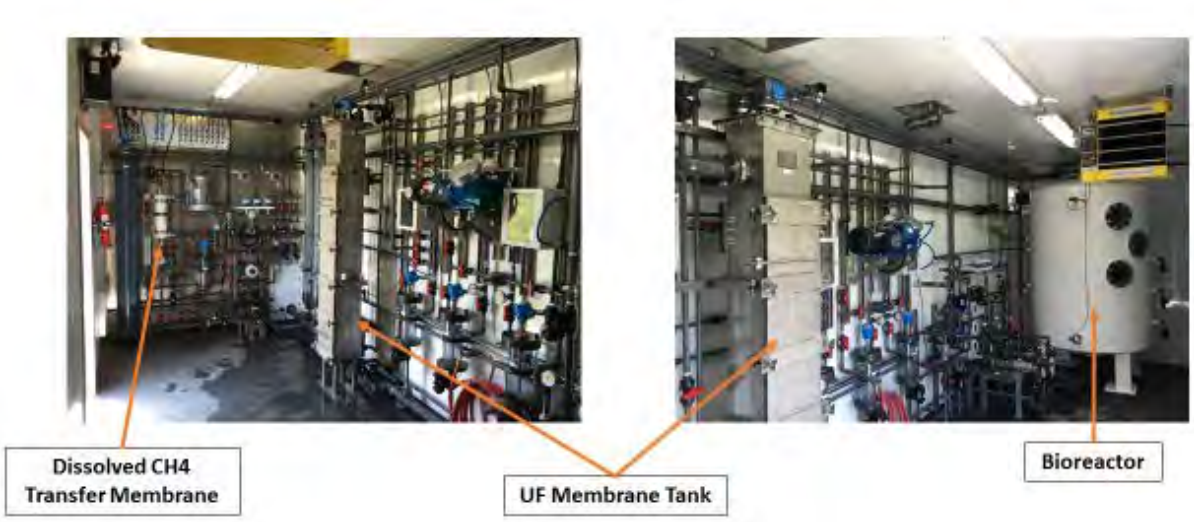
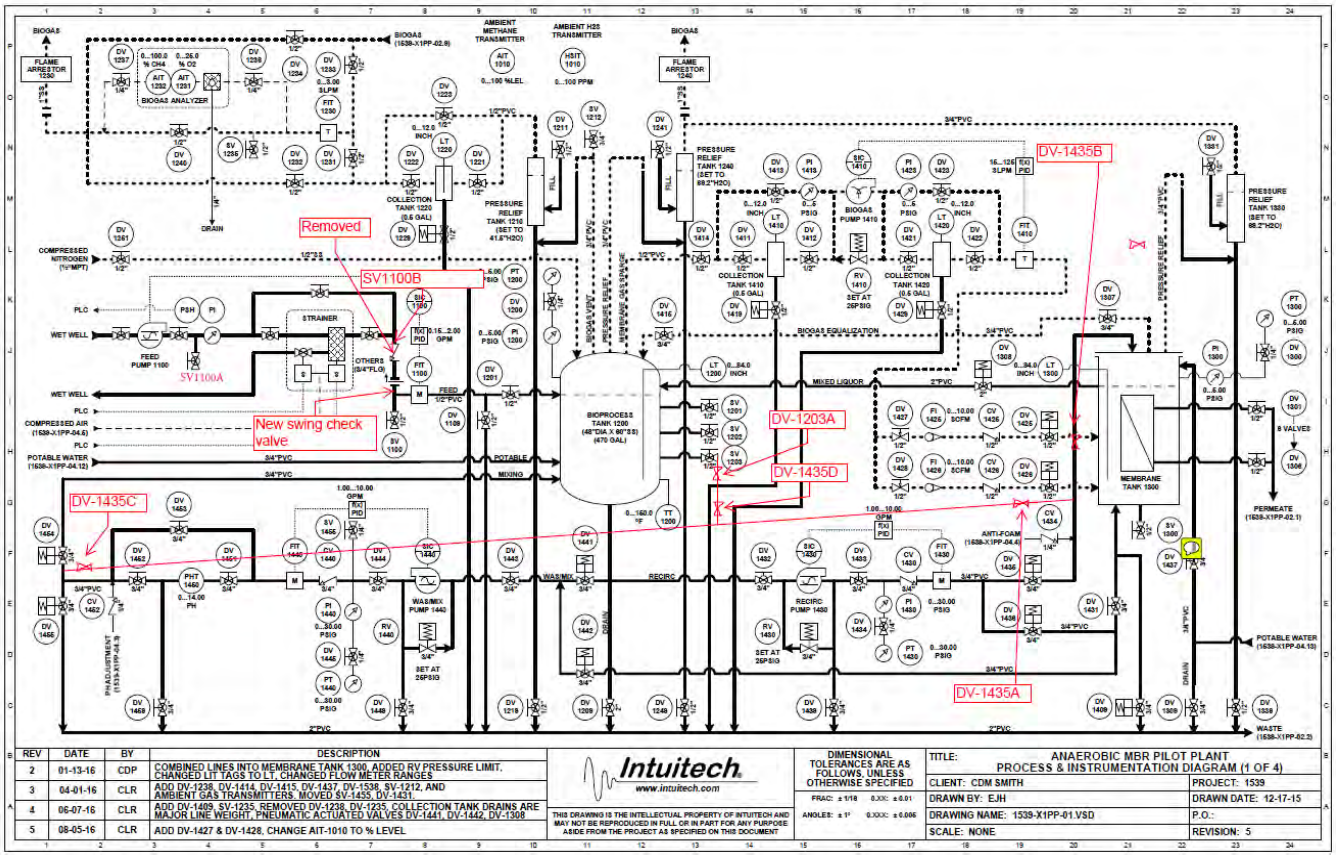


Figure 5.3 Gas-sparged AnMBR Bioreactor, UF Membrane Tank, and Dissolved Methane Removal Contactor.

Biogas production occurred in two main locations within the process: the primary reactor and the secondary membrane reactor. Biogas produced in the headspace of the primary bioreactor was pumped using a double-diaphragm blower (KNF model N0150.1.2) to the sparge the membranes in the secondary bioreactor (see Figure 5.4). Dissolved gas in the bioreactor permeate from the secondary reactor was pulled out of solution in the hollow fiber gas contact membrane. A vacuum pump connected to the permeate side of the membrane drew the vacuum (see Figure 5.5).

The volume of biogas produced in this pilot-scale system was small and was vented to the atmosphere rather than used beneficially to generate power. Other details about the process are included in Table 5.1.



REV	DATE	BY	DESCRIPTION
2	01-13-16	CDP	COMBINED LINES INTO MEMBRANE TANK 1300, ADDED RV PRESSURE LIMIT. CHANGED LIT TAGS TO LT, CHANGED FLOW METER RANGES
3	04-01-16	CLR	ADD DV-1238, DV-1414, DV-1415, DV-1437, DV-1538, SV-1212, AND AMBIENT GAS TRANSMITTERS. MOVED SV-1423, DV-1431.
4	06-07-16	CLR	ADD DV-1409, SV-1235. REMOVED DV-1238, DV-1235. COLLECTION TANK DRAINS ARE MAJOR LINE WEIGHT, PNEUMATIC ACTUATED VALVES DV-1441, DV-1442, DV-1308
5	08-05-16	CLR	ADD DV-1427 & DV-1428, CHANGE AIT-1010 TO % LEVEL

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DIMENSIONAL TOLERANCES ARE AS FOLLOWS, UNLESS OTHERWISE SPECIFIED
FRAC: ± 1/16 .XXX: ± 0.01
ANGLES: ± 1° .XXXX: ± 0.005

Figure 5.4 Process and Instrumentation Diagram for the Bioreactor and UF Systems.

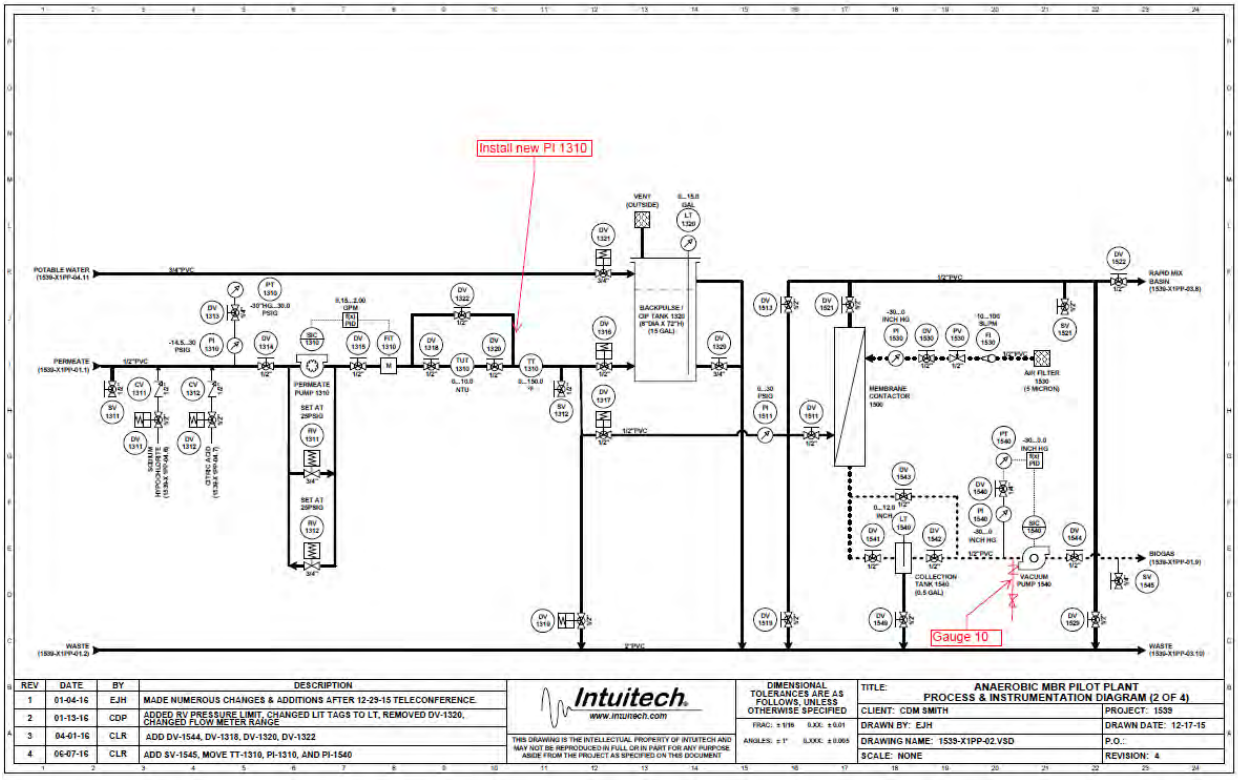


Figure 5.5 Process and Instrumentation Diagram for the Permeate Pump and Dissolved Methane Removal System.

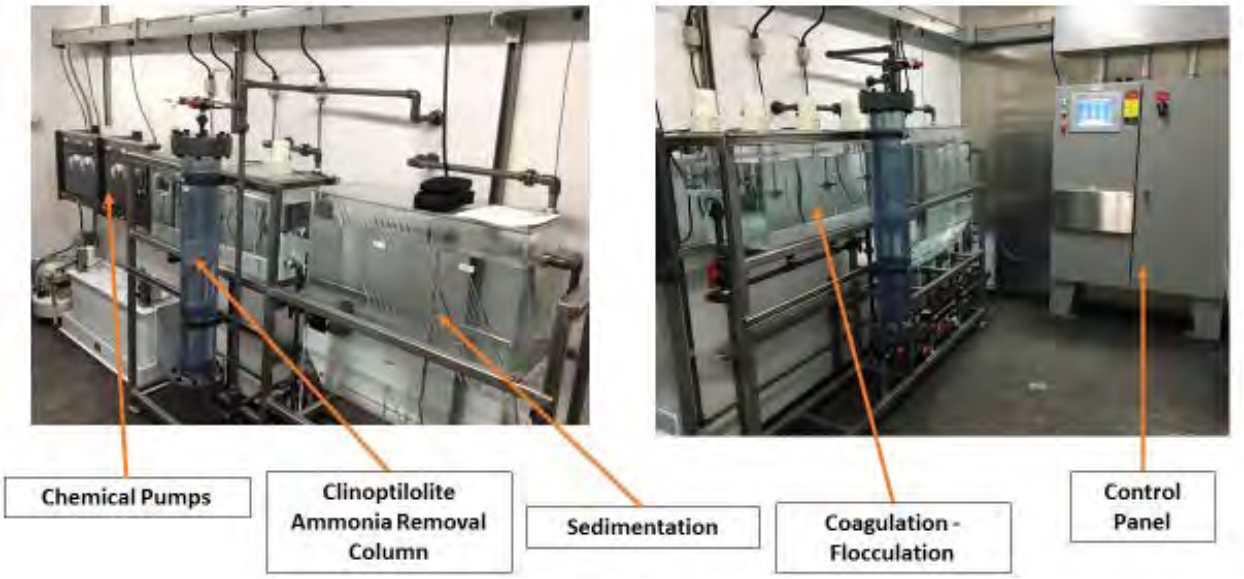
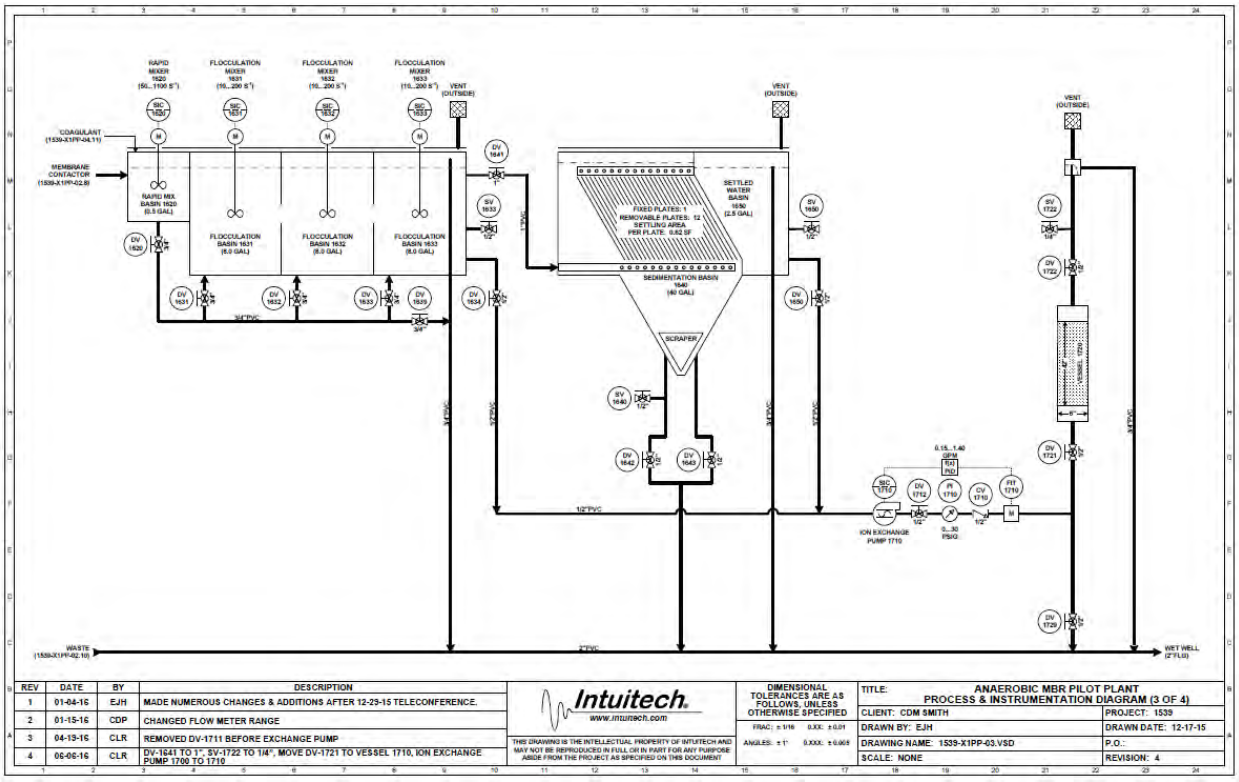


Figure 5.6 Gas-sparged AnMBR Coagulation-flocculation, Sedimentation, and Ammonia Removal Processes.



REV	DATE	BY	DESCRIPTION
1	01-04-16	EJH	MADE NUMEROUS CHANGES & ADDITIONS AFTER 12-29-15 TELECONFERENCE.
2	01-15-16	CDP	CHANGED FLOW METER RANGE
3	04-19-16	CLR	REMOVED DV-1711 BEFORE EXCHANGE PUMP
4	06-06-16	CLR	DV-1641 TO 1", SV-1722 TO 1/4", MOVE DV-1721 TO VESSEL 1710, ION EXCHANGE PUMP 1700 TO 1710

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DIMENSIONAL TOLERANCES ARE AS FOLLOWS, UNLESS OTHERWISE SPECIFIED
FRAC: ± 1/16 .XXX: ± 0.01
ANGLES: ± 1° .XXXX: ± 0.005

TITLE:	ANAEROBIC MBR PILOT PLANT PROCESS & INSTRUMENTATION DIAGRAM (3 OF 4)
CLIENT: CDM SMITH	PROJECT: 1539
DRAWN BY: EJH	DRAWN DATE: 12-17-15
DRAWING NAME: 1539-X1PP-03.VSD	P.O.:
SCALE: NONE	REVISION: 4

Figure 5.7 Process and Instrumentation Diagram for the Coagulation-flocculation-Sedimentation and Ammonia Removal Processes.

5.4.3 GAC-Fluidized AnMBR Pilot System

The GAC-fluidized AnMBR pilot system has been described previously (Shin et al. 2014) and is summarized here. Rather than treating effluent from the Bucheon wastewater treatment plant primary sedimentation process, grit chamber effluent at the Bucheon plant was screened with 2-mm screen and then pumped to the first-stage AFBR. Individual pumps recirculated fluid upward in each stage to fluidize the GAC (see Figure 5.8 and Figure 5.9). A third pump recirculated fluid between the AFMBR and AFBR. A permeate pump withdrew fluid from the hollow-fiber membranes, which was not further treated. Unfiltered water not containing GAC was also wasted at a predetermined rate for the purpose of wasting solids. The hollow-fiber membrane modules used in the AFMBR were obtained from Lotte Chemical and modified to enable GAC-fluidization. The modification involved removing 50% of the hollow fibers and sealing the holes in the headers. Characteristics of the modified membrane modules and other details about the process are listed in Table 5.1.

Figure 5.8 Photograph of the First-stage (AFBR - left) and Second-stage (AFMBR - right) GAC-fluidized AnMBR Systems.

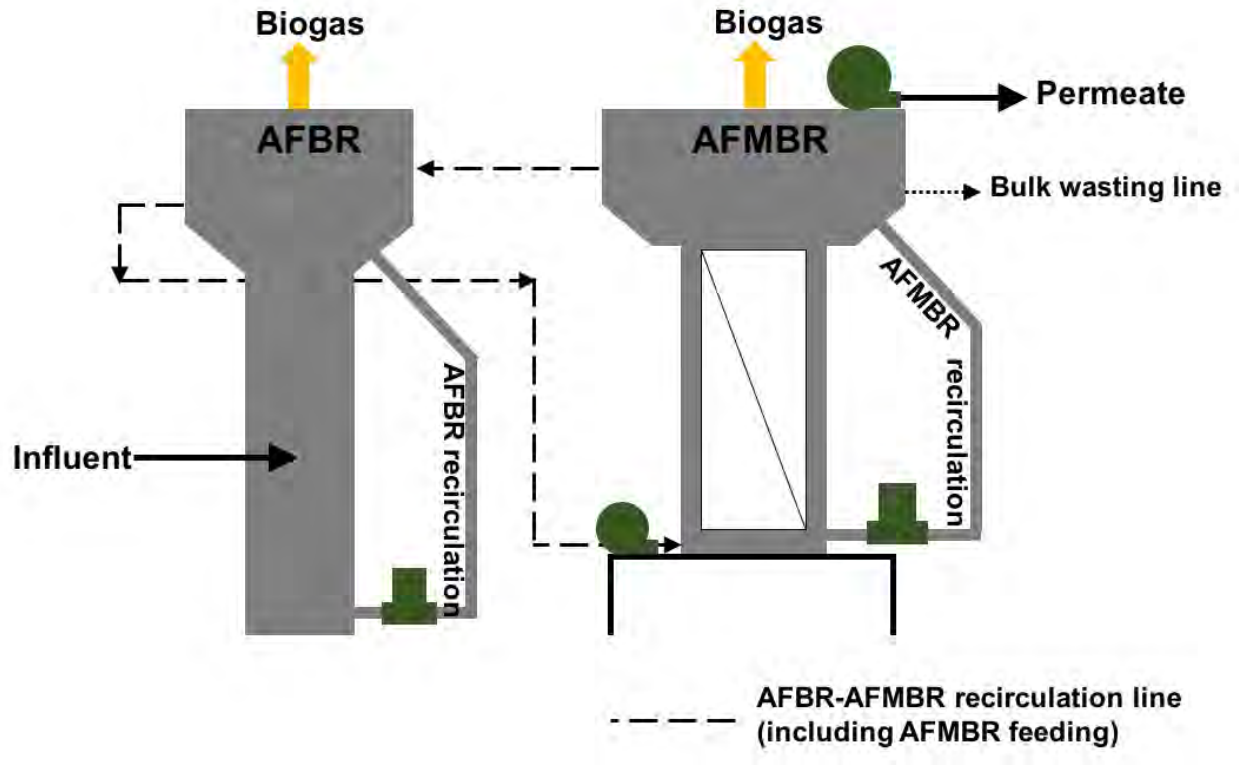

Figure 5.9 Process Flow Diagram of the GAC-fluidized AnMBR Showing the First-stage Anaerobic Fluidized Bioreactor (AFBR) and Second Stage Anaerobic Fluidized Membrane Bioreactor (AFMBR).

5.5 FIELD TESTING

A Gannt chart for the field demonstration is shown in Figure 5.10. A description of the various demonstration phases follows.

5.5.1 Commissioning and Startup

Commissioning and startup of the gas-sparged AnMBR involved installation, seeding, and initiation of Ft. Riley wastewater flow. It was seeded with 1360 L of mesophilic anaerobic digester sludge from the Oakland wastewater treatment plant in Topeka, Kansas on July 13, 2016. Wastewater flow to the AnMBR was initiated, and day 0 of the demonstration was defined as July 15, 2016.

The GAC-fluidized AnMBR was already installed at the Bucheon wastewater treatment plant and has been operating since June 21, 2012, treating settled wastewater (i.e., primary clarifier overflow) (Shin et al. 2014). In February 2014 operation of the AFMBR was stopped so that it could be retrofitted for the current demonstration. The AFBR was operated in recirculation mode during this time. GAC was removed from the AFMBR and placed in drums for storage. Kolon membranes were installed in the AFMBR and a 2-mm screen was installed upstream of the AFBR. Stored GAC was returned to the AFMBR on October 29, 2015 and operation with raw sewage commenced. Fouling with the Kolon membranes was immediate; therefore, operation was once again stopped in February 2016.

The GAC in the AFMBR was transferred to the AFBR and the Kolon membranes in the AFMBR were replaced with the Lotte Chemical membranes. The GAC was redistributed between the AFBR and AFMBR and raw sewage flow was resumed in April 2016. Day 0 of the demonstration is defined as April 5, 2016. COD of the Bucheon wastewater was supplemented near the end of the demonstration to test increased COD concentrations. The stock solution was comprised of 1,600 mg/L urea, 280 mg/L NH_4Cl, 800 mg/L K_2HPO_4, 2,800 mg/L starch, 2,000 mg/L milk powder, and 900 mg/L dried yeast.

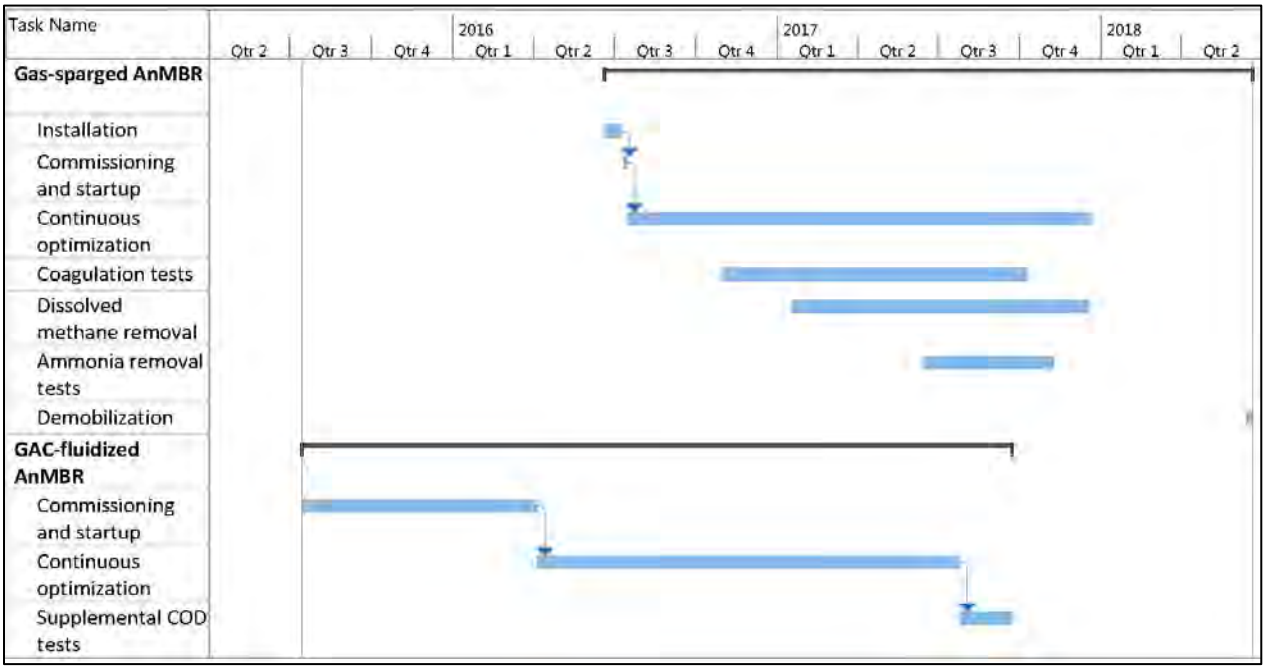

Figure 5.10 Gannt Chart for the Demonstration.

5.5.2 Continuous Optimization Phase

General Approach

The continuous optimization phase involved operating the AnMBR systems for over one year to allow data collection throughout an annual cycle of wastewater temperature changes. During this time, operations and maintenance of the AnMBR systems was optimized to meet or exceed the quantitative performance objectives of effectiveness, energy footprint, and implementability. Several control variables were available for optimization. Table 5.2 illustrates which variables were controllable and which were not.

The key variables that were applicable to both systems and were adjusted for optimization included liquid flow rate and membrane cleaning strategies. The suspended solids concentration is an additional key variable that was controlled by varying the sludge wasting rate. While the majority of the active microorganisms in the GAC-fluidized AnMBR are present as biofilm on the GAC, they are suspended in the gas-sparged AnMBR. Therefore, wasting sludge in the gas-sparged AnMBR may allow increased flux and lower TMP, but at the same time, can result in lower organic removal effectiveness. Optimization of TMP, membrane flux, and COD removal rates was

particularly important at lower wastewater temperatures. Table 5.3 summarizes the adjustments that were made to the pilot systems and the general decision-making process that was used to determine if and when adjustments are necessary. This approach facilitated better comparability of the results from both AnMBR systems. The decision approach outlined in Table 5.3 was used as a general guide and was not rigid.

Table 5.2 Primary process variables used for continuous process optimization.

Variables	Gas-Sparged AnMBR	GAC-Fluidized AnMBR
Temperature	Not controllable	
Wastewater composition	Not controllable	
Flow rate, HRT, and membrane flux	Controllable but not independently	
Organic loading rate	Partially controllable by flow rate variation. Influent wastewater composition is not controllable	
Biomass concentration	Controllable	Not controllable
Suspended solids concentration	Controllable by adjusting solids wasting rate	Controllable by adjusting solids wasting rate
Recycle rate	Controllable	Not applicable
pH	Partially controllable by organic loading rate variation	
UF membrane area	Not controllable	
Biogas sparging rate	Controllable	Not applicable
GAC-fluidization velocity	Not applicable	Not controllable
Membrane relaxation frequency, cleaning protocol and cleaning frequency	Controllable	
Gas-liquid contactor pressure	Controllable	Not applicable
Coagulation chemical, dose, and mixing	Controllable	Not applicable
Clinoptilolite mass	Not controllable	Not applicable

Table 5.3 AnMBR Continuous Optimization Decision Matrix.

Observed Effluent COD	Observed TMP	Flow Rate/Flux[a]	Biogas Sparge Rate[b]	Membrane Cleaning Frequency
< 60 mg/L	< 30 kPa	increase or maintain	decrease or maintain	maintain or decrease
< 60 mg/L	> 30 kPa	decrease or maintain	increase or maintain	increase
> 60 mg/L	< 30 kPa	decrease	decrease or maintain	maintain or decrease
> 60 mg/L	> 30 kPa	decrease	increase or maintain	increase

[a] The system designs did not allow the flow rate and membrane flux to be adjusted independently.
[b] Applicable to gas-sparged AnMBR only.

The quantitative performance objective of energy footprint was also considered during optimization. Factors that affected energy consumption (e.g., biogas sparging flow rate) were adjusted to increase the potential for energy-positive operation. The optimization process often involved trade-offs. For example, when the gas-sparged AnMBR system was energy-negative and the biogas sparging rate was determined to be the primary energy sink, decreasing the biogas sparging flow rate was sometimes conducted. However, this change sometimes resulted in greater membrane fouling and increased TMP. Deteriorated membrane performance affected the implementability performance objective. Therefore, evaluation of all data and careful consideration was required during the optimization process. In general, the quantitative performance objectives were assigned the following priorities with regard to optimization:

- Priority 1: Effectiveness – Water quality must be met to meet regulatory standards, minimize environmental impact, and provide maximum opportunities for water reuse. Therefore, optimization first strived to meet the effectiveness objectives.
- Priority 2: Energy Footprint – The AnMBR has the potential to provide a decreased national energy footprint as well as reduce sludge production. Therefore, this objective was important, but considered secondary to that of effectiveness.
- Priority 3: Implementability – Implementability as defined in Table 3.1 primarily drives cost. While cost is important, the overall objective of this demonstration was to determine the conditions under which the AnMBR processes can meet performance objectives for effectiveness and energy footprint (i.e., performance) and then determine the associated cost. Therefore, this objective was tertiary.

Specific Procedures and Tests

Membrane Maintenance and Recovery Cleaning

UF membrane maintenance and recovery cleaning procedures are shown in Table 5.4 and Table 5.5. In general, the process involved back-to-back cleaning with citric acid, followed by sodium hypochlorite.

Table 5.4 Maintenance Cleaning Procedure.

Step Number	Gas-Sparged AnMBR Action	GAC-Fluidized AnMBR Action
1	Stop permeating from all cassettes in train to be cleaned and continue biogas sparging or GAC-fluidization and recirculation for 5-10 minutes.	Stop permeating from all cassettes in train to be cleaned and continue GAC-fluidization and recirculation for 5 minutes.
2	Stop sludge recirculation and biogas sparging or GAC-fluidization of train to be cleaned.	Backpulse the chemical solution at 15 LMH through the membranes for 8 minutes (via injecting the chemical into the backpulse line to achieve the desired chemical concentration after mixing), and relax the membranes for 30 minutes with continuous GAC fluidizing and sludge recirculation • For sodium hypochlorite (NaOCl) a concentration of 750 mg/L was used • For citric acid a concentration of 2,000 mg/L was used Note: Initial pulse duration varied based on the length of piping between the chemical injection point and the membrane cassettes.
3	Backpulse the chemical solution at 20 LMH through the membranes for 2 minutes (via injecting the chemical into the backpulse line to achieve the desired chemical concentration after mixing), and relax the membranes for 4.5 minutes (no backpulse, no biogas sparging or GAC-fluidization). • For sodium hypochlorite (NaOCl), a concentration of 500 mg/L was used. • For citric acid, a concentration of 2,000 mg/L was used. Note: Initial pulse duration varied based on the length of piping between the chemical injection point and the membrane cassettes.	Remove the remaining chemical solution from pipe, headers and membrane fibers by permeating at 7 LMH for 4 minutes.
4	Backpulse the chemical solution at 20 LMH for 30 seconds and then relax for 4.5 minutes	Return train to operation.
5	Repeat step 4 for a total of 5 to 10 chemical pulses and soak iterations	
6	Backpulse membranes with clean permeate without chemicals at 20 LMH through the membranes for 2 minutes (Note: this final backpulse is used to purge the remaining chemical solution from the headers and membrane fibers into the membrane tank where it will be readily consumed by the mixed liquor without affecting performance; and pulse duration should be adjusted accordingly).	
7	Biogas sparge for 5-10 minutes.	
8	Return train to operation.	

Table 5.5 Recovery cleaning procedure.

Step Number	Gas-Sparged AnMBR Action	GAC-Fluidized AnMBR Action
1	Stop permeating from train to be cleaned, continue biogas sparging and sludge recirculation for 5 minutes to 1 hour to dislodge any accumulated solids.	Stop permeating from train to be cleaned, continue GAC-fluidization for 5 minutes to dislodge any accumulated solids.
2	Drain membrane tank by transferring mixed liquor to another train(s)/channel, digester or waste. Default location is the digester.	Transfer all GAC particles in secondary membrane reactor (AFMBR) to the primary bioreactor (AFBR).
3	Fill membrane tank with permeate until a high level is reached in the membrane tank.	Drain membrane tank by transferring mixed liquor to another train(s)/channel, digester or waste.
4	Further clean membranes for 5 minutes to 1 hours by sparging.	Fill membrane tank with permeate until a high level is reached in the membrane tank
5	Drain membrane tank by transferring mixed liquor to another train(s)/channel, digester or waste. Default location is the digester.	Allow membranes to soak in residual chemical concentration (1,000 mg/L for NaOCl or 5,000 mg/L for citric acid) for 24 hours.
6	If required, wash down and drain the tank completely. Note: In certain cases or configurations, manual flushing and draining of the membrane tanks may be a more practical option.	
8	Backpulse cleaning solution with the following cycle at 1.1 times the desired soak concentration to fill the tank to about 90% of the membrane cleaning level. Backpulse cycle includes backpulsing at 33 LMH for 120 seconds (5 – 200 second timer, default = 120 seconds), followed by a 120 second relax (0 – 600 second timer, default = 120 seconds). ● For sodium hypochlorite (NaOCl), backpulse at concentration of 1,100 mg/L for soak solution concentration of approximately 1,000 mg/L (pump limitations on the gas-sparged AnMBR limited NaOCl concentrations to 200-400 mg/L). ● For citric acid, backpulse at a concentration of 2,200 mg/L for soak solution concentration of approximately 2,000 mg/L.	
9	Add permeate to the tank by backpulsing the membranes at 33 LMH to completely submerge the membrane fibers to 100% of the cleaning level and reduce the dosed chemical concentration down to a required soak concentration.	
10	Allow membranes to soak in residual chemical concentration (1,000 mg/L for NaOCl or 2,000 mg/L for citric acid) for 6-16 hours.	

Dissolved Methane Removal Testing

Dissolved methane was removed with a Liqui-Cel Extra-Flow membrane contactor. The contactor was a 2.5×8-inch model G420 welded housing filled with 1.5-m^2 of X40 membranes (serial number 020407L040259 manufactured in 2007). UF permeate was pumped upward through the shell side of the vertically-oriented contactor, and a controlled vacuum was pulled from both ends of the contactor. Vacuum was drawn by either a water liquid ring pump (Airtech 3AV30-1B-NR-XP) or a compressed-air operated venturi vacuum pump (Cole Parmer EW-78165-30; equivalent to Vaccon HVP-100). No sweep gas flow was used.

Coagulation-Flocculation-Sedimentation Testing

Jar testing for the gas-sparged AnMBR was conducted initially to determine the optimal chemicals and approximate dosages to be used in the pilot system. A standard Phipps and Bird jar tester was used. For each test, the mixing was started with 120 revolutions per minute (rpm) for 2 minutes, followed by slow mixing at 30 rpm for 20 minutes. After mixing, the beaker contents were poured into 1-liter (L) graduated cylinders and allowed to settle for 30 minutes prior to sampling and analysis. After a series of screening tests, the primary coagulant for sulfide and phosphorus removal was selected to be ferric chloride (Chemtreat P8281L) with aluminum chlorohydrate (ACH, Chemtreat P891L) and medium to high molecular weight cross-linked, low-charged cationic emulsion polymer (Chemtreat P847E) as coagulant aids. Technical data sheets for these products are included in Appendix C.

Pilot testing for the gas-sparged AnMBR used the same products as in jar testing. All products were added to the UF permeate in the rapid mix chamber (400 per second [s^{-1}]) and then flowed in series through three flocculation chambers (10 s^{-1}) prior to entrance into the sedimentation basin. The sedimentation basin had 7500 square centimeters (cm^2) of lamellar plates (12 removable plates and 1 fixed plate, each with an area of 580 cm^2) and was operated at a surface loading rate of 1.0 to 1.5 meters per hour (m/h).

Only jar testing was conducted for the GAC-fluidized AnMBR. Initial tests with $FeCl_3$ resulted in a colored settled water and further tests were conducted with alum ($Al_2(SO_4)_3 \cdot 16H_2O$) and a cationic polymer (SWC-910, Songwoo Chemience Co., Ltd., South Korea). Test conditions included 1 minute (min) rapid mix, 15 min flocculation, and 30 min sedimentation.

Ammonia Removal Testing

Clinoptilolite media (Zeobest®, NFM Pools, Muscatine, Iowa) was loaded dry into the column prior to testing. Initial tests used a 6-inch (15-cm) diameter column, which broke halfway through the demonstration and was replaced with a 2-in (5-cm) column. Settled water from the sedimentation tank was pumped upward through the column at a surface loading rate of 9-10 cm/min in both columns during permeate pumping. The empty bed contact time was 12-20 minutes (min). Water was pumped through the clinoptilolite bed and monitored for ammonia breakthrough. Pre-breakthrough samples were collected after four hours of operation (~50 residence volumes) and these data were used to estimate effectiveness. Then the water continued to be pumped through the clinoptilolite column until complete breakthrough was achieved (i.e., the effluent and influent concentrations were equal). The clinoptilolite was then

removed from the column and shipped to the CERL for regeneration. The regenerated clinoptilolite media was sent back to Ft. Riley for the next sorption cycle. Two batches of clinoptilolite were tested as duplicates, and a total of three sorption cycles were conducted per duplicate.

Clinoptilolite was transferred to upflow columns at CERL upon receipt. Initially a solution of 10% NaCl was used for the regeneration based on previous studied by CERL (Guy et al. 2016). This was then changed to a 0.5 M NaOH solution which promoted faster ammonia removal. The flow rate was adjusted to maintain a slow but continuous effluent stream. The actual flow rate varied at column loading volumes with an average rate of 65 milliliters per minute (mL/min). The regeneration effluent was collected for subsequent analysis of ammonia concentrations. Ammonia loading totals were calculated by multiplying effluent concentrations by the volume collected.

During regeneration, samples were periodically collected from the effluent stream to determine when the column had been fully regenerated. Total effluent ammonia concentrations were measured per 20-L of collected volume. All samples were analyzed within an hour of collection to minimize ammonia loss. Ammonia concentrations were obtained based on the colorimetric salicylate method. Reagents were added to 5 mL of solution and allowed to react for 20 minutes. Absorbance at 700 nanometers (nm) was recorded and compared to standard calibration values. Samples were diluted as necessary to obtain absorbance values within the linear calibration range (0.2 – 1.3 mg-N/L).

Brine collected from regenerating the clinoptilolite media was transferred to an ammonia electrolysis process. The brine was heated to 55°C before treatment. A voltage of 0.925 volts (V) was applied across the membrane supported electrodes. Gas volumes were measured in 100 mL increments with a tip meter.

5.6 SAMPLING METHODS AND ANALYSIS

Table 5.6 and Table 5.7 summarize the sampling and analytical methods, respectively, conducted for the demonstration. Additional details on specialized analytical methods are presented below. Quality assurance is discussed in Appendix D.

Table 5.6 Performance Monitoring Schedule Indicating Total Number of Analyses Conducted for the Gas-sparged and GAC-fluidized AnMBRs.

	Strainer Effluent Composite[a]	AnMBR[a]	UF Permeate[a]	UF Membranes	Gas-Liquid Contactor Effluent[b]	Coagulation-Flocculation[b]	Sedimentation[b]	Ion Exchange[b]
Liquid Samples								
pH	61		106			5	59	5
ORP[b]								4
Total COD	196		211				23	4
Filtered COD		216						
Total BOD_5	108		101					3
Volatile fatty acids (VFAs)			53					
Alkalinity[b]								4
Hardness[b]								3
Specific conductivity[b]								4
TDS[b]								4
Total nitrogen[b]	42		45				27	4
NH_3-N[b]	25		40				28	34
NO_3[b]								3
NO_2[b]								2
Sulfate	134		137					1
Sulfide	3		66		16		34	5
Total phosphorus[b]	43		44				28	3
Filtered iron[b]							57	4
TSS	197		132			12	25	4
VSS	175		132			12	25	
FSS	44							
Turbidity			17					3
Dissolved methane			137		36			
Chlorine demand[b]								4
E. coli and total coliforms[b]								2
TS[b]		76						
VS[b]		70						
FS[2]								
Microbial Ecology		See text						
Solid/Sludge/Media/Membrane Samples								

	Strainer Effluent Composite[a]	AnMBR[a]	UF Permeate[a]	UF Membranes	Gas-Liquid Contactor Effluent[b]	Coagulation-Flocculation[b]	Sedimentation[b]	Ion Exchange[b]
RCRA metals (As, Ba, Cd, Cr, Pb, Hg, Se, Ag)[b]		2						
Metals/non-metals (Al, Ca, Fe, K, Mg, Na, P, S)[b]							1	
Chlorine[b]							1	
Carbon, hydrogen, and nitrogen[b]							1	
Oxygen[b]							1	
Sulfur[b]							1	
Dewaterability[b]		2					1	
Part 503 biosolids analyses[b,c]		2						
NH_3-N[b]								6
Membrane autopsy				6				
Gas Samples								
CH_4, CO_2, N_2, O_2[b]		8						
Siloxanes[b]		2						
H_2S[b]		6						

Notes
[a] Both Ft. Riley and Bucheon demonstrations.
[b] Ft. Riley demonstration only.
[c] Enteric viruses, fecal coliforms, *Salmonella*, total solids, and viable helminth ova.

Table 5.7 Analytical Methods for Sample Analysis.

Analyte	Lab	Lab or Field Analysis	Method	Container	Preservatives	Hold Time	Minimum Sample Required
Liquid Samples							
pH	KSU/Inha	Field	SM 4500	NA	Analyze immediately	Analyze immediately	50 mL
ORP	KSU/Inha	Field	SM 2580	NA	Analyze immediately	Analyze immediately	50 mL
Total COD	KSU/Inha	Lab	Aerate 10 min then SM 5200D/Hach 8000	250 mL poly	H_2SO_4, Cool to 4° C± 2°	28 days	50 mL
Filtered COD	KSU/Inha	Lab	Aerate 10 min then SM 5200D/Hach 8000	250 mL poly	H_2SO_4, Cool to 4° C± 2°	Filter immediately, 28 days	50 mL
Total BOD_5	KSU/Inha	Lab	Aerate 10 min and then SM 5210B	250 mL poly	Cool to 4° C± 2°	48 hours	100 mL
Volatile fatty acids (VFAs)	KSU	Lab	HPLC (see text for method description)	2 mL amber glass vial	H_2SO_4, Cool to 4° C± 2°	14 days	5 mL
Alkalinity	KSU	Lab	SM 2320B	250 mL poly	Cool to 4° C± 2°	14 days	50 mL
Hardness	KSU	Lab	Hach 8030	250 mL poly	Cool to 4° C± 2°	6 months	50 mL
Specific conductivity	KSU	Lab	SM 2510	250 mL poly	14 days, Cool to 4° C± 2°	28 days	100 mL
TDS	KSU	Lab	SM 2540C	250 mL poly	Cool to 4° C± 2°	7 days	500 mL
Total nitrogen	KSU	Lab	USGS WRIR 03-4174	250 mL poly	Cool to 4° C± 2°	7 days	150 mL
NH_3-N	KSU/Inha	Lab	SM 4500-NH3	500 mL poly	H_2SO_4, Cool to 4° C± 2°	28 days	400 mL
NO_3	KSU	Lab	EPA 353.2	250 mL poly	H_2SO_4, Cool to 4° C± 2°	48 hours	150 mL
NO_2	KSU	Lab	EPA 353.2	250 ml poly	H_2SO_4, Cool to 4° C± 2°	48 hours	150 mL
Sulfate	KSU/Inha	Lab	SM 4110B	250 mL poly	Cool to 4° C± 2°	28 days	60 mL
Total sulfide	KSU	Field	SM 4500 S2 D (Hach method 10254)	250 mL poly	Analyze immediately	Analyze immediately	60 mL
Total sulfide	Inha	Field	SM 4500G	250 mL poly	Analyze immediately	Analyze immediately	60 mL
Total phosphorus	KSU	Lab	USGS WRIR 03-4174/EPA 365.2	250 mL poly	Cool to 4° C± 2°	7 days	150 mL
Total phosphorus	Inha	Lab	SM 4500P	250 mL poly	Cool to 4° C± 2°	28 days	150 mL
Filtered iron	KSU	Field	Hach 8112	250 mL poly	filtered, no preservative	Analyze immediately	100 mL
TSS	KSU/Inha	Lab	SM 2540 D (some KSU samples were not able to be filtered, thus reported value is TS and not TSS)	250 mL poly	Cool to 4° C± 2°	7 days	200 mL
VSS	KSU/Inha	Lab	SM 2540 E (some KSU samples were not able to be filtered, thus reported value is VS and not VSS)	250 mL poly	Cool to 4° C± 2°	7 days	200 mL
FSS	KSU/Inha	Lab	SM 2540 E (some KSU samples were not able to be filtered, thus reported value is FS and not FSS)	250 mL poly	Cool to 4° C± 2°	7 days	200 mL
Turbidity	KSU	Field	EPA 180.1	250 mL poly	Analyze immediately	48 hours	50 mL
Dissolved methane	Contract Lab	Lab	EPA RSK SOP-175, (Kampbell et al. 1989)	40 mL vial (2)	Cool to 4° C± 2°	7 days	80 mL
Dissolved methane	Inha	Lab	GC (see text for method description)	54 mL serum bottle	Analyze immediately	Analyze immediately	54 mL
Chlorine demand	KSU	Lab	Hach 10223 (adapted from SM 2350B)	250 mL poly	Cool to 4° C± 2°	24 hours	1 L
Temperature	KSU/Inha	Field	Thermometer	250 mL poly	no preservative	Analyze immediately	-

Analyte	Lab	Lab or Field Analysis	Method	Container	Preservatives	Hold Time	Minimum Sample Required
E. coli and total coliforms	KSU	Lab	SM 9223B (Colilert)	250 mL poly	NaS_2SO_3 (tablet), Do not freeze	24 hours	250 mL
TS	KSU	Lab	SM 2540 B	250 mL poly	Cool to 4° C± 2°	7 days	100 mL
VS	KSU	Lab	SM 2540 G	250 mL poly	Cool to 4° C± 2°	7 days	100 mL
FS	KSU	Lab	SM 2540 G	250 mL poly	Cool to 4° C± 2°	7 days	100 mL
Microbial ecology	KSU/Inha	Lab	See text for methods	NA	Cool to -80° C	1 year	50 mL
Solid/Sludge/Media/Membrane Samples							
RCRA Metals (As, Ba, Cd, Cr, Pb, Hg, Se, Ag)	Contract Lab	Lab	EPA 3050B/EPA 6010B/EPA 7470	250 mL poly or 2 oz. glass wide mouth	Cool to 4° C± 2°	28 days for Hg, 180 days for rest of metals	200 mL of 2 oz.
Metals/non-metals (Al, Ca, Fe, K, Mg, Na, P, S)	KSU	Lab	EPA 3051A/ICP-OES	250 mL poly or 2 oz. glass wide mouth	Cool to 4° C± 2°	180 days	0.5 g
Chlorine	KSU	Lab	EPA 9056A	250 mL poly or 2 oz. glass wide mouth	Cool to 4° C± 2°	28 days	0.5 g
Carbon, hydrogen, and nitrogen	Contract Lab	Lab	ASTM D5373	250 mL poly or 2 oz. glass wide mouth	Cool to 4° C± 2°	28 days	0.5 g
Oxygen	Contract Lab	Lab	ASTM5622	250 mL poly or 2 oz. glass wide mouth	Cool to 4° C± 2°	28 days	0.5 g
Sulfur	Contract Lab	Lab	ASTMD439	250 mL poly or 2 oz. glass wide mouth	Cool to 4° C± 2°	28 days	0.5 g
Dewaterability	Bucknell University	Lab	See text for method	5-gallon bucket	None	NA	5 gallons
Part 503 Biosolids Analyses Enteric viruses Fecal coliforms *Salmonella* Total Solids Viable Helminth Ova	Contract Lab	Lab	ASTM Method D 4994-89, Part A and B EPA 1680 (MPN) EPA 1682 SM 2540G Yanko, 1987/EPA600/1-87-014	Five 1-L bottles	Cool to 4° C± 2°	Method-dependent	5 L
NH_3-N	CERL	Lab	See text for method	250 mL poly	Cool to 4° C± 2°	7 days	250 mL
Membrane autopsy	American Water Chemicals	Lab	See text for methods	NA	NA	NA	NA
Gas Samples							
CH_4, CO_2, N_2, O_2	Contract lab	Lab	Grab sample = ASTM D1945	1-L Tedlar bag	no preservative	72 hours	1 liter
Siloxanes	Contract lab	Lab	ALS Global Siloxane Method 111	Siloxane sorbent tube	no preservative	14 days	6 liters gas
H_2S	Contract lab	Lab	ASTM D5504	1-L Tedlar bag	no preservative	24 - 48 hours	1 liter

5.6.1 Volatile Fatty Acids

Kansas State University (KSU) measured volatile fatty acids (VFA) using a high performance liquid chromatograph (HPLC) equipped with an Aminex HPX-87H column, photo diode array, and refractive index detectors, as described previously (Parameswaran et al. 2009). At Inha, VFA concentrations were determined with an HP 6890 series gas chromatograph (GC) using a flame ionization detector (FID) as described previously (Shin et al. 2011).

5.6.2 Gas and Dissolved Methane Analysis

Gas samples collected from the gas-sparged AnMBR were analyzed by contract laboratories using methods listed in Table 5.7. For the GAC-fluidized AnMBR, biogas was collected in a Tedlar bag (Dupont Corp., Delaware) and measured volumetrically with a MilliGascounter (Ritter, Germany). Gas composition (methane, carbon dioxide, nitrogen and oxygen) was determined using a GC with thermal conductivity detector (HP6890 series gas chromatograph, Hewlett-Packard Company, USA). Dissolved methane concentrations were measured as described previously (Shin et al. 2012). For this, effluent samples were collected without air contact in 54-mL serum bottles which were then sealed with rubber stoppers and aluminum caps. A 27-mL sample was removed from each bottle with a syringe and simultaneously replaced with N_2 gas. NaOH (3 N, 0.2 mL) was then injected into the serum bottle to inactivate bacteria and capture CO_2. The serum bottles were then equilibrated for about an hour on a 35^{o}C shaker, and head-space gas composition was measured.

5.6.3 UF Membrane Analyses

Diagnostic analysis (i.e., autopsy) of the membranes from the AnMBRs at the end of the demonstration was conducted by American Water Chemical (www.membranechemicals.com). These analyses included:

- Scanning electronic microscopy (SEM) with energy dispersive spectroscopy (EDS) to characterize the elemental composition of membrane foulants.
- Fourier transform infrared spectroscopy to characterize organic foulants.
- Raman spectroscopy to determine the presence of elemental activated carbon on the GAC-fluidized AnMBR UF membranes.
- Loss on ignition test on foulants for volatiles, organic carbon, total inorganic carbon, total inorganic non-carbon for further characterization.

Additional information is included in the reports in Appendix E.

5.6.4 Dewaterability Testing

Dewaterability testing of gas-sparged AnMBR samples was conducted by Dr. Matt Higgins at Bucknell University and included determining optimum polymer dose, dewatering the sludge using belt filter press fabric placed inside a centrifuge, and then analyzing the TS and VS contents of the dewatered sludge and monovalent/divalent cation contents of the centrate.

These analyses were conducted using previously published methods (Higgins et al. 2014, Higgins and Novak 1997). Additional details from the Bucknell University Report (see Appendix F) are included below.

Two shipments of samples were received. The first shipment was in late April 2017 and contained a sample from the AnMBR while the second shipment contained two samples, one from the AnMBR and the other from the sedimentation basin. A high molecular weight, cationic polymer (SNF, 6440) was made to a 0.25% concentration on the day of the dewatering experiment. First, the optimum polymer dose was determined by establishing the polymer dose-response curve using capillary suction time (CST) as the measure of the extent of conditioning and floc formation. A 500-mL sample of digestate was placed in a 2-L, baffled circular container. The polymer was added to the solids and mixed using a single-paddle mixer at 563 rpm for 30 seconds (s), followed by 54 rpm for 90 s, after which the CST was measured. The dosage with the lowest CST was considered the optimum polymer dose, and this sample was then dewatered.

Dewatering was performed by first gravity draining the solids on belt filter press fabric for a minute. The drained solids were then placed in a specially designed belt filter press centrifuge cup. These cups comprise a piece of belt filter press fabric that was suspended approximately half way up the height of the cup. The samples were then centrifuged at 2075 × the gravitational force on earth (g) for 10 minutes, and the cake was scraped off the belt filter press fabric for analysis for TS and VS. The cakes are also analyzed for their odorant production potential. Duplicate cake samples were generated and analyzed for each sample.

5.6.5 Microbial Ecology Analyses for the Gas-Sparged AnMBR

The objective of the microbial ecology analyses for both the gas-sparged AnMBR and GAC-fluidized AnMBR is to: 1) characterize transitions between various acetoclastic and hydrogenotrophic methanogenenic archaea as temperatures change, and 2) identify any potential associations between microbial ecology and biofouling of the membranes. For example, we know that with such low COD concentrations in municipal wastewater, Methanosaeta rather than Methanosarcina will be the dominant aceotclastic methanogen present. If not, then we are not likely to get efficient treatment. Additionally, as temperatures decrease, hydrogenotrophic methanogenesis may become more dominant than acetoclastic methanogenesis. Temperature also dictates the nature of the syntrophic partnership between the volatile fatty acid degrading bacteria and the methanogens, which is critical for process stability. For instance, propionate degrading bacteria in association with the methanogens could hold a key role to avoid VFA buildup and their microbial diversity and predominance could change with temperature. Microbial ecology studies in combination with other analyses (e.g., volatile fatty acid distribution) and knowledge of AnMBR operating conditions may provide useful diagnostic information with respect to understanding AnMBR performance under a variety of environmental conditions. Biofouling can also be strongly controlled by microbial ecology. The microbial startup dynamics of the AnMBR for a mesophilic or a psychrophilic startup followed by ambient operation could also be valuable information for future successful deployments of AnMBR technology under various climatic conditions. One can optimize the startup time through a thorough understanding of the microbial interactions during the startup phase as a function of temperature, through bioaugmentation and continued monitoring of the chemical parameters and the critical microbial partners. These analyses in combination with other analyses such as extracellular polymeric substances may enhance our understanding.

It is not clear whether these analyses will lead to useful tools for full-scale AnMBR applications, but they may do so. In either case, the results may allow us to increase our understanding of the process.

Sample preparation and DNA extraction

A biomass sample was preserved from the seed inoculum, and subsequent bioreactor samples (8 total) were collected from the middle sample port of the primary bioreactor. The bioreactor samples represented a great range of temperatures and operational performance conditions, as shown in Table 5.8 below.

Table 5.8 Summary of Key AnMBR Operation Parameters During Biomass Sampling

Reaction Condition	AnMBR operation time corresponding to DNA sampling (days)								
	0	**157**	**203**	**222**	**229**	**243**	**257**	**262**	**271**
Dates of Operation	**7/13/16**	**12/19/16**	**2/3/17**	**2/22/17**	**3/1/17**	**3/15/17**	**3/29/17**	**4/3/17**	**4/12/17**
Influent COD (mg/L)	430	560	410	610	980	840	320	510	540
Permeate COD (mg/L)	--	42	46	46	48	61	74	96	64
HRT (h)	8.6	13	14	15	13	14	10	11	10
SRT (days)	N.D.	68	68	68	68	69	66	66	66
OLR (kg m-3 d-1)	0.88	1.5	0.9	1	1.9	1.5	0.73	1.2	1.3
Bioreactor VS (mg/L)	13,000	5,800	7,100	8,700	5,500	4,300	9,900	N/A	11,000
COD removal (%)	--	92	89	92	95	93	77	81	89
Net flux (LMH)	13	6	5.9	6	7	7	8	8	8

Bioreactor sludge samples were centrifuged in an Eppendorf centrifuge 5920 R (Hauppauge, New York, USA) at 21,000 relative centrifugal force to concentrate the biomass so that the excess water could be easily excluded. Table 5.9 shows the results of three different deoxyribonucleic acid (DNA) kits, MO BIO PowerSoil DNA Isolation Kit (Carlsbad, California, USA), and E.Z.N.A.® Water and Soil DNA Kit (Norcross, Georgia, USA), that were used to compare the effectiveness of each one using the same sample. Higher nucleic acid concentrations and a ratio of 1.8-2.2 is considered adequate for the 260/280 and 260/230 ratios, which are ratios of the nucleic acid to contaminants.

Table 5.9 Comparison of Three Different DNA Extraction Kit Results Using the Same Sample.

Kit Type	Nucleic Acid Concentration (ng/µl)	260/280	260/230
MoBio Soil	51	1.78	1.44
E.Z.N.A. Soil	228	1.87	1.56
E.Z.N.A. Water	694	1.9	1.58

DNA was extracted from roughly 0.5 g (wet weight) biomass samples using the most effective DNA kit, the E.Z.N.A.® Water DNA Kit (Norcross, Georgia, USA) and samples were stored at -20°C. The Thermo Scientific NanoDrop™ 2000c (Wilmington, Delaware, USA) was used to quantify nucleic acid concentrations and quality of DNA samples.

High-throughput microbial community analysis

To determine the structure of the Bacterial and Archaeal community during startup of the AnMBR, DNA was sequenced at MR DNA (www.mrdnalab.com, Shallowater, TX, USA) on an Illumina MiSeq (Illumina, USA). 16S ribosomal ribonucleic acid (rRNA) universal prokaryotic primers 519F and 806R (Angenent et al. 2002), with barcode on the forward primer, were used to amplify the V3 and V4 hyper-variable region of this highly conserved gene (Ariesyady et al. 2007). The reads were paired-end sequenced with DNA fragments consisting of 2 × 300 base pair (bp) reads using an Illumina MiSeq with the MiSeq Reagent Kit v3.

MR DNA provided sequencing data in fasta, mapping, and quality files that were processed using the QIIME v. 1.9.1 pipeline (Caporaso et al. 2010). The data set was first de-multiplexed by barcode decoding and the sequences were filtered to remove low-quality reads using the script, split_libaries.py. The total sequence count was 760,810 with a minimum of 74,698 for sample 6 and a maximum of 91,511 for sample 2. Next, the sequences were aligned and binned into operational taxonomic units (OTUs) in a BIOM-formatted OTU table at 97% similarity and the taxonomy was assigned with UCLUST consensus taxonomy assigner using the script, pick_de_novo_otus.py. This script uses the 16S rRNA gene database, Greengenes 13_8 (McDonald et al. 2012). Finally, the singletons were removed and taxonomy charts and tables were created using the scripts, filter_otus_from_otu_table.py and summarize_taxa_through_plots.py.

5.6.6 Microbial Ecology Analyses for the GAC-Fluidized AnMBR

Biomass sample collection and total genomic DNA extraction

Biomass samples from the GAC-fluidized AnMBR were taken at day 342, 436 and 555. GAC samples were collected from the AFBR and AFMBR reactors at all time points. The bulk liquid from AFMBR reactor was sampled at all time points while an additional bulk liquid from the AFBR reactor was obtained for day 436. To examine the influence of influent sewage on the system's microbiome, the influent sewage was also sampled at day 555. The reaction conditions at the points of sampling are provided in Table 5.10.

Table 5.10 Reactor Conditions at the Three Sampling Time Points.

Reactor Condition	Sample		
	Day 342	Day 436	Day 555
Influent	Raw sewage	Raw sewage	Raw sewage supplemented with COD
Temperature (°C)	14	25	26
HRT (h)	7.3	4.8	3.2
SRT for suspended solids (h)	490	320	130
OLR (kg m^{-3} d^{-1})	0.9	1.0	2.7
Influent COD concentration (mg/L)	290	200	360
Permeate COD concentration (mg/L)	69	32	63
COD removal efficiency (%)	76	84	83
Influent SS concentration (TSS/VSS) (mg/L)	160/120	87/65	160/140
Bulk SS concentration (TSS/VSS) (mg/L)	4000/3100	2700/1700	2200/1800

Total genomic DNA extraction was performed using the PowerSoil DNA Isolation Kit (MO BIO Laboratories, Carlsbad, CA, USA) according to the manufacturer's instruction. Prior to DNA extraction, biomass pre-concentration was performed. For bulk and influent sewage samples, the samples were filtered through 0.2-μm sterilized cellulose nitrate filters to pre-concentrate the biomass. The filters were cut into smaller pieces and placed into the PowerBead Tubes supplied with the PowerSoil DNA Isolation Kit for DNA extraction. For the GAC samples, the samples were washed with 4% autoclaved NaCl solution twice before the liquid was decanted. The layer of GAC sample was suspended in autoclaved water and sonicated to promote the detachment of biofilm from GAC. The suspension was transferred to a mortar and grinded to powder with a pestle followed by another round of sonication. The resultant blacken suspension was collected with a 50-mL centrifuge tube and centrifuged at 8,000 rpm, room temperature for 10 min. The supernatant was discarded, and the residual pellet was used for DNA extraction. The concentration and purity of the extracted DNA were assessed by NanoDrop Lite spectrophotometer (Thermo Scientific, USA) at A260 nm and A260/A280 absorbance ratio, respectively.

Bacterial and archaeal 16S rDNA sequencing, data processing and analysis

Extracted DNA samples were sent to Novogene (Beijing, China) for bacterial and archaeal 16S rDNA sequencing using primer sets 515F (5' GTGCCAGCMGCCGCGGTAA 3')/ 806R (5' GGACTACNNGGGTATCTAAT 3') and 519F (5' CAGCCGCCGCGGTAA 3')/ 915R (5' GTGCTCCCCCGCCAATTC 3'), respectively. Both primer sets amplify the V4 variable region of the 16S rRNA gene. Sequencing was performed on the Illumina HiSeq 2500 platform (Illumina Inc, San Diego, CA, USA) with at least an average of 30,000 raw reads per sample.

A total of 796,949 clean bacterial 16S rDNA sequences and 714,124 clean archaeal 16S sequences were generated and processed with the Mothur pipeline (version 1.39.5) (Schloss et al. 2009) according to the parameters described in Tan et al. (2016). Chimeric sequences and sequences with ambiguous bases were discarded. Non-bacterial and non-archaeal sequences were further removed from the bacterial 16S rDNA and archaeal datasets, respectively. Clean bacterial 16S rDNA sequences (350 to 400 bp) were aligned to the SILVA database (release 132) (Wang et al. 2007) at a pseudo-bootstrap cutoff value of 60%. The reads were subsequently clustered into OTUs at a 97% sequence similarity. Cluster analysis employing the Bray-Curtis index was performed to compare the bacterial and archaeal community structure and composition between the samples. The Bray-curtis index was chosen, as it considers the presence and absence of taxa as well as abundance of species. Because the samples were obtained from the same reactor system, the changes in taxa make-up and species abundance are integral features of the system operation. Hence, the Bray-Curtis index is well-suited for this cluster analysis application. To compare the 16S rDNA sequences to available sequences in GenBank, The National Center for Biotechnology Information (NCBI) BLAST program (http://www.ncbi.nlm.nih.gov/) was used.

5.6.7 Data Analysis

Data evaluation involved comparison of results for each pilot system to the performance objectives and to each other. The systems are different in several aspects as described above, and the wastewater composition and concentration were also different. Therefore, it was important to provide a basis for comparison.

Several types of comparisons were made, including: 1) percent contaminant removal and effluent contaminant concentrations, 2) membrane flux, TMP and permeability, and 3) energy footprint. Comparisons to performance objectives were made using Student's t-test. Estimation of rate constants was conducted, but the results were not accurately reflective of system kinetics, so results are not reported.

A steady-state mass balance conducted on element *i* (e.g., S, P, Fe) entering and leaving the coagulation-flocculation process is presented below where Q is the water flow rate, $C^{in}{}_i$ and $C^{out}{}_i$ are the aqueous (i.e., dissolved) concentrations of component *i* in the water, $C^{out}{}_{TSS}$ is the TSS concentration in the aqueous solid suspension leaving the flocculator (i.e., prior to sedimentation), and $C^{solids}{}_i$ is the weight percentage (dry basis) of component *i* in the TSS.

$$QC_i^{in} - QC_i^{out} = QC_{TSS}^{out}C_i^{solids} \quad (1)$$

Recovery is defined as:

$$Recovery = \frac{C_{TSS}^{out}C_i^{solids}}{C_i^{in} - C_i^{out}} \quad (2)$$

The energy footprint determined whether each system was energy-negative, -neutral, or -positive. Engineering calculations in combination with measured parameters (e.g., flow rates, pressure loss, methane yield) were used to estimate energy consumption of the various processes. Energy consumption associated with pumping (e.g., recirculation for mixing or GAC-fluidization) of incompressible fluids (i.e., water) was estimated as follows (Kim et al. 2011):

$$\hat{E}_{pumping} = \frac{Q_{pump} H g \rho}{\eta Q_{permeate}} \quad (3)$$

Where $\hat{E}_{pumping}$ is the pumping energy consumed per unit volume of permeate, Q_{pump} is the recirculation or fluidization pump flow rate for which the energy consumption was calculated, H is the head loss associated with pumping, g is the gravitational constant, ρ is the density of water, η is the pump efficiency (assumed to be 65%), and $Q_{permeate}$ is the permeate flow rate averaged over the combined pumping/relaxation cycle.

Energy consumption associated with adiabatic pumping of compressible fluids (i.e., biogas sparging and vacuum extraction of dissolved methane) was estimated as follows (Crone et al. 2016, Green and Perry 2008):

$$\hat{E}_{adiabatic} = \frac{k Q_{in} P_{in}}{(k-1)\eta Q_{permeate}} \left[\frac{P_{out}^{\left(\frac{k-1}{k}\right)}}{P_{in}} - 1 \right] \quad (4)$$

where $\hat{E}_{adiabatic}$ is the adiabatic sparging or evacuation energy consumed per unit volume of permeate, k is the heat capacity ratio, Q_{in} is the actual inlet volumetric flow rate, P_{in} is the inlet absolute gas pressure (i.e., atmospheric pressure in the case of biogas sparging or absolute pressure of the vacuum in the gas-liquid contactor in the case of dissolved methane removal using a vacuum pump), P_{out} is the outlet absolute gas pressure (i.e., compressed gas in the case of biogas sparging or atmospheric pressure in the case of dissolved methane removal using a vacuum pump), η is the pump efficiency (assumed to be 65%), and $Q_{permeate}$ is the permeate flow rate averaged over the combined pumping/relaxation cycle. An average value of 1.3 was used for k based on the values for methane (1.32), nitrogen (1.4), and carbon dioxide (1.28).

Energy production from generated methane was estimated as follows:

$$\hat{E}_{generation} = \frac{W_{methane} Q_{LHV} \eta}{F W_{methane} Q_{permeate}} \quad (5)$$

Where $\hat{E}_{generation}$ is the electrical energy produced by a generator per unit volume of permeate, $W_{methane}$ is the methane mass flow rate, Q_{LHV} is the lower heating value of methane (0.222 kWh/gram-mole), η is the generator efficiency (assumed to be 38%), $FW_{methane}$ is the formula weight of methane, and $Q_{permeate}$ is the net permeate flow rate averaged over the combined pumping/relaxation cycle.

5.7 SAMPLING RESULTS

5.7.1 Gas-Sparged AnMBR Bioreactor Operating Conditions

The gas-sparged AnMBR bioreactor tank was filled with 1.3 cubic meters (m^3) (350 gal) of mesophilic anaerobic digester sludge from the Topeka, Kansas wastewater treatment plant on July 13, 2016 and operated for 487 days. The initial operating conditions included a feed flow rate of 3.3 cubic meters per day (m^3/d) and a bioreactor operating volume of 1.3 m^3. The feed flow rate and bioreactor volume were varied over the course of the demonstration.

Certain periods of no or low flow were associated with mechanical failures (e.g., high pressure shutdown associated with a clogged strainer). These variations in combinations with natural variations in the feed COD concentration led to operating over a range of HRTs and OLRs (Figure 5.11). The average HRT was 11±3 h which is less than the performance objective of 20 h ($p < 0.0001$). The level sensor in the bioreactor tank became fouled with sludge and overestimated the liquid volume through day 283. Thus, the average HRT is likely overestimated. The average OLR was 1.3±0.5 kg-COD m^{-3} d^{-1}, which is greater than the performance objective of 0.6 kg-COD m^{-3} d^{-1} ($p < 0.0001$).

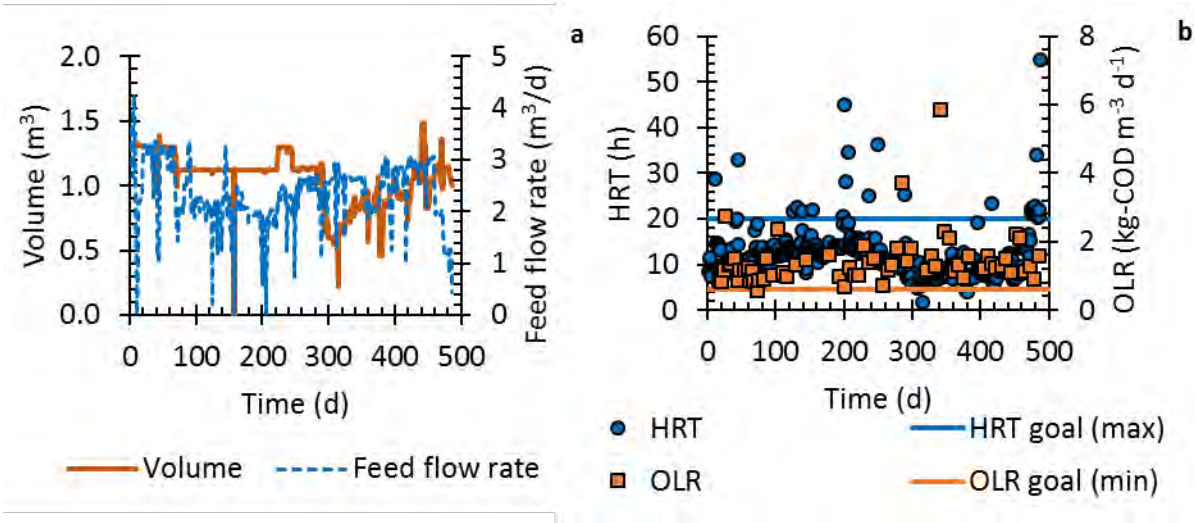

Figure 5.11 Gas-sparged AnMBR Volume and Flow Rate (a) and Calculated Hydraulic Residence Time and Organic Loading Rate (b).

Volume and hydraulic residence time include both the bioreactor and the membrane tank. Volume measurements through day 283 are approximate because the level transmitter became fouled with sludge. Volume measurements from day 284 onward were from manual level measurements. HRT and OLR values are thus estimated prior to day 284.

Initial operation of the bioreactor did not involve regular wasting of sludge to allow time for the inoculum to acclimate to the Ft. Riley wastewater. During this time, efforts were made to improve mixing in the bioreactor by varying the flow rates of the mixing pumps, varying the recirculation piping configuration, changing the bioreactor operating volume, and periodically wasting sludge. Regular wasting of sludge commenced on day 224 (Figure 5.12). The wasting percentage (defined as the volume wasted divided by the volume of wastewater treated) for this period was 0.7±1.1% and translated to an SRT of 60±27 d. Combined total solids and volatile solids concentrations and masses in the bioreactor and membrane tanks varied over time as shown in Figure 5.13. The average TSS and VSS concentrations were 9,100±6,100 mg/L and 7,100±4,700 mg/L, respectively. The initial decrease is thought to be due to inadequate mixing and sludge settling in the bioreactor. A second perturbation and ultimate decrease occurred around day 300 during a major wasting event intended to decrease the concentrations of colloidal organics (i.e., defined herein as 0.04 to 1.2 µm). This colloidal fraction was hypothesized to be fouling the ultrafiltration membranes as described in Section 5.7.14.

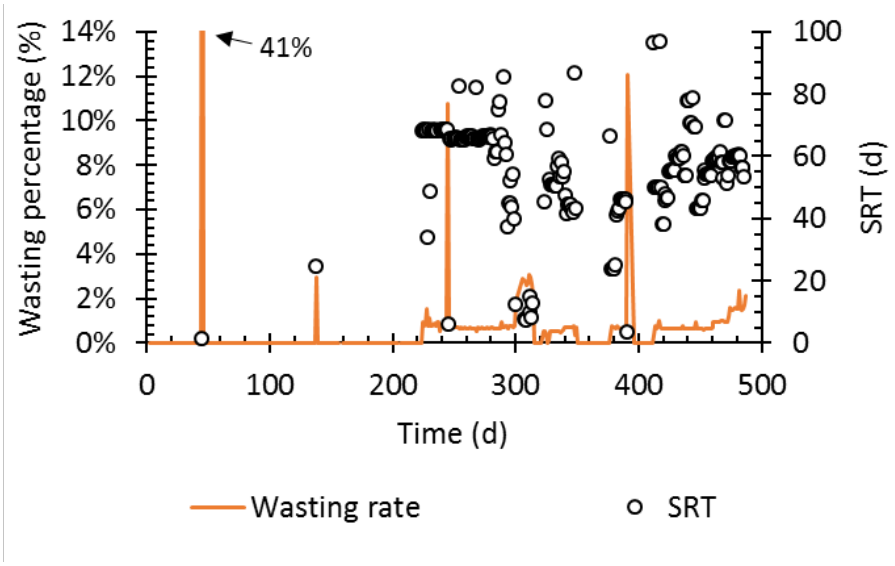

Figure 5.12 Gas-sparged AnMBR Solids Wasting Rate and Rsidence Time.

Wasting percentage is volume wasted as a percentage of volume fed. Regular wasting did not commence until day 224.

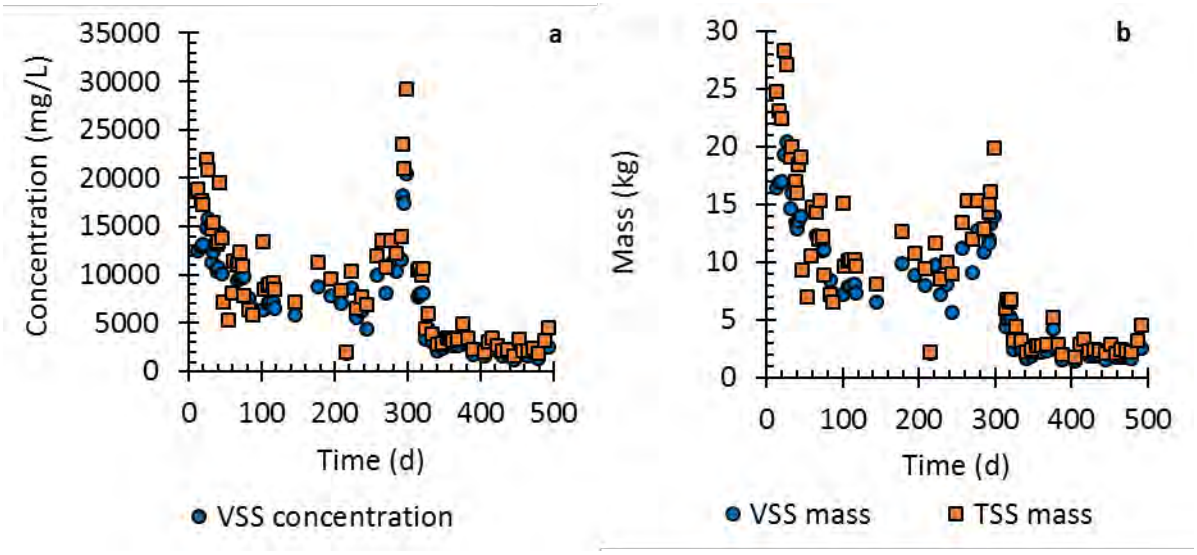

Figure 5.13 Gas-sparged AnMBR TSS and VSS Concentrations (a) and Mass (b) in the Bioreactor and Membrane Tank.

The apparent increases around day 300 may be associated with mixing of solids that may have settled in the bottom of the bioreactor.

5.7.2 GAC-Fluidized AnMBR Bioreactor Operating Conditions

The demonstration for this study was initiated on April 5, 2016 which is defined as day 0. The initial operating conditions included a feed flow rate of 8.9 m^3/d. The total active volume (i.e., volume occupied by fluidized GAC and inclusive of the bioreactor and the membrane tank) was constant (1.8 m^3) and was not varied. The feed flow rate was varied over the course of the demonstration. Certain periods of no or low flow were associated with mechanical failures. These variations, in combinations with natural variations in the feed COD concentration, led to operating over a range of HRT and OLR (Figure 5.14). The average HRT was 3.9±1.0 h, which is less than the performance objective of 20 h ($p < 0.0001$) and 65% less than the average HRT for the gas-sparged AnMBR. The average OLR through day 475 was 1.4±0.5 kg-COD m^{-3} d^{-1}, which is greater than the performance objective of 0.6 kg-COD m^{-3} d^{-1} ($p < 0.0001$) and similar to the OLR for the gas-sparged AnMBR. OLR based on total GAC mass is also presented for comparison (Figure 5.14c). Supplemental COD comprised of urea, NH_4Cl, K_2HPO_4, starch, milk powder, and dried yeast was fed to the GAC-fluidized AnMBR after day 475 to increase the COD concentration. From day 476 to day 535, the OLR was increased incrementally but averaged 2.2±0.5 kg-COD m^{-3} d^{-1}.

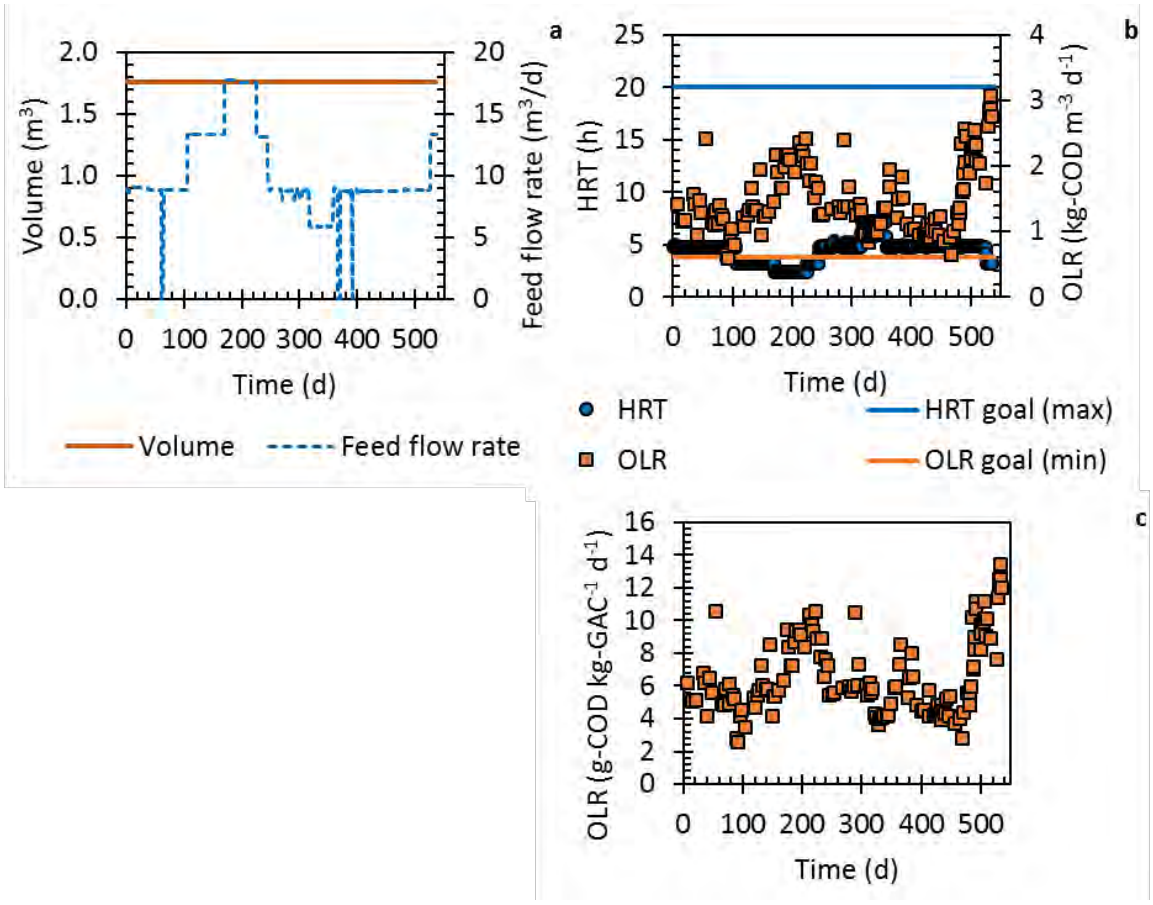

Figure 5.14 GAC-fluidized AnMBR Volume and Flow Rate (a), Hydraulic Residence Time, Volumetric Organic Loading Rate (b), and Organic Loading Rate per ass GAC (c).

Volume and hydraulic residence time include both the bioreactor and the membrane tank and only the volume occupied by fluidized GAC.

The wasting percentage was varied over the demonstration for the purpose of maximizing UF membrane flux and minimizing fouling (Figure 5.15). This percentage (2.1±1.0%) was about three-fold greater than that for the gas-sparged AnMBR (0.7±1.1%), which would lead to a greater volume of waste sludge volume requiring management. The average suspended solids residence time (sSRT) was 11±5 d but varied in response to the varying wasting rate and HRT. The sSRT accounts only for sloughed solids and solids that enter the bioreactor with the feed flow and remain suspended. It does not consider the biofilm, which would be expected to have a much greater SRT. The sSRT for the GAC-fluidized AnMBR was less than the SRT for the gas-sparged AnMBR (60±27 d). Variation in the GAC-fluidized AnMBR wasting rate, HRT, sSRT, and possibly influent solids concentrations led to changes in the TSS and VSS concentrations (Figure 5.16). The average TSS and VSS concentrations were 2,700±1,600 mg/L and 1,800±960 mg/L, respectively. These values are 25 to 30% of the gas-sparged AnMBR values. Thus, the GAC-fluidized AnMBR generally operated with lower solids concentrations and HRTs than the gas-sparged AnMBR, as would be expected for a biofilm system.

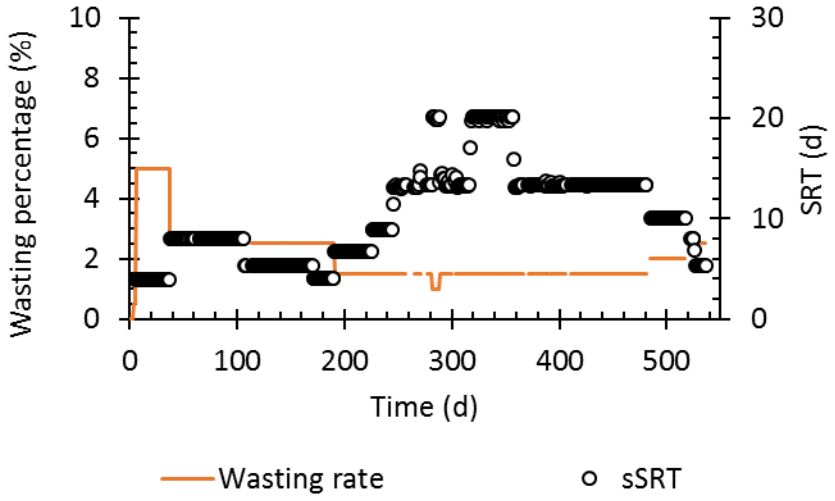

Figure 5.15 GAC-fluidized AnMBR Solids Wasting Rate and Suspended Solids Residence Time.

Wasting percentage is volume wasted as a percentage of volume fed. Suspended solids residence time includes suspended solids only and not biofilm solids.

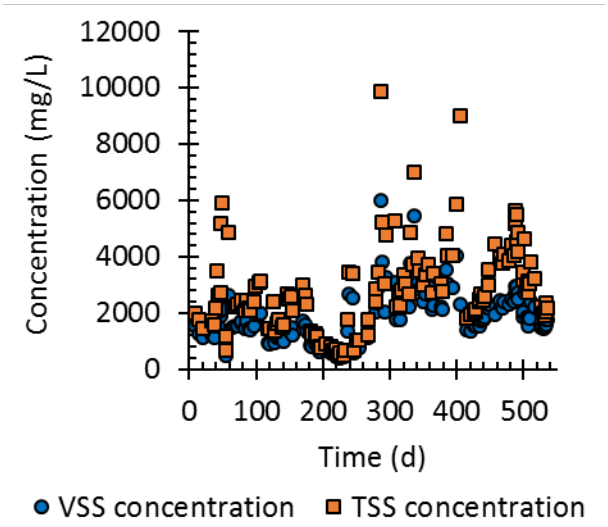

Figure 5.16 GAC-fluidized AnMBR TSS and VSS oncentrations.

5.7.3 Gas-Sparged AnMBR Organics Destruction

Performance data for COD and BOD_5 removal in the gas-sparged AnMBR are shown in Figure 5.17. Average influent and effluent COD concentrations for the period spanning from 17 to 472 days were 610±260 mg/L and 71±41 mg/L, respectively. The period from 1 to 16 days was excluded because this represented startup, and much of the COD was associated with the Topeka wastewater treatment plant anaerobic digester digestate. The period after 472 days was excluded because the pH of the raw sewage decreased, which led to a decrease in the bioreactor pH (Figure 5.17c). The effluent COD concentration is the AnMBR UF membrane permeate concentration and does not reflect further removal that may have occurred during coagulation, dissolved methane removal, or clinoptilolite ion exchange. The average permeate concentration of 71 mg/L was greater than the performance objective of 60 mg/L. However, an intentional sludge wasting event was conducted from day 300 to 314 (Figure 5.12) which led to a large decrease of volatile solids in the bioreactor (Figure 5.13b). The active microbial population would have decreased commensurately during this wasting event, resulting in less potential to destroy the organics and the operating OLR (Figure 5.10b). The percent removal of COD decreased in response to the decrease in bioreactor VS mass (Figure 5.17c). While the bioreactor pH did not decrease in response to this apparent overloading (Figure 5.17c), an increase in VFAs was observed in response to the wasting event (Figure 5.18). The permeate COD was similar to the calculated COD of the measured VFAs, and the increase was associated with acetate, butyrate, isobutyrate, and valerate. VFA concentrations returned to pre-wasting concentration around day 360 (Figure 5.18) as did the total permeate COD (Figure 5.17a). Thus, the wasting event, which was conducted to address membrane fouling as described below, led to an overloading condition and was the cause of the temporarily elevated permeate COD. If the permeate data from day 300 to 355 (i.e., during the wasting event and during the period of elevated VFAs) are not included in the analysis, the effluent COD concentration was 58±27 mg/L, which is less than the performance objective, but the difference is not statistically significant ($p=0.34$). The average COD removal was 90±4%.

The BOD_5 concentrations followed a similar pattern to the COD concentrations. The influent and effluent BOD_5 concentrations for the period spanning from 17 to 472 days were 250±110 mg/L and 29±15 mg/L, respectively. The BOD_5 was observed to increase transiently following the intentional wasting event on day 300 (Figure 5.17b). The percent removal of BOD_5 decreased simultaneously to the decrease in bioreactor VSS mass (Figure 5.17c). If the period from day 300 to 355 is excluded, the permeate concentration was 25±12 mg/L. This value is less than the performance objective of 30 mg/L ($p=0.004$) but greater than the reuse objective of 10 mg/L. The average BOD_5 removal was 89±5%.

One of the objectives of this demonstration was to evaluate the effect of temperature on organics removal. Figure 5.17c illustrates that COD and BOD_5 removals were not negatively impacted by low temperatures reaching a minimum of 12.7 °C. The overloading condition did lead to transient COD and BOD_5 concentrations greater than the 60- and 30-mg/L performance objectives (Figure 5.18a and b). A reduction in organics removal was also observed on day 257, when the temperature was 18°C and increasing; the reason for the organics removal reduction at this time could not be determined. Organics removal was seriously impacted on day 479 as a result of low influent and bioreactor pH. The effects of temperature on organics removal are evaluated further in Section 5.7.5.

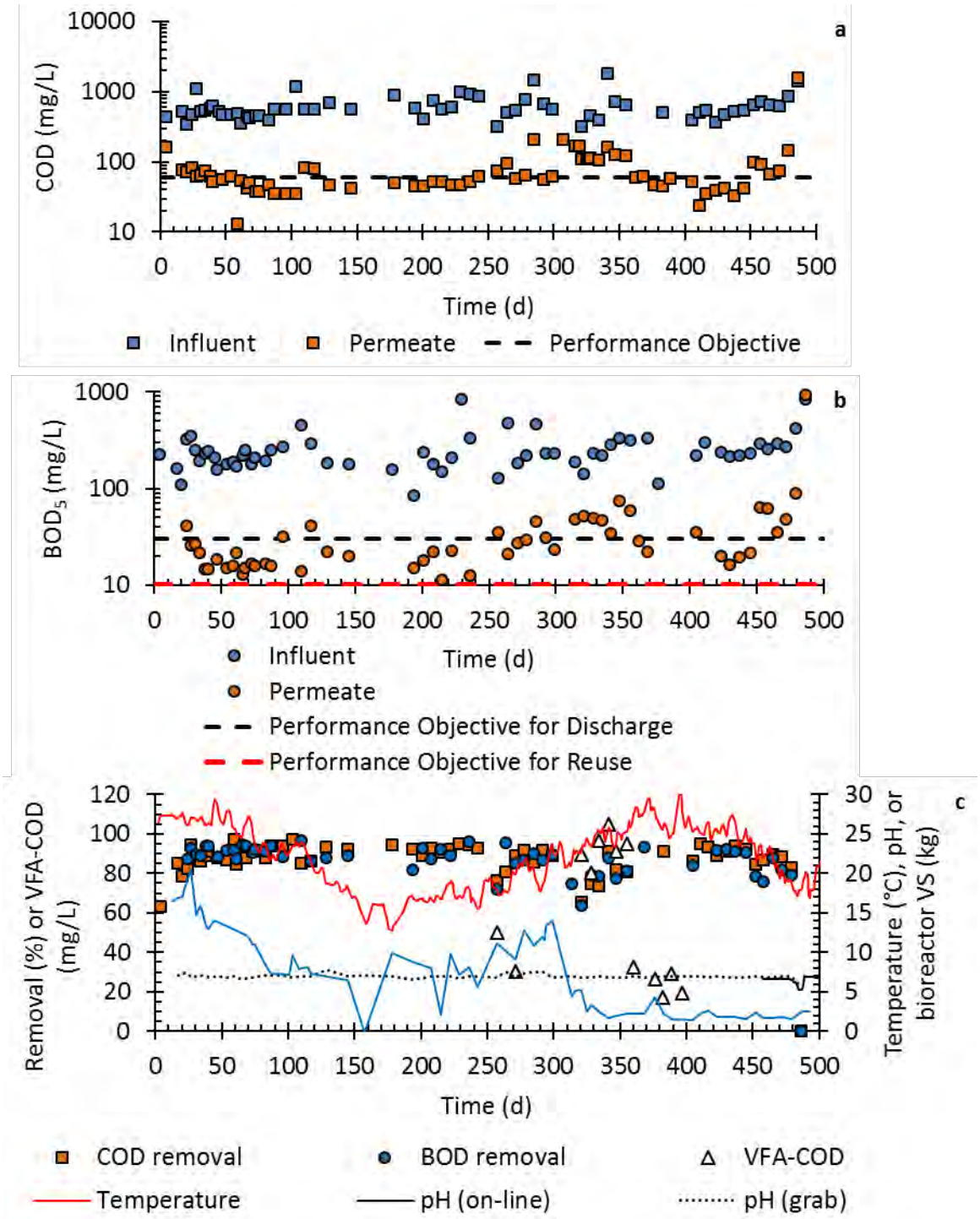

Figure 5.17 Gas-sparged AnMBR COD (a), BOD_5 (b), and Removals (c) by the Bioreactor and UF Systems.

Effects of temperature, volatile solids mass, and pH on VFA concentrations and removals (c) are also shown.

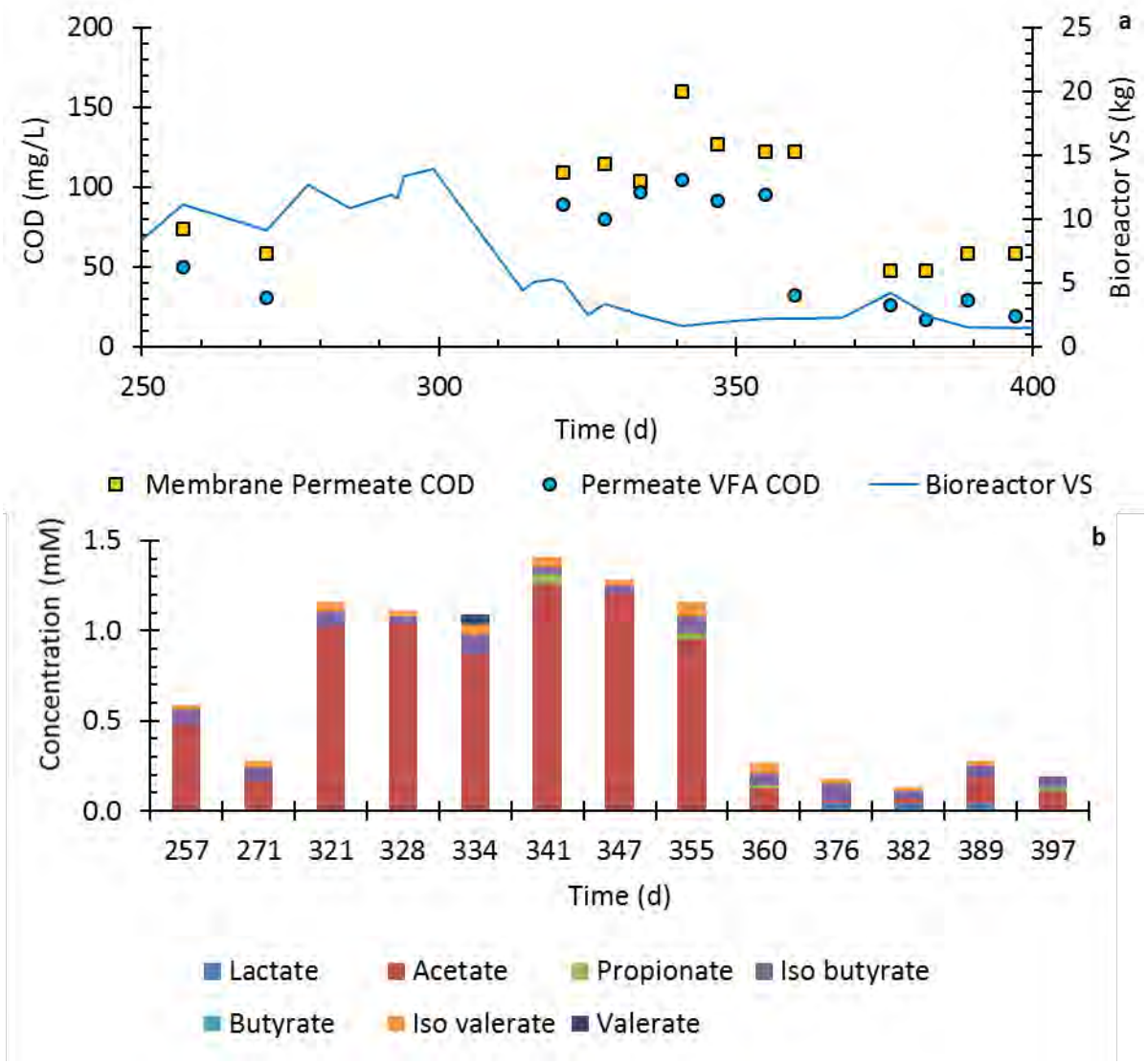

Figure 5.18 Gas-sparged AnMBR Permeate COD and VFAs Expressed as COD in Response to Bioreactor Sludge Wasting Event (a) and VFA Composition (b).

5.7.4 GAC-Fluidized AnMBR Organics Destruction

Performance data for COD and BOD_5 removal in the GAC-fluidized AnMBR are shown in Figure 5.19. Average influent and effluent COD concentrations for the period of no COD amendment spanning from 8 to 475 days were 240±70 mg/L and 40±20 mg/L, respectively. The average permeate concentration of 40 mg/L was less than the performance objective of 60 mg/L ($p < 0.001$). On day 263 the bioreactor recirculation pump was accidentally reversed, and about 30% of the GAC was ground and discharged from the system. New, virgin GAC was added to the bioreactor on day 277. Similar to the data analysis done for the gas-sparged AnMBR, the data during the upset and the period of elevated VFAs (i.e., through day 439) were excluded from the analysis. In this case, the effluent COD was 29±9 mg/L. The average COD removal was 86±3%

compared to 90±4% for the gas-sparged AnMBR. The reason for the difference in percent removal is mainly associated with the different influent COD concentrations (i.e., 610±240 mg/L for the gas-sparged AnMBR and 210±50 for the GAC-fluidized AnMBR during the non-upset periods).

The BOD_5 concentrations followed a similar pattern to the COD concentrations. The influent and effluent BOD_5 concentrations for the period spanning from day 8 to 475 were 150±44 mg/L and 22±13 mg/L. This value is less than the performance objective of 30 mg/L ($p < 0.001$) and greater than the re-use objective of 10 mg/L. The permeate concentration was 15±9 mg/L, excluding the upset period, and the percent removal was 89±5% which is identical to that for the gas-sparged AnMBR.

Figure 5.19c illustrates that COD and BOD_5 removals started decreasing around day 300. The minimum temperature of 9.3°C was measured on day 303, which was 40 days after the upset. Minimum COD and BOD_5 removals occurred around day 330. VFA concentrations increased following the upset and remained elevated for about 150 days compared to ≤70 days for the gas-fluidized AnMBR (Figure 5.17c and Figure 5.18). It is not clear whether the upset condition, the low temperature, or a combination of the two led to decreased performance. Nevertheless, the result was transient COD and BOD_5 concentrations greater than the 60- and 30-mg/L performance objectives (Figure 5.19a and b). The effects of temperature on organics removal are evaluated further in Section 5.7.5.

COD supplementation after day 475 increased COD to a maximum of 510 mg/L with an average concentration of 390±79 mg/L. The permeate COD concentration was 33±15 mg/L, which is less than the performance objective and less than the permeate concentration of 39±20 mg/L when no COD supplement was added. However, COD removal did not appear to be stable during COD supplementation, and the permeate COD increased to more than 60 mg/L at the end of this short-term experiment (Figure 5.19a). The OLR of more than 3 kg m^{-3} d^{-1} may have been too high for the system (Figure 5.14).

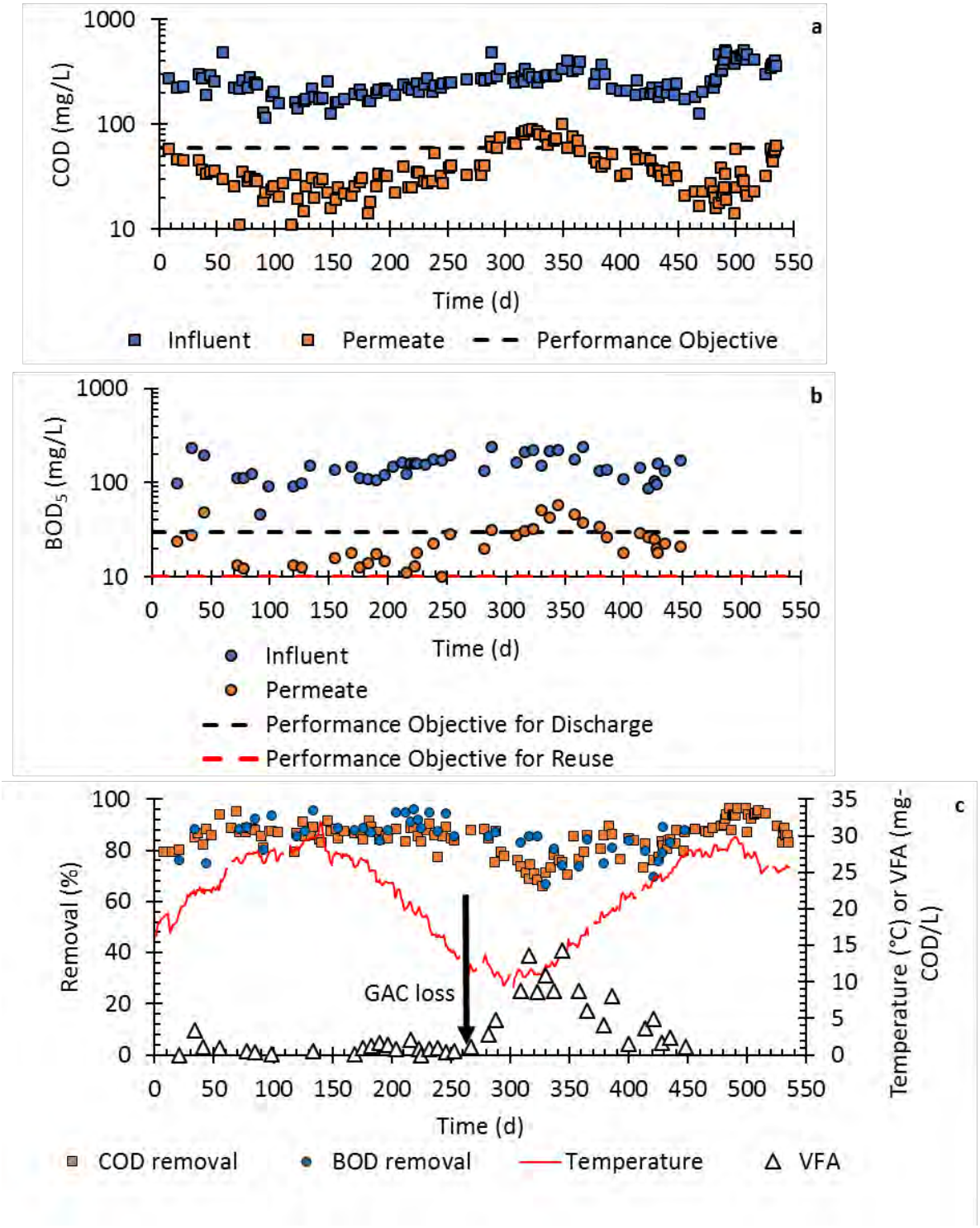

Figure 5.19 GAC-fluidized AnMBR COD (a), BOD_5 (b), and Removals (c) by the Bioreactor and UF Systems.

Effects of temperature on removals and VFA concentrations (c) are also shown. The arrow shows the time when fluidization pump flow was accidentally reversed for about one week resulting in GAC grinding and about 30% loss of GAC from the system. Virgin GAC was supplemented on around day 277.

5.7.5 Comparison of Gas-Sparged and GAC-Fluidized AnMBR Organics Destruction

Further evaluation of the effect of temperature on organics removal was conducted by directly comparing the performance of the gas-sparged and GAC-fluidized AnMBRs. Figure 5.20 through Figure 5.23 present various comparisons of the COD and BOD_5 data sets for both systems. Data for upset periods (i.e., overloading in the gas-sparged AnMBR and GAC grinding and loss in the GAC-fluidized AnMBR) are treated similarly (see sections 5.7.3 and 5.7.4) and presented separately from the non-upset data. For the GAC-fluidized AnMBR, only conditions without COD supplementation are shown.

Figure 5.20 shows the percent removals of COD and BOD_5. For temperatures greater than 15°C, COD removal by the gas-sparged AnMBR was slightly better than by the GAC-fluidized AnMBR. As described previously, this difference is attributable mainly to greater gas-sparged AnMBR feed COD concentrations as compared to those for the GAC-fluidized AnMBR (Figure 5.21). COD removal by the GAC-fluidized AnMBR decreased as temperatures declined from 15 to about 11°C however most of the decrease is associated with upset conditions. Non-upset data (3 data points) represent temperatures from 14.0 to 14.8°C. Therefore, conclusions regarding GAC-fluidized AnMBR performance at temperatures less than 14°C is not possible. Insufficient data for the gas-sparged AnMBR exist to make conclusions regarding COD removal effectiveness at temperatures less than 15°C. BOD_5 removal data are more scattered, and trends related to temperatures are difficult to interpret (Figure 5.20b). Wastewater temperatures at Ft. Riley did not decrease as much as they did in Bucheon, which resulted in only one data point at less than 15°C.

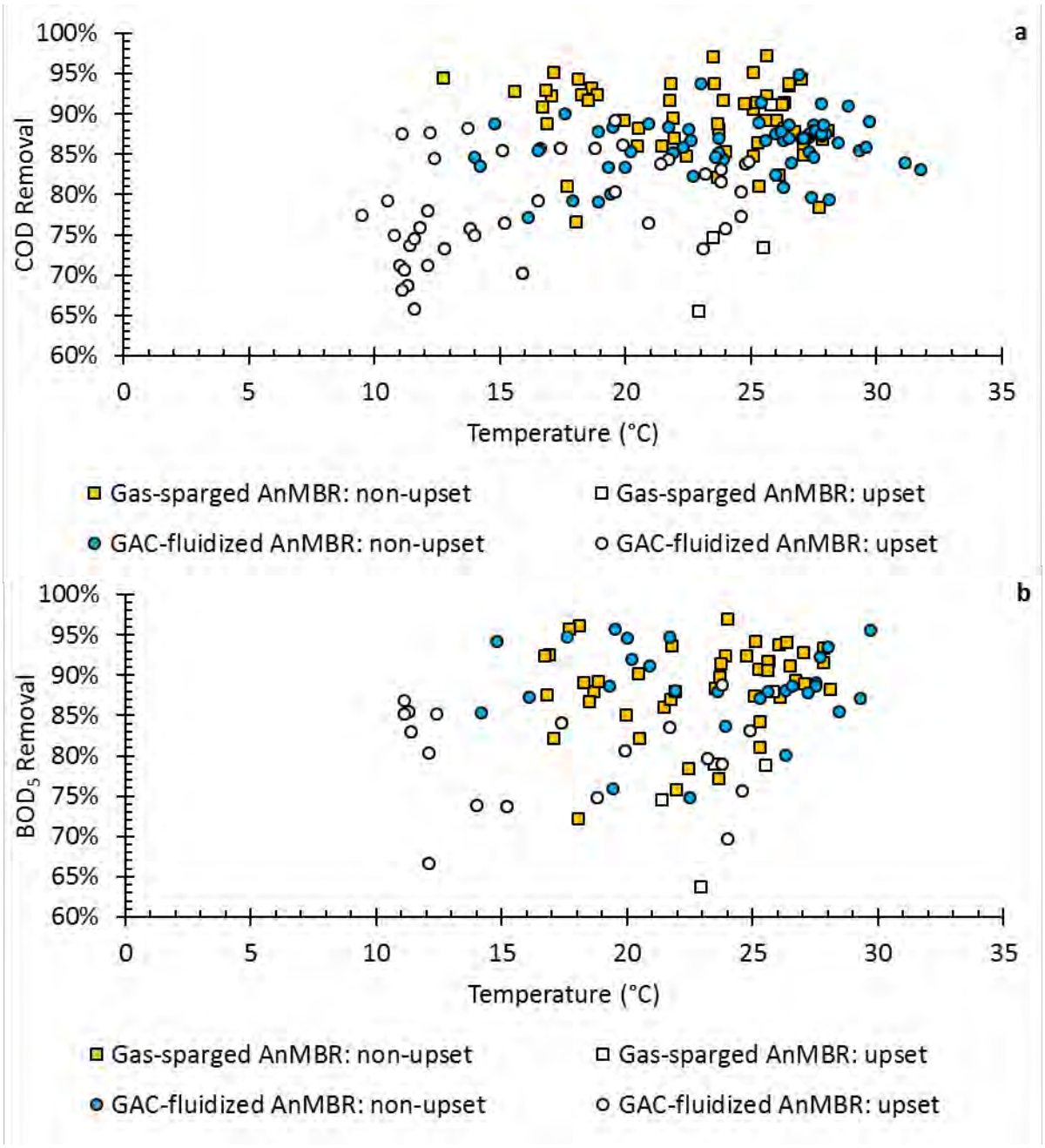

Figure 5.20 Comparison of Gas-sparged and GAC-fluidized AnMBR Performance at Different Temperatures for COD (a) and BOD_5 (b) Removal.

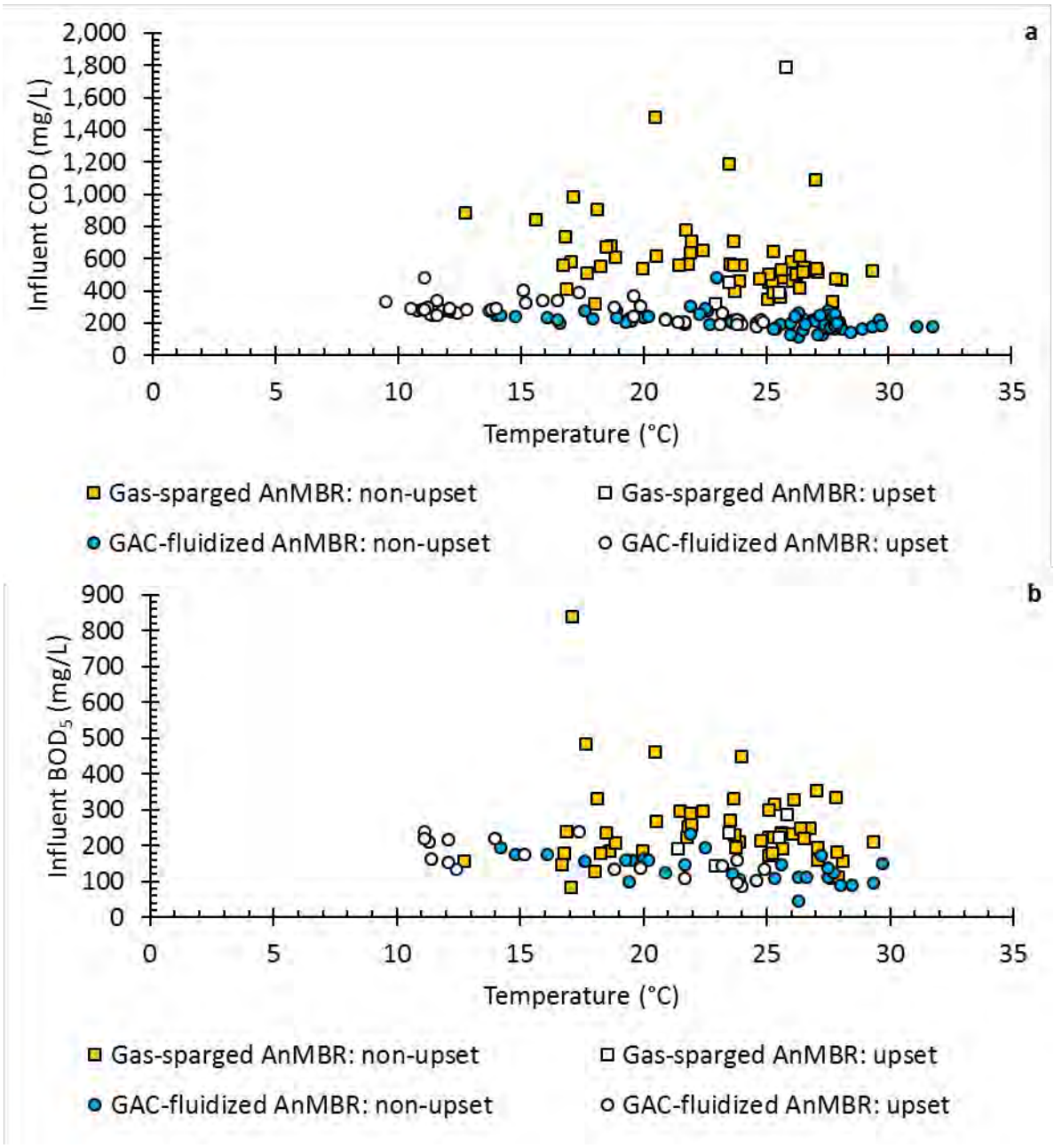

Figure 5.21 Comparison of Gas-sparged and GAC-fluidized AnMBR Influent Concentrations at Different Temperatures for COD (a) and BOD_5 (b).

Permeate COD and BOD_5 concentrations for both systems are presented in Figure 5.22. The GAC-fluidized AnMBR permeate COD and BOD_5 concentrations gradually increased as temperatures decreased from about 30 to 11°C. No discernable trend exists for the gas-sparged AnMBR data. The average COD and BOD_5 permeate concentrations (non-upset data only) for 5°C increments are shown in Figure 5.23. The gas-sparged AnMBR permeate COD concentrations did not increase as the temperature decreased. The GAC-fluidized AnMBR permeate COD and BOD_5 permeate concentrations for adjacent 5°C increments are not significantly different (Table 5.11) with the exception of 20 to < 25°C and 25 to < 30°C COD data ($p < 0.001$).

Both AnMBR systems were capable of maintaining low permeate COD and BOD_5 concentrations even though the influent concentrations appeared to increase as the temperature decreased (Figure 5.21). Differences in influent concentrations may also explain the greater permeate COD and BOD_5 concentrations observed in the gas-sparged AnMBR compared to the GAC-fluidized AnMBR (Figure 5.21 to Figure 5.23). The COD and BOD_5 permeate concentrations for temperatures greater than 15°C were less than the performance objectives with the exception of gas-sparged AnMBR COD for the 20 to < 25°C temperature range. This exception appears to be more attributable to data scatter rather than an actual performance issue. Thus, both AnMBR systems were capable of meeting the effectiveness performance objective for BOD5 and COD at temperatures as low as 15°C but conclusions regarding lower temperatures is not possible.

Table 5.11 Average GAC-fluidized AnMBR Permeate COD and BOD_5 Concentrations for 5°C Temperature Ranges and Associated Statistical Levels of Significance for the Differences.

Temperature Range (°C)	COD (mg/L)	p[a]	BOD_5 (mg/L)	p[a]
10 to < 15	35±7		19±13	
		0.33		0.39
15 to < 20	38±12		16±8	
		0.13		0.33
20 to < 25	33±6		19±14	
		< 0.001		0.13
25 to < 30	24±7		13±4	

[a] Probability value for Welch's t-test for significant difference between adjacent concentrations.

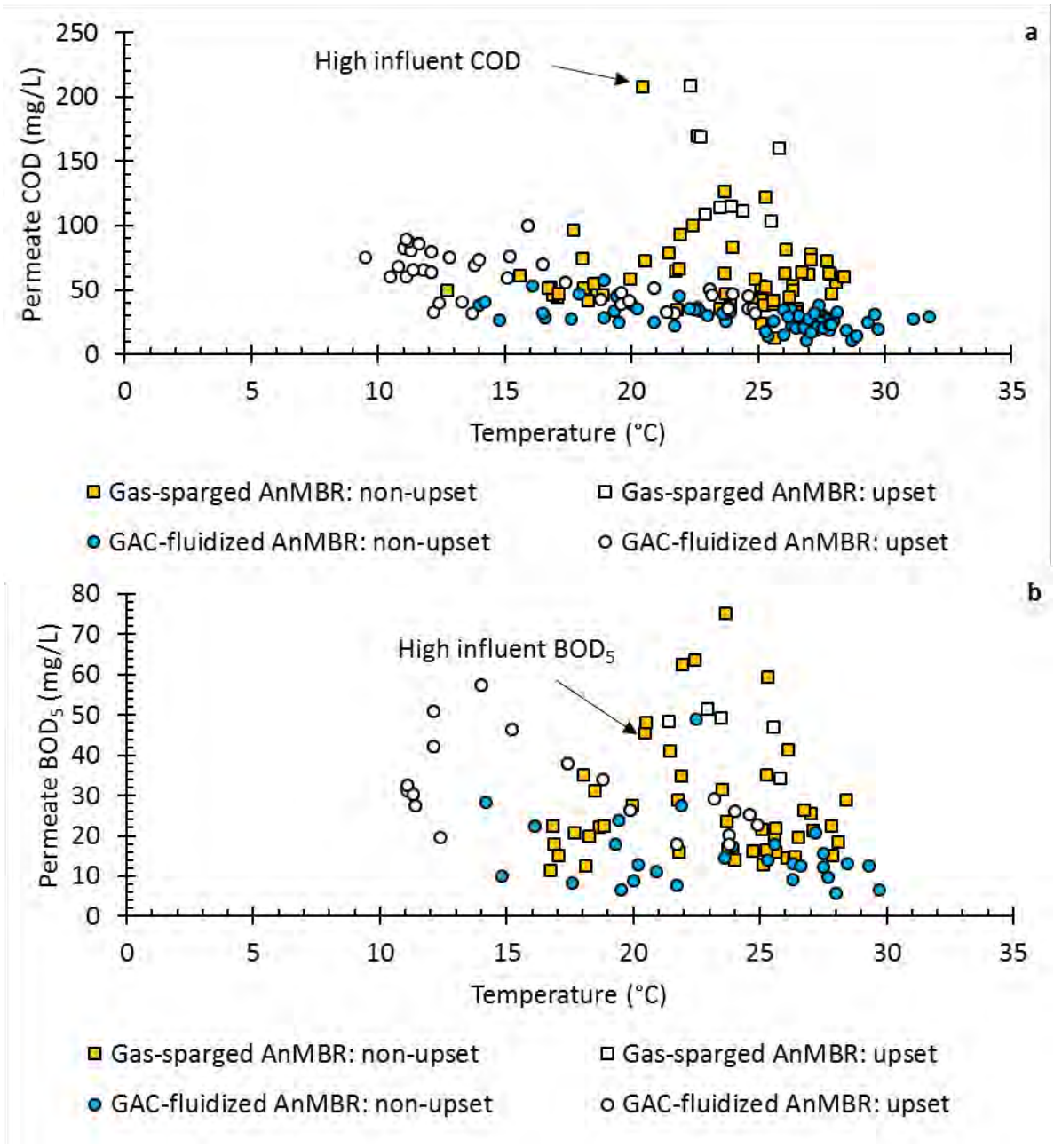

Figure 5.22 Comparison of Gas-sparged and GAC-fluidized AnMBR Permeate Concentrations at Different Temperatures for COD (a) and BOD_5 (b).

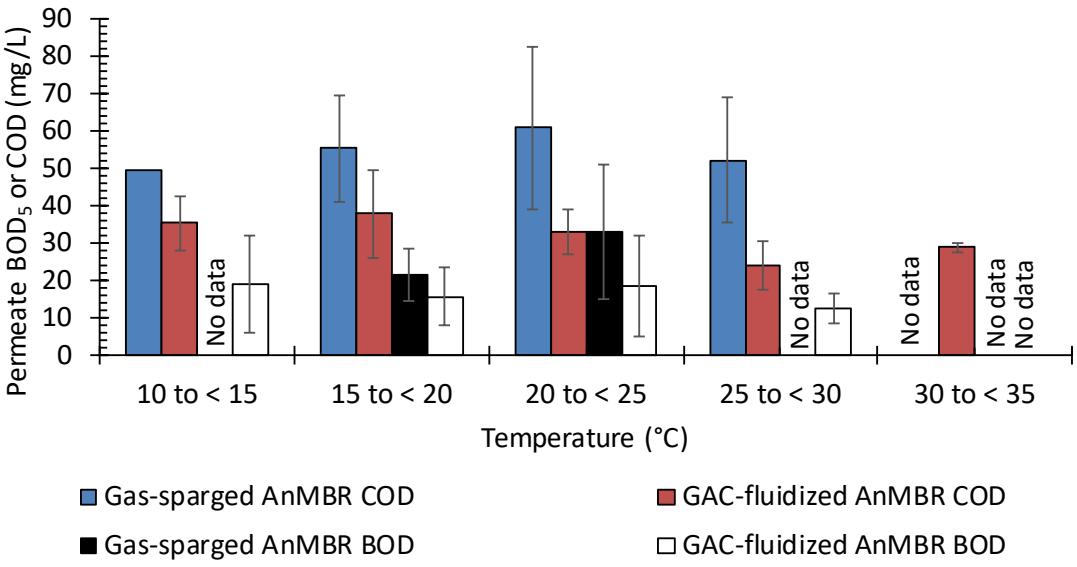

Figure 5.23 Comparison of Gas-sparged and GAC-fluidized AnMBR Permeate Concentrations at Different Temperature Ranges for COD and BOD_5.

Upset data not included. Error bars represent ±1 standard deviation. Only one value for gas-sparged AnMBR COD at 10 to < 15 °C.

5.7.6 Solids Generation

Table 5.12 presents the results of a comparable analysis of solids data for the two AnMBR systems. Inadequate mixing in the gas-sparged AnMBR led to settling of solids in the bottom of the bioreactor tank. These solids were recovered and quantified at the end of the demonstration. This problem was not encountered with the GAC-fluidized AnMBR. Therefore, estimation volatile solids generation per unit COD loaded was done by summation of total masses of solids entering and leaving the AnMBRs.

First the screened influent was evaluated. The average TSS, VSS, and fixed suspended solids (FSS) concentrations are presented along with the ratio of VSS/TSS. The solids concentrations in the gas-sparged AnMBR influent were greater than those in the GAC-fluidized AnMBR in line with the differences observed in COD and BOD_5. The VSS/TSS ratio for the GAC fluidized AnMBR (78±8%) was less than that for the gas-sparged AnMBR (89±4%). The VSS and FSS influent masses were calculated by multiplying the average concentrations by the total volume of wastewater treated. The wasted sludge volume as a fraction of the treated wastewater was greater in the GAC-fluidized AnMBR (2.1%) than in the gas-sparged AnMBR (0.7%). The total wasted solids were estimated by summing the daily or weekly masses generated and, in the case of the gas-sparged AnMBR, adding this sum to the mass recovered from the bottom of the bioreactor.

The fixed solids recovery was low for both systems. Part of the low recovery for both systems was low precision of the solids analyses. The ratios of sludge volatile to total solids in the gas-sparged and GAC-fluidized AnMBR systems were 70 and 66%, respectively, compared to the influent ratios of 89 and 78%. The relatively lower ratios in the sludge compared to the influent is consistent with volatile solids destruction and accumulation of fixed solids in the sludge.

Table 5.12 Gas-sparged AnMBR and GAC-fluidized AnMBR Solids Generation and Destruction.

Parameter	Gas-Sparged AnMBR	GAC-Fluidized AnMBR[a]
Average TSS in influent (mg/L)	330 ± 190	120 ± 50
Average VSS in influent (mg/L)	300 ± 170	89 ± 30
Average FSS in influent (mg/L)	35 ± 23	29 ± 22
Influent VSS/TSS	89% ± 4%	78% ± 8%
Total wastewater treated (m^3)	1200	4600
Influent VSS mass (kg)	340	410
Influent FSS mass (kg)	41	140
Wasted sludge (L)	6,000	94,000
Wasted sludge volumetric fraction[b]	0.7%	2.1%
Total wasted TS or TSS (kg)[c]	67	220
Total wasted VS or VSS (kg)[c]	47	150
Total wasted FS or FSS (kg)[c]	18	75
Fixed solids recovery	44%	55%
Wasted sludge VS/TS or VSS/TSS[c]	70%	66%
Average COD in influent (mg/L)	620 ± 250	240 ± 70
Influent COD mass (kg)	630	1,100
Sludge production (g-VS/g-COD loaded or g-VSS/g-COD loaded)[c]	0.074	0.13
Sludge production corrected for fixed solids recovery (g-VS/g-COD loaded or g-VSS/g-COD loaded)[c]	0.17	0.24

[a] COD supplementation period not included.
[b] Days 224 to 487 for gas-sparged AnMBR.
[c] Total values reported for gas-sparged AnMBR and suspended values reported for GAC-fluidized AnMBR.

The volatile solids generation per unit mass of loaded COD was calculated and compared to the performance objective of 0.2 g-VS/g-COD. The results were 0.074 and 0.13 g-VS/g-COD for the gas-sparged and GAC-fluidized AnMBR. Both of these values met the performance objective. The value for the gas-sparged AnMBR may be low in part because of solids settling in the bioreactor and incomplete recovery. On the other hand, the greater SRT (60±27 d versus 11±5 d) in the gas-sparged AnMBR could have promoted greater hydrolysis and lower solids generation. When values for both systems are corrected based on the fixed solids recovery, the values (0.17 and 0.24 g-VS/g-COD) are similar to the performance objective.

Primary treatment other than screening was not conducted before wastewater was pumped to the bioreactors. Attempts to directly estimate the amounts of solids removed by screening were unsuccessful; however, Suez provided values (Table 5.13). Based on these data, the estimated amounts of TSS and COD removed by 1.7-mm screening at Ft. Riley were 20% and 15%, respectively. Designing any wastewater treatment system requires consideration of the primary treatment requirements. In this demonstration, only screening was conducted. Primary sedimentation may also be considered prior to secondary treatment. In any case, treatment of all residuals will need to be considered. Such consideration is given in Section 7.

Table 5.13 Screening Estimates for COD and TSS Removal.

Influent COD and TSS concentrations were 570 and 270 mg/L, respectively.

	Screen size (mm)		
Screen (mm)	0.5	1	2
TSS removal (%)	38%	26%	15%
COD removal (%)	22%	18%	12%

5.7.7 Gas-Sparged AnMBR Biogas Production

The gaseous methane concentration was initially 78±4% through day 200 and then decreased slightly to 74±4% between days 200 and 300 (Figure 5.24). From day 300 through the end of the demonstration, the methane content was 65±4%. The reason for the gradual decrease in methane content is uncertain but may be associated with the sludge wasting event that occurred around day 300. The initially high methane content has been observed previously with AnMBR treatment of low-strength domestic strength wastewater and is associated with lower carbon dioxide content (Shin et al. 2016c). Such a low carbon dioxide content was also observed with the AnMBR at Ft. Riley as shown in Section 5.7.20.

The biogas and methane flow rates (Figure 5.24) and methane mass rate (Figure 5.25) decreased around day 150 and was associated with lower temperatures. Methane mass rates increased as the temperature increased (Figure 5.25), and the changes were associated with variation in methane yield (see Section 5.7.9). The variation in methane mass rate was not associated with organic loading rate (Figure 5.26). The methane mass rate decreased temporarily after the sludge wasting around day 300. The mass rate increased around day 360 consistent with system recovery and reduction of VFA concentrations (Figure 5.18). The dissolved portion of the methane mass rate was relatively small compared to the gaseous fraction at relatively high temperatures (Figure 5.25); the dissolved and gaseous mass rates were similar at lower temperatures.

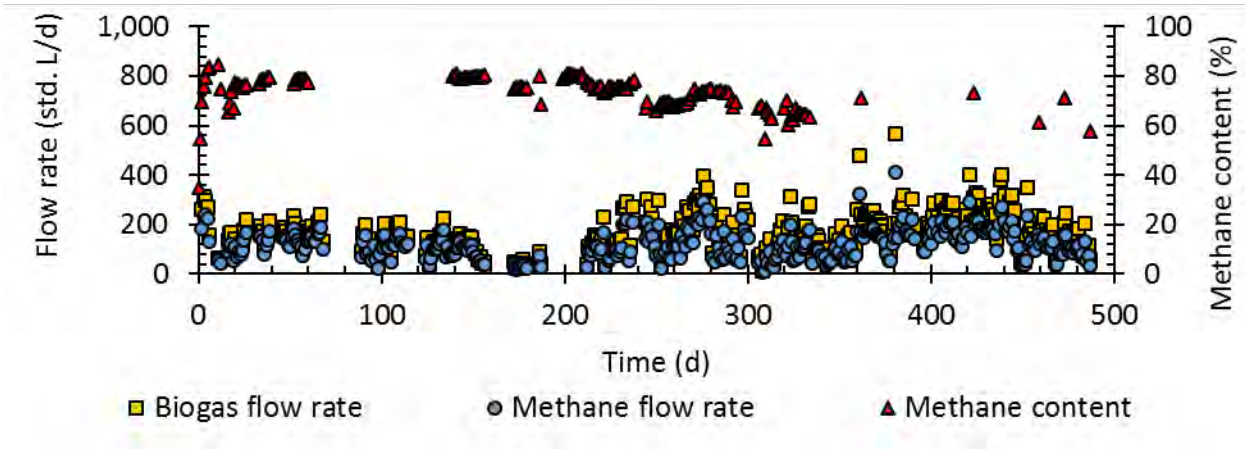

Figure 5.24 Gas-sparged AnMBR Daily Average Biogas and Gaseous Methane Flow Rates and Methane Composition.

Data prior to day 334 are from on-line gas analyzer. Later data are from laboratory analyses.

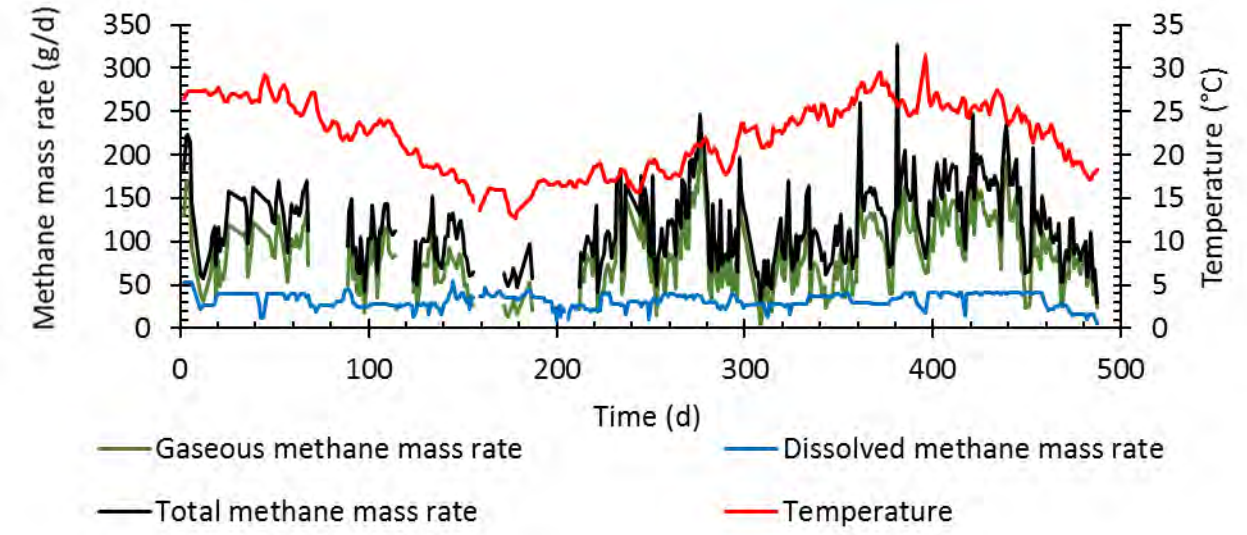

Figure 5.25 Gas-sparged AnMBR Daily Average Gaseous, Dissolved, and Total Methane Mass Rates Compared to Temperature.

Periods of missing data are associated with equipment malfunctions. Methane production rates include interpolated values for gas flow rates and methane concentrations.

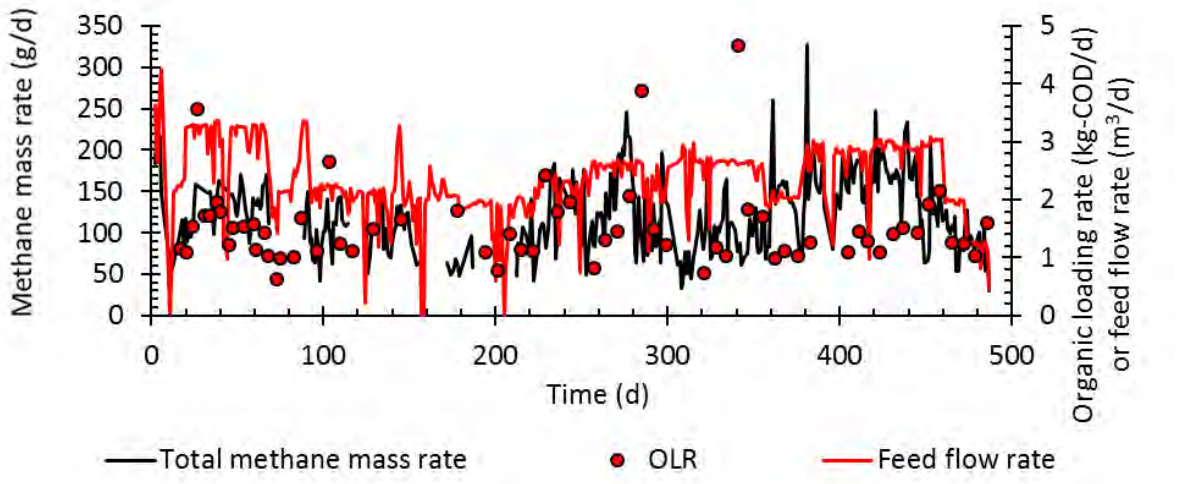

Figure 5.26 Gas-sparged AnMBR Daily Average Total Methane Mass Rate Compared to Organic Loading Rate and Feed Flow Rate.

Periods of missing data are associated with equipment malfunctions.

5.7.8 GAC-Fluidized AnMBR Biogas Production

The gaseous methane concentration was initially 73±1.3% through day 100 and then decreased to 60±4.9% between days 100 and 239 (Figure 5.27). From day 373 through the end of the unsupplemented COD demonstration (day 475), the methane content was 62±5.9%. The decline in methane concentrations over the duration of the demonstration was similar to that observed for the gas-sparged AnMBR. The reason for the gradual decrease in methane content is uncertain. No intentional sludge wasting occurred during the GAC-fluidized AnMBR demonstration, but a GAC grinding and loss event did occur on day 263. This time, it was after the reduction in methane concentration. Therefore, loss of GAC biomass was not the cause of the reduction in methane concentration in the GAC-fluidized AnMBR.

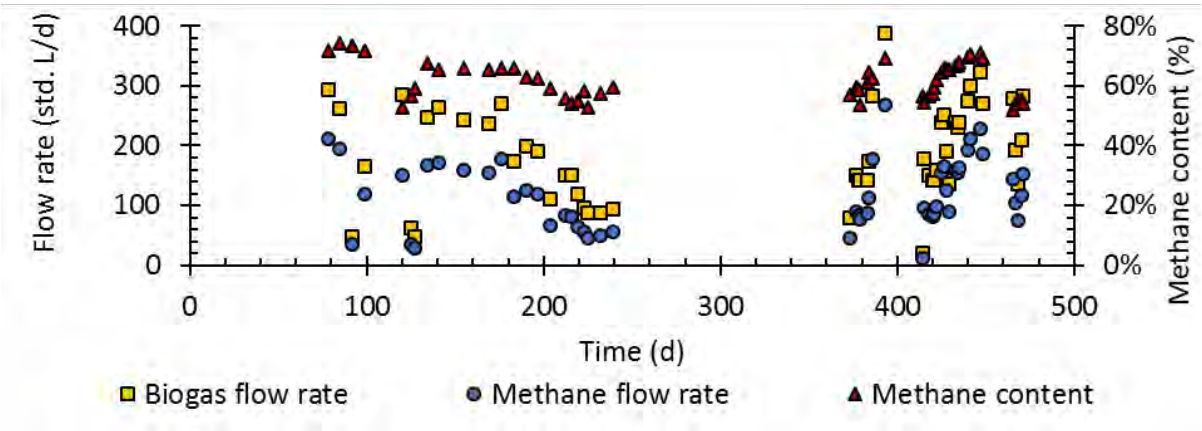

Figure 5.27 GAC-sparged AnMBR Daily Average Biogas and Gaseous Methane Flow Rates and Methane Composition without COD Supplementation.

Gas leakage from the bioreactor from day 240 to 371 prevented collection of accurate gas data.

The biogas and methane flow rates (Figure 5.27) and the methane mass rate (Figure 5.28) decreased around day 200 and was associated with lower temperatures. The lower mass rates were associated with lower methane yield (see Section 5.7.10) than that for the gas-fluidized AnMBR and not with lower organic loading rate (Figure 5.29). Methane mass rates increased as the temperature increased. The dissolved portion of the methane mass rate was equal to or greater than the gaseous fraction at (Figure 5.28). This result was unexpected but may be attributable to the relatively lower COD of the wastewater compared to the gas-sparged AnMBR. With a lower COD, a relatively greater proportion of methane will remain dissolved (Shin et al. 2016c).

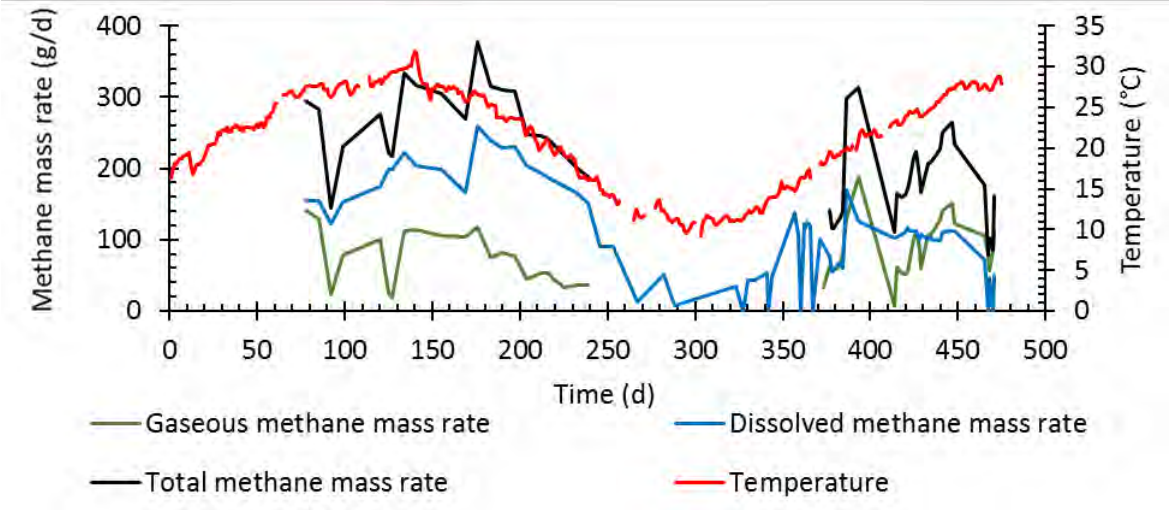

Figure 5.28 GAC-sparged AnMBR Gaseous, Dissolved, and Total Methane Mass Rates without COD Supplementation Compared to Temperature.

Gas leakage from the bioreactor from day 240 to 371 prevented collection of accurate gas data.

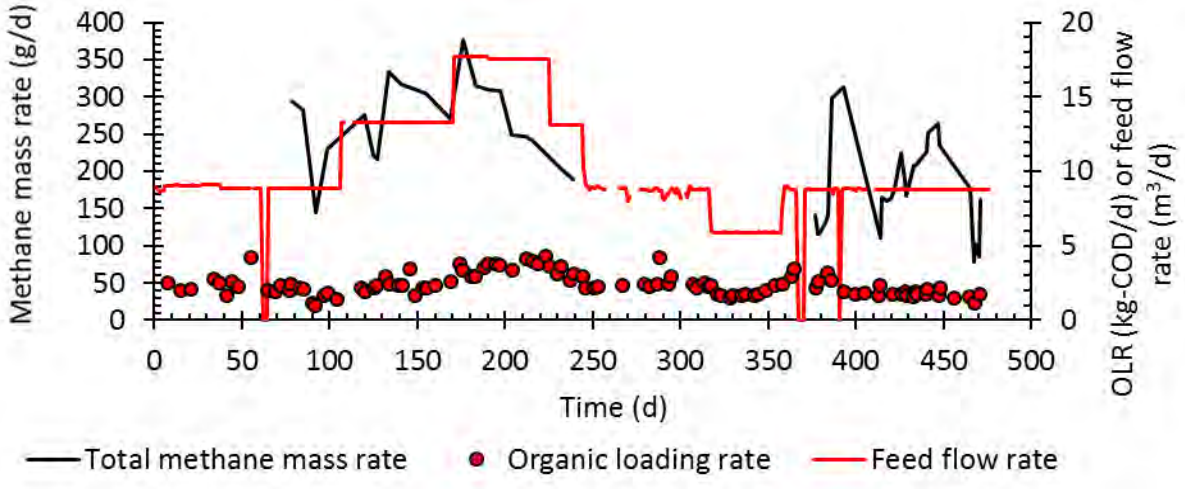

Figure 5.29 GAC-sparged AnMBR Total Methane Mass Rate without COD Supplementation Compared to Organic Loading Rate and Feed Flow Rate.

Gas leakage from the bioreactor from day 240 to 371 prevented collection of accurate gas data.

5.7.9 Gas-Sparged AnMBR COD Balance and Methane Yield

A COD balance was conducted by totalizing the amounts of wastewater COD, permeate COD, gaseous and dissolved methane, sulfate reduction, and wasted sludge volatile solids and calculating their COD equivalents. The sludge recovered from the bottom of the bioreactor was also included in the COD balance. Results are presented in Table 5.14. The mass balance was not complete with 35% of the COD unaccounted (i.e., "other"). Possible explanations for the missing COD include underestimation of wasted solids, instrumentation inaccuracy (e.g., flow meters and the gaseous methane analyzer), and analytical accuracy. The most likely explanation is underestimation of wasted solids. First the fixed solids balance was poor (Table 5.12). Additionally, the volatile solids generated per unit mass loaded COD was low compared to that for the GAC-fluidized AnMBR. While a greater SRT may explain the relatively lower sludge yield, an underestimate of the concentrations could also be a factor. The solids in the bioreactor were not well mixed. This was observed several times by analyzing the concentrations at different water heights in the bioreactor. Because of this issue, measurements of total and volatile solids concentrations were conducted by sampling the sludge recirculation line. This approach may have underestimated the actual sludge concentration.

Table 5.14 Gas-sparged AnMBR COD Balance.

Parameter	Aqueous concentration (mg/L)[1]	Equivalent aqueous COD (mg/L)[a]	Total COD equivalent mass (kg)	Percentage of influent COD mass
Influent COD	620±250	620±250	630	100
Permeate COD	66±34	66±34	70	11
Gaseous methane	NA	140±50	154	24
Dissolved methane	14±2	57±9	57	9
Total methane	NA	NA	210	33
Sulfate reduction	63±17	44±10	44	7.0
Wasted sludge volatile solids[b]	NA	NA	86	14
Other	NA	NA	220	35

[a] Average ± standard deviation of samples collected during operation.
[b] Includes sludge recovered from bottom of bioreactor at end of study. COD equivalent is based on a measured value of 1.84 g-COD/g-VS.

Despite these challenges, the total methane generated represented 33% of the influent COD with most being in the biogas. These are average values for the entire demonstration. As was noted previously, temperature has an effect on this apportionment (see Figure 5.25). The remaining COD was associated with the permeate (11%), sulfate reduction (7%), and sludge volatile solids (14%).

The average methane yield for the entire demonstration was 140±60 mL-methane per gram removed COD (mL-CH_4/g-$COD_{removed}$ or mL/g). The theoretical value of 350 mL/g was not achieved because influent COD was not converted to methane; rather, it was distributed amongst the permeate, sulfate reduction, sludge generation, and other unaccounted COD (Table 5.14).

The methane yield was compared to wastewater temperature (Figure 5.30). The methane yields presented here are thus net or effective yields which are relevant for design, economic analysis, and practical implementation of the process. A general trend where lower yields were associated with lower temperatures was observed. The average yields for > 25°C and < 20°C were 180±40 and 110±50 mL/g, respectively. These yields are significantly different (p=0.00016). The yield between 20 and 25°C was intermediate at 140±50 mL/g. Therefore, temperature had a strong effect on methane yield and is likely associated with decreased hydrolysis and greater sludge production at lower temperatures. This observation has important implications with regard to attainment of energy neutrality, as discussed in Section 5.7.23.

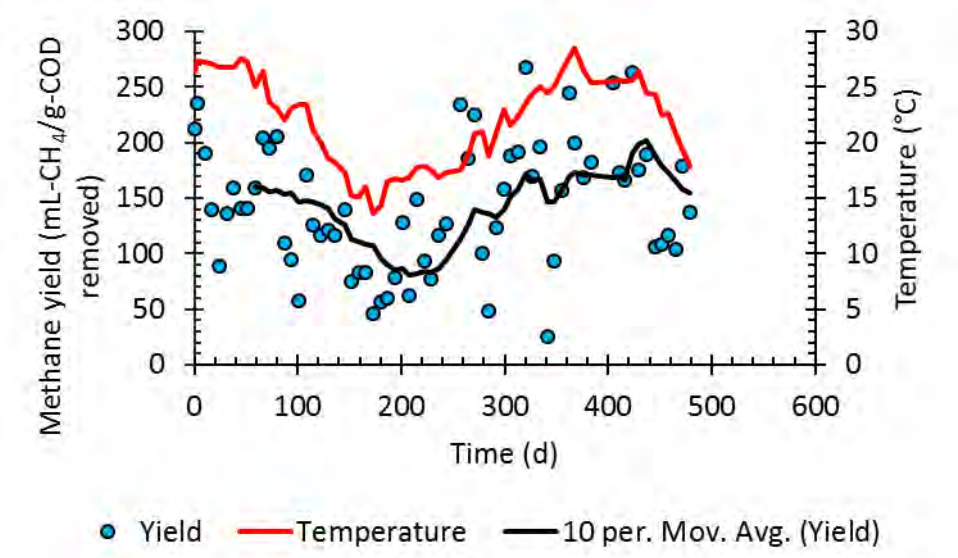

Figure 5.30 Gas-sparged AnMBR Methane Yield in Relationship to Temperature.

5.7.10 GAC-Fluidized AnMBR COD Balance and Methane Yield

A COD balance for the GAC-fluidized AnMBR was also conducted but did not account for any sludge associated with GAC lost from the system. Results are presented in Table 5.15. The mass balance was not complete with 19% of the COD unaccounted (i.e., "other"), which is less than that for the gas-sparged AnMBR (35%). In addition to the possible explanations for the missing COD listed for the gas-sparged AnMBR, the GAC-fluidized AnMBR experienced a gas leak from around day 240, when the leak was observed, to day 371, when it was sealed. This time period was not included in the COD balance, but additional leakage could have occurred prior to day 240. Underestimation of wasted solids may have also contributed to an incomplete solids balance because the fixed solids balance was also poor (Table 5.12).

Table 5.15 GAC-fluidized AnMBR COD Balance.

Parameter	Aqueous concentration (mg/L)[a]	Equivalent aqueous COD (mg/L)[a]	Percentage of influent COD mass
Influent COD	240±66	240±66	100
Permeate COD	40±20	40±20	17
Gaseous methane[b]	NA	32±19	14
Dissolved methane[b]	12±3	49±12	21
Total methane	NA	81	34
Sulfate reduction	13±9	9±6	3.6
Wasted sludge volatile solids	34±15	62±28	26
Other	NA	46	19

[a] Average ± standard deviation of samples collected during operation.
[b] Excludes data from days 240 to 371 when a gas leak existed.
NA - Not applicable

The total methane generated represented 34% of the influent COD, which was similar to that for the gas-sparged AnMBR (33%). Relatively more methane was present in the aqueous phase in contrast to the gas-sparged AnMBR, and this was likely correlated to the lower COD concentrations in the influent and effluent. The remaining COD was associated with the permeate (17%), sulfate reduction (3.6%), and sludge volatile solids (26%).

The average methane yield for the portion of the demonstration where COD was not supplemented was 170±50 mL/g, which is similar to that for the gas-sparged AnMBR (140±60 mL/g). The methane yield was compared to wastewater temperature (Figure 5.31). A general trend was observed where lower yields were associated with lower temperatures. The average yields for >25°C and < 20°C were 200±40 mL/g and 100±20 mL/g, respectively. These yields were significantly different ($p < 0.00010$). The yields for > 25°C for < 20°C were similar to those for the gas-sparged AnMBR (180±40 and 110±50 mL/g, respectively). The differences in sSRT (11±5 d versus 60±27 d) did not lead to differences in effective methane yield. The yield between 20 and 25°C was intermediate at 140±50 mL/g. Therefore, temperature had a strong effect on methane yield, just as was observed with the gas-sparged AnMBR. The implications with regard to attainment of energy neutrality are discussed in Section 5.7.24.

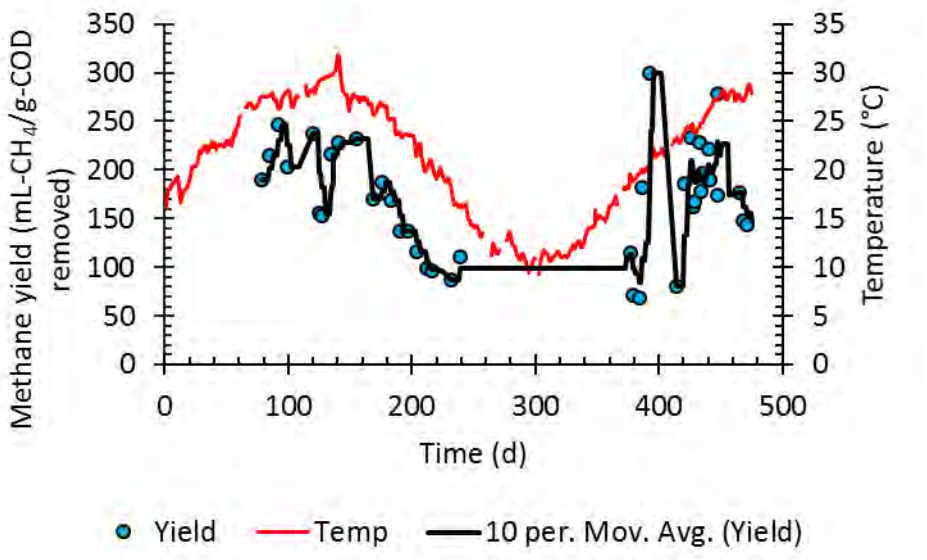

Figure 5.31 GAC-fluidized AnMBR Methane Yield without COD Supplementation in Relationship to emperature.

Data from 240 to 370 days not included because of bioreactor leakage.

5.7.11 Dissolved Methane Removal

Figure 5.32 illustrates the methane removal as a function of the lumen-side absolute pressure at two different permeate flow rates. The permeate flow rates, when normalized to contactor membrane area, were 0.55 and 1.1 cubic meters per square meter per day ($m^3\ m^{-2}\ d^{-1}$). The influent dissolved methane concentration for these tests was 13±2 mg/L. Methane removal increased as the absolute pressure decreased (i.e., the vacuum increased) as expected. Methane removal was also greater at the lower permeate flow rate. The maximum methane removal was 83%, which is lower than the performance objective of 90%. The average removal at the lower permeate flow rate and absolute pressures less than 100 millimeters of mercury (mm Hg) was 79±2%. According to 3M, the performance of the Liqui-Cel contactors can decrease over time because of oxidation of the membranes. Because of the age of this contactor (~10 years), the performance may have been less than would have been observed with a new contactor. Therefore, the results reported here are considered conservative.

3M ran their proprietary design model prior to execution of these tests. The results are also shown on Figure 5.32. The model and the experimental results do not match. The primary application of these contactors is for dissolved oxygen and carbon dioxide removal from water. Their design model has been tested and validated for these solutes but not for methane. To conduct the modeling, 3M used the relative Henry constants for methane and oxygen. This approach did not account for possible mass transfer differences between these two solutes. Therefore, the 3M model as it currently exists does not appear to be applicable to removal of dissolved methane. On the other hand, the age of the contactor could have affected the performance. Therefore, additional tests with new contactors in conjunction with modeling are recommended.

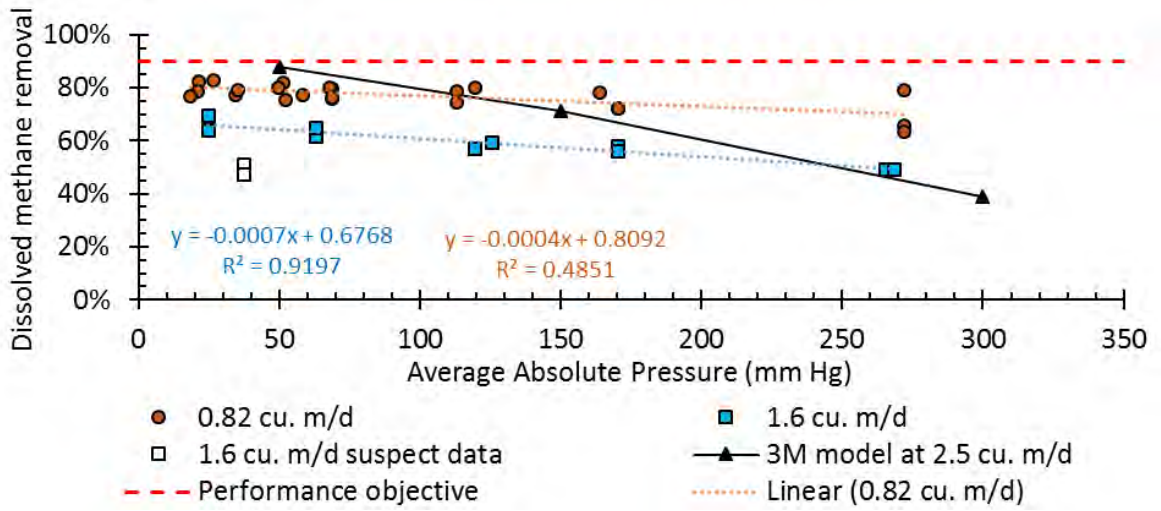

Figure 5.32 Dependence of Dissolved Methane Removal on Absolute Gas Pressure and Liquid Flow Rate in Comparison to 3M Model Results.

Removal of sulfide (as hydrogen sulfide) and bicarbonate or dissolved inorganic carbon (as carbon dioxide) was also evaluated (Figure 5.33). The maximum sulfide removal was 39%, but appreciable removal was not observed until absolute pressures were less than 100 mm Hg. Dissolved inorganic carbon removal was insignificant because it is mostly ionized at operating pH, though only a limited number of tests were conducted. The observation that appreciable sulfide removal occurred suggests that use of gas-liquid contactors for dissolved methane removal may also be useful for sulfide removal and provide an alternative to coagulation evaluated in Section 5.7.15. Considering the cost and environmental impact of chemical use associated with sulfide removal (see Section 7), this alternative is particularly attractive.

The performance objective for methane flux was 0.5 g m^{-2} d^{-1} and the observed flux was 6.5±1.8 g m^{-2} d^{-1} (Figure 5.34). This difference was significantly different ($p < 0.0001$). However, the performance objective was originally based on the system design rather than potential performance of the membrane contactor.

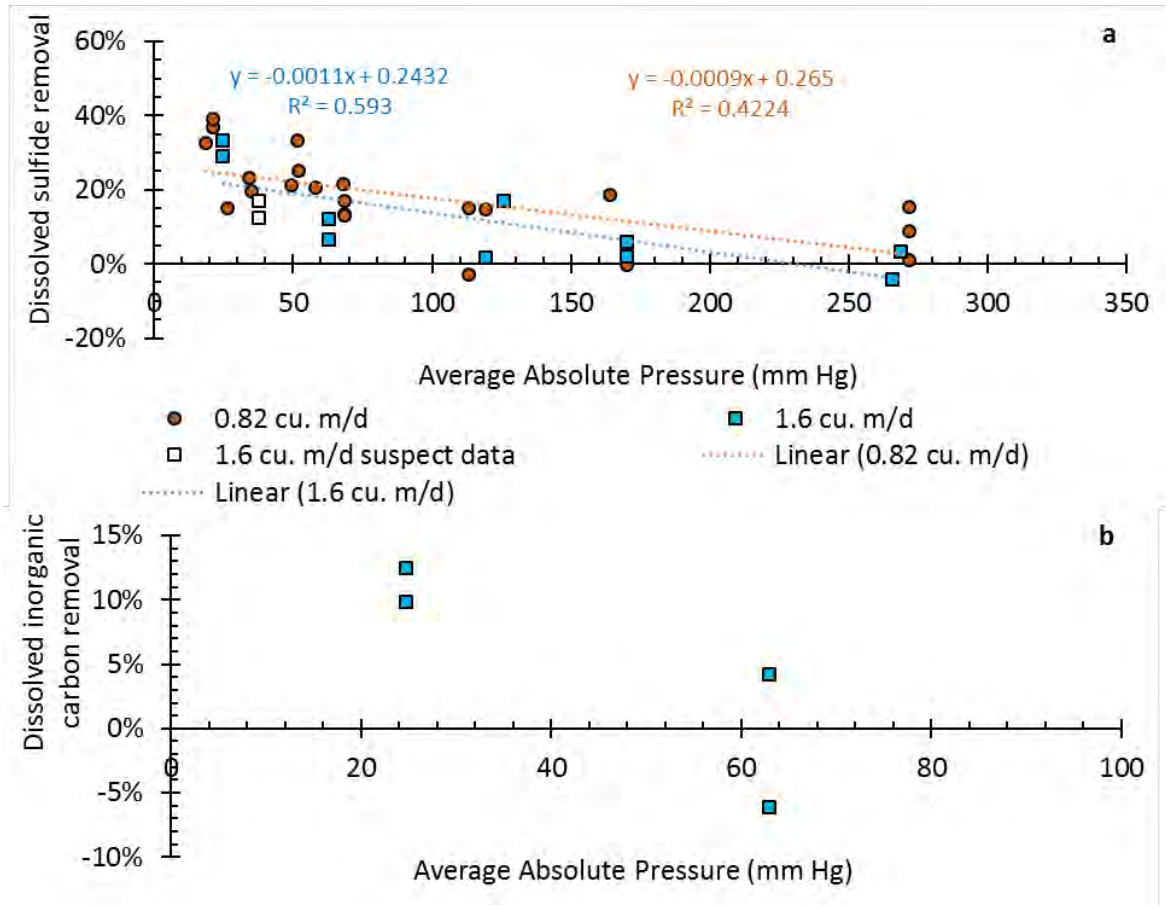

Figure 5.33 Relationship of Sulfide (a) and Dissolved Inorganic Carbon (b) Removal to Absolute Gas Pressure and Liquid Flow Rate.

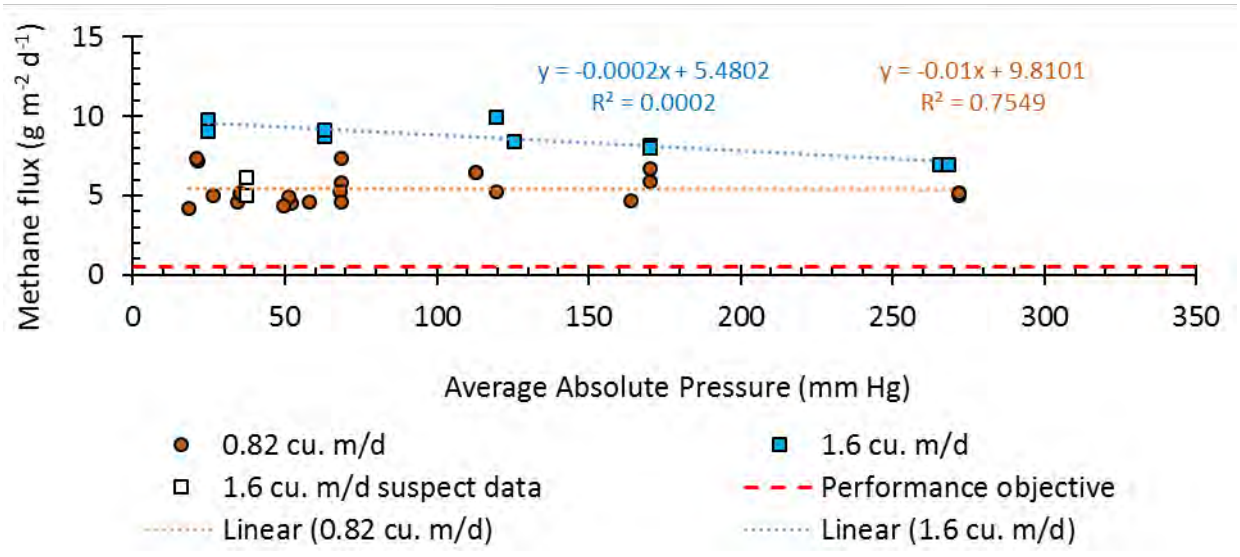

Figure 5.34 Comparison of Membrane Methane Flux to Performance Objective at Different Absolute Gas Pressures and Liquid Flow Rates.

5.7.12 Gas-Sparged AnMBR UF Membrane Performance

Operation of the gas-sparged AnMBR over the duration of the demonstration involved variation of several variables including the HRT, wasting rate, associated bioreactor VSS concentration, UF permeation flux, and biogas blower flow rate and duty (i.e., percent of time the biogas blower was on when cycling). The purpose of the above variations was to optimize the AnMBR and meet all of the performance objectives. Figure 5.35 shows the net flux and transmembrane pressure for the entire demonstration. Permeability, the ratio of net flux to TMP normalized to 20°C, is also shown. The average net flux was varied intentionally, and the TMP consequently varied in response to not just the flux, but also to the other variables, including VSS, blower operating conditions, accumulation of colloidal organics (estimated as 1.5-µm filtered COD), and maintenance and recovery cleaning events. These events and variables are discussed below in detail. The average net flux for the entire demonstration, excluding periods of mechanical shutdown, was 7.6±1.6 LMH. This flux was significantly greater than the goal of 6 LMH ($p < 0.0001$). The maximum net flux was 14 LMH. While not a performance objective, an operational objective was to maintain the TMP less than 30 kPa to prevent irreversible fouling of the UF membranes. Figure 5.35 shows this operational objective was met most of but not all of the time. The permeability was initially 300 to 400 LMH/bar (1 bar = 100 kPa) and steadily decreased over the course of the demonstration. Some of the decreases were associated with attempts to achieve energy neutrality by decreasing the biogas blower sparge rate as described below.

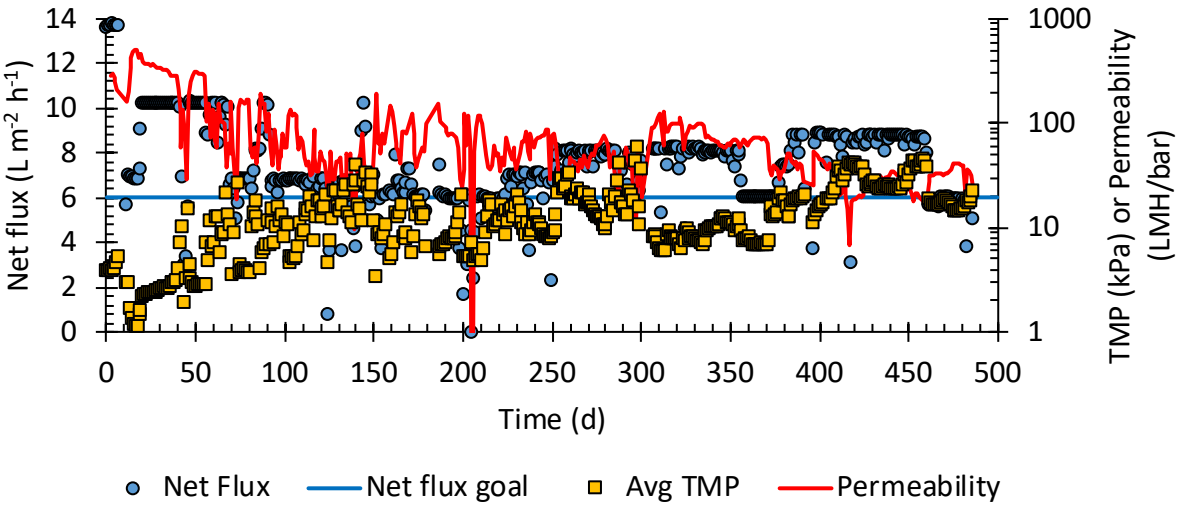

Figure 5.35 Gas-sparged AnMBR Net Ultrafiltration Flux Compared to Performance Objective, Transmembrane Pressure, and Permeability. Permeability is corrected to 20°C.

The following figures illustrate the operational changes that were made to achieve the general performance objectives of net energy production efficiency and implementability. Operational stability is also necessary for a process to be considered implementable.

Initial operating conditions were a net flux of 14 LMH and a sparge flow rate of ~60 standard liters per minute (std. L/min) with the blower operated at 100% duty (Figure 5.36). The UF membrane was operated with an 80% duty cycle – 8 minutes on and 2 minutes of relaxation unless otherwise stated.

The permeability was initially 290 LMH/bar but then started to decrease to 210 LMH bar from day 2 to 6 (permeability decrease rate = −20 LMH per bar per day [LMH bar^{-1} d^{-1}]). This decrease indicated an unstable condition, so the net flux was decreased to 7.5 LMH, and the blower flow rate was increased to 75 std. L/min. The permeability increased to 510 LMH/bar as a result. The flux was subsequently increased to an intermediate value of 10 LMH while maintaining the same blower flow rate. The permeability gradually decreased from 380 to 210 LMH/bar from day 21 to 39 days, indicating instability but at a lesser rate (−9.4 LMH bar^{-1} d^{-1}). A maintenance clean and sludge wasting was conducted between days 40 and 50, which promoted somewhat better stability with permeability ranging from 290 to 320 LMH/bar from days 49 to 55 (−5.0 LMH bar^{-1} d^{-1}). Tests were then initiated to evaluate varying blower operating scenarios and to improve bioreactor mixing.

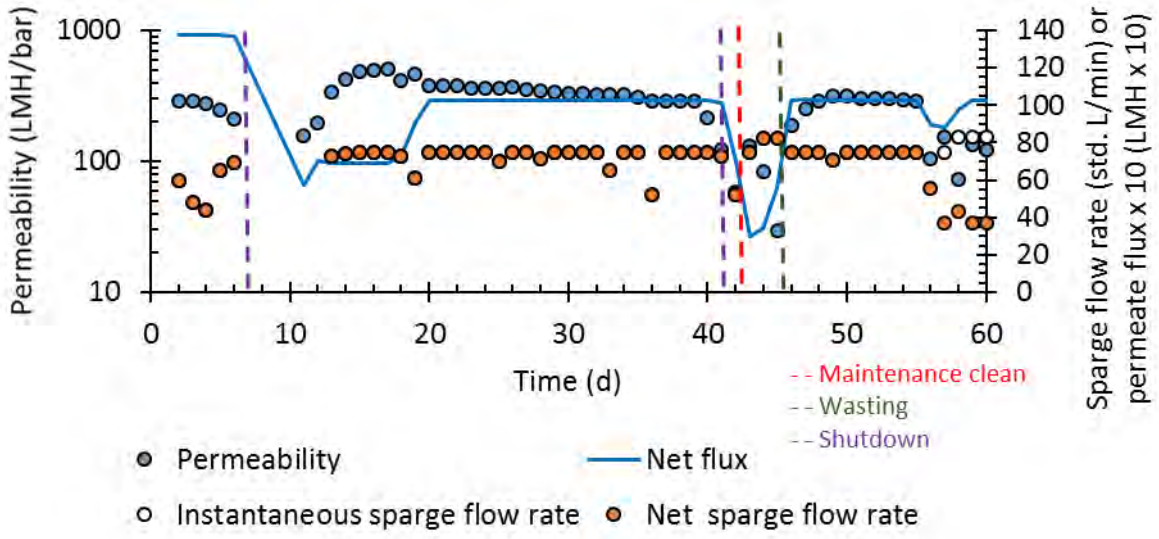

Figure 5.36 Gas-sparged AnMBR Ultrafiltration Performance from Days 0 to 60. Permeability is Corrected to 20°C.

The blower duty was decreased to 50% (30 s on/30 s off) on day 57 with an instantaneous blower flow rate of 75 to 80 std. L/min (Figure 5.37). This resulted in a lower permeability. Coincidentally during this time, incomplete mixing was observed in the bioreactor and optimization was conducted, including increasing recirculation flow rates and varying the bioreactor level. The net flux was also decreased. The permeability increased to 160 LMH/bar and was stable from days 75 to 80 (+0.8 LMH bar^{-1} d^{-1}). While the permeability was reasonably high and stable, the TMP was approaching 30 kPa (Figure 5.35). Therefore, an operational strategy called extended relax was implemented. This strategy involved turning off the permeate pump for about 25 to 30 minutes while continuing biogas sparging. This technique temporarily reduced the TMP but did not prevent subsequent TMP increases. On day 88, conditions that existed on day 50 were reinstated, and the permeability increased to 150 LMH/bar, which is lower than that observed on day 50 (320 LMH/bar). Therefore, the membrane performance decreased between days 50 and 88. The net flux and the blower flow rate and duty were changed on day 92, as described below.

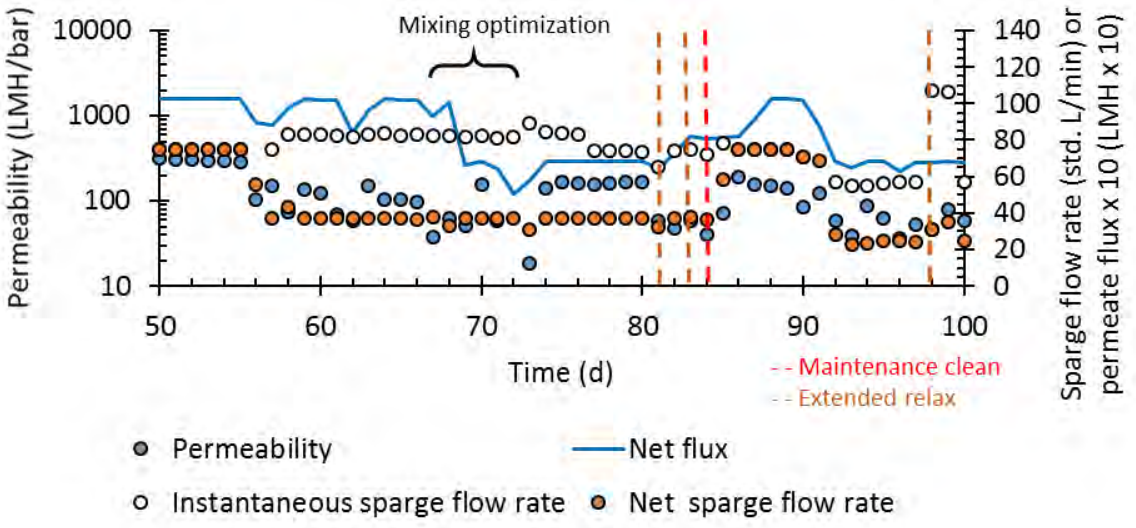

Figure 5.37 Gas-sparged AnMBR Ultrafiltration Performance from Days 50 to 100.

Permeability is corrected to 20°C.

The period from days 90 to 150 involved continued optimization of the UF process while keeping the net flux at around 7 LMH (Figure 5.38). Initial conditions from days 93 to 97 involved blower operation at 50% duty and an instantaneous flow rate of ~50 std. L/min. The average permeability for this period of time was 56±21 LMH/bar. Increasing the blower flow rate on day 101 while maintaining 50% duty increased the permeability to 120 LMH/bar but became unstable on day 106 (−14 LMH bar^{-1} d^{-1}). Extended relax events and a maintenance clean did not improve membrane performance. Periodic extended relax cycles (10 minutes every 4 to 12 hours) did not appear to improve performance though increasing the blower flow rate did from 140 to 145 days.

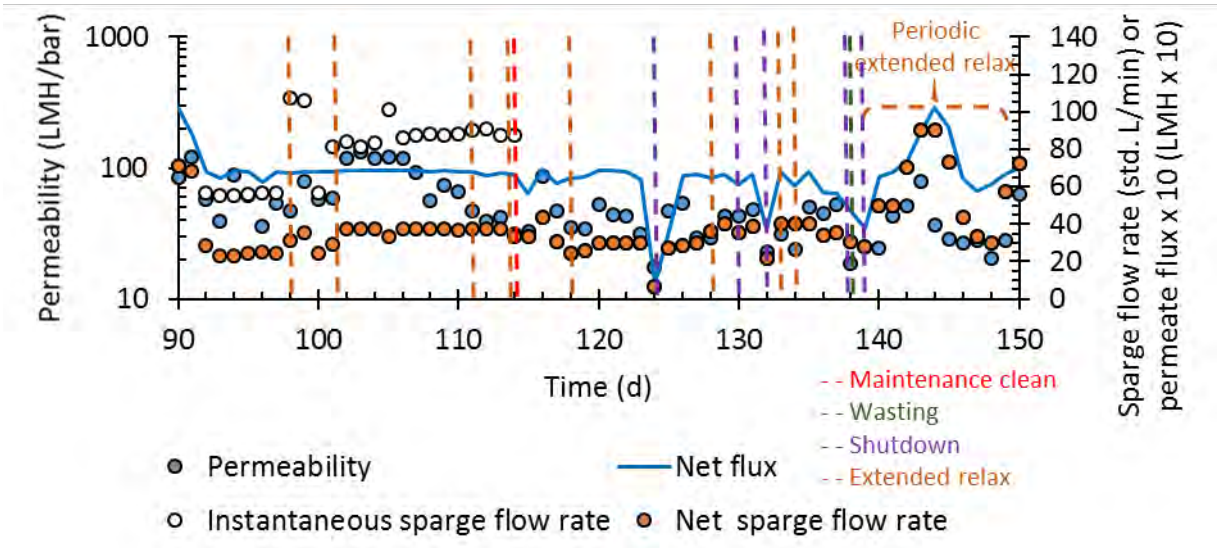

Figure 5.38 Gas-sparged AnMBR Ultrafiltration Performance from ays 90 to 150.

Permeability is corrected to 20°C.

Periodic extended relax was stopped on day 157, and a recovery clean was conducted on days 157 to 158 (Figure 5.39). The permeability was somewhat variable following the recovery clean and varied between 60 and 150 LMH/bar from days 159 to 197. Operation at a net sparge flow rate of 50 std. L/min and a net flux of 6 LMH from days 188 to 195 led to relatively stable permeability (−3.3 LMH bar^{-1} d^{-1}), decreasing from 100 to 77 LMH/bar. The recovery clean did not restore membrane permeability to the initial value of ~300 LMH/bar (Figure 5.36), but the blower flow rate was slightly higher (~60 std. L/min).

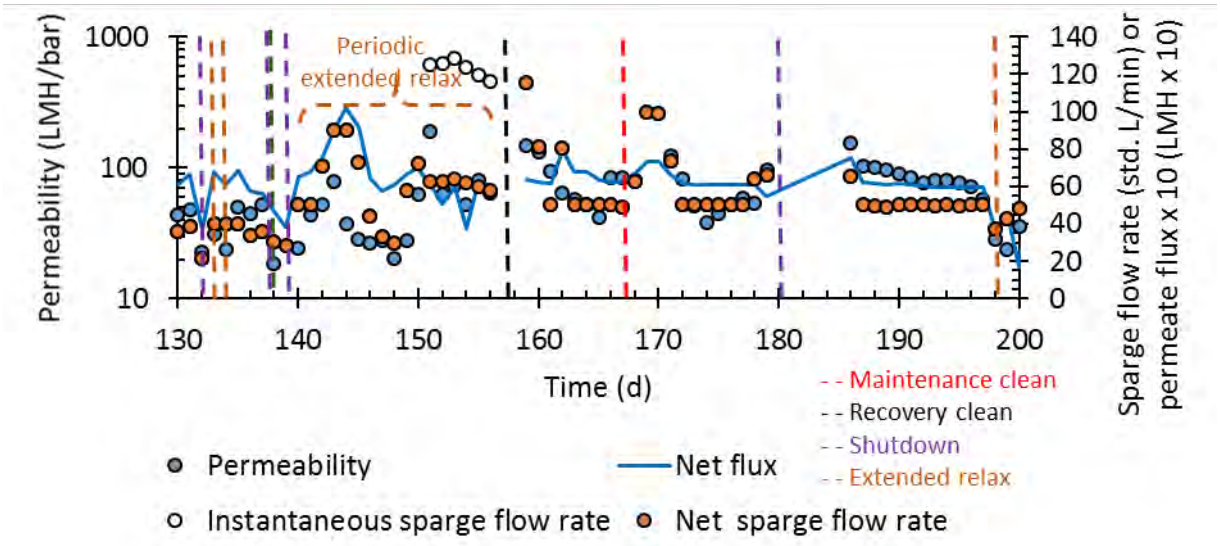

Figure 5.39 Gas-sparged AnMBR Ultrafiltration Performance from Days 130 to 200.

Permeability is corrected to 20°C.

Several mechanical shutdowns occurred from days 200 and 210 (Figure 5.40). Thereafter the permeability was relatively constant, though somewhat scattered, at a blower flow rate of 50 std. L/min operating at 100% duty. The relative stability may have been due to initiation of periodic maintenance cleans that were conducted every 2 to 11 days. Additionally, regular wasting of sludge from the bioreactor was initiated on day 222 (see also Figure 5.12). The net permeate flux was also increased from 6 to 7 LMH on day 225.

Permeability continued to be relatively stable from days 250 to 285 (Figure 5.41). The net permeate flux was increased to 8 LMH on day 251. The average permeability from days 210 to 285 was 55±18 LMH/bar.

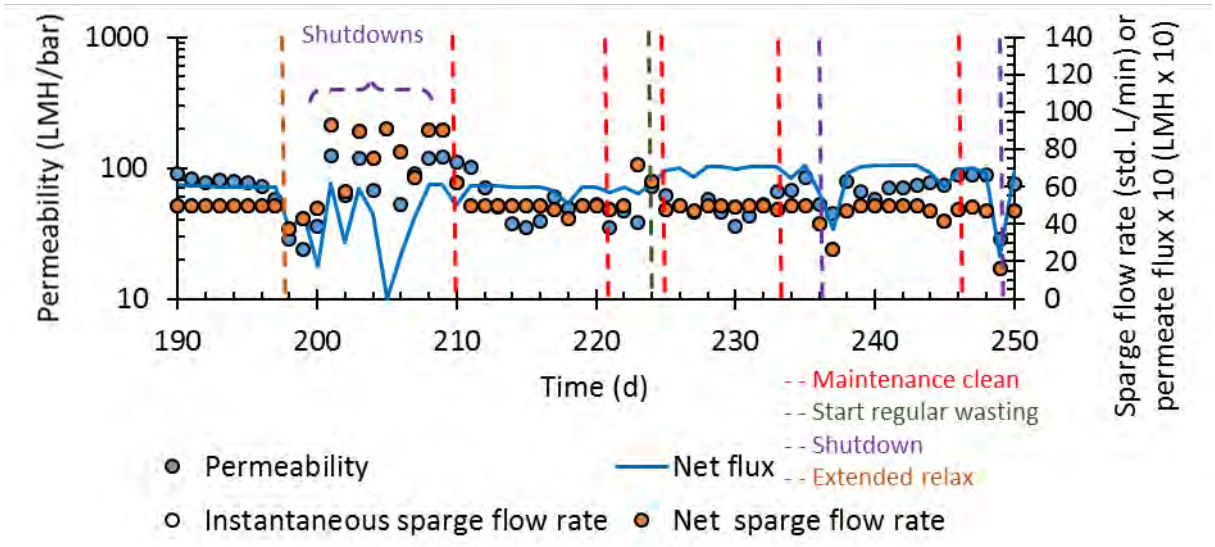

Figure 5.40 Gas-sparged AnMBR Ultrafiltration Performance from Days 190 to 250.

Permeability is corrected to 20°C.

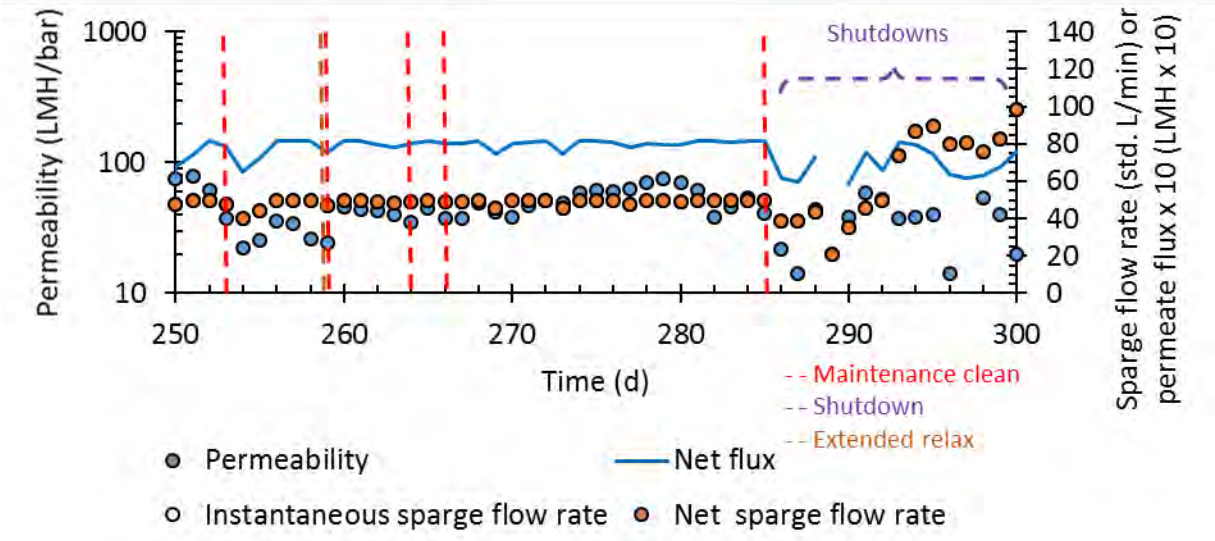

Figure 5.41 Gas-sparged AnMBR Ultrafiltration Performance from Days 250 to 300.

Permeability is corrected to 20°C.

A series of mechanical shutdowns occurred from days 286 to 300 and then a major sludge wasting event was conducted (Figure 5.42). This wasting event reduced the TSS in the bioreactor (Figure 5.13) and increased the permeability from 55±18 to 94±7.6 LMH/bar. The sparge flow rate was decreased from 50 to 25 std. L/min with the objective of decreasing power consumption and attaining the performance objective of energy neutrality. Following this decrease, the permeability decreased to 73±12 LMH/bar (days 326 to 370).

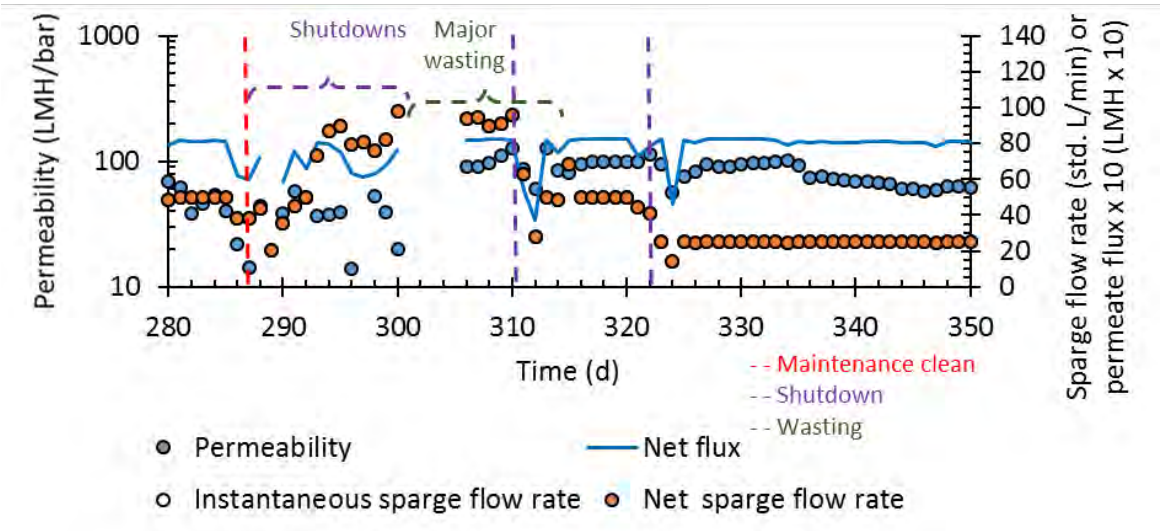

Figure 5.42 Gas-sparged AnMBR Ultrafiltration Performance from Days 280 to 350.

Permeability is corrected to 20°C.

Figure 5.43 further illustrates the effect of the major wasting event on permeability. Permeability gradually decreased between 0 and 100 days as the bioreactor solids concentration decreased. The solids concentration is one factor that can affect permeability, but it did not appear to be the major factor during this time. Therefore, some factor other than solids concentration alone must have caused the decrease in permeability. Between days 100 and 300, the permeability varied in response to operational changes (e.g., blower flow rate and maintenance cleans) but did not demonstrate a definitive increasing or decreasing trend. During this time, bioreactor total solids concentration was either constant or increasing. Following the major wasting event, the permeability increased, and the bioreactor total solids decreased. Filtered COD was measured as an indicator of colloidal organics that can potentially foul the UF membranes. Both 0.45- and 1.5-µm filtered COD decreased following the major wasting event. Their concentrations were also gradually decreasing prior to this time in response to regular sludge wasting, but the major wasting event resulted in greater decreases. While the major wasting event increased the permeability, it gradually decreased between days 300 and 400, as discussed further below.

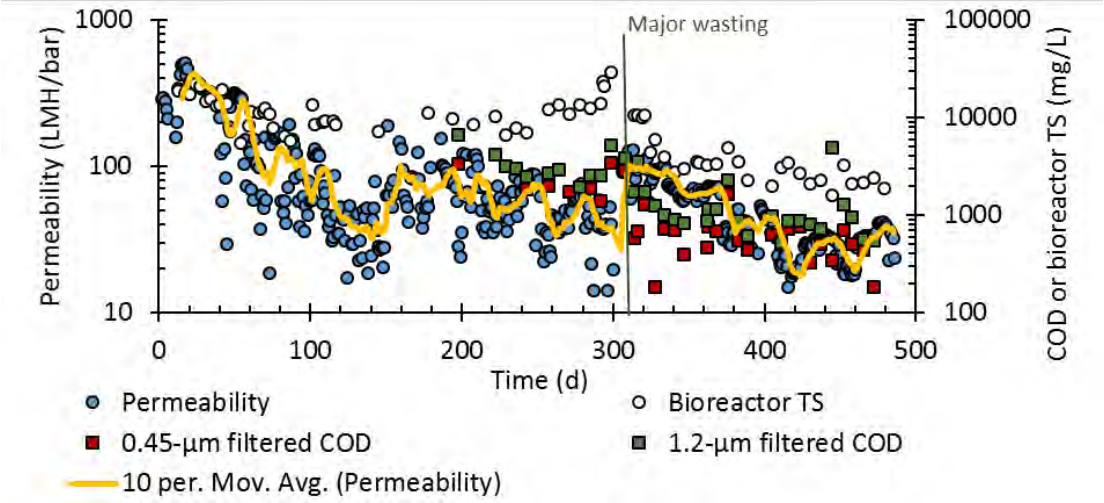

Figure 5.43 Gas-sparged AnMBR Ultrafiltration Performance in Relationship to Total Solids and Filtered COD Fractions in the Bioreactor Prior to and After the Major Wasting Event.

Permeability is corrected to 20°C.

Permeability was constant from days 350 to 370 with a blower sparge rate of 25 std. L/min and a net permeate flux between 6 and 8 LMH (Figure 5.44). Several attempts to further decrease blower power were conducted from days 372 to 381 but resulted in further decreases in permeability. These attempts included variation of the blower duty and flow rate. Following these attempts, the permeability was relatively lower compared to values prior to day 370. While the flux was increased on days 377 and 384, the reduction in permeability suggests membrane fouling. Note that maintenance cleans were not being done as frequently as compared to days 200 to 270. The decreased maintenance cleaning frequency, in combination with lower blower flow rates, likely led to membrane fouling, as discussed further below and in Section 5.7.14.

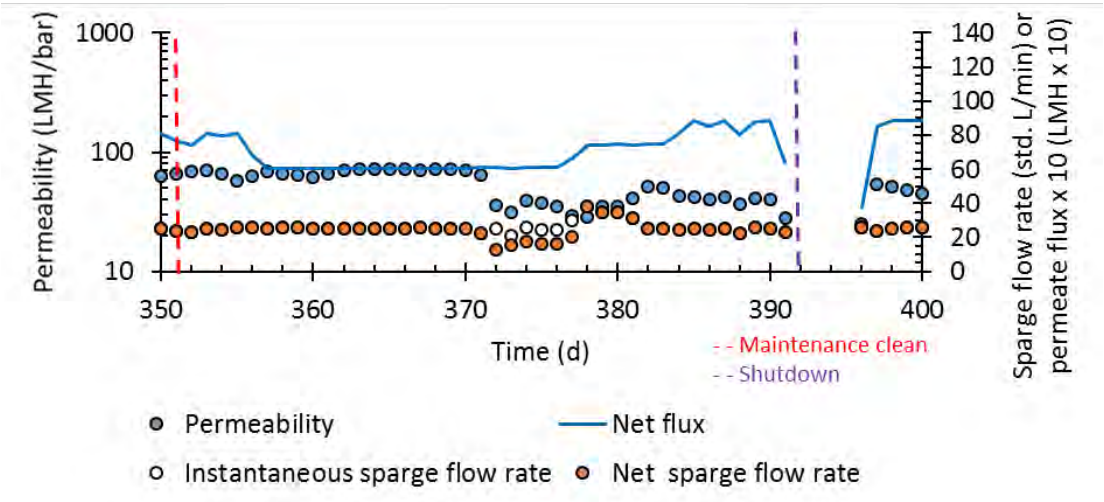

Figure 5.44 Gas-sparged AnMBR Ultrafiltration Performance from Days 350 to 400.

Permeability is corrected to 20°C.

Regular maintenance cleaning was re-initiated on day 405 (Figure 5.45). The average permeability from days 397 to 485 was 30±9 LMH/bar, which is lower than was observed from days 326 to 370 at the same blower flow rate.

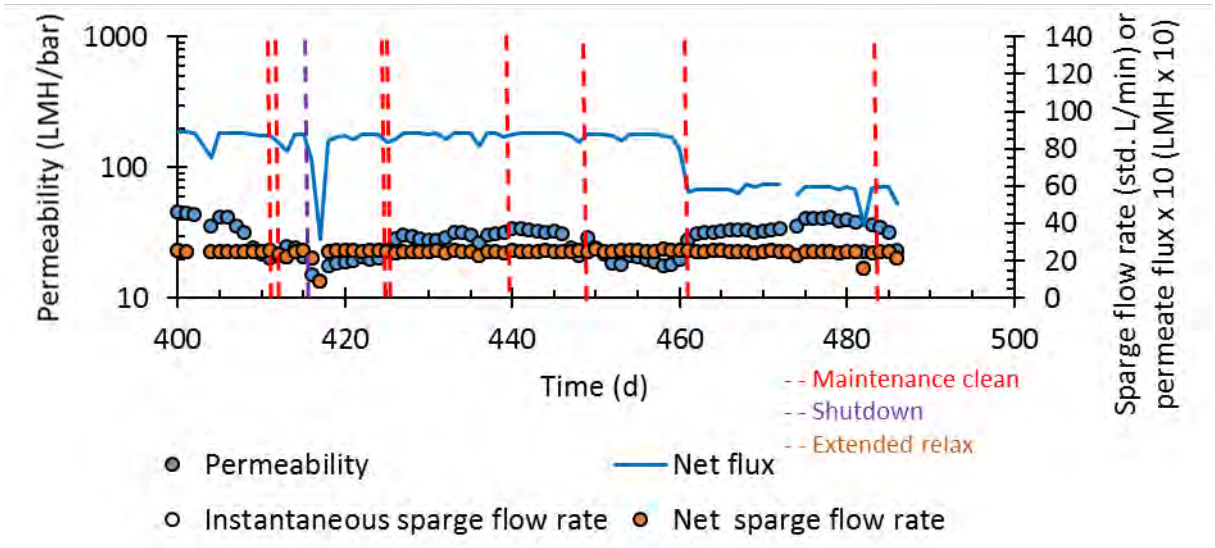

Figure 5.45 Gas-sparged AnMBR Ultrafiltration Performance from Days 400 to 500.

Permeability is corrected to 20°C.

Figure 5.46 condenses and summarizes the results presented in the previous figures. The main conclusions that can be made with regard to UF performance are:

- Permeability decreased three-fold between days 2 to 56 and days 57 to 85. While the instantaneous sparge flow rate was kept constant, the blower duty was decreased from 100 to 50%. The permeability decrease was in part attributable to a lower net sparge flow rate.

- Sparging conditions from days 2 to 56 were reinstated from days 86 to 91. The permeability increased but not to the same value observed from days 2 to 56, suggesting a loss of membrane performance over time even though solids concentrations were decreasing.

- Intermittent sparging (50% duty) conditions from days 98 to 115 were similar to those from days 57 to 85 but also resulted in lower permeability. These data further suggest a continued decrease in membrane performance.

- Increasing sparge flow rates (e.g., compare days 91to 97 to days 98 to 115, days 98 to 115 to days 151-156, and days 116 to 150 to days 157to 288) resulted in permeability increases, suggesting that permeability could be controlled through variation of the sparge flow rate even though membrane performance was decreasing over time.

- Permeability from 289-300 days was relatively low, but mechanical shutdowns and inconsistent operation occurred during this time.

- The major sludge wasting event from days 300 to 314 resulted in decreased bioreactor solids concentrations as well as concentrations of colloidal organics (i.e., 1.2-µm filtered COD). The net effect on permeability was positive (compare days 311 to 322 to days 157 to 288, where sparging conditions were similar).

- As a result of sludge wasting, sparge flow rates could be decreased from 50 to 25 std. L/min with a relatively minor reduction in permeability (compare days 323 to 371 to days 311 to 322).

- Testing of intermittent sparging for the purpose of energy reduction (compare days 372 to 377 to days 323 to 371) led to permeability reductions, suggesting that intermittent sparging was not promoting consistent membrane performance.

- Reinstating continuous sparging did not increase permeability to previous levels (compare days 378 to 486 to days 323to 371). These data suggest membrane performance decreased over time. Also, the final permeability (days 378 to 486) was 10 times lower than the original permeability (days 2 to 56), though the sparge flow rate was 65% lower.

- Several factors contributed to the reduction in membrane performance over time:
  - Maintenance cleaning was not done consistently, which likely led to accumulation of foulants.
  - The pilot unit was designed to be operated at a constant sparge flow rate of 180 std. L/min. Sparge flow rates less than this value were tested for the purpose of attaining the performance objective of energy neutrality. However, this approach likely led to inefficient membrane scouring and accumulation of foulants as described below.
  - Regular sludge wasting was not initiated until day 224, which likely led to accumulation of colloidal organics prior to this period and can contribute to membrane fouling.

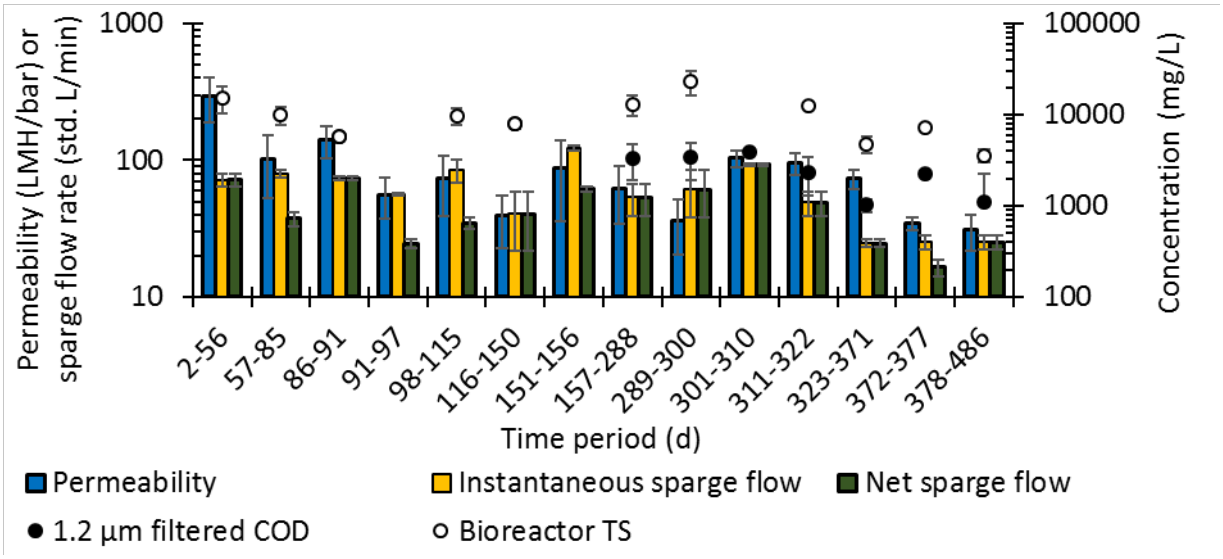

Figure 5.46 Gas-sparged AnMBR Ultrafiltration Summary.

Permeability is corrected to 20°C.

Photographs of the UF membranes prior to and after the demonstration are shown in Figure 5.47. The UF membranes uniformly changed color, likely because of reduced sulfur compounds deposited on the fibers. Notably, the bottom of the fibers (Figure 5.47g,h) became coated with a solid substance, which is discussed further in Section 5.7.14. This material was clayey, thick, and bound the individual fibers together. The presence of this material clearly would have affected permeability and is indicative of ineffective sparging.

Figure 5.47 Gas-sparged AnMBR Ultrafiltration Membrane Modules Prior to (a) and After (b) the Demonstration.

Close-up photos of the top (c,d), middle (e,f), and bottom (g,h) of the fibers prior to (c,e,g) and after (d,f,h) the demonstration.

5.7.13 GAC-Fluidized AnMBR UF Membrane Performance

Operation of the GAC-fluidized AnMBR over the duration of the demonstration involved variation of several variables including the HRT, wasting rate, bioreactor VSS concentration, and UF permeation flux. The purpose of the above variations was to optimize the AnMBR and meet all of the performance objectives. Figure 5.48 shows the net flux and transmembrane pressure for the entire demonstration. Permeability, the ratio of net flux to TMP normalized to 20°C, is also shown. The average net flux was intentionally varied and the TMP consequently varied in response to not just the flux but also to the other variables including VSS, accumulation of colloidal organics, and maintenance and recovery cleaning events. These variables are discussed below in detail. The average net flux for the entire demonstration, excluding periods of mechanical shutdown and COD supplementation, was 7.1±2.2 LMH (compared to 7.6±1.6 LMH for the gas-sparged AnMBR). This flux was significantly greater than the goal of 6 LMH ($p < 0.0001$). The maximum net flux was 12 LMH (compared to 14 LMH for the gas-sparged AnMBR). While not a performance objective, an operational objective was to maintain the TMP less than 30 kPa to prevent irreversible fouling of the UF membranes. Figure 5.48 shows this operational objective was met for the first 170 days and then inconsistently thereafter. The permeability was initially ~200 LMH/bar for the first 100 days and then decreased until day 350 when it seemed to stabilize.

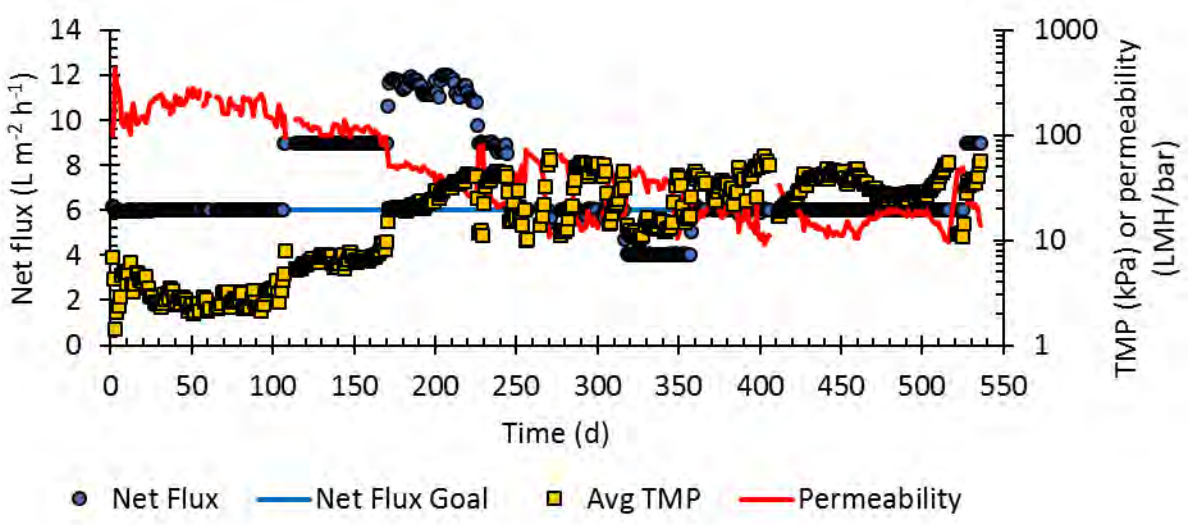

Figure 5.48 GAC-fluidized AnMBR Ultrafiltration Flux Compared to Performance Objective, Transmembrane Pressure, and Permeability.

Permeability is corrected to 20°C.

The following figures illustrate the operational changes that were made to achieve the general performance objectives of net energy production efficiency and implementability. Operational stability is also necessary for a process to be considered implementable.

Initial operating conditions were a net flux of 6 LMH and a wasting rate of 5% (Figure 5.49). The UF membrane was operated with an 80% duty cycle – 24 minutes on and 6 minutes of relaxation. The permeability was relatively stable for the first 106 days (−0.075 LMH bar^{-1} d^{-1}). But following an initial increase, permeability subsequently decreased from days 50 to 106 (−1.5 LMH bar^{-1} d^{-1}).

During the first 106 days, the wasting rate was decreased from 5 to 2.5% and did not appear to have a negative effect on permeability. The net flux was increased to 9 LMH on day 106, and the permeability continued to decrease from 160 to 83 LMH/bar (−0.46 LMH bar^{-1} d^{-1}). On day 71, the flux was increased to a setpoint of 12 LMH but proved to be unstable. In addition, the TMP exceeded 30 kPa (Figure 5.48). Permeability decreased (−0.55 LMH bar^{-1} d^{-1}) from 171 to 221 days. Maintenance cleans were conducted during this time and wasting became unstable.

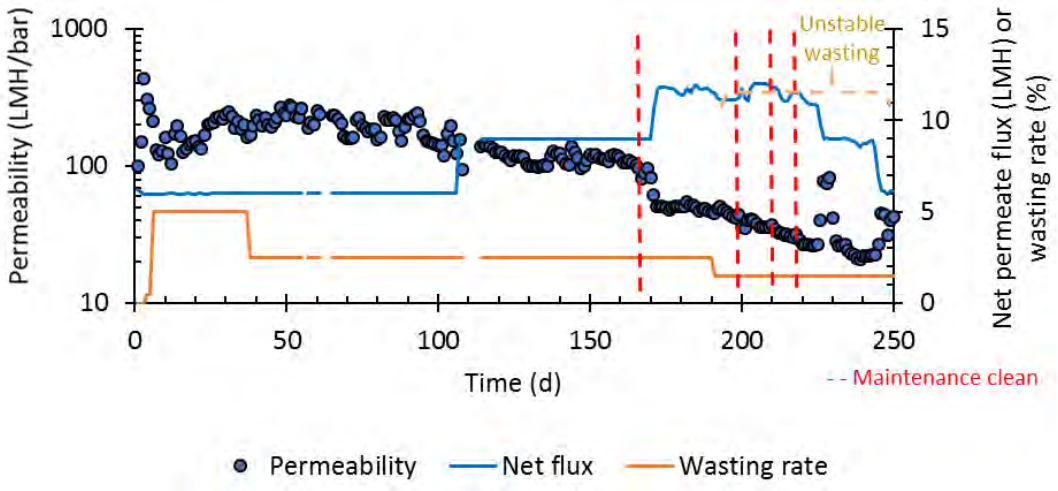

Figure 5.49 GAC-fluidized AnMBR Ultrafiltration Performance from Days 0 to 250.

Permeability is corrected to 20°C.

The flux was reduced to 9 LMH on day 226 and to 6 LMH on day 246 (Figure 5.50). Permeability increased to 72 LMH/bar (+2.2 LMH bar^{-1} d^{-1}) in response to the flux decrease from 9 to 6 LMH until the process upset and GAC loss occurred. Upon restart the permeability was unstable both before and after (−6.2 and −5.0 LMH bar^{-1} d^{-1}, respectively) a recovery clean was conducted on day 270. Initiation of weekly maintenance cleans, in combination with a recovery clean on day 300 and reduction of net flux to 4 LMH on day 317, stabilized the permeability at ~40 LMH/bar, increasing the flux back to 6 LMH led to instability.

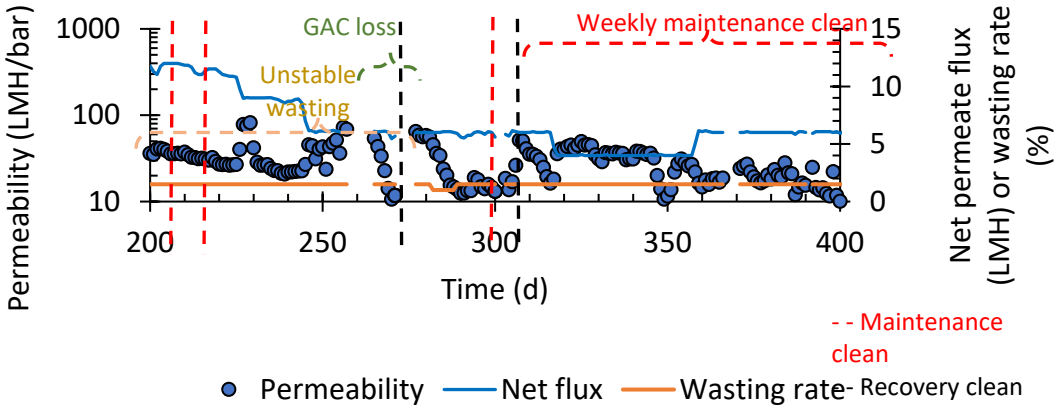

Figure 5.50 GAC-fluidized AnMBR Ultrafiltration Performance from Days 0 to 250.

Permeability is corrected to 20°C.

Figure 5.51 illustrates the overall change in permeability before and after the upset and GAC loss. The upset resulted in increased bioreactor solids likely associated with GAC grinding cause by accidental reverse pump operation. The permeability became unstable but stabilized somewhat from days 300 to 350. This is different from what occurred in the gas-fluidized AnMBR where the major wasting event led to decreased solids in the bioreactor and increased permeability. Colloidal organics represented by a 1.2-µm filtered COD decreased during the first 100 days and then gradually increased, likely in response to decreased wasting rates. However, the 1.2-µm filtered COD concentrations are about 10 times lower than those observed in the gas-fluidized AnMBR (Figure 5.43).

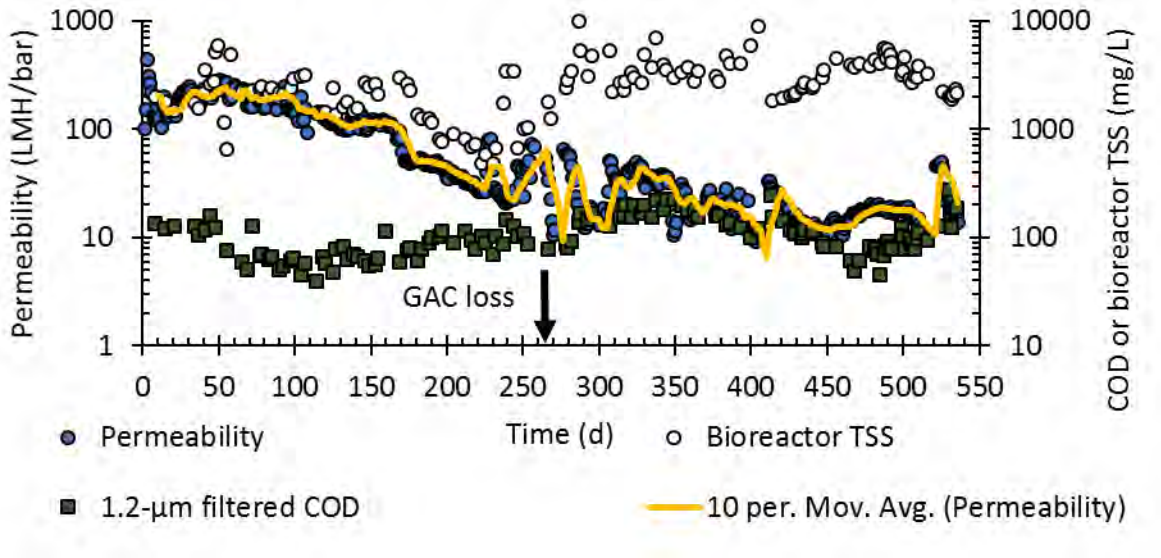

Figure 5.51 GAC-fluidized AnMBR Ultrafiltration Performance in Relationship to Total Suspended Solids and Filtered (1.2 µm) COD.

Permeability is corrected to 20°C.

Permeability continued to be unstable from day 350 to the end of the demonstration (Figure 5.52). Recovery cleans temporarily increased the permeability, but it then decreased. The final permeability prior to initiation of COD supplementation on day 476 was 18 LMH/bar compared to an initial permeability of ~200 LMH/bar. Both the GAC-fluidized AnMBR and gas-sparged AnMBR permeabilities decreased ten-fold over the duration of the demonstration, indicating inadequate fouling control.

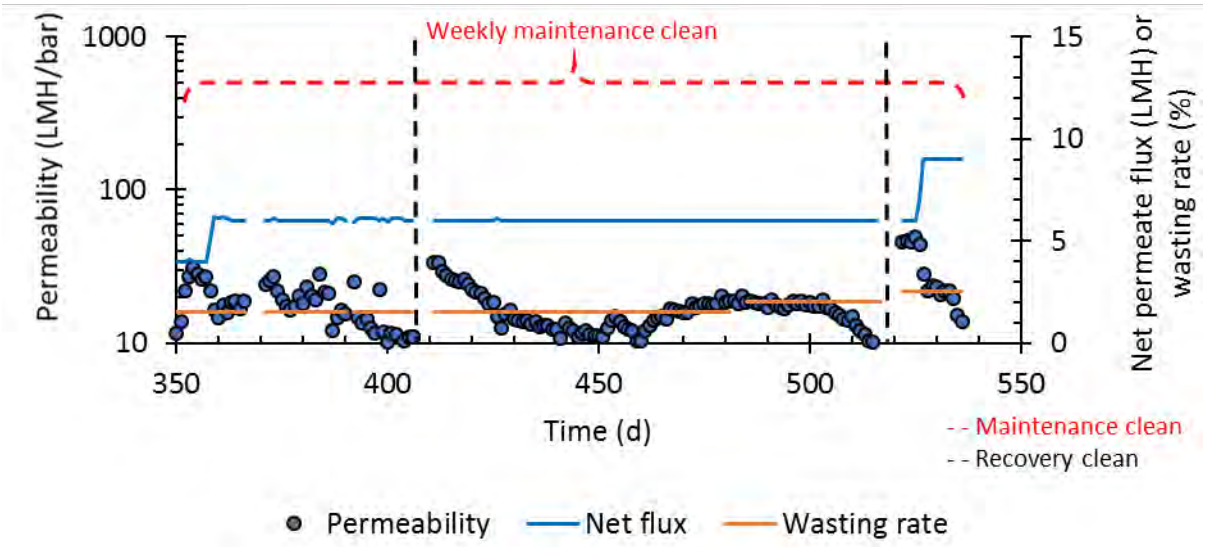

Figure 5.52 GAC-fluidized AnMBR Ultrafiltration Performance from Days 350 to 536.

Permeability is corrected to 20°C.

Figure 5.53 condenses and summarizes the results presented in the previous figures. The main conclusions that can be made with regard to UF performance are:

- Permeability was relatively constant for the first 106 days of the demonstration while the net flux was maintained at 6 LMH. Increased fluxes of 9 LMH (days 107-170) and 12 LMH (days 171-190) resulted in permeability decreases. These data suggest that GAC fluidization alone was not capable of maintaining UF membrane permeability.
- Operations from days 191-357 led to relatively constant but decreased permeability (32-36 LMH/bar). This time period encompassed the upset condition around day 270.
- Continued operation led to a further decrease in permeability from days 358 to 475.
- COD supplementation from days 476 to536 resulted in a slight permeability increase.
- The final permeability prior to COD supplementation (days 358 to 475) was 10 times lower than the original permeability (days 1 to 106).
- Several factors contributed to the reduction in membrane performance over time:
  - Maintenance cleaning was not done consistently until day 300, potentially leading to accumulation of foulants.
  - GAC grinding during the upset produced powdered activated carbon, which likely fouled the membranes (see Section 5.7.14).

Unlike the gas-sparged AnMBR where the biogas sparging flow rate can be varied, the fluidization flow rate in the GAC-fluidized AnMBR cannot be varied without changing the GAC particle size, which limits an operator's ability to control permeability in real time.

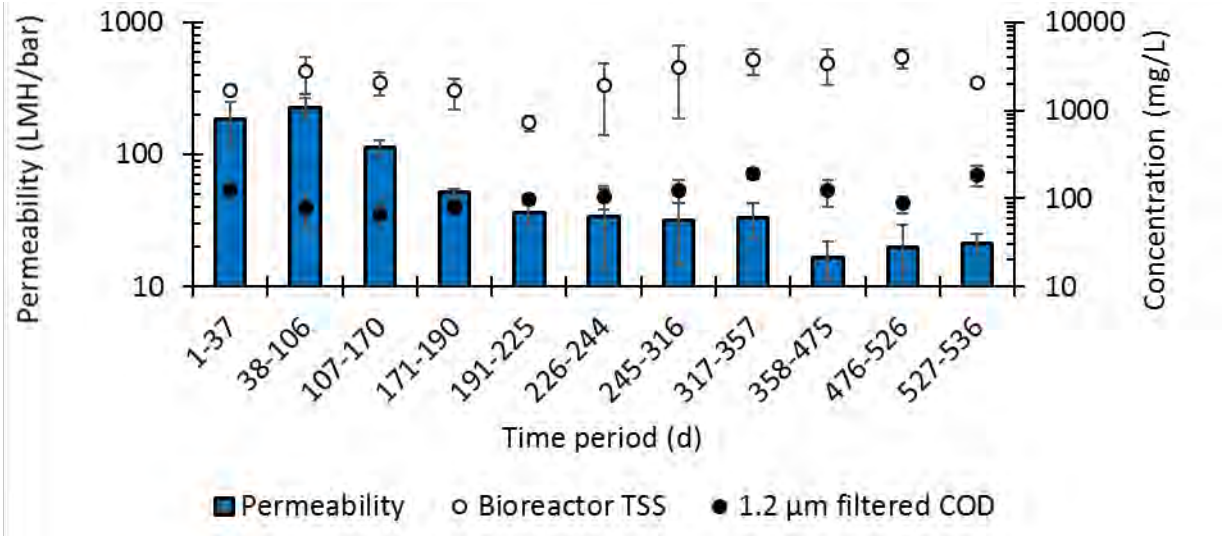

Figure 5.53 GAC-fluidized AnMBR Ultrafiltration Summary.

Permeability is corrected to 20°C.

Photographs of the UF membranes prior to and after the demonstration are shown in Figure 5.54. The UF membranes uniformly changed color, likely because of reduced sulfur compounds deposited on the fibers. GAC particles are evident in the bottom of the modules (Figure 5.54b,e,f). Notably, the top of the fibers (Figure 5.54c) became coated with a solid substance, which is discussed further in Section 5.7.14. This material was clayey, thick, and bound the individual fibers together. A similar deposit was noted in the gas-sparged AnMBR but at the bottom of the fibers. The presence of this material clearly would have affected permeability and is an indication of inadequate fouling management.

5.7.14 Comparison of Gas-Sparged and GAC-Fluidized AnMBR UF Membrane Performance

Figure 5.55 is a comparison of gas-sparged and GAC-fluidized AnMBR ultrafiltration performance. Permeability in both AnMBR systems decreased over time. The ability to vary biogas sparge rate provided the gas-sparged AnMBR a means to control permeability. For example, note the decrease and increase in permeability on days 60 and 150 in response to changes in biogas sparge flow rate. This control variable was not available in the GAC-fluidized AnMBR. In this system, the only control variable available is the wasting rate, which affects the concentration of solids being filtered. Solids concentration also affected permeability in addition to sparge gas flow rate. For example, at ~290 days, the increase in sparge rate did not increase permeability (Figure 5.55a), but solids wasting and reduction of gas-sparged solids concentration did increase permeability ~300 to 320 days (Figure 5.55b). Variation of the biogas sparge flow rate was not the only factor affecting permeability.

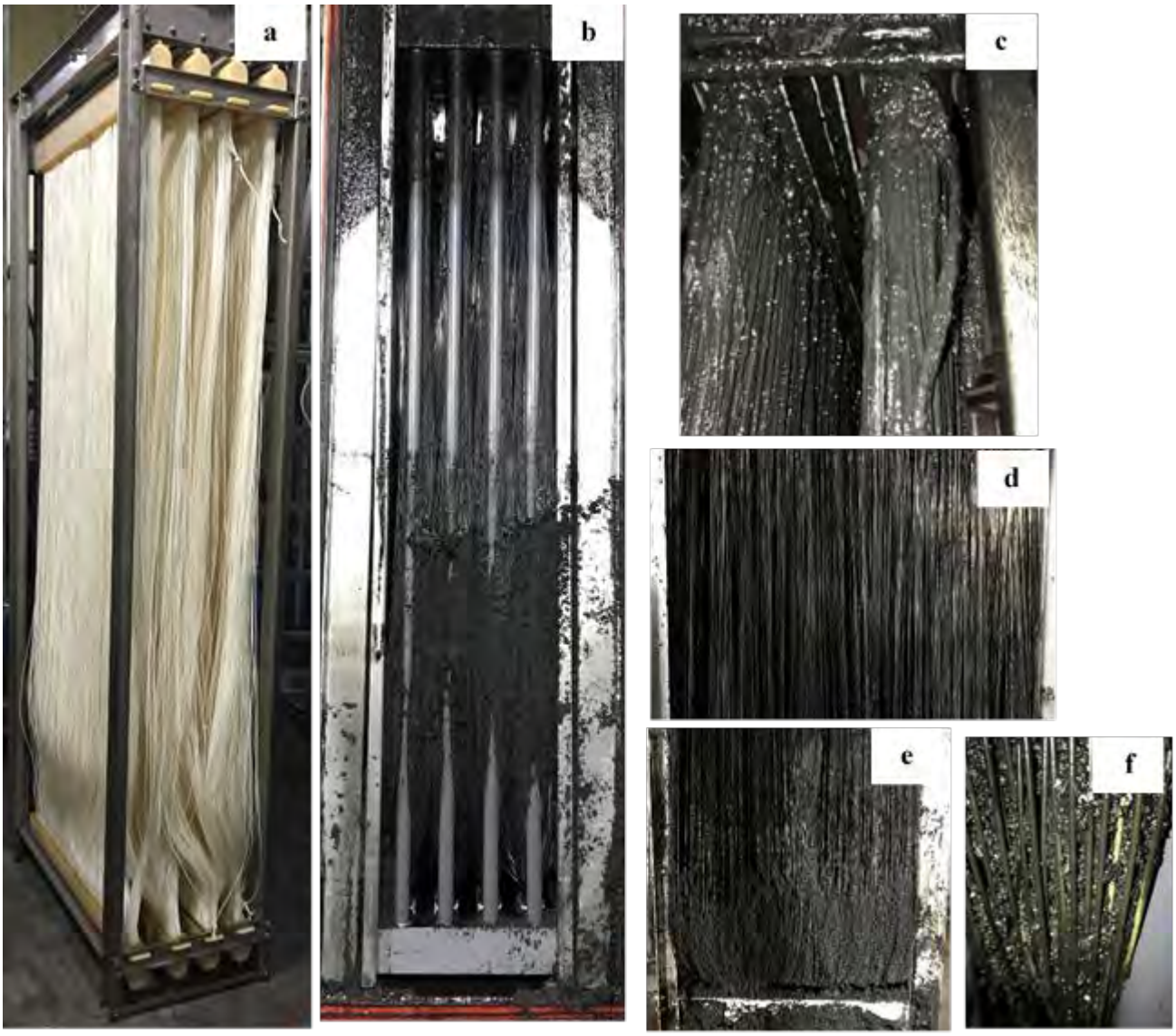

Figure 5.54 GAC-fluidized AnMBR Ultrafiltration Membrane Modules Prior to (a) and After (b) the Demonstration. Close-up Photos of the Top (c), Middle (d), and Bottom (e,f) of the Fibers After (d,f,h) the Demonstration.

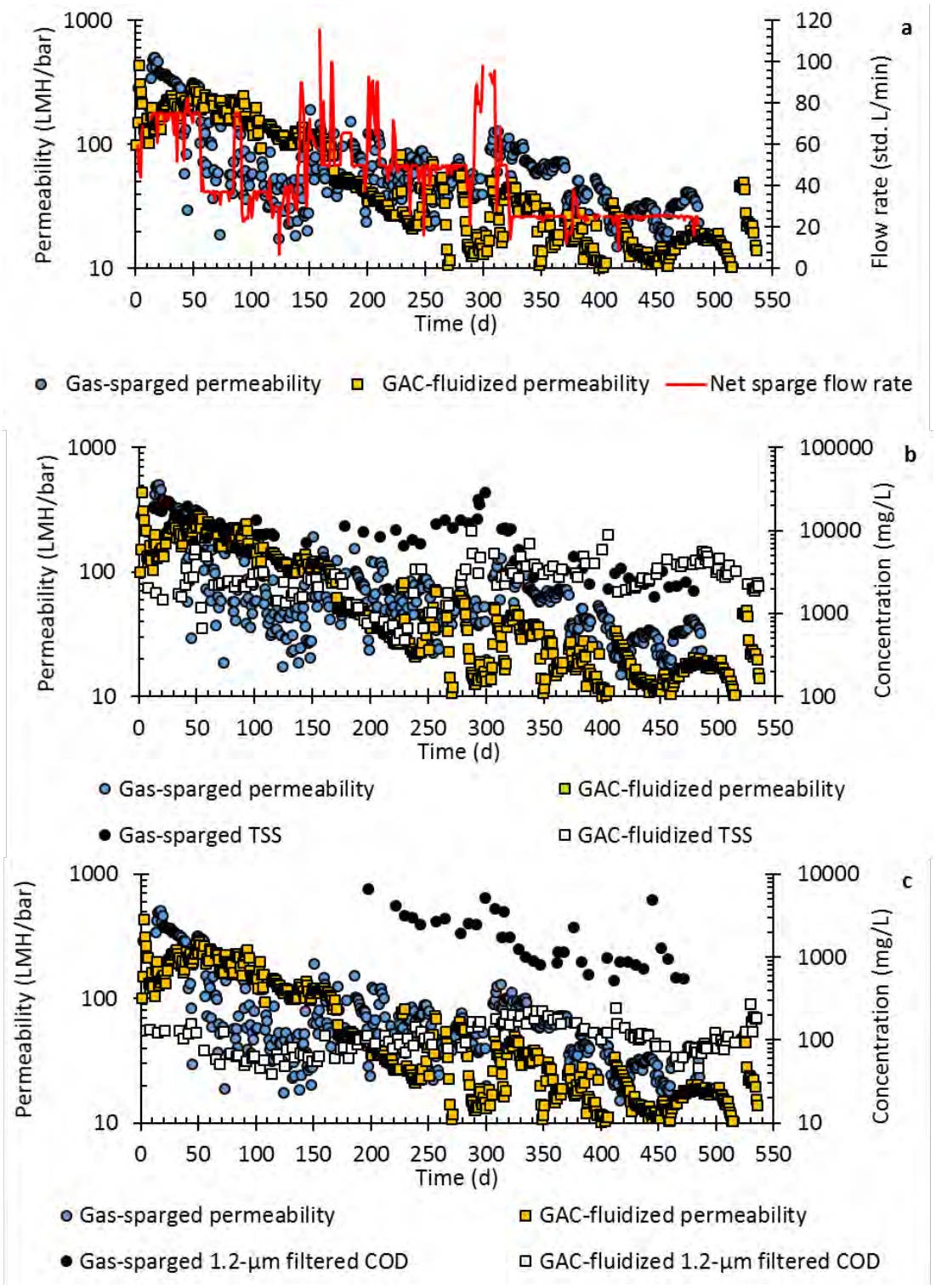

Figure 5.55 Comparison of Gas-sparged and GAC-fluidized AnMBR Ultrafiltration Permeability in Relation to Net Gas Sparge Rate (a), Total Solids Concentration (b) and 1.2-µm Filtered COD Concentration (c).

Permeability is corrected to 20°C.

The initial permeabilities from days 0-60 were variable but greater in the gas-sparged AnMBR (Figure 5.56). The GAC-sparged AnMBR permeability was greater from days 61 to 150, as was the solids concentration (Figure 5.55b). The permeabilities became more similar to each other from days 151 to 250, though the gas-sparged AnMBR permeability was slightly greater. During this time, the solids concentrations in the gas-sparged AnMBR were about 10 times greater. The gas-sparged AnMBR was capable of similar or greater permeabilities at greater solids concentrations because of the ability to control the biogas sparging rate. The permeability of the gas-sparged AnMBR was greater than that of the GAC-fluidized AnMBR from days 251 to 475, when the solids concentrations were similar, and the biogas sparging rate was reduced from ~50 to ~25 std. L/min. The solids reduction in the gas-sparged AnMBR was due to the major wasting event at ~300-320 days.

Bioreactor filtered COD was measured as an indicator of potential colloidal organic membrane foulants. The concentration of 1.5-µm filtered COD in the gas-sparged AnMBR was about 10 times greater than in the GAC-fluidized AnMBR (Figure 5.55c). The permeability in the gas-sparged AnMBR was similar to (days 150 to 250) or greater than (days 250 to 475) that in the GAC-fluidized AnMBR despite this concentration difference.

Overall, the gas-sparged AnMBR ultrafiltration process demonstrated similar or greater permeability in the presence of elevated concentrations of suspended solids and colloidal organics (Figure 5.55). However, both systems demonstrated instability (i.e., variable permeability over time) which was attributable not only to varying operational conditions and mechanical upsets but also to differences in membrane performance caused by the different methods of fouling management (i.e., variable biogas sparging versus constant GAC fluidization). Inconsistent maintenance cleaning also likely contributed to these instabilities.

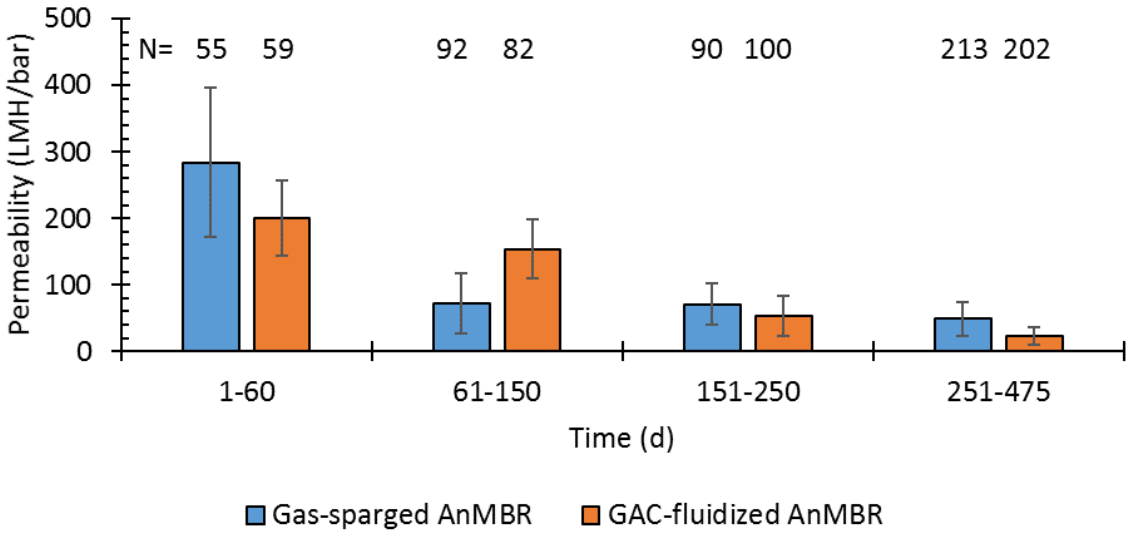

Figure 5.56 Comparison of Gas-sparged and GAC-fluidized AnMBR Ultrafiltration Permeability for Different Time Periods.

Permeability is corrected to 20°C. Error bars are ± 1 standard deviation. Differences are significant at $p < 0.0001$.

Membrane samples were submitted to American Water Chemicals (AWC, Plant City, FL) at the end of the demonstration for analysis. Subsamples from the top, middle, and bottom of the membrane module were analyzed for the parameters listed in Table 5.16 and laboratory reports are included in Appendix E. The gas-sparged AnMBR permeability increased slightly from 184 to 199 LMH/bar following high-pH cleaning with two separate proprietary reagents (see Appendix E), whereas the GAC-fluidized AnMBR permeability did not change appreciably (196 to 201 LMH/bar). The permeability of the gas-sparged AnMBR membrane was 7% greater than that of the GAC-fluidized AnMBR membrane following a 24-h water soak and prior to cleaning. The laboratory difference of 7% is less than the operating permeability difference of 110% (49±25 versus 24±13 LMH/bar) observed at the end of the demonstration (Figure 5.56). The measured permeabilities were also similar to those measured for a virgin Lotte Chemical fiber of 194 LMH/bar (7.776 gfd/psi). Additionally, clayey material (Figure 5.54c) was scraped off of the GAC-fluidized membranes prior to shipment, whereas the gas-sparged AnMBR membranes were shipped as is. Therefore, it appears the physical and chemical changes in the foulants during preparation and shipment led to laboratory permeabilities that were not representative of the fouled membranes.

Other laboratory analyses provided more useful information. The loss on ignition test indicated the foulants in both systems contained both organic and inorganic fractions. The inorganic fraction was not insignificant and was comprised of silt and clay substances and sulfur compounds. Fourier transform infrared spectroscopy demonstrated the organic content was similar to biofilm. Raman spectroscopy demonstrated the presence of elemental carbon in the GAC-fluidized AnMBR membrane foulant. These results indicate the foulants in both systems were similarly comprised of silty/clayey inorganics derived from the raw sewage and biofilm; the foulant of the GAC-fluidized AnMBR membrane also contained ground GAC particles. All of these foulants contributed to decreased permeabilities over the duration of the demonstration. Operational strategies used during each demonstration (i.e., biogas sparging, GAC-fluidization, maintenance cleaning, recovery cleaning) did not completely prevent accumulation of these foulants. Several strategies could be employed to prevent or minimize accumulation of these foulants. These include:

- Include sedimentation for primary treatment in addition to screening to minimize inorganics entering the AnMBR.
- Implement regular (i.e., two to three times per week) maintenance cleaning.
- Conduct more aggressive recovery cleaning in response to observed permeability reduction.
- Minimize grinding or attrition of GAC.
- Addition of a coagulant to the bioreactor to control fouling by colloidal matter similarly to what others have found (Dong et al. 2015b, 2018).

Table 5.16 Ultrafiltration Membrane Autopsy Summary Based on Reports from AWC.

Analysis	Gas-Sparged AnMBR UF Membranes	GAC-Fluidized AnMBR UF Membranes
Permeability	• Initial[a] (184 LMH/bar) • Post-cleaning[b] (199 LMH/bar)	• Initial[a] (196 LMH/bar) • Post-cleaning[b] (201 LMH/bar)
Loss on ignition	• 59% organic • 41% inorganic	• 66% organic • 34% inorganic
Scanning electron microscopy/energy dispersive spectroscopy	• Top: Organic matter, calcium sulfate[3], and silt/clay • Middle: Organic matter, calcium sulfate[c], phosphate salts, titanium dioxide, and silt/clay • Bottom: Organic matter, calcium sulfate[c], silt/clay phosphate salts, iron hydroxide, and titanium dioxide	• Top: Organic matter, elemental sulfur, iron hydroxide, titanium dioxide, and silt/clay • Middle: Calcium sulfate[c], organic matter, iron hydroxide, and silt/clay • Bottom: Calcium sulfate[c], organic matter, iron hydroxide, and silt/clay
Fourier transform infrared spectroscopy	• Dehydrated foulant similar to biofilm • Inorganic residue similar to aluminosilicate clay	• Dehydrated foulant similar to biofilm • Inorganic residue similar to aluminosilicate clay
Raman spectroscopy	• No match to spectra in database	• Results indicate presence of coal; likely activated carbon
Membrane surface analysis	• "Surface damage" observed ranging from ~1.5 to ~6 µm. See Figure 5.57.	• "Pores" observed ranging from ~0.7 to ~5 µm. See Figure 5.57.

[a] Following 24-hour soak in de-ionized water.
[b] Following two six-hour high-pH cleanings proprietary cleaning agents.
[c] Reported as calcium sulfate but may have been a sulfide.

SEM demonstrated membrane damage on membrane samples from both systems (Table 5.16 and Figure 5.57). The damage appeared to be more severe on the GAC-fluidized AnMBR membranes. Additional SEM analyses conducted by Inha University demonstrated the PVDF membrane was severely compromised, especially at the bottom location, where most of the GAC is located (Figure 5.58).

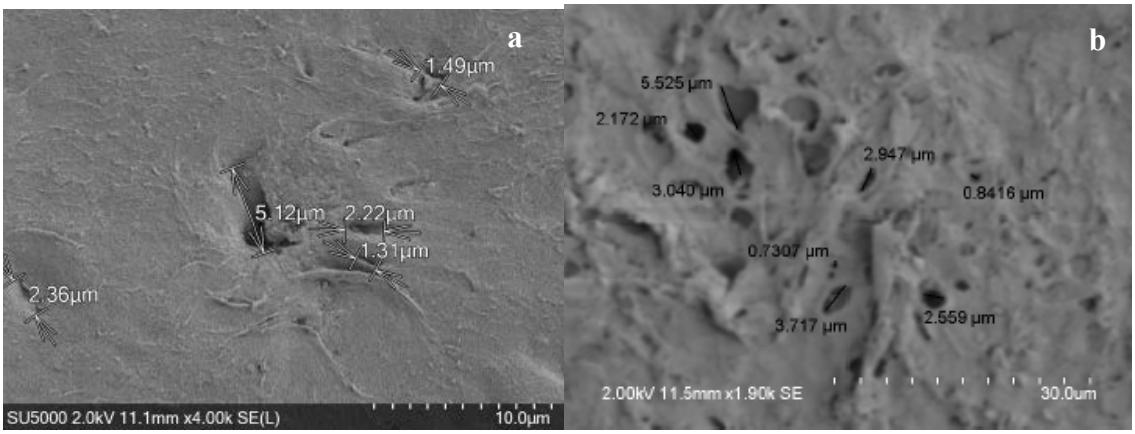

Figure 5.57 Electron Photomicrographs of Cleaned Gas-sparged (a) and GAC-fluidized (b) UF Fibers.

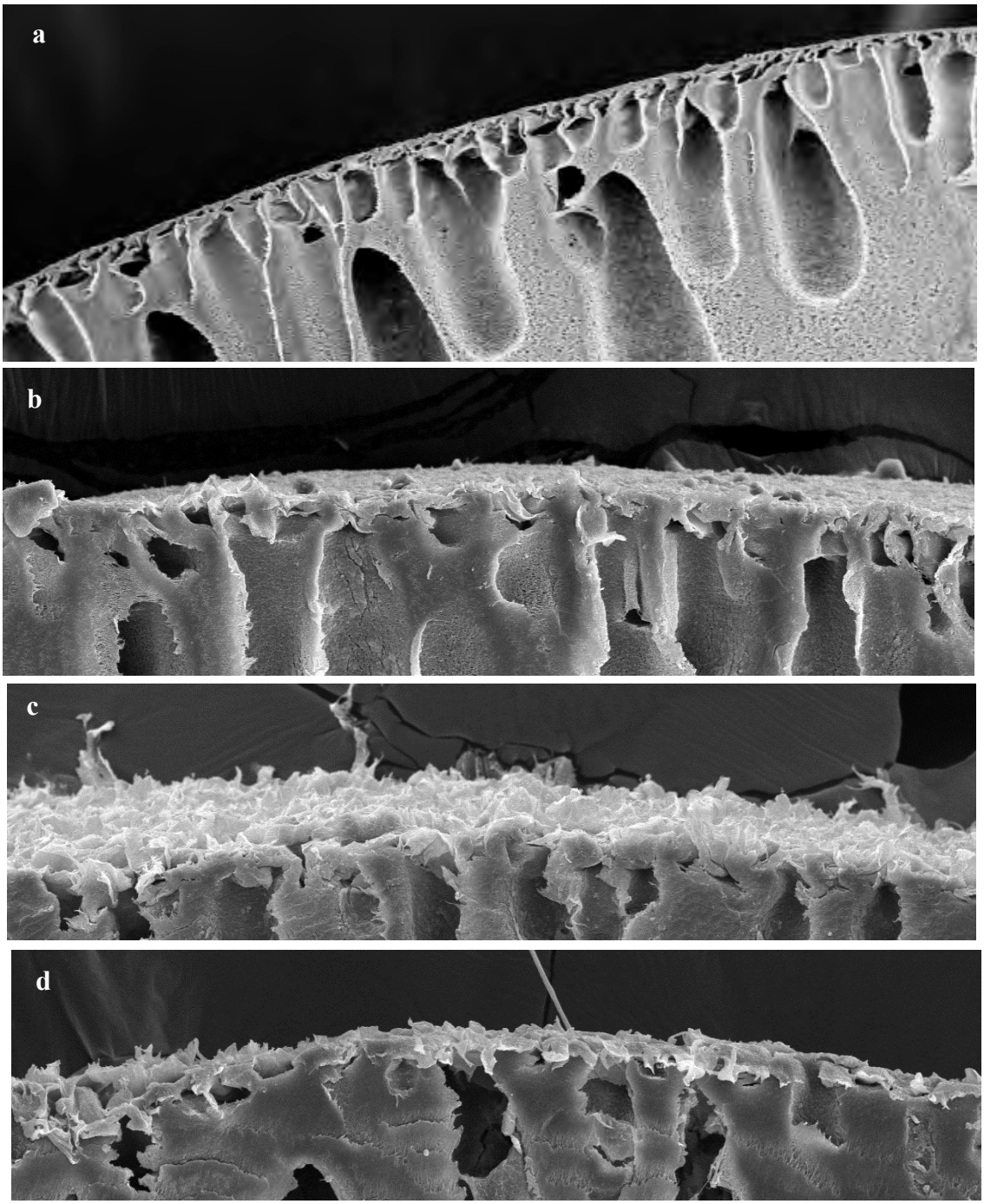

Figure 5.58 GAC-fluidized AnMBR Ultrafiltration Membrane Scanning Electron Photomicrographs of UF Membranes Including an Intact Membrane (Shin et al. 2016a) (a), and Samples from the Top (b), Middle (c) and Bottom (d) of the GAC-fluidized AnMBR in this Study.

Elemental analysis via EDS was conducted to characterize the membrane surface and associated foulant prior to cleaning (Figure 5.59 and Table 5.17). Low fluorine atomic concentrations and low fluorine:carbon atomic ratios relative to that for a virgin membrane (0.69) are indicative of a foulant coating on the membrane. The lowest fluorine:carbon ratios were associated with the gas-sparged AnMBR membrane bottom sample and the GAC-fluidized AnMBR membrane top sample. These results indicate most of the foulant in the gas-sparged AnMBR was located at the bottom of the membrane, which is consistent with visual observations of a clayey deposit (Figure 5.47). Most of the foulant was located at the top of the GAC-fluidized AnMBR membrane sample, which is also consistent with visual observations (Figure 5.54) and the knowledge that most of the GAC is located near the bottom. Fluorine:carbon ratios for the gas-sparged AnMBR ranged from 0.7 to 4% of the virgin membrane, whereas the GAC-fluidized AnMBR ratios ranged from 4 to 84%. These data suggest the amount of foulant on the GAC-fluidized AnMBR was less than that on the gas-sparged AnMBR, but the foulant on the GAC-fluidized AnMBR membranes was physically scraped off with a spatula prior to shipment. The oxygen:carbon ratios provide an additional indication of the amount of foulant. Virgin PVDF membranes have a ratio of 0.17. The ratio ranges for the gas-sparged AnMBR and GAC-fluidized AnMBR membranes were 0.40 to 0.50 and 0.16 to 0.29, respectively. These results support the presence of relatively more foulant on the *as-received* gas-sparged AnMBR membrane samples.

Considering the limitations described above, the main conclusions from the AWC study are:

- Foulants were present on both AnMBR membrane samples and were predominately located at the bottom in the gas-sparged AnMBR and at the top in the GAC-fluidized AnMBR.
- Foulants on both sets of membranes included organic and biological substances (i.e., biofilm) and inorganic substances similar to silt/clay.
- Sulfur compounds were present in foulants on membranes from both AnMBRs.
- Elemental carbon was deposited only on the GAC-fluidized AnMBR membranes resulting from GAC attrition and/or grinding.
- The GAC-fluidized AnMBR membranes appear to be more physically compromised from GAC-abrasion compared to the gas-sparged AnMBR membranes (Figure 5.57).

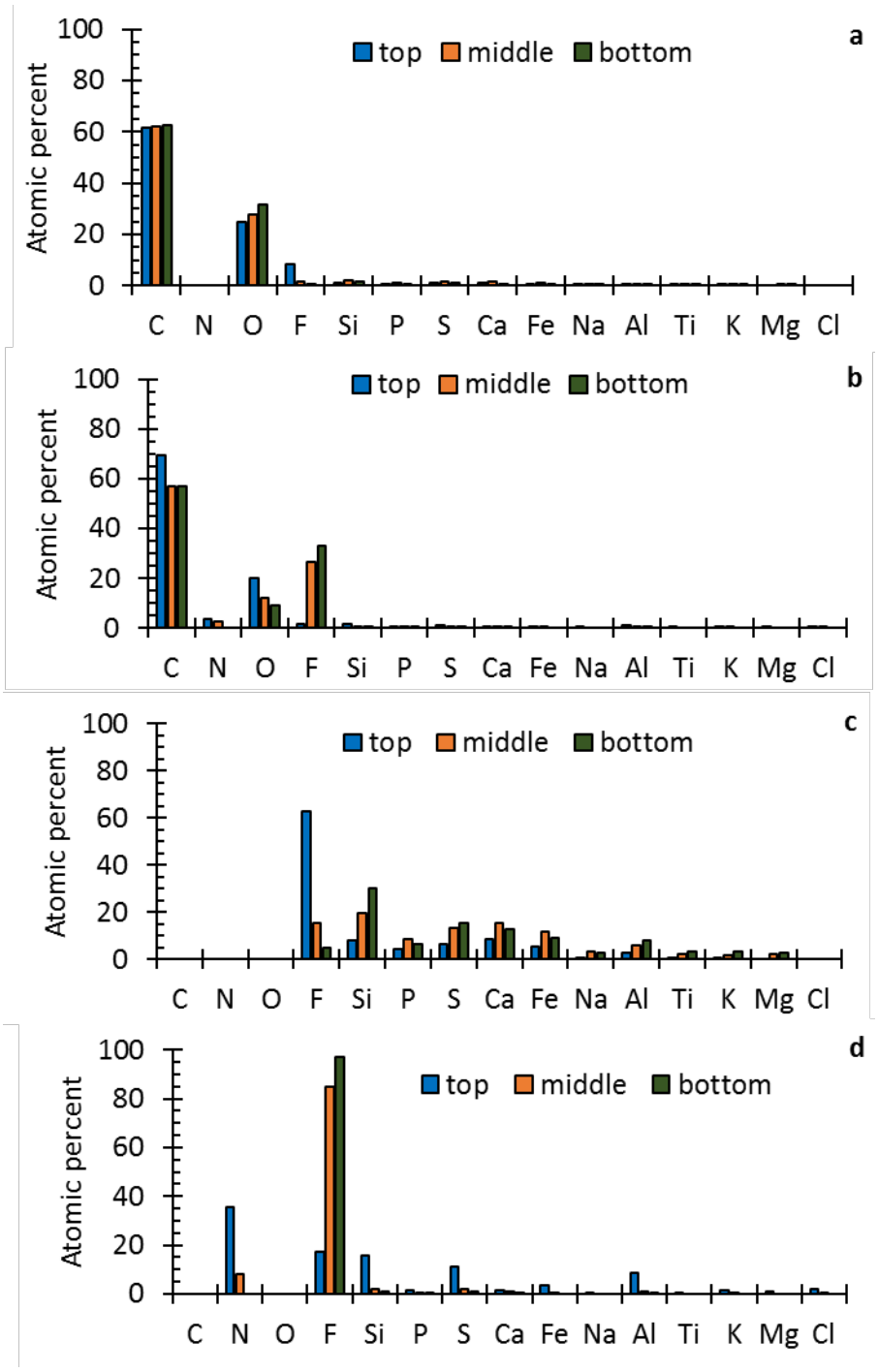

Figure 5.59 Energy Dispersive Spectroscopic Elemental Analysis of UF Fiber Sections for gas-sparged (a,c) and GAC-fluidized (b,d) Reporting All Detected Elements (a,b) and Excluding Carbon and Oxygen (c,d).

Table 5.17 Ultrafiltration Membrane Atomic Ratios.

Membrane	Gas-Sparged UF Membrane		GAC-Fluidized UF Membrane	
	Fluorine:Carbon	Oxygen:Carbon	Fluorine:Carbon	Oxygen:Carbon
Virgin	0.69	0.17	0.69	0.17
Top	0.13	0.40	0.03	0.29
Middle	0.03	0.44	0.46	0.21
Bottom	0.005	0.50	0.58	0.16

5.7.15 Gas-Sparged AnMBR Sulfide and Phosphorus Removal

A matrix of jar tests was performed with the primary objective of removing sulfide, and a secondary objective of producing low turbidity. The results of tests where concentrations of ferric chloride and aluminum chlorohydrate (ACH) were varied, while cationic polymer (P847E) was kept constant at 1 mg/L, shown in Figure 5.60. The results of the jar tests demonstrate that lower concentrations of residual sulfide were achieved at higher doses of iron (Figure 5.61a). While sulfide removal was achieved through the addition of iron alone, floc size was small and led to poor settling. The addition of ACH and cationic polymer helped to form stronger, larger flocs and improved settling. Keeping the polymer dose constant at 1 mg/L, ferric chloride and ACH were varied to find a suitable combination of doses to achieve sulfide removal and low turbidity. The most promising results were achieved in two tests with iron dosing at 180 mg/L and 1 mg/L polymer, which demonstrated removal rates greater than 99% and 96% in sulfide and phosphorus, respectively, while forming large flocs with acceptable settling at ACH doses of 50 milligrams aluminum per liter (mg-Al/L) and 67.5 mg-Al/L (Figure 5.61b).

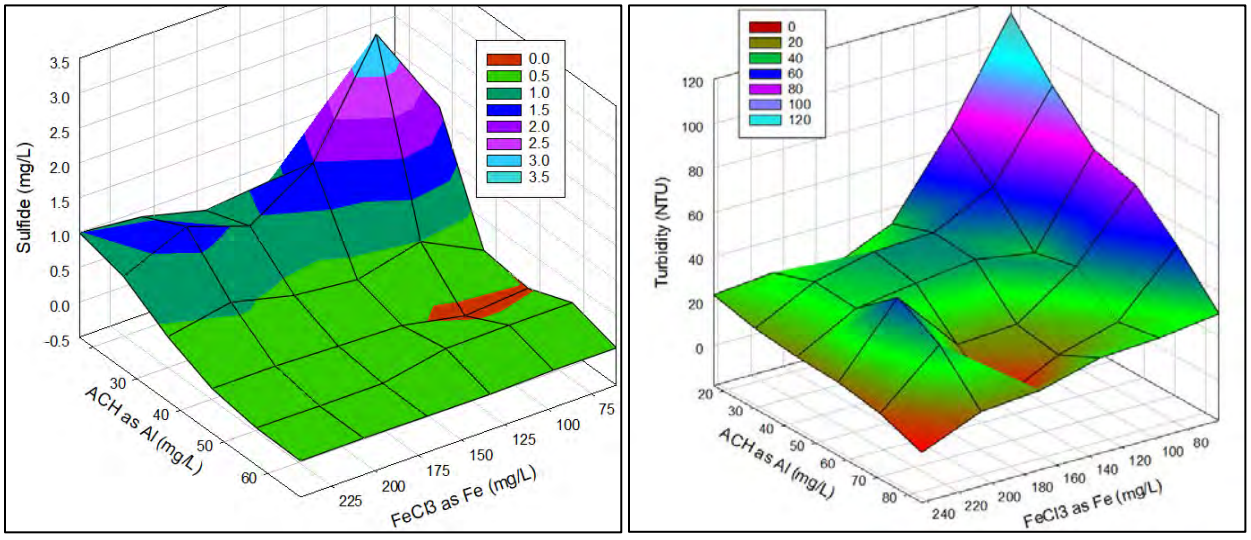

Figure 5.60 Surface Plots Demonstrating the Results of the Matrix of Jar Tests Conducted by Varying Ferric Chloride and ACH Concentrations, While Holding Polymer Dosing to a Consistent 1 mg/L to Determine Optimal Dosages for Reduction of Sulfide Residual Concentrations (a) and Turbidity (b).

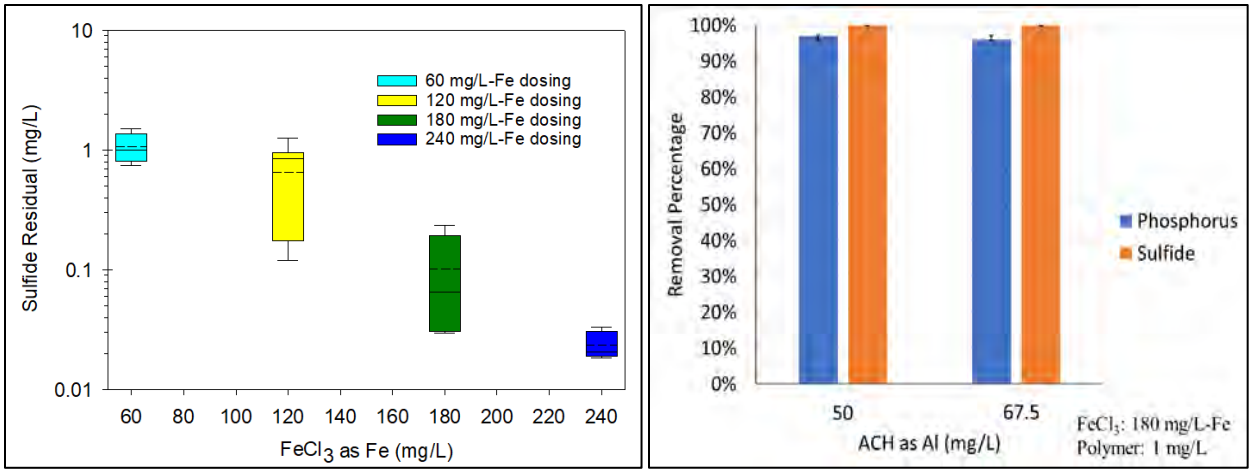

Figure 5.61 (a) Sulfide Residuals in Response to Varying Concentrations of Ferric Chloride (a) and Removal of Phosphorus and Sulfide in Response to Varying Concentrations of ACH (b).

Based on the results of jar testing, a combination of ACH, ferric chloride, and medium to high molecular weight, low-charged cationic emulsion polymer was used in gas-sparged AnMBR continuous-flow coagulation-flocculation-sedimentation tests. Figure 5.62 shows chemical doses and the measured sedimentation basin pH.

Sulfide concentrations were reduced from ~30 mg/L to less than the performance objective of 0.1 mg/L from days 328 to 360 at times, but removal was inconsistent (Figure 5.62b). During this time, the $FeCl_3$ dose was 55-76 mg-Fe/L and dissolved iron was < 1 mg/L. The $FeCl_3$ dose was increased to 100-125 milligrams iron per liter (mg-Fe/L) to improve sulfide removal from days 361 to 479. With the exception of a transitional period from days 361 to 362, sulfide removal consistency improved, and the effluent concentration was 0.7±1.7 mg/L (Table 5.18). Sulfide was > 1 mg/L on days 382 and 437 for unknown reasons, which contributed to the high standard deviation. The median and minimum effluent concentrations were 0.10 and 0.04 mg/L, respectively. Sulfide removal was 99±2%. The dissolved iron concentration increased to 5.1±4.3 mg/L as a result of the increased $FeCl_3$ dose. While the median sulfide concentration met the performance objective, the average concentration did not, and the elevated dissolved iron concentration indicates further process optimization is required. The performance objective of 0.1 mg/L sulfide may also be too strict for some applications. A goal of 1 mg/L sulfide would have been achieved more easily.

Total phosphorus was reduced from 7.0±2.9 mg/L in the screened AnMBR influent to 0.43±0.29 in the clinoptilolite effluent for an overall removal of 94±3%, which was greater than the performance objective of 90% (p=0.052) (Figure 5.62c). The overall removal for total phosphorus was a result of the individual removals observed in the AnMBR, coagulation, and clinoptilolite sorption. The coagulation-flocculation-sedimentation process removed most of the phosphorus. Total phosphorus concentrations in the coagulation influent were reduced from 4.2±0.6 mg/L by 83±9% (effluent concentration 0.72±0.36 mg/L) (Table 5.18). Coagulation removal ranged from 88 to 91% from days 363 to 383 but then decreased to 67 to78% from days 416 to 465 (Figure 5.62c).

The reason for this decrease is uncertain. The phosphorus removal rate by coagulation-flocculation was 53±12 mg L^{-1} d^{-1}, which was less than the performance objective of 60 mg L^{-1} d^{-1}. This rate is based on the combined volume of the coagulation, flocculation, and sedimentation vessels. Further optimization may have resulted in the performance objective being met.

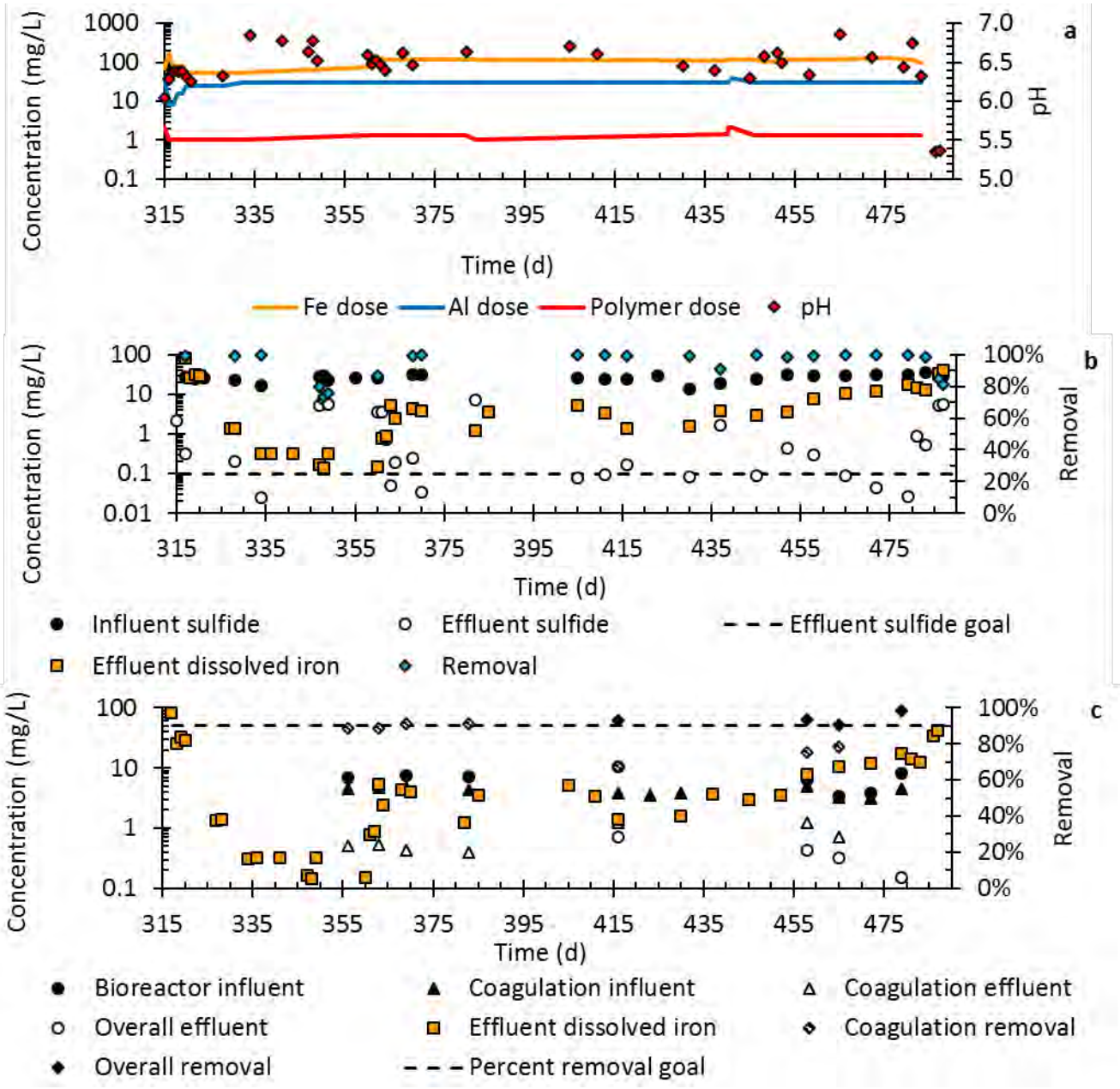

Figure 5.62 Gas-sparged AnMBR Coagulation-flocculation Chemical Doses and Resultant pH Values (a) Along with Associated Removals of Sulfide (b) and Total Phosphorus (c).

Chemical doses are reported as mg-Fe/L, mg-Al/L, and mg/L of polymer product. Overall removal of total phosphorus (c) is inclusive of bioreactor removal and clinoptilolite removal.

Table 5.18 Gas-sparged AnMBR Coagulation-flocculation-sedimentation Effectiveness for Period of Elevated Iron Dose from 362 to 479 Days.

Concentration (mg/L)			
Analyte	**Influent**	**Effluent**	**Removal**
Sulfide	27±5	0.7±1.7	99%±2%
Total phosphorus	4.2±0.6	0.72±0.36	83%±9%
Dissolved iron	NA	5.1±4.3	NA

Note:
Average Fe dose was 116 ± 3 mg-Fe/L
Average Al dose was 31 ± 2 mg-Al/L
Average polymer dose was 1.2 ± 0.3 mg/L

5.7.16 GAC-Fluidized AnMBR Sulfide and Phosphorus Removal

Table 5.19 summarizes the results of jar testing for the purpose of removing sulfide and phosphorus from the GAC-fluidized AnMBR permeate using alum and a cationic polymer. Permeate sulfide concentrations were lower than those for the gas-fluidized AnMBR and were reduced to < 1 mg/L. The 0.1-mg/L performance objective was not met in these short-duration tests. Total phosphorus was reduced to undetectable concentrations, and thus, the 90% performance objective was met. COD was also measured and demonstrated the potential for additional COD removal – about 50% of the permeate COD was removed. These data demonstrate that coagulation with alum (compared to ferric chloride and ACH) has good potential for treatment of AnMBR permeate and must be optimized for each system.

Table 5.19 Jar Testing Results for GAC-fluidized AnMBR Pemeate.

	pH	**Turbidity (NTU)**	**Sulfide (mg/L)**	**COD (mg/L)**	**Total Phosphorus (mg/L)**
Permeate	7.1	75	6.3	40	3.2
Alum 10 mg/L + 1 mg/L polymer	6.9	3	0.2	22	< 0.1
Alum 30 mg/L + 1 mg/L polymer	6.2	5	0.3	19	< 0.1
Alum 50 mg/L + 1 mg/L polymer	5.2	10	0.5	22	< 0.1

5.7.17 Gas-Sparged AnMBR Ammonia Removal

Coagulated and settled permeate was pumped through a column of clinoptilolite to evaluate ammonia removal efficiency and loading. The clinoptilolite column was operated until ammonia effluent concentrations were equal to influent concentrations (i.e., complete breakthrough).

The clinoptilolite media was then shipped to CERL for regeneration (discussed below). The regenerated clinoptilolite media was then subjected to another sorption run with coagulated and settled water. Two batches of clinoptilolite were tested as duplicates. Figure 5.63 shows breakthrough curves for two different tests with virgin clinoptilolite. Initial breakthrough was observed around 50 to 100 empty bed volumes. These values are about half of what has been observed in a previous study with ammonia-amended tap water (U.S. EPA 1971). Variation in breakthrough was attributed to variations in influent water chemistry and process interruptions. These interruptions involved intentional shutdowns required to empty the sludge settling basin. The average effluent pH values of day 335 and day 348 runs were 7.2±0.1 and 6.7±0.2, respectively. This difference may have affected the breakthrough curves though the pKa of ammonium is 9.24 – more than 2 pH units greater than the effluent pH values.

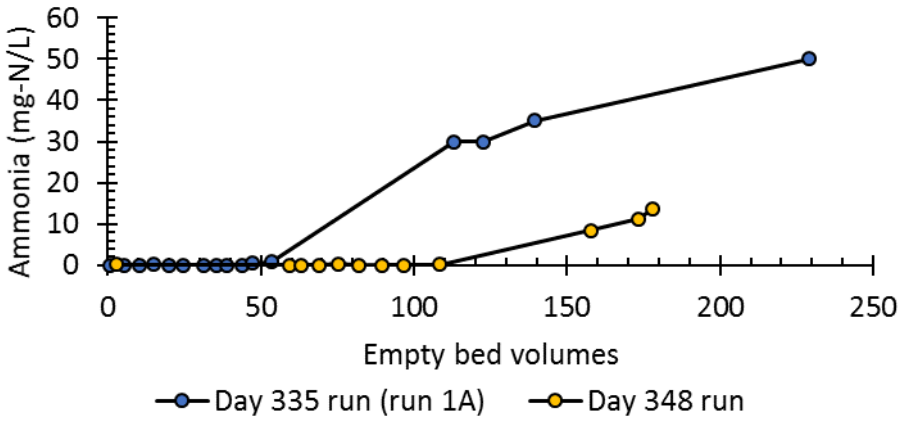

Figure 5.63 Gas-sparged AnMBR Ammonia Breakthrough Curves for Two Runs with New Clinoptilolite Media.

Influent ammonia concentrations for day 334 and day 348 runs were 45 and 35 mg-N/L, respectively.

Three sorption cycles were completed in duplicate (Figure 5.64). The influent and initial effluent ammonia concentrations were 37±4 and 0.05±0.05 mg-N/L, respectively. The initial effluent concentrations were taken after ~4 hours of operation, which was equivalent to 12 to 20 empty bed volumes. The percent removal was 99.9±0.1%, which exceeded the performance objective of 90% ($p < 0.0001$). The effluent concentrations and percent removals did not change over time, indicating both the virgin and regenerated clinoptilolite batches were capable of effectively removing ammonia from coagulated AnMBR permeate. The ammonia removal rate prior to breakthrough was 4.4±0.9 g L^{-1} d^{-1}, which is greater than the performance objective of 2 g L^{-1} d^{-1} ($p=0.00063$).

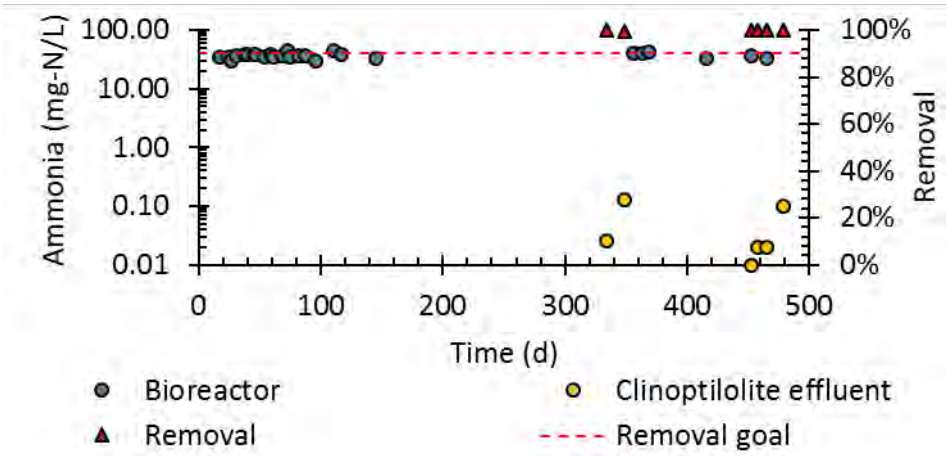

Figure 5.64 Gas-sparged AnMBR Ammonia Concentrations Over Time, Clinoptilolite Effluent Concentrations Prior to Breakthrough, and Percent Removal Compared to Performance Objective.

Ammonia loading on the clinoptilolite was measured to evaluate sorption capacity both before and after two regeneration cycles (Figure 5.65). The initial loading was 6.4 and 4.8 grams nitrogen per kilogram (g-N/kg) for batches A and B, respectively, compared to the design loading of 13 g-N/kg based on CERL laboratory tests with ammonia in deionized water. After the first regeneration with NaCl brine, the loading decreased by 21 to 50% (Figure 5.65b) compared to the performance objective of 10%. The decrease in loading may have been attributable to either insufficient removal of sorbed iron or competition by ferrous ion during the second sorption cycle (Figure 5.65c). The second regeneration (NaCl and NaOH for batch A and NaOH for batch B) did not result in further decreases in ammonia loading. The loading of batch B may have been greater than that of batch A because of elevated dissolved iron concentrations (Figure 5.65c). Regenerated clinoptilolite had reduced loading but a second regeneration did not further reduce loading. Further regenerations were not conducted, therefore extrapolation to long-term regeneration performance was not possible. Dissolved iron appears to have also negatively affected ammonia loading.

Clinoptilolite regeneration was possible with either NaCl brine or 0.5-molar (M) NaOH; however, regeneration was faster with NaOH. At elevated pH, ammonia is removed by both ion exchange and charge neutralization mechanisms, which increased regeneration rates over pH neutral NaCl. Electrolysis of the ammonia-laded regenerant solutions was conducted with GreenBox^{TM} technology. Electrolysis was not observed with any of the six solutions. It is believed that iron from upstream coagulation processes interfered negatively with the electrodes. Further studies on the linkage of clinoptilolite ion exchange with ammonia electrolysis will require non-iron based coagulants and/or a change in process order.

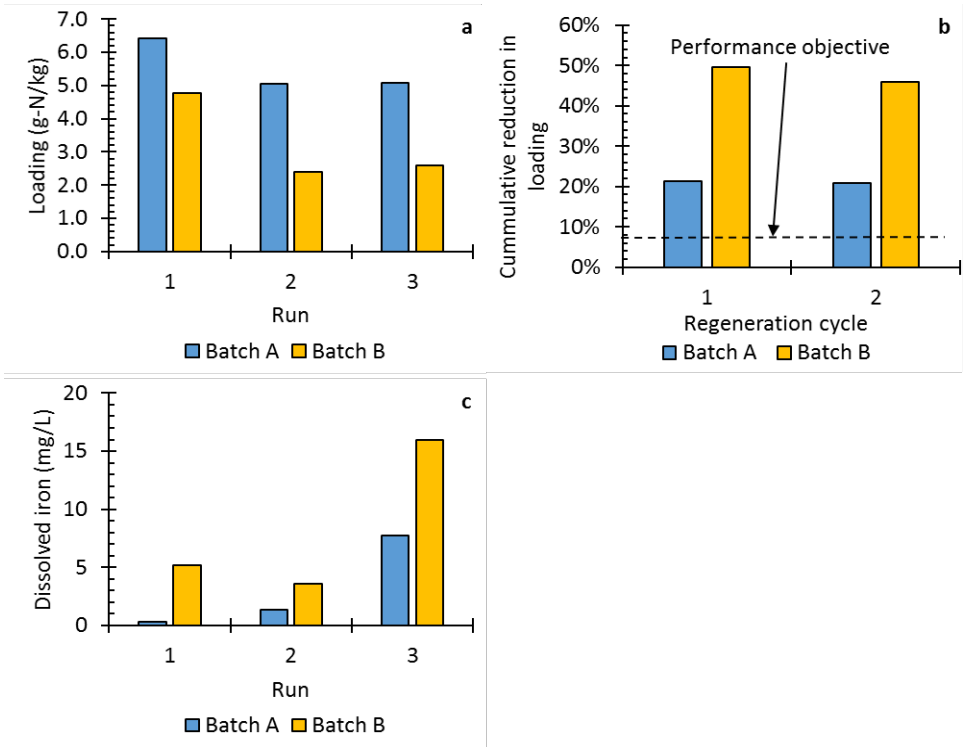

Figure 5.65 Gas-sparged AnMBR Clinoptilolite Loading per Run (a), Overall Reduction in Loading After Each Regeneration Cycle (b), and Dissolved Iron Concentrations in the Column Influent (c).

5.7.18 Gas-Sparged and GAC-Fluidized AnMBR Treated Water Quality

Table 5.20 summarizes water quality following treatment by the gas-sparged and GAC-fluidized AnMBR systems. The values listed for the gas-sparged AnMBR are following treatment by the entire treatment train, including the AnMBR, dissolved methane removal, coagulation-flocculation-sedimentation, and ammonia removal. The GAC-fluidized AnMBR values are only for the AnMBR process because the downstream processes were not tested. General conclusions regarding these results are as follows:

- BOD_5 concentrations were less than the EPA secondary treatment standard of 30 mg/L but greater than the ANSI reuse standard of 10 mg/L. Implementation of primary treatment prior to the AnMBR would likely have resulted in lower effluent concentrations based results of a previous study with primary effluent (Shin et al. 2014). The primary effluent contains predominately soluble COD which is more degradable in an AnMBR than solids that must be hydrolyzed. The GAC-fluidized AnMBR was capable of achieving lower concentrations than the gas-sparged AnMBR; though, the influent concentration to the gas-sparged AnMBR was greater than that to the GAC-fluidized AnMBR. Similar conclusions apply to COD.

Table 5.20 Gas-sparged and GAC-Fluidized AnMBR Treated Water Quality.

Analyte	Gas-Sparged AnMBR[a]	GAC-Fluidized AnMBR[b]
BOD5 (mg/L)[c]	25±12	15±9
COD (mg/L)[c]	58±27	29±9
Ammonia (mg-N/L)	0.046±0.045	29±5
Nitrite (mg-N/L)	0.015±0.007	NA
Nitrate (mg-N/L)	0.023±0.012	NA
Total nitrogen (mg/L)	1.4±0.6	29±7
Total phosphorus (mg/L)	0.43±0.29	2.7±0.3
Sulfate (mg/L)	1.3	10±7
Sulfide (mg/L)	0.29±0.25	3.9
Dissolved iron (mg/L)	0.29±0.07	NA
Oxidation-reduction potential (mV)	-120±30	NA
pH	8.1±1.1	7.2±0.2
Hardness (mg/L)	56±60	NA
Alkalinity (mg-$CaCO_3$/L)	370±70	240±20
Total dissolved solids (mg/L)	820±90	NA
Specific conductivity (µS/cm)	1200±100	NA
LSI[d]	-0.14±1.00	NA
Total suspended solids (mg/L)	25±17	NA
Turbidity (NTU)	9.8±8.8	5.3±3.2
E. coli (MPN/100 mL)[e]	< 1	NA
Total coliforms (MPN/100 mL)[e]	370±210	NA
Chlorine demand (mg/L)	12±2	NA
Dissolved methane[f]	2.6±0.5	12±3

[a] Data for clinoptilolite effluent with the exception of BOD_5 and COD.
[b] Data for AnMBR permeate.
[c] Data for non-upset conditions.
[d] Langalier saturation index calculated using specific conductivity data and a temperature of 15°C.
[e] Prior to disinfection.
[f] In permeate prior to dissolved methane removal for the GAC-fluidized AnMBR and minimum value observed following dissolved methane removal in the gas-sparged AnMBR.

- Ammonia was effectively removed by the clinoptilolite media. Nitrate and nitrite were very low, as expected in an anaerobic system. Total nitrogen in the screened sewage to the gas-sparged AnMBR was reduced from 60±4 mg/L to 1.4±0.6 mg/L. Total phosphorus was reduced from 7.0±2.9 mg/L to 0.43±0.29 for an overall removal of 94±3% which was greater than the performance objective of 90% (p=0.052). The overall removal for total phosphorus was a result of the individual removals observed in the AnMBR, coagulation, and clinoptilolite sorption (Figure 5.66).

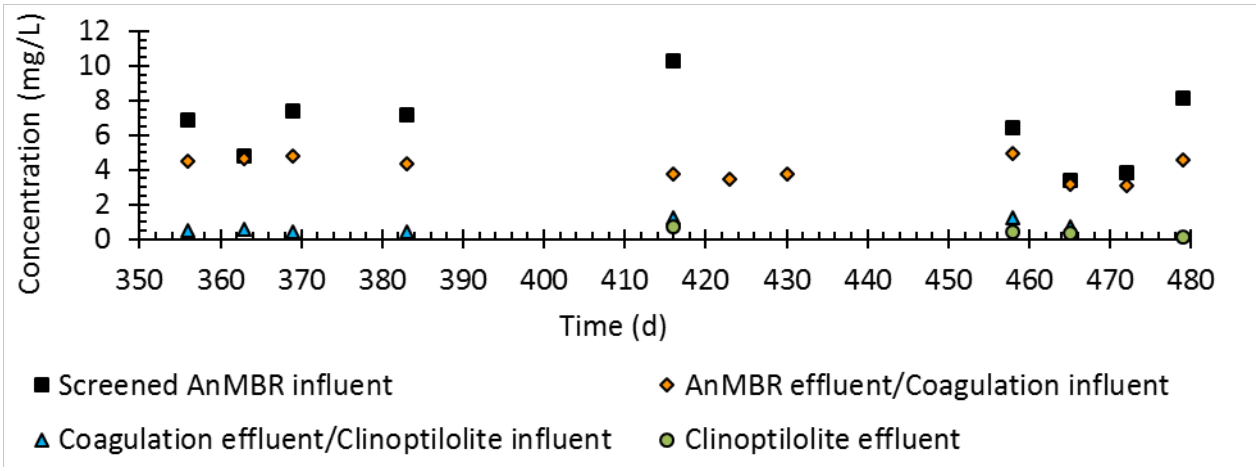

Figure 5.66 Gas-sparged AnMBR Total Phosphorus Concentrations Through the Entire Process.

- Sulfide was reduced by the coagulation-flocculation-sedimentation process from 31±2 mg/L in the AnMBR permeate to 0.29±0.25 mg/L in the clinoptilolite bed effluent. The performance objective of 0.1 mg/L was not met, suggesting further refinement of the coagulation process is required (see also Section 5.7.15).
- Dissolved iron in the clinoptilolite effluent (0.29±0.07 mg/L) was less than the coagulation-flocculation-sedimentation effluent (9.7±7.2 mg/L) for these sorption test runs. These data demonstrate the clinoptilolite sorbed ferrous iron, which in turn, negatively affected the electrolysis process (see Section 5.7.17). While further coagulation optimization is warranted to minimize dissolved iron concentrations, the clinoptilolite could be an effective polishing step for residual dissolved iron.
- The oxidation-reduction potential was negative, which could adversely affect receiving surface water. While dissolved oxygen was not measured, its concentration was likely low. Post aeration of treated effluent may be necessary, and use of energy-efficient methods (e.g., cascade aeration) should be considered. This process would also remove residual sulfide and dissolved iron. This may not be necessary for certain reuse applications, such as toilet flushing.
- General water quality parameters were measured, including pH, hardness, alkalinity, total dissolved solids, and specific conductivity. The Langelier saturation index (LSI) was calculated and was highly variable because of variations in coagulation pH. This result indicates corrosion potential would need to be considered further. Total dissolved solids concentration was greater than the EPA secondary MCL of 500 mg/L, which could potentially affect potable reuse applications.
- Total suspended solids were detected in the gas-sparged AnMBR effluent because of inefficient sedimentation and presence of fines released from the friable clinoptilolite but were less than the EPA secondary treatment standard of 30 mg/L, although not at a statistically significant level ($p=0.30$). Turbidity was elevated in both the gas-sparged and GAC-fluidized AnMBR and greater than the performance objective of 2 NTU. Elevated turbidity could have been a result of precipitation in addition to the above factors.

- *E. coli* was not detected, and total coliform concentrations were less than typically found in treated but undisinfected wastewaters (Elmund et al. 1999). The chlorine demand was high in light of the negative oxidation-reduction potential.
- Dissolved methane concentrations prior to removal were similar in both systems (14±2 and 12±3 mg/L for the gas-sparged and GAC-fluidized AnMBRs, respectively). The concentration in the gas-sparged AnMBR permeate following removal by the Liqui-Cel contactor was reduced by 79% but still detectable and a potential source of greenhouse gas emissions.

5.7.19 Gas-Sparged AnMBR Residuals Characterization

Bioreactor and sedimentation solids collected from the gas-sparged AnMBR were characterized and compared to regulations including Resource and Conservation Recovery Act (RCRA) hazardous waste and part 503B biosolids regulations (Table 5.21 and Table 5.22). Note that RCRA exempts wastewater residuals because they are regulated separately under the Clean Water Act. Therefore, the RCRA hazardous waste regulatory limits for the toxicity characteristic are provided for reference only. None of the metals concentrations in both residuals exceeded regulatory limits. Pathogens exceeded part 503B class A biosolids limits but not the class B biosolids limit for fecal coliforms.

The suspended solids concentration following coagulation-flocculation and prior to sedimentation was 180±90 mg/L TSS and 58±29 mg/L VSS for the period 362 to 479 days. Thus, 180 mg of solids was produced for each liter of permeate generated. The phosphorus and sulfur recoveries were acceptable, but the iron recovery was low (Table 5.22). The iron recovery estimate is based on calculated dose rather than actual measured iron concentration fed. Thus, the actual dose may be less than reported.

The sedimentation residual has potential use as fertilizer, especially as a source of iron, phosphorus and sulfur. The nitrogen to phosphorus to potassium (NPK) ratio (i.e., in standard terms of weight percentages of $N:P_2O_5:K_2O$) is 0.35:12:0.22, indicating the nitrogen content is low. The residuals are a good source of phosphorus (in addition to iron and sulfur), assuming it is available to plants and not irreversibly complexed with aluminum or iron.

Table 5.21 Gas-sparged AnMBR Bioreactor Solids Characteristics.

Analyte	Gas-sparged AnMBR	RCRA limit	503B limit class A	503B limit class B
Total solids (mg/L)	9,200±6,000	NA	NA	NA
Volatile solids (mg/L)	7,200±4,800	NA	NA	NA
VS/TS	78%±6%	NA	NA	NA
Metals				
Arsenic (mg/kg dry)	4.5±1.1	NA	75	NA
Barium (mg/kg dry)	160±90	NA	NA	NA
Cadmium (mg/kg dry)	2.1±1.3	NA	85	NA
Chromium (mg/kg dry)	73±49	NA	NA	NA
Lead (mg/kg dry)	8.0±6.8	NA	840	NA
Mercury (mg/kg dry)	0.099±0.028	NA	57	NA
Selenium (mg/kg dry)	11±5	NA	100	NA
Silver (mg/kg dry)	2.1±1.1	NA	NA	NA
Arsenic (max TCLP mg/L)[a]	0.22±0.05	5	NA	NA
Barium (max TCLP mg/L)[a]	7.9±4.5	100	NA	NA
Cadmium (max TCLP mg/L)[a]	0.10±0.067	1	NA	NA
Chromium (max TCLP mg/L)[a]	3.7±2.5	5	NA	NA
Lead (max TCLP mg/L)[a]	0.40±0.34	5	NA	NA
Mercury (max TCLP mg/L)[a]	0.0049±0.0014	0.2	NA	NA
Selenium (max TCLP mg/L)[a]	0.56±0.24	1	NA	NA
Silver (max TCLP mg/L)[a]	0.10±0.053	5	NA	NA
Pathogens				
Enteric viruses (plaque forming units/4 g dry)	17±6	NA	1	NA
Viable helminth ova (number per 4 g dry)	≤ 2.7	NA	1	NA
Fecal coliforms (MPN/g dry)	620,000	NA	1,000	2,000,000
Salmonella (MPN/4 g dry)	1,200±700	NA	3	NA

[a] Calculated assuming 100% leaching in toxicity characteristic leaching procedure (TCLP).

Table 5.22 Gas-sparged AnMBR Coagulation-Flocculation-Sedimentation Sludge Elemental Analysis and Calculated Recovery for Period of Elevated Iron Dose from Days 361 to 479.

Analyte	Concentration (dry wt %)	Recovery	Maximum TCLP (mg/L)[a]	RCRA limit (mg/L)
Al	19%	NA	NA	NA
As	0.0009%	NA	0.45	5
B	0.0004%	NA	0.2	100
C	3.0%	NA	NA	NA
Ca	0.42%	NA	NA	NA
Cl	0.09%	NA	NA	NA
Co	0.0009%	NA	NA	NA
Cr	0.003%	NA	1.5	5
Cu	0.003%	NA	NA	NA
Fe	20%	33%±17%	NA	NA
H	2.9%	NA	NA	NA
K	0.09%	NA	NA	NA
Mg	0.07%	NA	NA	NA
N	0.35%	NA	NA	NA
Na	0.18%	NA	NA	NA
O	28%	NA	NA	NA
P	2.6%	166%±99%	NA	NA
S	15%	107%±38%	NA	NA
Pb, Cd, Zn,Co	ND	NA	ND	1 to 5
Total	92%	NA	NA	NA

[a] Calculated assuming 100% leaching in TCLP.

Sludge dewatering tests were conducted by Dr. Matt Higgins at Bucknell University. The total solids contents of the original sample, as well as the cake solids and polymer demand measured during the dewatering test are summarized in Table 5.23. The cake solids for the AnMBR samples average about 16% for the two different samples analyzed in duplicate. The polymer demand had an average around 32 kilograms per metric ton (kg/tonne), which is relatively high. For the sample from the sedimentation basin, the average cake solids concentration was 19.6% and the polymer demand was 9.2 kg/tonne.

Table 5.23 Dewatering Results for Gas-sparged AnMBR Bioreactor Sludge and Coagulation-Flocculation-Sedimentation Sludge.

Sample	Sample Date	Sample TS (%)	Cake Solids (%)	Polymer Dose (kg/tonne)
AnMBR Bioreactor	4/26/17 (day 285)	1.03	16.2 ± 0.98	29.6
AnMBR Bioreactor	10/19/17 (day 461)	0.22	15.9 ± 0.55	34.4
Sediment Basin	10/19/17 (day 461)	1.24	19.6 ± 0.13	9.2

5.7.20 Gas-Sparged and GAC-Fluidized AnMBR Biogas Characterization

Biogas samples were collected and analyzed from each AnMBR system (Table 5.24). Methane concentrations were similar to those observed in standard anaerobic digesters; however, the residual gas was predominately nitrogen rather than carbon dioxide as has been observed in other AnMBR systems (Shin et al. 2016c). Hydrogen sulfide was present in the gas-sparged AnMBR biogas as would be expected, especially considering the influent sulfate concentrations. Hydrogen sulfide treatment would be required, as has been previously studied (Evans et al. 2016, Jayaraman et al. 2015, Vandenburgh and Evans 2016). Biogas was sampled and analyzed once for siloxanes and only octamethylcyclotetrasiloxane D4 was detected.

Table 5.24 Biogas, Gas-sparged and GAC-fluidized AnMBR Biogas Composition.

Analyte	Gas-Sparged AnMBR	GAC-Fluidized AnMBR
Fixed gases (volume %)		
Methane	68±6.5	61±7.7
Carbon dioxide	6.4±7.2	6.9±1.8
Nitrogen	24±5.9	32±8.6
Oxygen/argon	1.0±0.3	NA
Hydrogen sulfide (mg/m^3)	4,900±1,800	NA
Siloxanes (ppbV)		
Trimethylsilanol	< 13	NA
Hexamethyldisiloxane (L2)	< 6.3	NA
Hexamethylcyclotrisiloxane (D3)	< 4.8	NA
Octamethyltrisiloxane (L3)	< 4.3	NA
Octamethylcyclotetrasiloxane (D4)	4.7	NA
Decamethylcyclotetrasiloxane (L4)	< 3.3	NA
Decamethylcyclopentasiloxane (D5)	< 2.8	NA
Dodecamethylpentasiloxane (L5)	< 2.7	NA
Dedecamethylcyclohexasiloxane (D6)	< 2.3	NA

5.7.21 Gas-Sparged AnMBR Microbial Ecology

Phylum level distribution of bacterial communities in AnMBR

Out of 639 bacterial operational taxonomic units (OTUs) recognized, a core group of bacterial phyla *Bacteroidetes*, *Proteobacteria*, *Firmicutes*, and to a lesser extent, *Chloroflexi* and *Synergistetes*, were observed throughout the period of AnMBR sampling from the gas-sparged AnMBR bioreactor (Figure 5.67). Phylum *Bacteroidetes* accounted for roughly 20 to 35% of the relative abundance and did not significantly change from summer startup through winter operation. *Proteobacteria* increased in relative abundance from 14.7% at startup to 26.9% and *Firmicutes* from 8% to 16.6%, respectively, when the average effective bioreactor temperature decreased from 25°C to 16°C (7/13/2016 [day –2] to 3/15/2017 [day 243]). Temperatures are shown on top of the graphs in Figure 5.67 through Figure 5.70. On the other hand, *Chloroflexi* to decrease from 29.3% to 9.1% during the same period. *Synergistes* exhibited a minor increase in relative abundance, more noticeably from startup to winter, before achieving stable but low relative abundance levels.

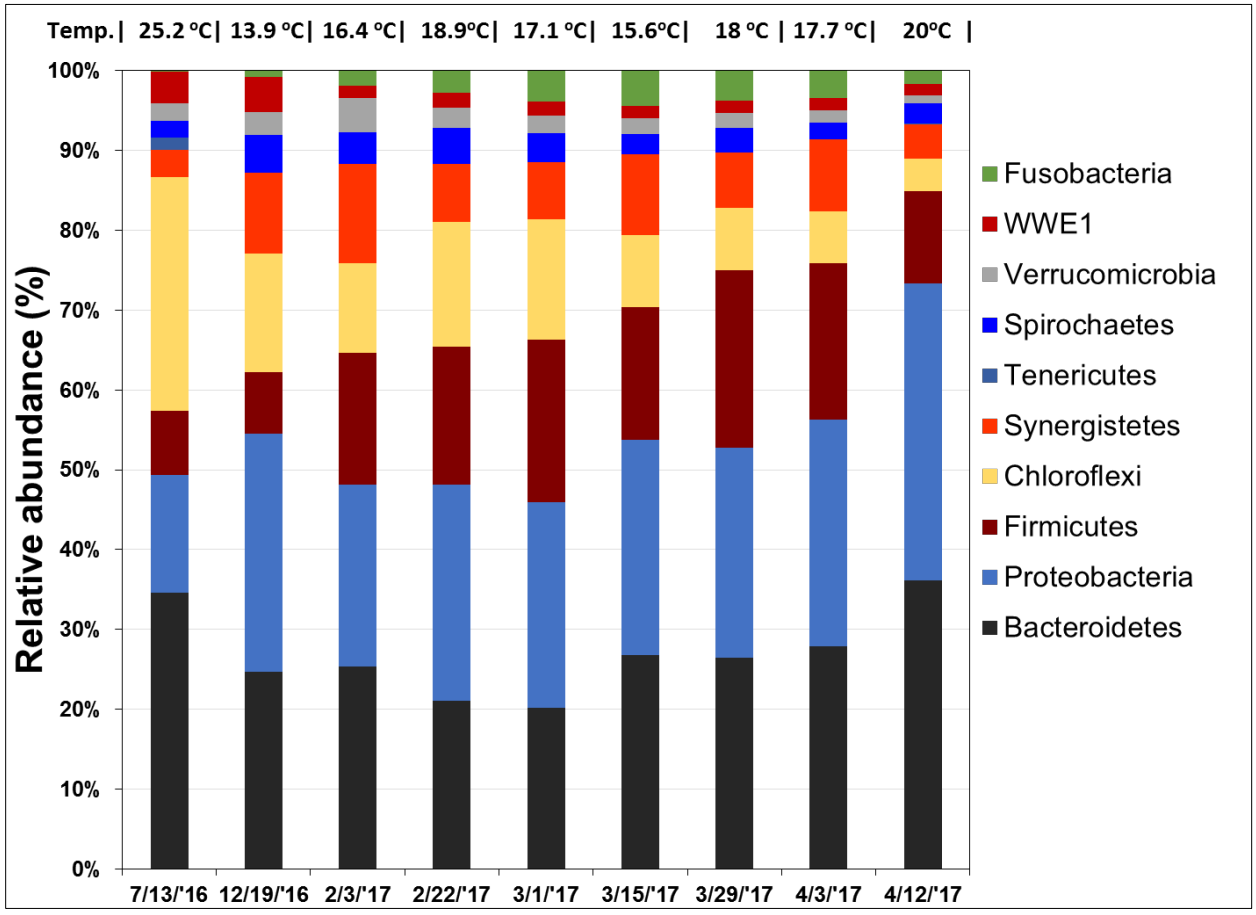

Figure 5.67 Phylum Level Relative Abundance of Bacteria with ≥ 1% Relative Abundance for at Least One Sample Date.

It is likely that members of *Bacteroidetes* performed proteolysis in the AnMBR, which is the degradation of proteins into smaller polypeptides or amino acids (acidogenesis), and can also ferment amino acids to acetate (Devereux et al. 1990, Riviere et al. 2009). The *Proteobacteria* were mainly composed of *Betaproteobacteria* and a higher abundance of *Deltaproteobacteria. Betaproteobacteria* are also likely involved in the first steps of the degradation and are the main consumers of propionate, butyrate, and acetate (Ariesyady et al. 2007, Riviere et al. 2009). The *Deltaproteobacteria* members present are sulfate-reducing bacteria (SRB) and microorganisms involved in syntrophic activity, such as the genus *Syntrophus*. *Firmicutes* are another group of syntrophic bacteria that were present in increasing abundance with temperature. They are known to degrade VFAs such as butyrate and its analogs, which produces H_2 that can be degraded by hydrogenotrophic methanogens, along with acetate that can be consumed by acetoclastic methanogens. The metabolic capacities of *Chloroflexi* are still unclear, but several studies have showed their potential role in the degradation of carbohydrates (Riviere et al. 2009). They did decrease in relative abundance with the bioreactor operation and temperature decrease. *Synergistetes* convert amino acids into short-chain fatty acids (SCFAs) and sulfate that terminal degraders, such as SRB and methanogens, can use (Riviere et al. 2009). Predominant phyla in mesophilic anaerobic reactors matches the trends observed here, except for *Chloroflexi*, which underwent a marked decrease in relative abundance, and which warrants further investigation on the effects of psychrophilic conditions on this *Chloroflexi* (Garcia and Angenent 2009, Holmes et al. 2017).

Family/genus level distribution of bacterial communities in the gas-sparged AnMBR

Besides other *Bacteroidetes* and *Clostridiales; Synergistaceae, Anaerolinaceae,* and *Syntrophaceae* exhibited the highest abundances on the family rank (Figure 5.68). The *Synergistaceae* family showed the single largest abundance in the *Synergistetes* phylum (*Synergistia* class, *Synergistales* order) and is known to have the ability to degrade amino acids into VFAs and contribute to acidogenesis and acetogenesis via syntrophic relationships with methanogens (Devereux et al. 1990). Their abundance seems to have benefited from the temperature reduction experienced in the autumn, but then it declines in the spring.

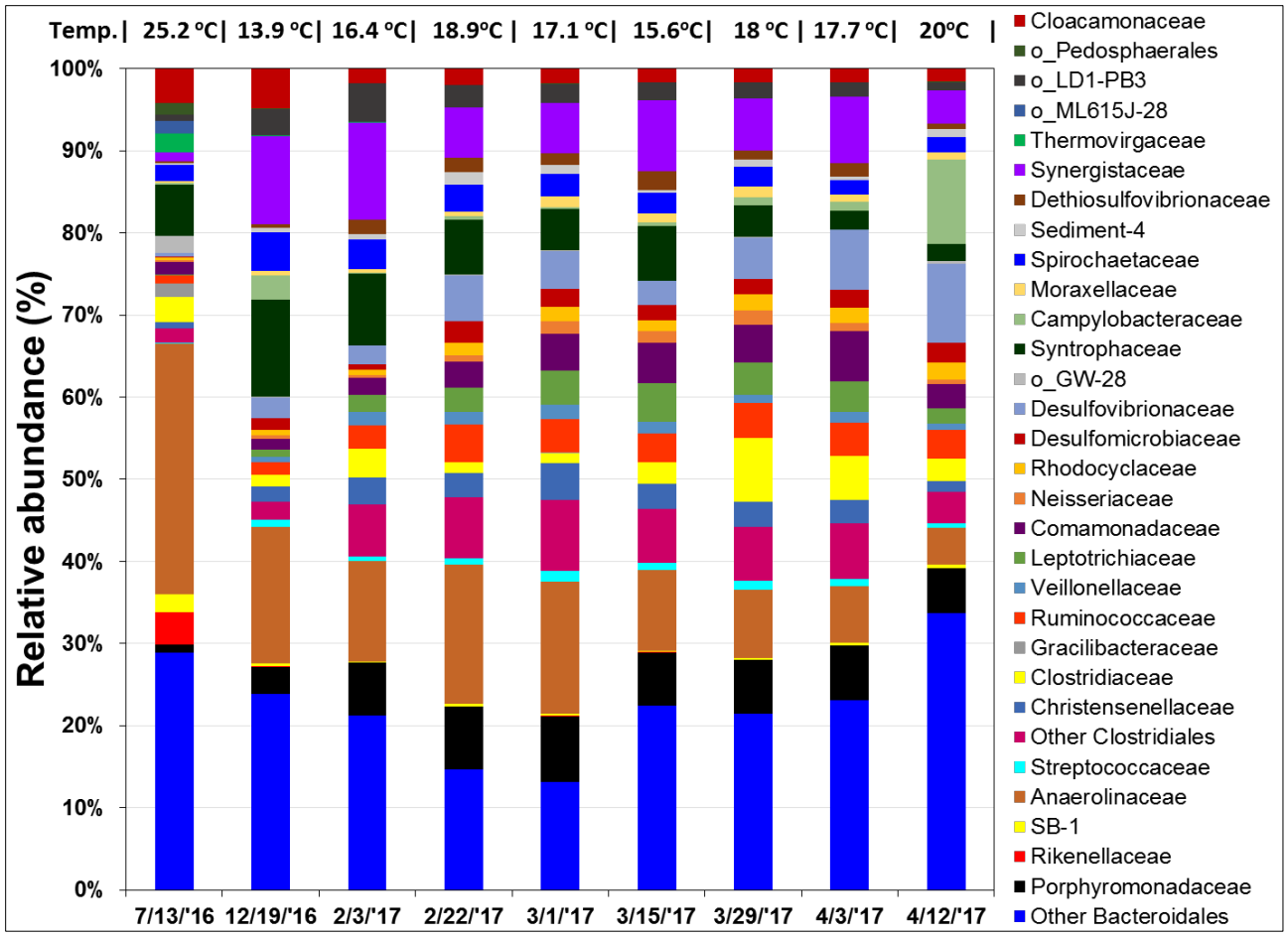

Figure 5.68 Family Level Relative Abundance of Bacteria with ≥ 1% Relative Abundance for at Least One Sample Date.

o_indicates order level.

Three bacterial genera varieties (SHD-231, T78, WCHB1-05) found in the *Anaerolinaceae* family (*Chloroflexi* phylum, *Anaerolineae* class, *Anaerolineales* order) comprised a significant portion (30.46%) of the relative abundance of bacteria for the first sample date, but their presence declines through the winter and spring months (down to 4.47%) (Figure 5.69). *Anaerolineae* is identified as one of the core populations, as primary and secondary fermenting groups, in methanogenic bioreactors and most often comprises a dominating proportion of anaerobic digestive systems. *Anaerolineae* are considered to be anaerobic semi-syntrophic organisms, degrading carbohydrates and conducting reverse electron transfer via tightly coupled mutualistic interactions with hydrogenotrophic methanogens, and in comes cases, posing the genetic potential to metabolize ethanol to acetate, implying their reputed role as anaerobic syntrophs with acetoclastic methanogens. The adhesive feature of *Anaerolineae* enabled by active pilA expression (active type VI pili [Tfp] assembly) might serve as the adhesive matrix for the aggregation of fermentative populations in sludge granules and the causative agent of filamentous flocs in upflow anaerobic sludge blanket reactors. Observations of this advantageous bonding capacity in *Anaerolinales* may provide an explanation for its ubiquity and accumulation in anaerobic digestive systems (McDonald et al. 2012, Mouser et al. 2016).

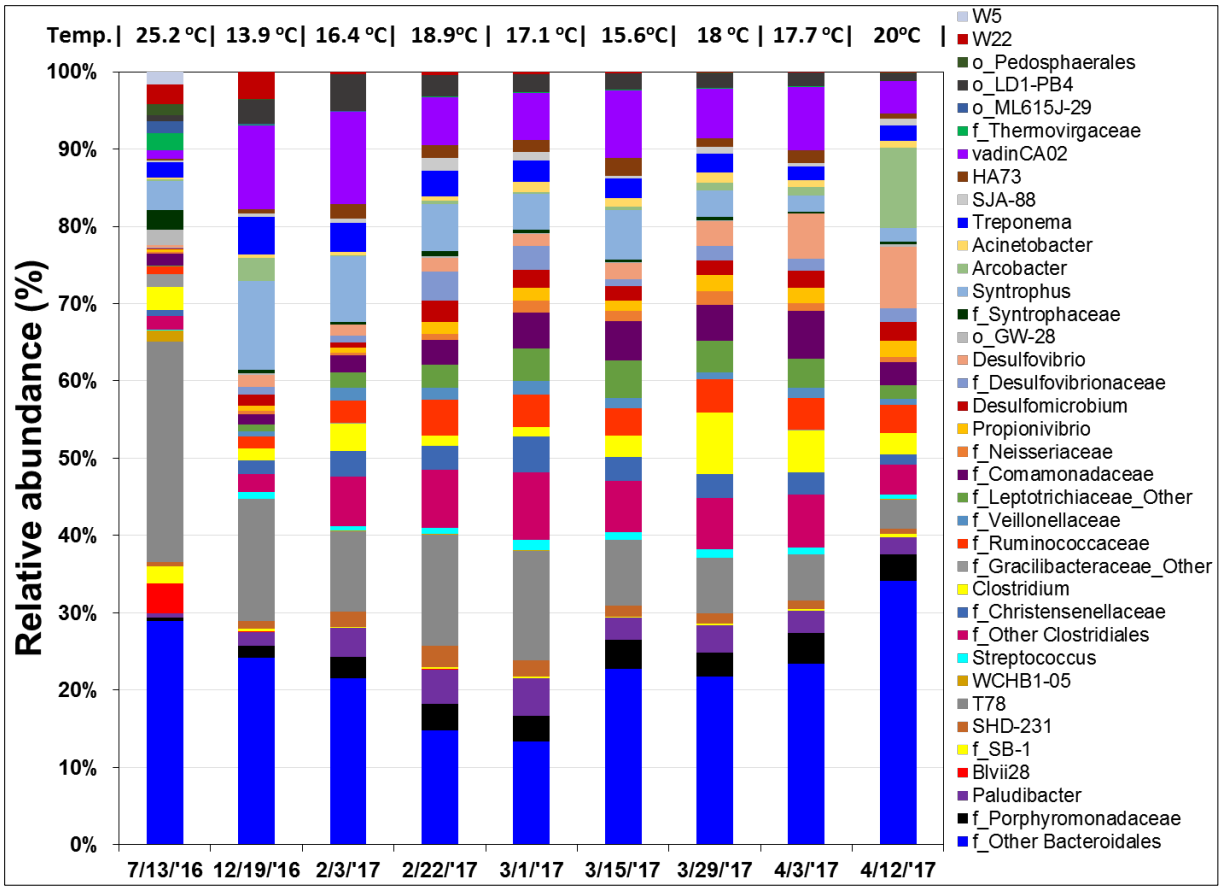

Figure 5.69 Genus Level Relative Abundance of Bacteria with ≥ 1% Relative Abundance for at Least One Sample Date.

o_indicates order level, f_indicates family level.

Along with *Anaerolineae*, the genera *Syntrophus* (*Syntrophaceae* family) also performs reverse electron transfer in mesophilic anaerobic environments and shows a similar trend of abundance as *Synergistaceae* (*vadinCA02* genus) because of their apparent increase in abundance on the coldest sample date and their abundance waning in warmer temperatures (Figure 5.69). *Syntrophus*, as the name implies, is a syntrophic bacterium capable of degrading important intermediates in the methanogenic decomposition of organic matter, such as benzoate, fatty acid chains, and aromatic compounds in a symbiotic relationship with methanogens (Mouser et al. 2016). This anaerobic bacterium ferments alcohols, fatty acids longer than two carbon atoms, and benzoate to acetate, CO_2 and H_2 in the presence of hydrogen-utilizing methanogenic partners that, in turn, produce methane and CO_2 (Schocke and Schink 1998). The hydrogen-consuming populations that maintain low H_2 partial pressures in anaerobic environments allow the conversion of benzoate to H_2, acetate, and CO_2 to be thermodynamically feasible, which are otherwise unfavorable at standard conditions (Becker et al. 2005).

The *Desulfovibrio* genus *(Desulfovibrionaceae* family) showed increasing abundance throughout the experiment with the largest abundance on the last sample date. This SRB utilizes sulfate as a terminal electron acceptor and derive their energy for growth from the oxidation of H_2, formate,

ethanol, and lactate and hydrogen gas (Narihiro et al. 2012). Particular species perform sulfur disproportionation with elemental sulfur (S), sulfite (SO_3^{-2}), and thiosulfate ($S_2O_3^{-2}$) to produce both hydrogen sulfide (H_2S) and sulfate (SO_4^{-2}). The SRB *Desulfomicrobium* genus that utilizes H_2 as an electron donor and acetate as carbon source also showed increasing abundance but to a lesser extent (Auvinen et al. 2009). The increasing abundance of *Desulfovibrionaceae*, with a subsequent increase in hydrogen sulfide production, causes concern because of the potential of microbially induced sulfide corrosion that degrades the inner workings of the AnMBR system. The presence of SRB also correlates with sulfate reduction that actively occurred in the AnMBR with concomitant generation of sulfide.

The potential enteric human pathogen *Arcobacter* showed the second highest abundance for the last sample date (Vandenberg et al. 2004). This curious spike in abundance might be explained by its inoculation from influent wastewater microbiota that has changed microbial community composition within systems in other studies (Becker et al. 2005).

Order/genus level distribution of archaeal communities in the AnMBR

The high-throughput sequencing reveals low populations of methanogens and archaea altogether. The relative abundance of the total archaea population never amounts to > 2% of the entire microbial community population (Figure 5.70). This observation is in accordance with findings on other methanogenic ecosystems that are typically comprised of < 2% relative abundance of methanogens (Liu et al. 2009).

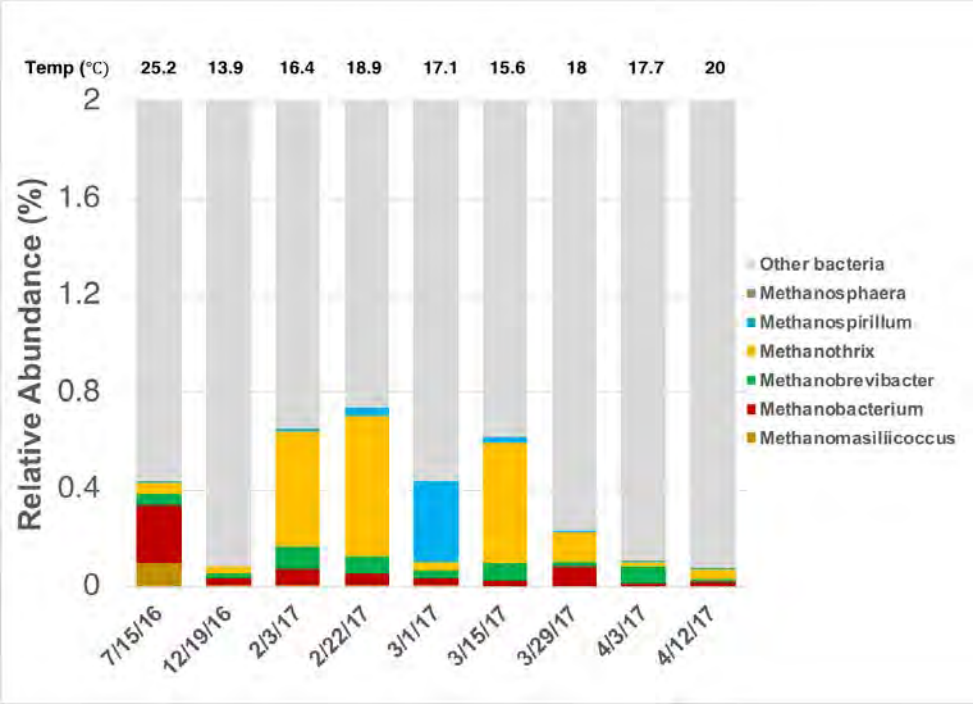

Figure 5.70 Relative Abundance of Archaea Compared to Bacteria.

Methanosaeta = Methanothrix.

Out of 12 archaeal OTUs recognized, the core Archaea group was composed of the methanogens in the order *Methanosarcinales*, *Methanobacteriales*, and *Methanomicrobiales* (Figure 5.71a). The obligate acetoclast, *Methanothrix* (formerly *Methanosaeta*) genus (*Methanosarcinales* order, *Methanosaetaceae* family) represents the pathway for acetoclastic methanogenesis and showed the overall highest abundance and higher abundances for more sample dates. *Methanothrix* seems to have gained a delayed advantage in the bioreactor after the temperature reduction. *Methanobacteriales* and *Methanomicrobiales* represent the pathway for which hydrogenotrophic methanogenesis takes place. *Methanobacteriales* order, *Methanobacterium* genus' dominance for the first sample might be due to its selection in the digester from which it originates. Anaerobic digesters treating municipal wastewater are known to be predominated by the acetoclastic *Methanothrix*, although several studies indicate hydrogentophic predominance as well, especially if the influent wastewater exhibits unusual composition (Garcia and Angenent 2009, Padmasiri et al. 2007, Zhang et al. 2009). It shows predominance that lasts through the fall and into the beginning of winter (Figure 5.71), after which a sharp shift in predominance takes place towards the acetoclastic genera.

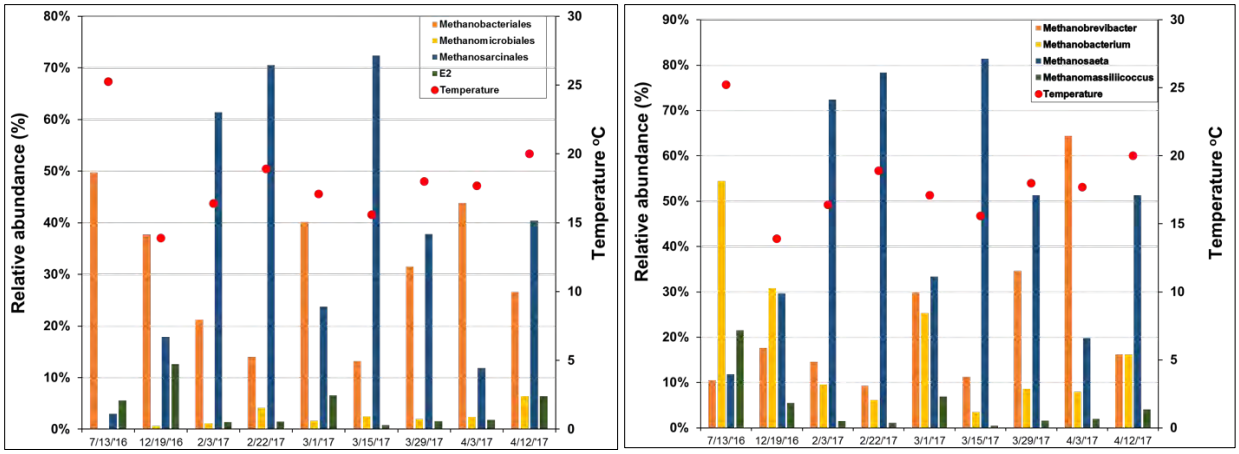

Figure 5.71 Relative Abundance of Key Methanogen Orders (a – top) and Genera (b – bottom) Compared to the Total Abundance of the Set.

Methanosarcina (*Methanosarcinales* order, *Methanosarcinaceae* family) was not present in the inoculum and is suspected to be absent in the source sludge anaerobic digester. If it were present, the generalist *Methanosarcina* would be a better competitor for acetate; instead, we observed high abundances of the acetate specialist, *Methanothrix*, which is favored in systems with a low acetate concentration, such as this one (Angenent et al. 2002).

Proposed Microbial Interactions in the AnMBR with Decreasing Temperature

It is hypothesized that *Anaerolinaceae*'s provides the bonding capacity that builds an adhesive matrix that aggregates key archaea and bacteria (McDonald et al. 2012), including *Synergistaceae* and *Syntrophaceae* altogether. This relationship is thought to couple the reactions of *Synergistaceae* degrading amino acids into VFAs with the metabolism of *Syntrophaceae,* which further converts VFAs into acetate and H_2 that are syntrophically tied to methanogens, such as *Methanosaetaceae* and *Methanobacterium*, respectively (Figure 5.72). *Methanothrix,* that comprise the entire *Methanosaetaceae* population in this study, might contribute in this adhered

relationship because they are commonly found in methanogenic biomass due to their filamentous morphology and granulogenesis ability in forming biofilms in bioreactors (Becker et al. 2005, Nelson et al. 2012). This points to the fact that direct acetate utilization by acetoclastic methanogens might downplay the occurrence of acetate oxidation, often considered a preferred pathway under thermodynamically and metabolically unfavorable conditions for acetoclastic methanogenesis. On the other hand, the high shear environment created by biogas sparging and sludge circulation might disrupt these syntrophic relationships found in suspension. An interesting factor that needs to be further examined is the role of decrease or increase in bioreactor temperature in forging these microbial community interactions, as shown below.

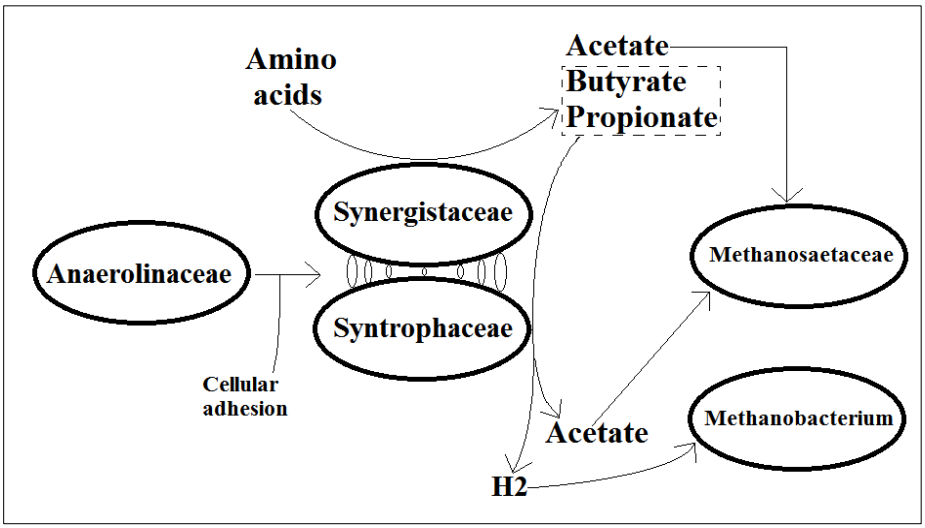

Figure 5.72 Diagram of Hypothesized Relationships of Key Microbes.

On the basis of the results, we can glean a fascinating perspective about direct interspecies electron transfer in these systems under sub-ambient temperature conditions as well. Recent studies have repeatedly suggested syntrophic cooperation between *Methanothrix* and iron-reducing bacteria, such as *Geobacter* (Holmes et al. 2017, Lovley 2017). The microbial community results do show the possibility of the increasing proportion of *Methanothrix* to be a component of aggregates, which is not, however, matched by a corresponding increase in *Desulfuromonodales* (to which *Geobacteracea* belong). This does raise an intriguing research question on the mechanism of acetate uptake by *Methanothrix* in the AnMBR system at low temperatures.

Statistical Significance of Data

R (RGui) v. 3.4.1 was used to test the statistical significance of correlations in our dataset based on Pearson correlations and Spearman's Rho rank correlation. The significance of the Pearson correlation coefficient (r) by comparing the p values from each dataset pair with alpha (α) equal to 0.05, meaning at least 95% certainty is needed to prove that the correlation is not random. $p < 0.05$ was considered to be significant. Furthermore, a Pearson correlation coefficient is significant if the absolute value of r is greater than r Critical, which is dependent on α. Additionally, Spearman's rho rank correlation using two-tailed tests were also performed on the dataset, and $p < 0.05$ was considered to be significant.

Pearson Correlation Test

Only the relative abundance of *Synergistaceae* showed a strong negative correlation with temperature, $r = -0.894$, $p = 0.001$, meaning its relative abundance generally increased with decreasing temperatures. *Syntrophus* exhibited the same trend, $r = -0.603$, $p = 0.084$, but did not exhibit a 95% certainty. The relative abundances of *Methanobacterium, Bacteroidetes, Anaerolinaceae*, and *Chloroflexi* in general exhibited a moderate positive correlation with temperature, $r = 0.571$, $p = 0.109$, $r = 0.622$, $p = 0.074$, $r = 0.528$, $p = 0.146$, $r = 0.558$, $p = 0.119$, respectively. Again though, these correlations did not exhibit a 95% certainty. The correlation seen with *Methanobacterium, Anaerolinaceae*, and *Chloroflexi* in general can be attributed to the initial abundance in the inoculum followed by ever decreasing abundances throughout the sample time range.

Spearman's Rho Rank Correlation Test

Only the relative abundances of *Synergistaceae* and *Syntrophus* showed a strong negative correlation with temperature, $p = 0.0061$ and $p = 0.0311$, respectively. This is in line with the Pearson correlation test and can be seen in Figure 5.68 and Figure 5.69, where it seems that the relative abundance of *Synergistaceae* and *Syntrophus* grow and reach peak abundance during the coldest temperature period.

5.7.22 GAC-Fluidized AnMBR Microbial Ecology

Diversity Analyses of Microbial Community

A total of 2,158 bacterial genera and 87 archaeal genera were detected in the 11 samples analyzed. cluster analysis was performed to compare the microbial structure and composition between the samples. For both the bacterial and archaeal communities, it was observed that the GAC samples were clustered together (Figure 5.73 and Figure 5.74), indicating that the GAC microbial communities showed high similarity over the sampling period. Additionally, the primary GAC-fluidized bioreactor (i.e., AFBR) GAC samples and secondary UF membrane tank (i.e., AFMBR) GAC samples that were taken at the same time point were always clustered together. This meant that the similarity in GAC communities is more temporal-dependent than spatial-dependent. In other words, the GAC communities in the AFBR and AFMBR reactors evolved similarly over time. This could be due to the internal recirculation between the two reactors, exposing the AFBR and AFMBR GAC microbial communities to a completely mixed condition rather than a plug-flow condition.

For the bulk samples, both the bacterial and archaeal community structures of samples taken at days 436 and 555 clustered together. However, the sample obtained on day 342, was clustered distantly (Figure 5.73 and Figure 5.74). This suggests that the bulk microbial community structure gradually stabilized overtime. This is also evident from the distant clustering between the influent sewage and bulk sample at day 555, indicating that the biomass brought into the GAC-fluidized AnMBR by the incoming sewage had little impact on the bulk microbial community structure.

Microbial Community Structure: Syntrophs, Exoelectrogens and Methanogens

Syntrophs and methanogens are key players in critical syntrophic oxidation-reduction reactions required for methane formation. Additionally, the electrically conductive property of GAC is known to promote the growth of exoelectrogens, which is a group of microbes that has the ability to transfer electrons extracellularly and interact with syntrophs and methanogens to promote methane formation (Aslam et al. 2018). Hence, the dynamics of these 3 groups of microbes were examined. Specifically, the dominant genera (i.e., relative sequence abundance of ≥ 1% in one or more samples) of these 3 microbial groups were identified and investigated.

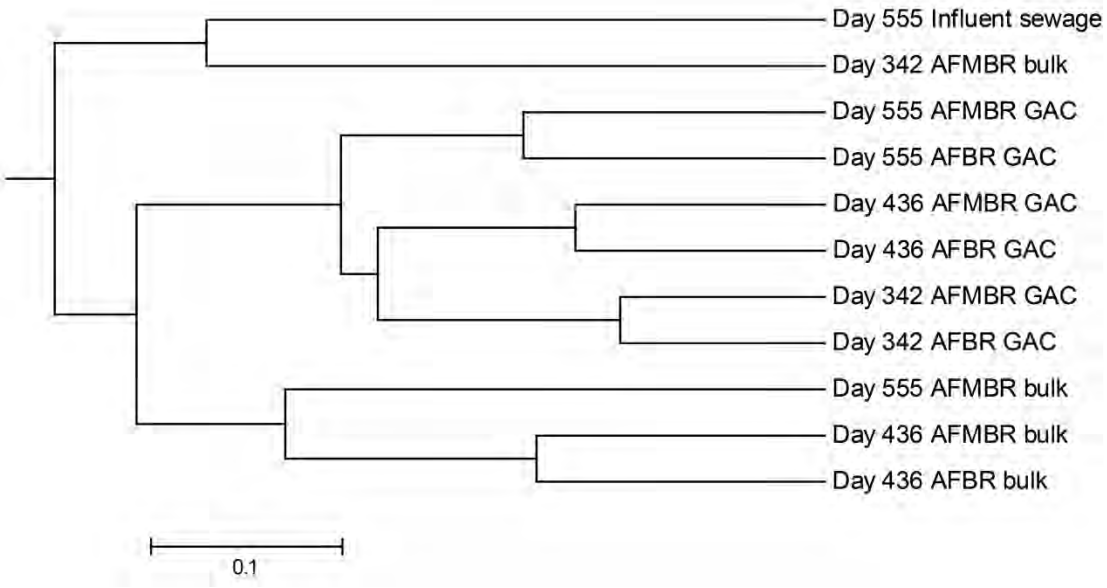

Figure 5.73 Dendrogram of Cluster Analysis Based on the Bray-Curtis Dissimilarity for Bacterial Community at Days 342, 436 and 555.

The scale bar represents the difference in the Bray-Curtis indices between samples.

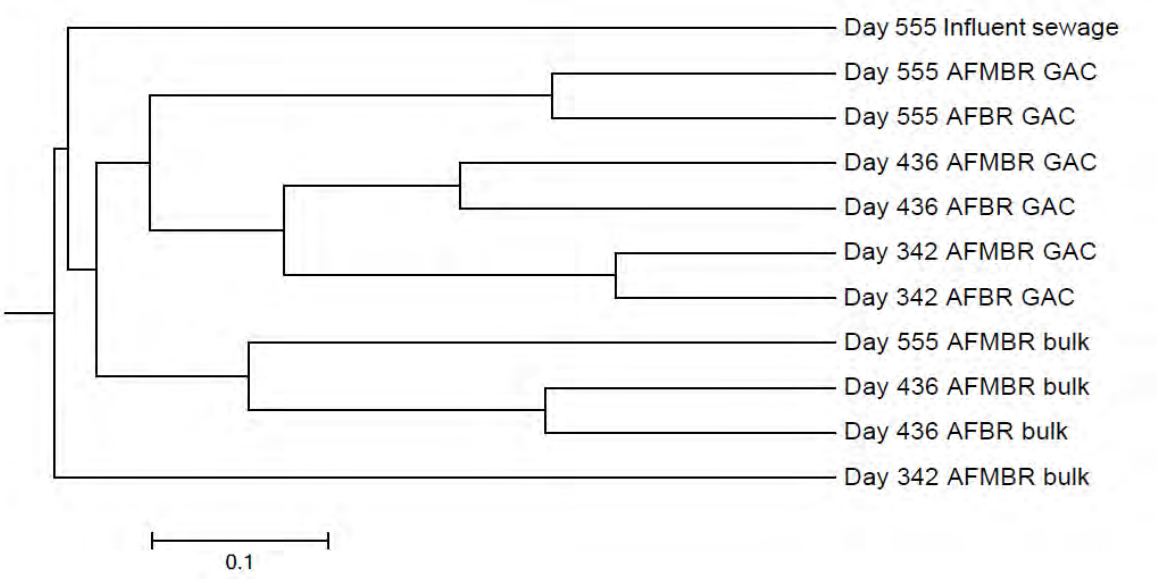

Figure 5.74 Dendrogram of Cluster Analysis Based on the Bray-Curtis Dissimilarity for Archaeal Community at Days 342, 436 and 555.

The scale bar represents the difference in the Bray-Curtis indices between samples.

Syntrophs

Five syntroph genera were identified as dominant. Collectively, the dominant syntroph genera formed 5 to 10% of the total bacterial population for all GAC samples (Figure 5.75). The dominant syntroph population was also observed at similar levels (6 to 7%) in all bulk samples with the exception of day 342 AFMBR bulk. These findings indicate that syntroph population was enriched in the GAC-fluidized AnMBR. Conversely, the day 555 influent sewage had about 1.2% syntroph, suggesting that the system's syntroph population was predominantly developed through enrichment rather than augmentation with the incoming sewage. The enrichment could be attributed to the combination of GAC particles, which acted as a biocarrier and provided surface for biomass attachment, and the presence of membrane in the second stage AFMBR, aiding with biomass residence.

The five syntroph genera were taxonomically assigned to *Syntrophus*, *Smithella*, *Syntrophobacter*, *Syntrophorhabdus* and *Syntrophomonas*. The genera *Smithella*, *Syntrophobacter* and *Syntrophomonas* are fatty acids oxidizers (Brenner et al. 2006, Vos et al. 2011). Specifically, *Syntrophomonas* is responsible for oxidizing a wide range of long-chain fatty acids (LCFAs), ranging from 18-carbon to 4-carbon, into SCFAs such as propionate and acetate. One the one hand, propionate oxidation is carried out by *Smithella* and *Syntrophobacter*. On the other hand, *Syntrophorhabdus* performs oxidation of various aromatic compounds including, hydroxybenzoates, benzoate, phenol and phthalates (Brenner et al. 2006). *Syntrophus* is able to oxidize aromatic compound benzoate, LCFAs, and methyl esters of butyrate and hexanoate (Brenner et al. 2006). Together, they form a good mix of syntrophs to perform the thermodynamically demanding tasks of fatty acids and aromatics oxidation.

Despite having similar abundances of syntrophs, the compositions of the GAC and bulk syntroph population were different. *Syntrophomonas*, in particular, tends to predominate in the bulk solution at 5 to 7% rather than on the GAC (0.1 to 2.5%) (Figure 5.76). The other 4 syntroph genera showed greater dominance on the GAC than in the bulk solution. The propionate-oxidizing *Smithella* was the most dominant syntroph on the GAC (1.6 to 4.8%).

Exoelectrogens

Four dominant genera *Geobacter*, *Desulfobulbus*, *Arcobacter*, and *Aeromonas* were closely related to known exoeletrogenic species *Geobacter metallireducens* (Rotaru et al. 2014), *Geobacter lovleyi* (Sung et al. 2006), *Desulfobulbus propionicus* (Holmes et al. 2004), *Arcobacter butzleri* ED-1 (Fedorovich et al. 2010), and *Aeromonas hydrophila* (Pham et al. 2003) with Blastn identities of 98 to 100% (Figure 5.77). *Geobacter* and *Desulfobulbus* were two of the most dominant GAC exoelectrogens (*Geobacter*: 3 to 4%; *Desulfobulus*: 0.7 to 2.7%). However, their population reduced at day 555 (*Geobacter*: 0.8 to 1.4%; *Desulfobulus*: 0.3 to 0.5%), while *Arcobacter* increased, suggesting that the addition of supplement COD may be associated with these changes. The predominating exoelectrogen in the bulk liquid was *Arcobacter* (2 to 15%). *Arcobacter* was also present at high abundance in influent sewage (25.7%), suggesting that the bulk liquid *Arcobacter* could be augmented constantly with the incoming sewage. *Aeromonas* tends to exist at similar and low levels on the GAC (0.03 to 0.07%) and in the bulk liquid (0.06 to 0.95%). Collectively, the exoelectrogen population could possibly generate electron extracellular during the assimilation of a wide variety of substrates, including, ethanol, acetate, pyruvate, lactate, propionate, hydrogen, etc.

Methanogens

Eight dominant methanogen taxa were present in the GAC-fluidized AnMBR. Methanogen population existed at disproportionately high levels on GAC samples compared to bulk liquid (Figure 5.78). The GAC methanogen population increased from 4% at day 342 to 70% at day 555 (Figure 5.78). Notably, a sharp spike was observed for day 555 samples, suggesting that the COD supplementation promoted the growth of GAC methanogens. Conversely, methanogens remained at much lower levels in the bulk liquid at day 342 and 436 (0.2 to 1.5%), up to day 555, where the addition COD caused a spike in levels. During this spike, *Candidatus Methanogranum* was observed to be the predominant methanogen taxa, which was similar to that of the influent sewage (Figure 5.79), implying that there is little to no enrichment of bulk methanogen population, and that the population tends to fluctuate according to influent properties.

GAC samples harboured seven main methanogen taxa (Figure 5.79). These taxa were identified as *Methanothrix* (formerly known as *Methanosaeta*), *Methanoregula*, *Candidatus Methanofastidiosum*, *Methanobacterium*, uncultured *Methanomassiliicoccaceae*, *Methanomassiliicoccus*, and *Methanomethylovoran*. In particular, *Methanothrix* existed at a much higher abundance on the GAC as compared to the bulk liquid. On the GAC, *Methanothrix* abundance increased from 0.16% to 40%, and became the predominant methanogen. *Methanothrix* has been reported to be capable of accepting electrons from exoelectrogens for methane production (Rotaru et al. 2014). Hence, the electrical-conductive surface of GAC is likely to have promoted the selective enrichment of *Methanothrix*. COD supplementation at day 555 also appeared to promote the growth of GAC methanogens, including *Methanothrix*, *Methanoregula*, *Candidatus Methanofastidiosum* and *Methanomassiliicoccus*.

Methanothrix is capable of forming methane from acetate and also accepts extracellular electrons for CO_2 reduction to methane (Rotaru et al. 2014). *Methanoregula* accepts formate and H_2/CO_2 for methane production (Zinder and Bräuer 2016). *Methanobacterium* typically uses H_2/CO_2 for methanogenesis; however, some strains can also utilize formate, secondary alcohols, and CO (Garrity et al. 2012). Aside from these classical methanogenic substrates, the other methanogen taxa in the GAC-fluidized AnMBR were also capable of reducing a wide variety of methyl donors for methane generation. These include methylated thiol (*Candidatus Methanofastidiosum*) (Nobu et al. 2016), methanol and methylamines (*Methanomassiliicoccus*, uncultured *Methanomassiliicoccaceae*, and *Methanomethylovoran*) (Cha et al. 2013, Nkamga and Drancourt 2016), and dimethyl sulfide and methanethiol (*Methanomethylovoran*) (Cha et al. 2013).

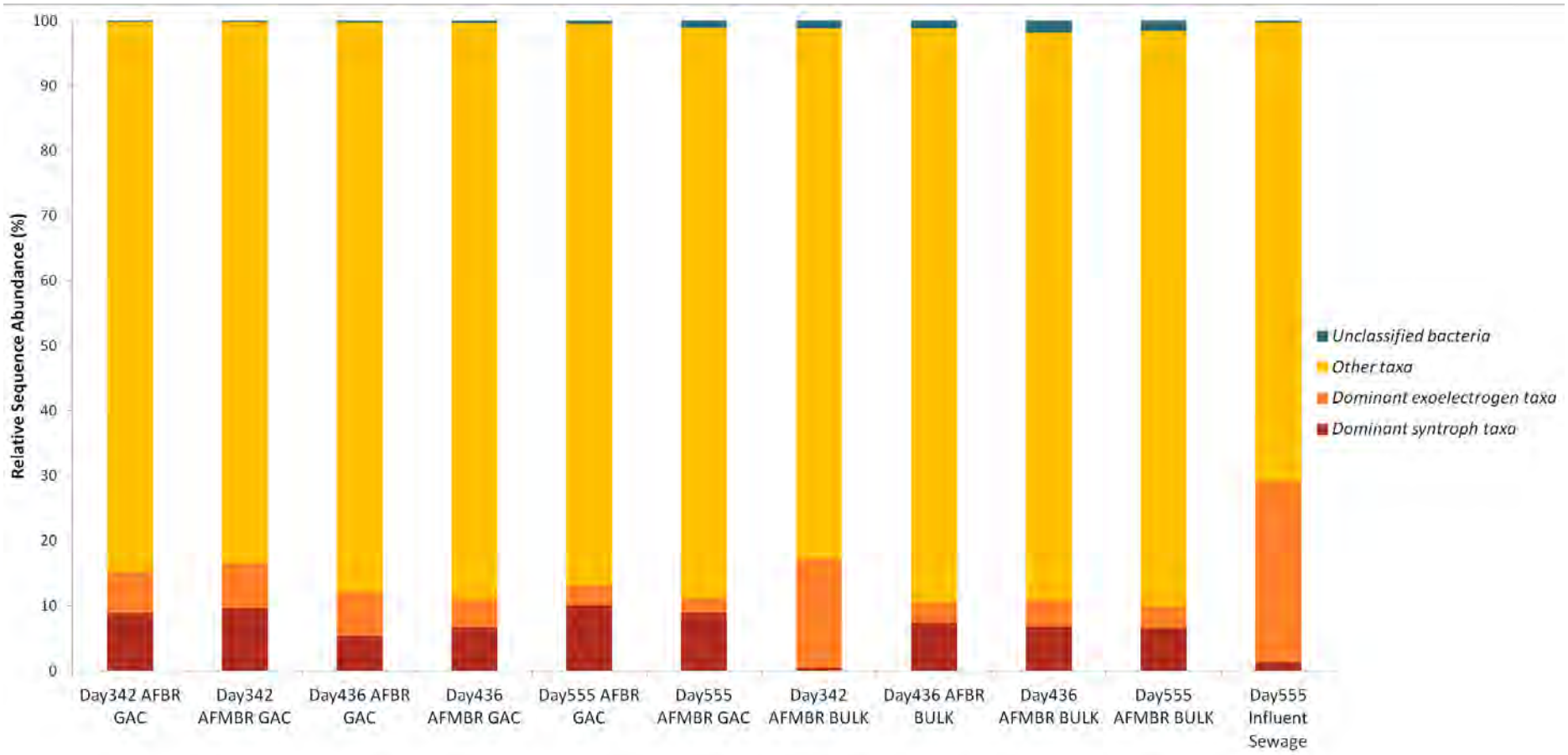

Figure 5.75 Overview of GAC, Bulk, and Influent Sewage Bacterial Community Compositions Sampled at Days 342, 436 and 555.

The unclassified bacteria consisted of bacterial sequences that could not be classified into any known phyla.

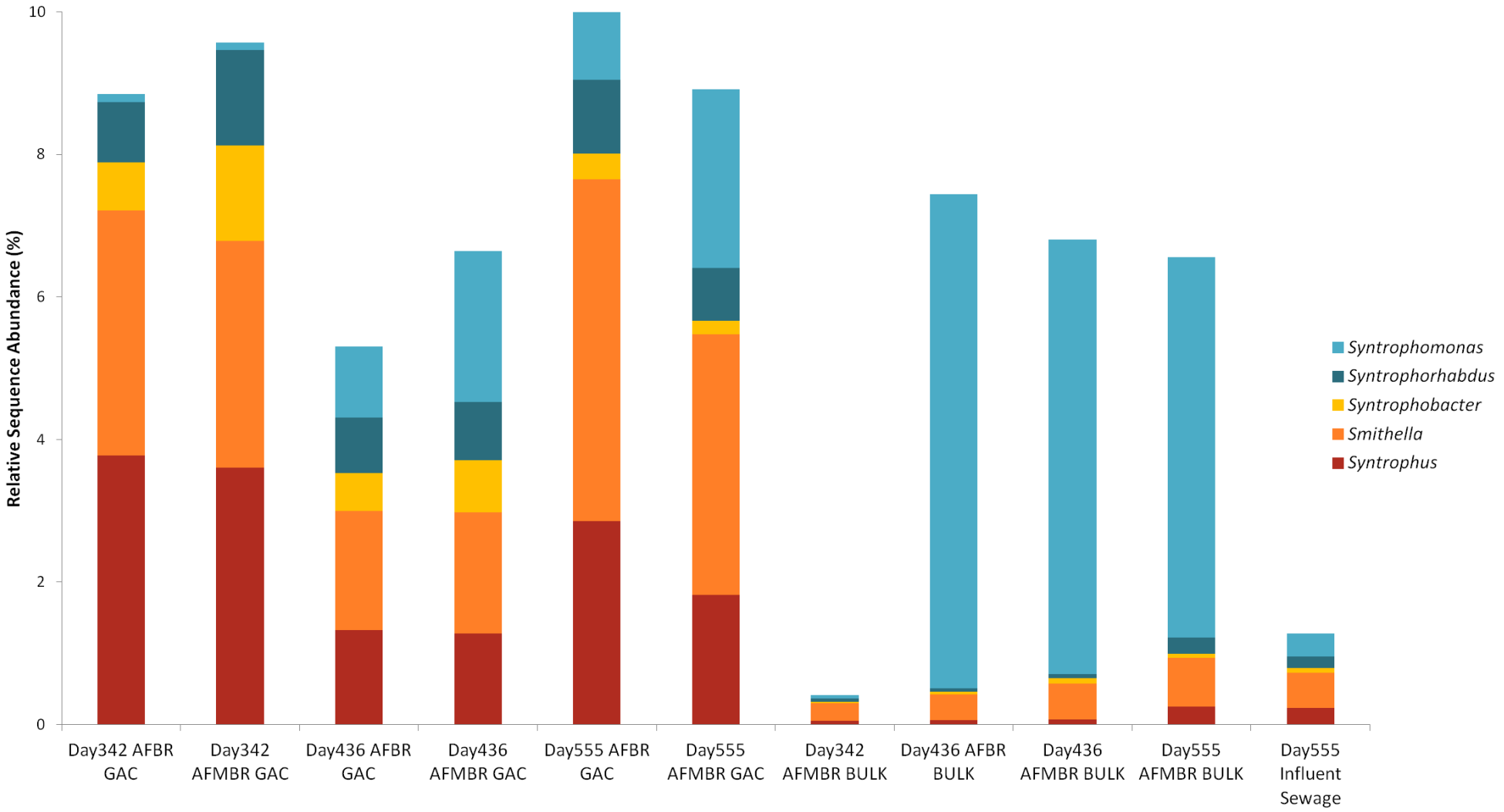

Figure 5.76 Composition of Dominant Syntroph Genera in GAC, Bulk, and Influent Sewage Samples Obtained on Days 342, 436 and 555.

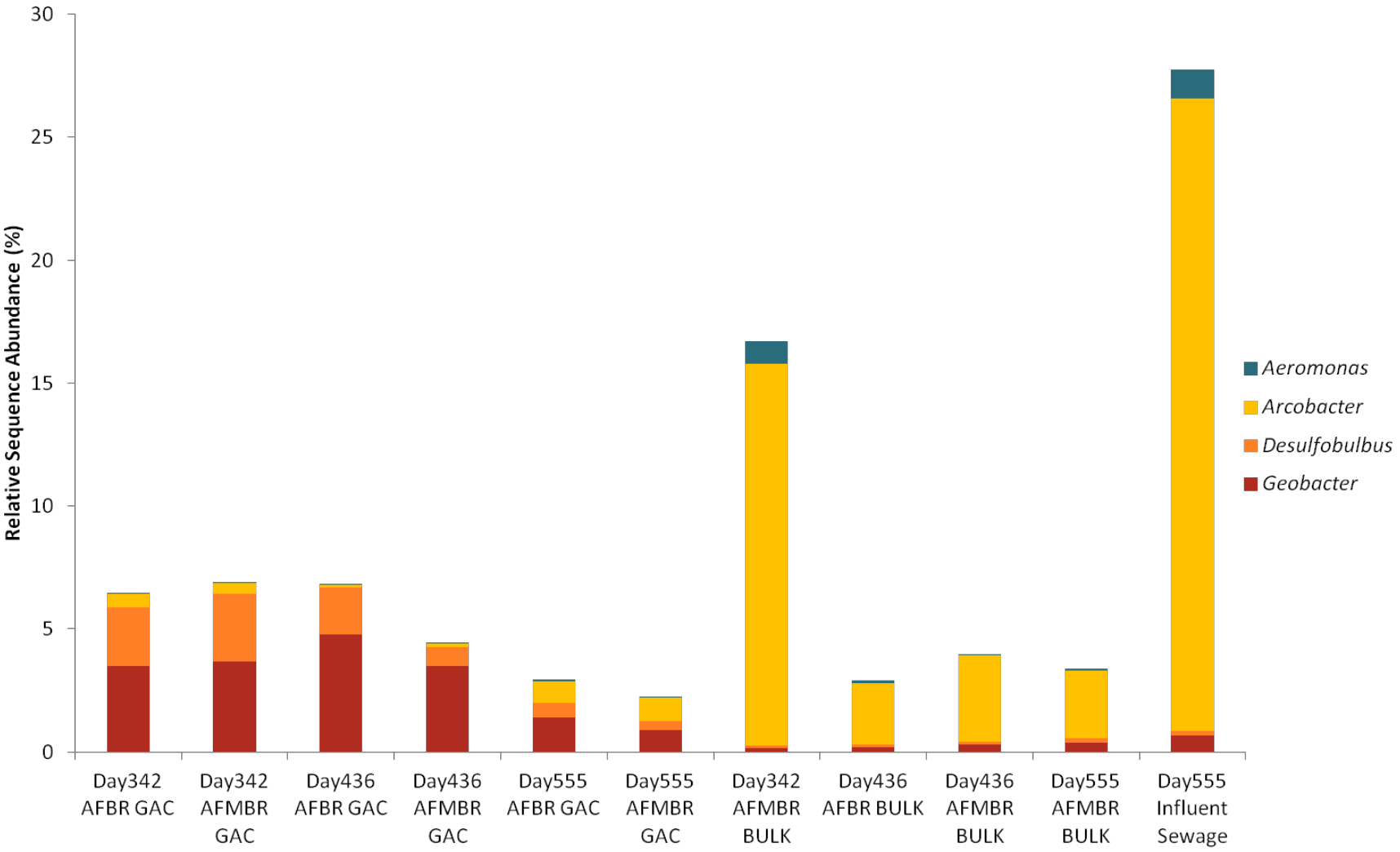

Figure 5.77 Composition of Dominant Exoelectrogen Genera Composition in GAC, Bulk, and Influent Sewage Samples Obtained on Days 342, 436 and 555.

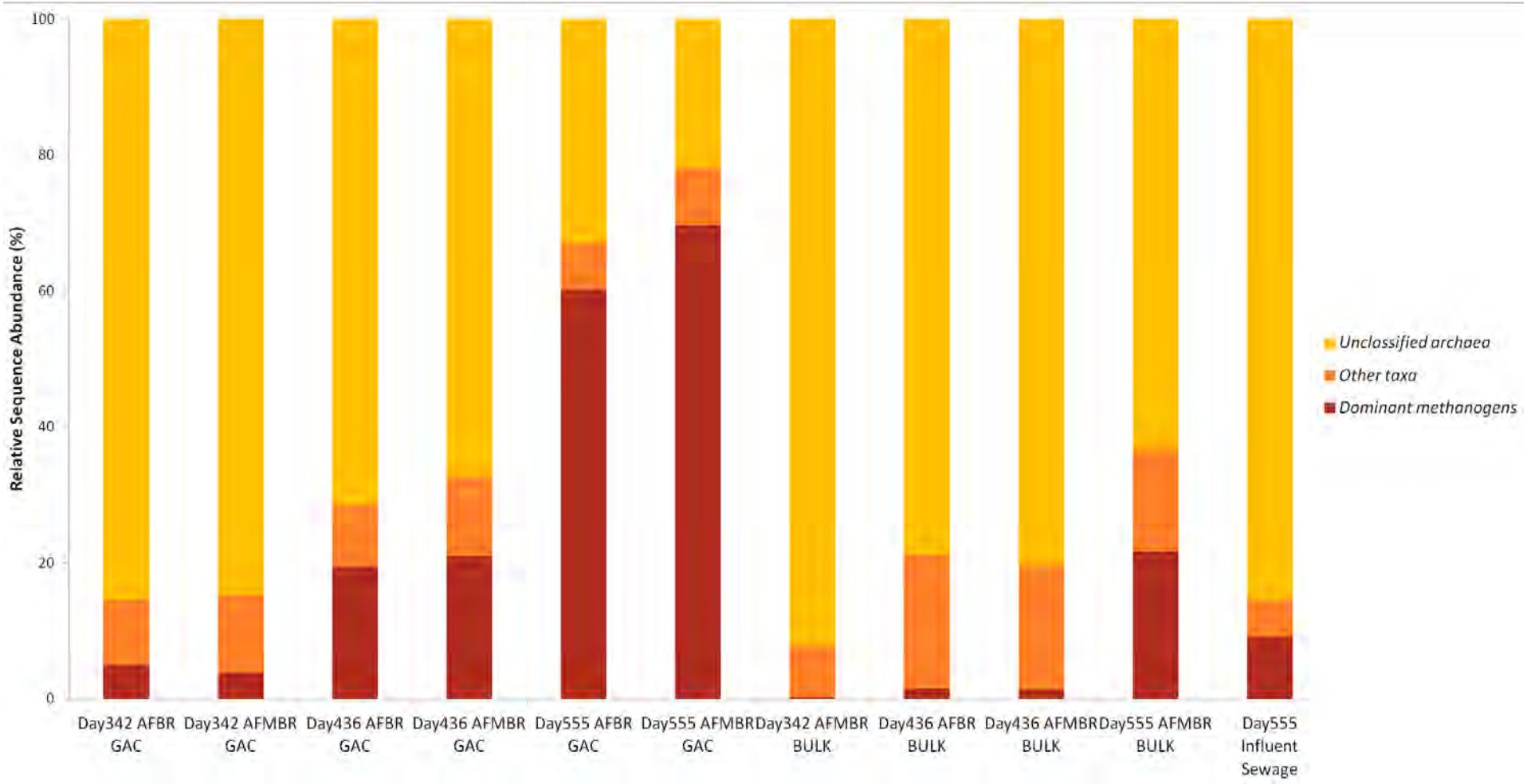

Figure 5.78 Overview of GAC, Bulk, and Influent Sewage Archaeal Community Compositions Sampled at Days 342, 436 and 555.

The unclassified archaea consisted of archaeal sequences that could not be classified into any known phyla.

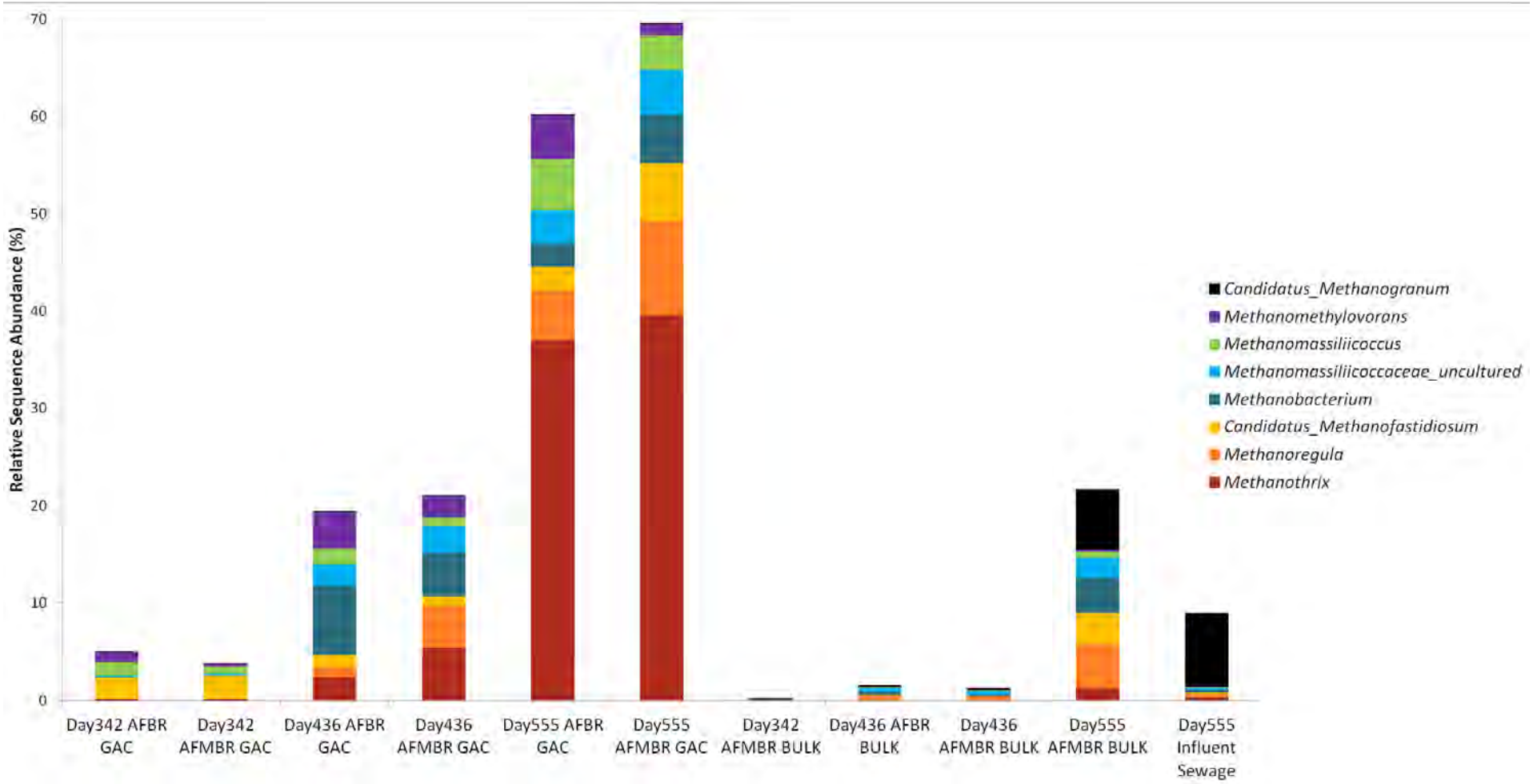

Figure 5.79 Methanogen Composition in GAC, Bulk, and Influent Sewage Samples Obtained on Days 342, 436 and 555.

Overview

Taken together, the microbial community results show that there is a selective enrichment of specific syntrophs (*Syntrophus*, *Smithella*, *Syntrophobacter*, *Syntrophorhabdus*, and *Syntrophomonas*), exoelectrogens (*Geobacter* and *Desulfobulbus*) and methanogens (*Methanothrix*, *Methanoregula*, *Candidatus Methanofastidiosum*, *Methanobacterium*, uncultured *Methanomassiliicoccaceae*, *Methanomassiliicoccus*, and *Methanomethylovoran*) on the GAC. Most notably, the growth of methanogen appeared to be mostly confined to GAC, implying that GAC is the main site of methane production. The co-location of syntrophs and exoelectrogens, together with methanogens, suggests tightly coupled syntrophic and electrical-syntrophic interactions underpinning methane formation in GAC-fluidized AnMBR. To give an example, *Smithella* oxidizes propionate to acetate. Subsequently, *Methanothrix* could directly uptake acetate for acetoclastice methanogenesis. Alternatively, acetate could be assimilated by *Geobacter*, which in turn produces extracellular electrons. These electrons could be electrically conducted to *Methanothrix* via GAC, which accepts the electrons for CO_2 reduction to methane. Given the complexity of the sewage matrix and ill-defined characteristics of several dominant microbial taxa, much of the GAC microbial network remains to be examined and disclosed through future studies.

Comparison of Gas-Sparged and GAC-Fluidized AnMBR Microbial Ecology

A high degree of similarity in the key microbial players enriched in the gas-sparged AnMBR and the GAC-fluidized AnMBR was observed. Specifically, the bacterial players include the families *Anaerolinaceae* and *Syntrophaceae* while the archaeal methanogenic players include *Methanothrix* (formerly known as *Methanosaeta*) and *Methanobacterium* genera. *Anaerolinaceae* is a group of fermentative bacteria, responsible for breaking down carbohydrates into simpler sugar intermediates. These intermediates include succinate and propionate, which could in turn be utilized by some syntrophic members of *Syntrophaceae* (e.g., *Smithella* and *Syntrophobacter* genera); and acetate and formate/CO_2 which are precursors for biomethane production by *Methanothrix* and *Methanobacterium*, respectively. Hence, *Anaerolinaceae* appears to have important trophic interactions with syntrophs, and is itself involved in a semi-syntrophic relationship with methanogens. *Anaerolinaceae* could also produce an adhesive matrix, facilitating the aggregation of syntrophs and methanogens in the bulk suspension of gas-sparged AnMBR. The adhesive matrix could have promoted the attachment of these key microbial players on the GAC biocarrier of the GAC-fluidized AnMBR. The electrically-conductive nature of GAC has also promoted the enrichment of exoelectrogens such as *Geobacter*, which could uptake *Anaerolinaceae*-produced ethanol intermediate, and exports electrons extracellularly, interacting with methanogens via GAC-mediated direct interspecies electron transfer.

5.7.23 Gas-Sparged AnMBR Energy Efficiency

Unit energy consumption (i.e., kWh consumed per m^3 of wastewater treated) was estimated for a range of gas-sparged AnMBR demonstration operating conditions. Figure 5.80 illustrates the estimates for permeate pumping, dissolved methane removal, mixing, and biogas sparging for different net UF flux and biogas sparging flow rates. Energy requirements for permeate pumping (0.015 kWh/m^3) and dissolved methane removal (0.0096 kWh/m^3) were negligible compared to those for mixing and biogas sparging. The unit energy consumption for dissolved methane recovery was similar to 0.009 kWh/m^3 reported previously (Crone et al. 2016).

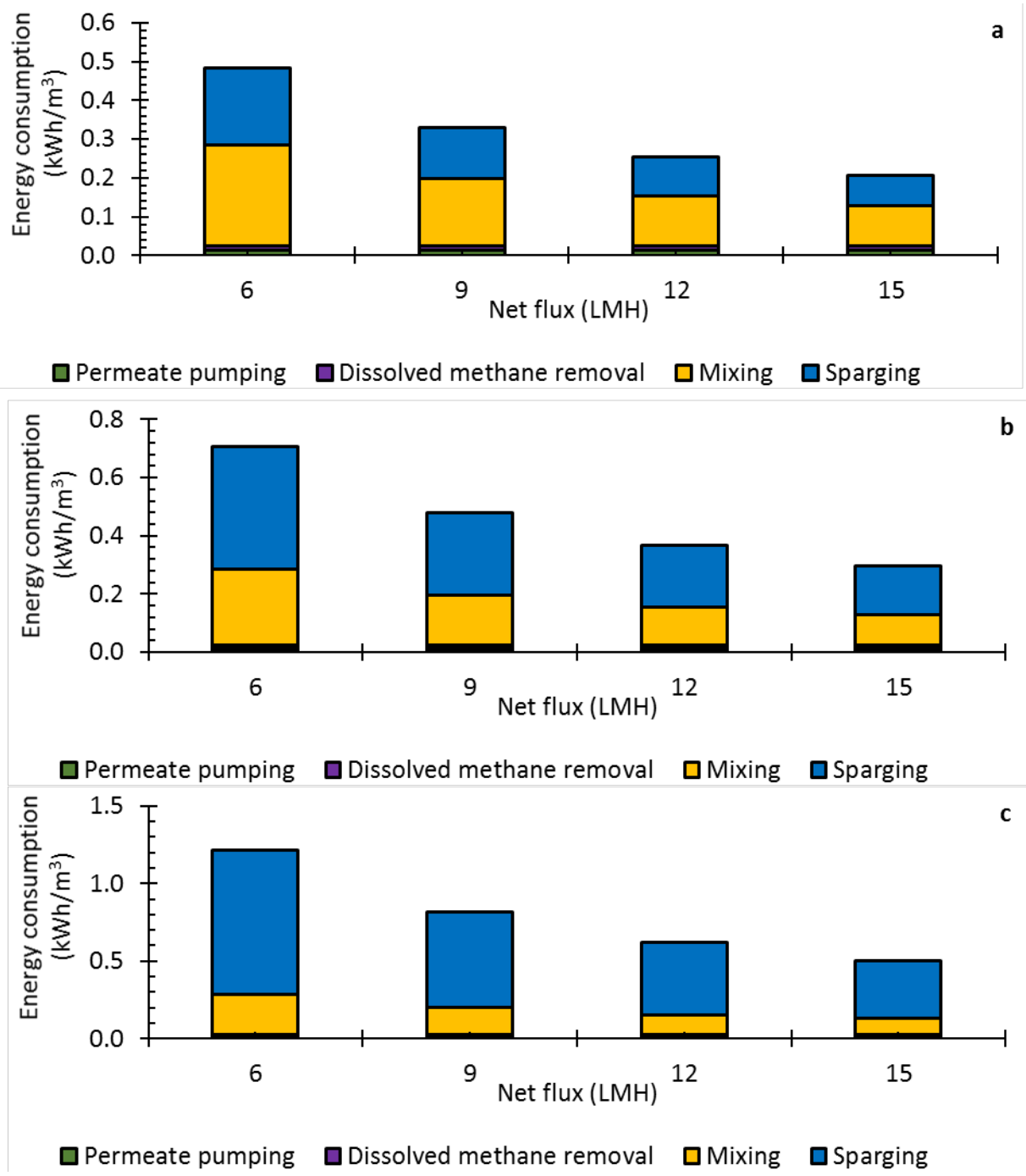

Figure 5.80 Gas-sparged AnMBR Energy Consumption Associated with Different Processes at Biogas Sparging Flow Rates of 25 (a), 50 (b), and 100 std. L/min (c).

According to CDM Smith's experience, mixing power per unit bioreactor volume was 18 W/m^3 compared to a typical value of 6 W/m^3 for anaerobic digesters. While the value for mixing was high compared to that for anaerobic digesters, the energy requirements for an AnMBR are likely to be greater than that for a standard anaerobic digester. AnMBR operation requires pumping

between the bioreactor tank and the UF membrane tank in addition to mixing of the bioreactor contents. Nevertheless, the unit mixing energy ranged from 0.10 to 0.26 kWh/m^3 and did not result in effective mixing of the bioreactor. Ineffective mixing was attributable to the simple pilot-scale bioreactor design. Full-scale design would involve use of computational fluid dynamics and better design of the bioreactor inlet and outlet structures. The unit mixing energy decreased as the UF flux increased because the power used for mixing was constant and independent of the flux.

The biogas sparging energy was another major contributor to the total unit energy requirement. It was a function of both the UF flux and the biogas flow rate. The lowest flow rate (25 std. L/min) required 0.08 to 0.20 kWh/m^3 but appears to have been ineffective in keeping the UF membranes clean in addition to other factors, including insufficient maintenance cleaning and inadequate biogas distribution in the membrane tank. The highest flow rate (100 std. L/min) required 0.37 to 0.93 kWh/m^3. The biogas sparging in the pilot-scale system was continuous. Newer and more energy-efficient processes for biogas sparging (e.g., Suez LEAPmbr) involve intermittent sparging using very high flow rates, which creates more turbulence. The unit energy requirements for this process is reported to be about 0.2 kWh/m^3 according to Suez.

The total unit energy requirements were functions of both biogas sparging flow rate and flux (Figure 5.81). Compared to typical wastewater treatment plant energy consumption ranging from 0.3 to 0.6 or more kWh/m^3 (McCarty et al. 2011, Seib et al. 2016, Smith et al. 2012b), the lowest sparge flow rate required less energy at all net fluxes. The greatest sparge flow rate required more or similar amounts of energy.

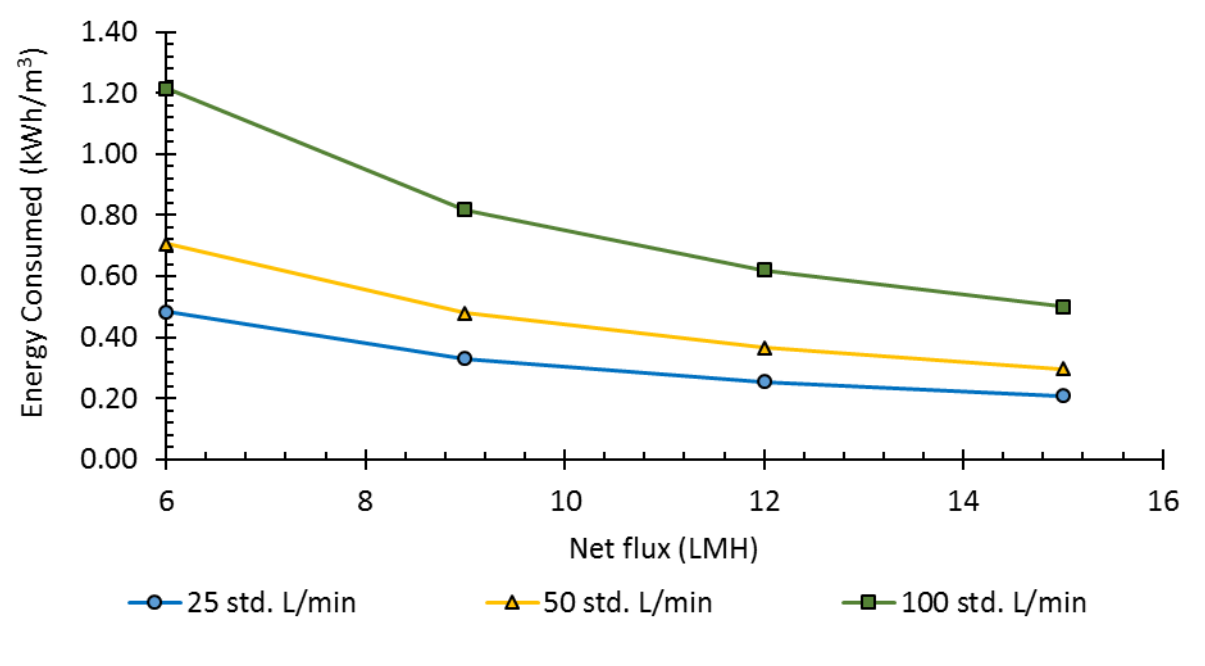

Figure 5.81 Gas-sparged AnMBR Total Energy Consumption for Different Permeate Flux and Biogas Sparging Flow Rates.

The combined energy content of methane in biogas and recovered dissolved methane was assumed to be recovered using a reciprocating engine (e.g., GE Jenbacher) to produce electricity with an efficiency of 48%. Heat energy recovery was not considered in these estimates. In situations where heat could be used, the energy efficiency would be better than reported here. The ratio of energy produced to energy consumed and the net energy consumed were estimated using the above energy consumption estimates and the observed methane production (Figure 5.82). The estimates were calculated for the average influent COD concentration (620 mg/L) and temperatures of < 20°C and > 25°C because methane yield was dependent on temperature (Figure 5.30). Increased flux, decreased sparge flow rate, and elevated temperature contributed independently to attainment of the energy-neutrality performance objective. For example, energy neutrality at temperatures < 20°C was possible only with a flux of 15 LMH and a sparge rate of 25 std. L/min. The unit energy consumption associated with sparging under this condition was estimated to be 0.08 kWh/m^3, which is unreasonably low. Energy neutrality at temperatures > 25°C was observed with a flux of 15 LMH and biogas sparge rates ranging from 25 to 50 std. L/min or a flux of 12 LMH and a biogas sparge rate of 25 std. L/min. The estimated unit energy consumption associated with sparging was 0.17 kWh/m^3 for 15 LMH and 50 std. L/min, which is more reasonable. These data demonstrate that multiple factors, namely temperature, flux, mixing, and biogas sparging contribute to the potential for attaining energy neutrality. Optimization of the engineering design can improve sustained flux and energy efficiency associated with mixing and biogas sparging, but wastewater temperature cannot be practically changed. Therefore, the geographic location of the AnMBR and the seasonal wastewater temperature must be considered when estimating net energy consumption and forecasting the potential for energy neutrality. Thus, the conclusion was that the energy-neutrality performance objective for the gas-sparged AnMBR was met under certain conditions.

While energy neutrality may not be possible under all conditions, decreasing the net energy consumption relative to conventional activated sludge can likely be achieved (Figure 5.82b). These results suggest the prospect of energy reduction using the gas-sparged AnMBR process is promising.

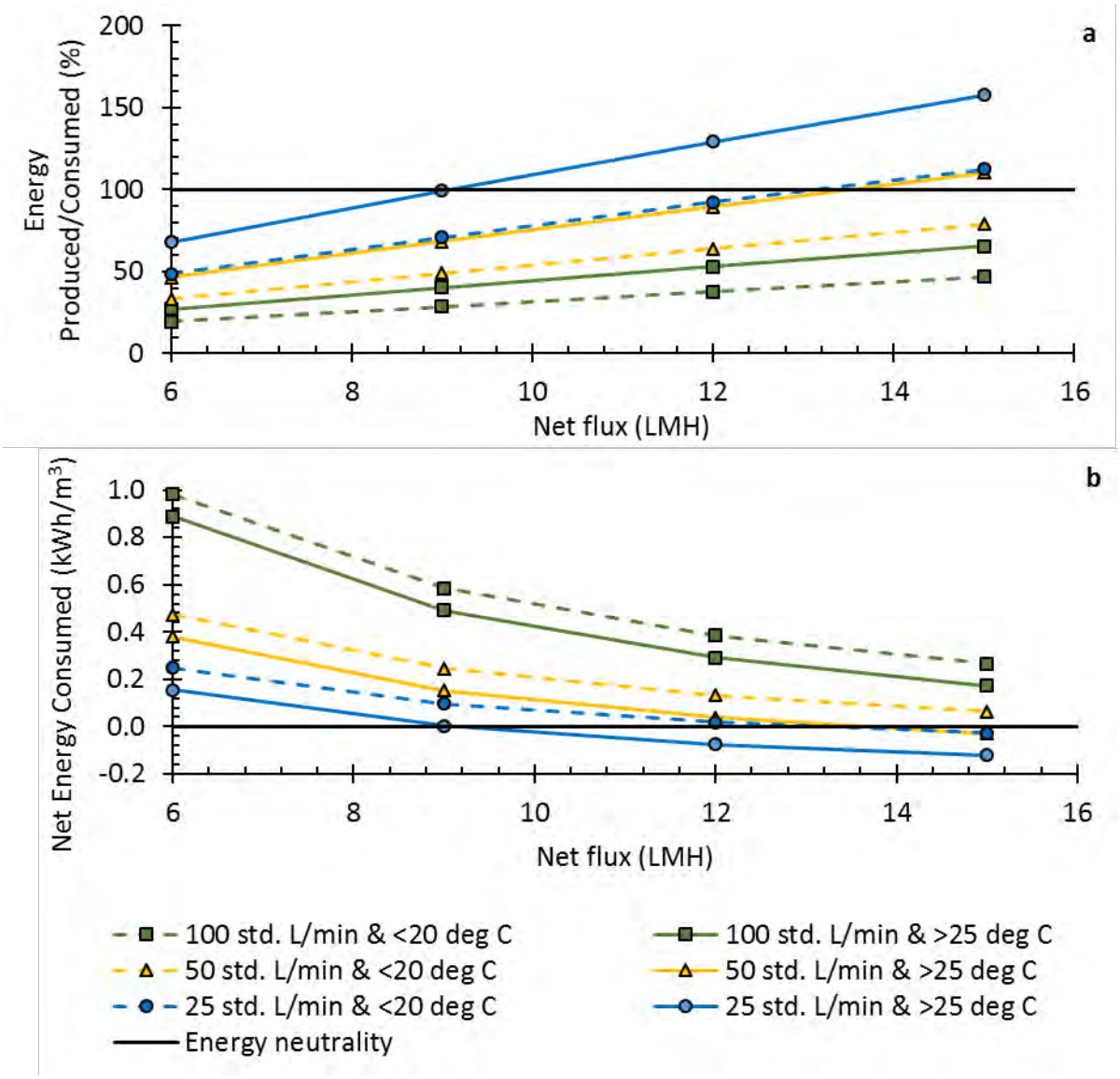

Figure 5.82 Gas-sparged AnMBR Ratio of Energy Production to Consumption (a) and Net Energy Consumption (b) for Different Operating Conditions and Temperatures.

COD concentration and removal were kept constant at 620 mg/L and 90%, respectively.

5.7.24 GAC-Fluidized AnMBR Energy Efficiency

Unit energy consumption (i.e., kWh consumed per m^3 of wastewater treated) was similarly estimated for a range of GAC-fluidized AnMBR demonstration operating conditions. Figure 5.83 illustrates the estimates for permeate pumping, dissolved methane removal (Figure 5.73b), and mixing for different net UF flux rates. Dissolved methane removal was not tested with the GAC-fluidized AnMBR; therefore, the estimates for the gas-sparged AnMBR were assumed to be applicable. The energy required for permeate pumping (0.015 kWh/m^3) and dissolved methane removal (0.0096 kWh/m^3) were negligible compared to those for mixing.

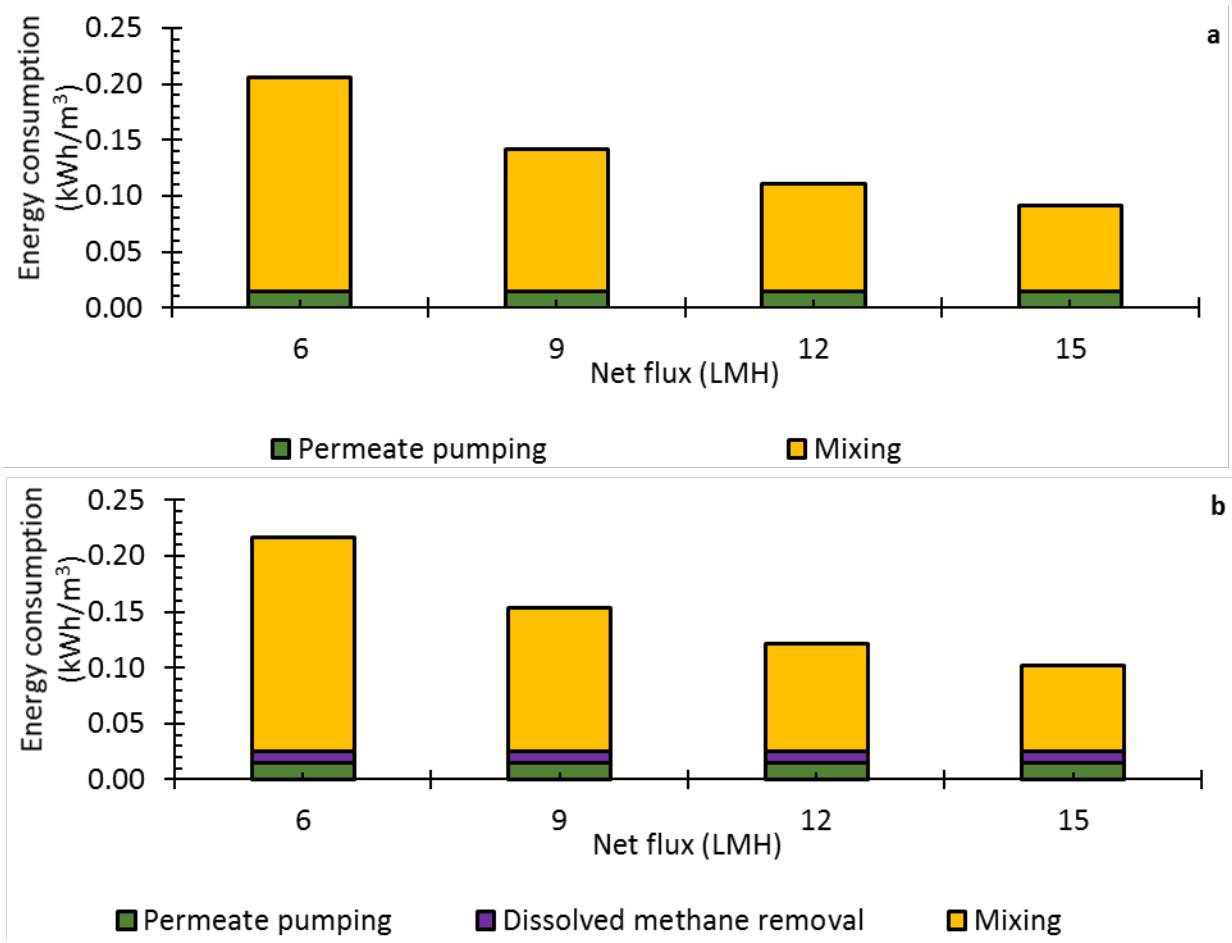

Figure 5.83 GAC-fluidized AnMBR Energy Consumption Associated with Permeate Pumping and Mixing as Tested (a) and with Dissolved Methane Removal Energy for the Gas-sparged AnMBR (b).

The unit mixing energy ranges from 0.08 to 0.19 kWh/m^3 and represents the energy used to recycle water and fluidize the GAC in both the bioreactor and UF membrane tanks. Mixing energy for the UF membrane tank was 89% of the total mixing energy. As with the gas-sparged AnMBR, increased flux decreased the unit energy requirement. Wastewater treatment energy consumption varies widely but typically ranges from about 0.3 to 0.6 or more kWh/m^3 (McCarty et al. 2011, Seib et al. 2016, Smith et al. 2012b). The maximum total unit energy requirement of 0.21 kWh/m^3 is lower than these values. Additionally, Suez/United Water has stated that the wastewater treatment plants they operate consumed 1000 to 3000 kilowatt-hours per million gallons (kWh/MG) (0.26 to 0.78 kWh/m^3) (Elizabeth Keddy, personal communication).

The unit energy requirements were low relative to those for the gas-sparged AnMBR. The mixing energy requirements of the GAC-fluidized AnMBR were compared to a full-scale fluidized bed reactor (FBR) for perchlorate destruction designed by Envirogen and installed by CDM Smith at the El Monte Operable Unit (EMOU) Superfund site in California (Table 5.25). Two metrics, the unit power per unit reactor volume and the recirculation flow rate per unit reactor volume, were calculated for the GAC-fluidized AnMBR bioreactor and UF membrane tank as well as for the EMOU FBR.

The results demonstrate the power used in the GAC-fluidized AnMBR is much less than the EMOU FBR even though the full-scale FBR is operating at much lower recirculation flow rates/unit reactor volume. The empty-bed upflow velocity of the GAC-fluidized AnMBR bioreactor and the EMOU FBR are similar, and the power required per unit reactor volume of the pilot system is 3% of the full-scale system. The main reason the energy requirement of the full-scale system is greater than the pilot system is the recirculation pump head loss (12 m).

Table 5.25 Comparison of Pilot- and Full-scale Fluidized-bed Reactor Energy Requirements.

Parameter	First-Stage Pilot AnMBR (Bioreactor)	Second-Stage Pilot AnMBR (UF Membrane Tank)	Full-Scale Envirogen FBR
FBR volume (m^3)	0.99	0.77	2.9
FBR height (m)	3.8	3.3	6.3
Recirculation flow rate (m^3/d)	220	840	300
Empty-bed up-flow velocity (m/h)	27	90	28
Recirculation pump head (m)	0.20	0.42	12
Power (kW)	0.0076	0.061	0.63
Unit power (kW/m^3 FBR volume)	0.0076	0.079	0.22
Recirculation flow rate/FBR volume (d^{-1})	220	1,100	110

The mechanical design of the pilot system was optimized to reduce this head loss and in turn minimize energy requirements. This optimization involved several aspects including:

- Minimization of the reactor aspect ratio (i.e., height divided by diameter).
- Optimization of the GAC type, size, and packing density.
- Use of in-line or axial pumps to reduce head loss.
- Use of large diameter piping with minimal bends and restrictions.
- Replacement of energy-consuming appurtenances, such as spring-loaded check valves, with automatic knife valves.

Such concepts are typically not practiced but are needed if energy-efficiency is to be achieved. The EMOU system was not designed with the intent of energy minimization. Future engineering designs can reduce energy requirements. Because of this future energy savings opportunity, the observed energy consumption was used in the current analysis.

As for the gas-sparged AnMBR, the combined energy content of methane in biogas and recovered dissolved methane was assumed to recovered with a reciprocating engine to produce electricity with an efficiency of 48%. Heat energy recovery was not considered in these estimates. The ratio of energy produced to energy consumed and the net energy consumed were estimated using the above energy consumption estimates and the observed methane production (Figure 5.84 and Figure 5.85).

The estimates were calculated for temperatures of < 20°C and > 25°C because methane yield was dependent on temperature (Figure 5.31). Estimates were also calculated unsupplemented (210 mg/L) and supplemented (390 mg/L) COD concentrations. Increased flux and elevated temperature contributed independently to attainment of the energy-neutrality performance objective. For example, energy neutrality at temperatures < 20°C was possible only under conditions of COD supplementation (390 mg/L total COD), a flux of 15 LMH, and dissolved methane recovery (Figure 5.85). Energy neutrality at temperatures > 25°C was observed with a flux of 9 LMH. Thus, the conclusion was that the energy-neutrality performance objective for the GAC-fluidized AnMBR was met under certain conditions. However, the above analysis (Table 5.25) demonstrates that engineering design attributes may decrease the potential for attainment of energy neutrality upon scale-up. Nevertheless, the prospect of energy neutrality exists with engineering design optimization and under certain conditions. While energy neutrality may not be possible under all conditions, decreasing the net energy consumption relative to conventional activated sludge can likely be achieved (Figure 5.84b and Figure 5.85b). These results suggest the prospect of energy reduction using the GAC-fluidized AnMBR process is promising.

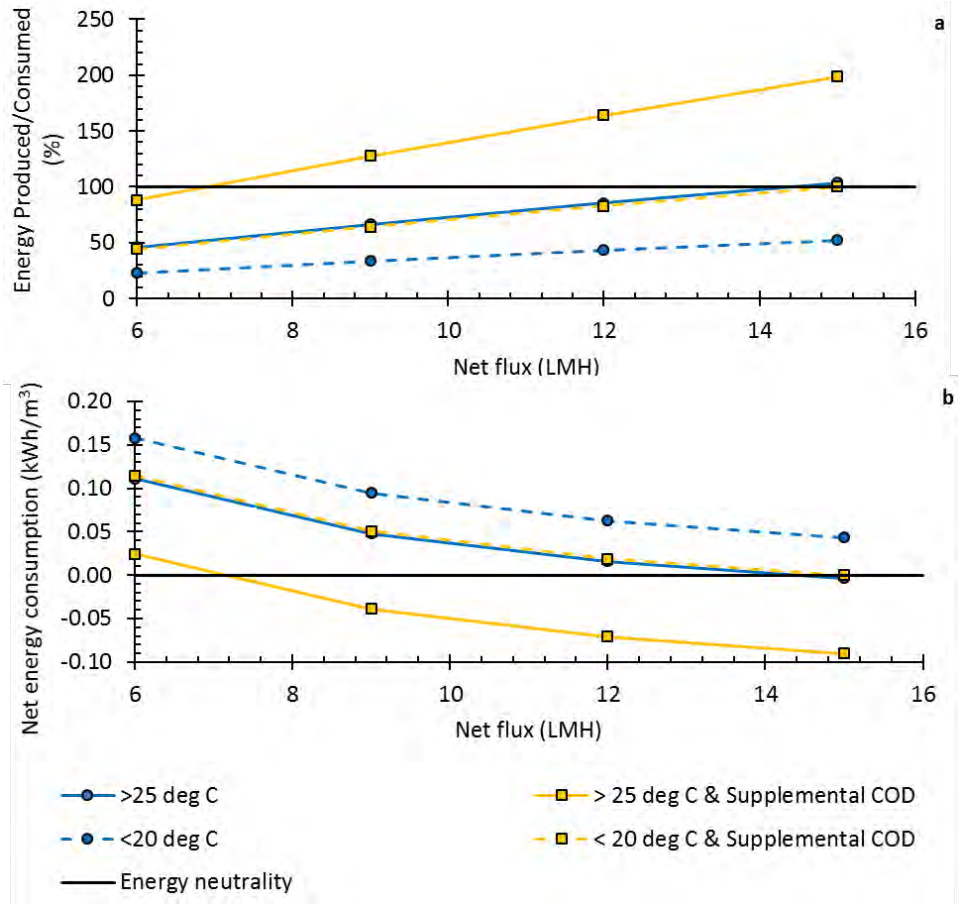

Figure 5.84 GAC-fluidized AnMBR Ratio of Energy Production to Consumption (a) and Net Energy Consumption (b) for Different Operating Conditions and Temperatures and Not Including Dissolved Methane Recovery.

COD concentrations and removals were kept constant at 210 mg/L and 86% (unsupplemented COD) and 390 mg/L and 91% (supplemental COD), respectively.

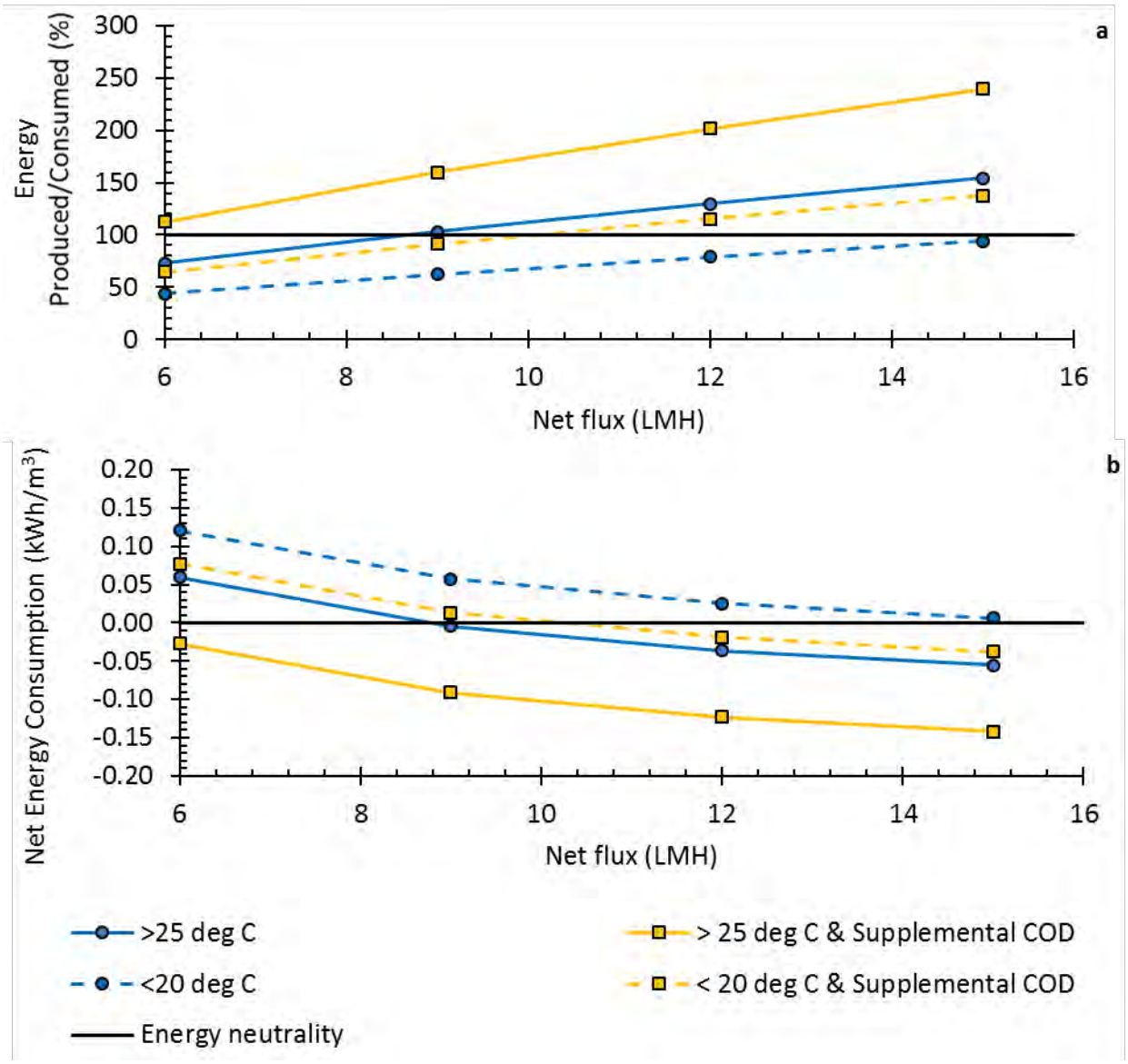

Figure 5.85 GAC-fluidized AnMBR Ratio of Energy Production to Consumption (a) and Net Energy Consumption (b) for Different Operating Conditions and Temperatures and Including Dissolved Methane Recovery Based on Gas-sparged AnMBR Results.

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6.0 PERFORMANCE ASSESSMENT

This section provides an integration between Performance Objectives results presented in Section 3 and data presented in Section 5.

6.1 QUANTITATIVE PERFORMANCE OBJECTIVES

6.1.1 Effectiveness

The effectiveness of the AnMBR technology was assessed with respect to treated water quality. The success was assessed by comparing water quality parameters to EPA secondary treatment standards, published criteria for water reuse, and other applicable metrics.

COD and BOD_5

The average effluent COD concentration in the gas-sparged AnMBR was 58±27 mg/L (Figure 5.17a), which is about equal to the performance objective of 60 mg/L. The average COD removal was 90±4%. The average effluent COD concentration in the GAC-fluidized AnMBR was 29±9 mg/L (Figure 5.19a), which is less than the performance objective ($p < 0.001$). The average COD removal was 86±3%. The influent COD concentrations in the gas-sparged and GAC-fluidized AnMBRs were 620±240 mg/L and 210±50 mg/L, respectively, which may have contributed to the differences in the effluent concentrations.

The average effluent BOD_5 concentration in the gas-sparged AnMBR was 25±12 mg/L (Figure 5.17b), which is less than the performance objective of 30 mg/L ($p=0.004$) but greater than the reuse objective of 10 mg/L. The average BOD_5 removal was 89±5%. The average effluent BOD_5 concentrations in the GAC-fluidized AnMBR was 15±9 mg/L (Figure 5.19b), which is less than the performance objective of 30 mg/L ($p < 0.001$) and greater than the re-use objective of 10 mg/L. The average BOD_5 removal was 85±7%. The influent BOD_5 concentrations in the gas-sparged and GAC-fluidized AnMBRs were 250±130 mg/L and 140±40 mg/L, respectively, which contributed to the differences in the effluent concentrations.

Fine screening was the only form of primary treatment used in this demonstration. Primary sedimentation may have resulted in even lower effluent concentrations and potentially less than 10 mg/L BOD_5 based on previous demonstrated with the GAC-fluidized AnMBR (Dagnew et al. 2011, Dong et al. 2016, Shin et al. 2014).

Ammonia

The ammonia removal by the clinoptilolite column prior to breakthrough was 99.9±0.1% (Figure 5.64), which is greater than the performance objective of 90% ($p < 0.0001$). The influent and effluent ammonia concentrations were 37±4 and 0.05±0.05 mg-N/L, respectively.

Total Phosphorus

Total phosphorus was reduced from 7.0±2.9 mg/L in the screened AnMBR influent to 0.43±0.29 in the clinoptilolite effluent for an overall removal of 94±3% (Figure 5.62c and Figure 5.66), which was greater than the performance objective of 90% ($p=0.052$). The overall removal for total

phosphorus was a result of the individual removals observed in the AnMBR, coagulation, and clinoptilolite sorption. The coagulation-flocculation-sedimentation process removed most of the phosphorus. Total phosphorus concentrations in the coagulation influent were reduced from 4.2±0.6 mg/L by 83±9% to an effluent concentration 0.72±0.36 mg/L (Table 5.18).

Total Sulfide

Sulfide was reduced from 27±5 to 0.7±1.7 mg/L (Figure 5.62b). Sulfide was > 1 mg/L on days 382 and 437 for unknown reasons, which contributed to the high standard deviation. The median and minimum effluent concentrations were 0.10 and 0.04 mg/L, respectively. Overall sulfide removal, including these elevated values, was 99±2%. While the median sulfide concentration met the performance objective, the average concentration did not. Further optimization would likely have improved the performance, which would have led to attainment of the performance objective.

Total Suspended Solids and Turbidity

Total suspended solids in the gas-sparged AnMBR final effluent (i.e., clinoptilolite column effluent) was 25±17 mg/L (Table 5.20) and less than the EPA secondary treatment standard of 30 mg/L, although not at a statistically significant level (p=0.30). Turbidity was elevated in both the gas-sparged and GAC-fluidized AnMBR and greater than the performance objective of 2 NTU (Table 5.20). The gas-sparged AnMBR sedimentation basin was undersized, which led to elevated total suspended solids and turbidity. These processes are standard and final effluent quality could be improved through process design and optimization. The GAC-fluidized AnMBR turbidity was likely associated with precipitation of the anaerobic ultrafiltration permeate following exposure to the atmosphere. Coagulation was not tested downstream of the GAC-fluidized AnMBR.

pH

The pH of the gas-sparged and GAC-fluidized AnMBR permeates were 6.9±0.2 and 7.3±0.2, respectively (Figure 5.17 and Table 5.20). The final gas-sparged AnMBR effluent (i.e., after coagulation and ammonia removal) was 8.1±1.1 (Table 5.20). All values met the performance objectives of 6 to 9 ($p \leq 0.017$).

Dissolved Methane

The average dissolved methane removal under optimized conditions was 79±2% (Figure 5.32), which was not greater than the performance objective of 90%. Performance may have been affected by the age of the contactor and associated membrane oxidation. Therefore, the methane removal result is considered conservative and an underestimate. The influent dissolved methane concentration for these tests was 13±2 mg/L.

6.1.2 Net Energy Production Efficiency

Energy consumption and production were calculated for a matrix of operating scenarios that included various net permeate fluxes and temperatures for the gas-sparged and GAC-fluidized AnMBRs. Temperature was an important factor because the total methane yield was observed to be greater at elevated temperatures (Figure 5.30 and Figure 5.31). Energy neutral or positive operation was estimated for some but not all of these scenarios (Figures 5.82, 5.84, and 5.85).

In general, energy-neutral or positive operation was more likely at greater flux, temperature, and influent COD concentration. At the average observed flux for the gas-sparged AnMBR (7.6 LMH), the ratio of energy produced:energy consumed was 60% for T < 20°C and 84% for T > 25°C (COD = 620 mg/L). At the maximum flux (14 LMH), the ratio was 100% for T < 20°C and 140% for T > 25°C. At the average flux for the GAC-fluidized AnMBR (7.9 LMH) and without supplemental COD (COD = 210 mg/L), the ratio was 55% for T < 20°C and 90% for T > 25°C. If the influent COD was greater (390 mg/L), the ratio at an average flux would be 77% for T < 20°C and 130% for T > 25°C. Therefore, the performance objective of energy neutrality was met by both systems under certain conditions.

While energy neutrality may not be possible under all conditions, decreasing the net energy consumption relative to conventional activated sludge can more likely be achieved. Gas-sparged AnMBR operating conditions at high flux and low sparge rates were more likely to result in net energy consumption less than 0.3 to 0.6 kWh/m^3 (Figure 5.82), which is typical for conventional wastewater treatment plants (McCarty et al. 2011, Seib et al. 2016, Smith et al. 2012b). All GAC-fluidized AnMBR operating conditions resulted in net energy consumption less than that for conventional wastewater treatment plants (Figure 5.84 and Figure 5.85). These results suggest the prospect of energy reduction using AnMBR processes in place of conventional activated sludge technologies is promising.

6.1.3 Implementability

Organic Loading Rate

The average organic loading rate in the gas-sparged AnMBR was 1.3±0.5 kg-COD m^{-3} d^{-1} (Figure 5.11), which is greater than the performance objective of 0.6 kg-COD m^{-3} d^{-1} ($p < 0.0001$). The average organic loading rate in the GAC-fluidized AnMBR without COD supplementation was 1.4±0.5 kg-COD m^{-3} d^{-1} (Figure 5.14), which is greater than the performance objective ($p < 0.0001$) and similar to the rate for the gas-sparged AnMBR. The organic loading rates of both AnMBRs were similar because both the hydraulic residence time and the influent COD for the gas-sparged AnMBR were greater than for the GAC-fluidized AnMBR. Supplemental COD was fed to the GAC-fluidized AnMBR after day 475 to increase the COD concentration. During this time (day 476 to day 535) the organic loading rate increased incrementally but averaged 2.2±0.5 kg-COD m^{-3} d^{-1}. BOD_5, and COD removals decreased during this time, suggesting the organic loading rate with supplemental COD may have been too high.

Hydraulic Residence Time

The average hydraulic residence time for the gas-sparged AnMBR was 11±3 h (Figure 5.11), which is less than the performance objective of 20 h ($p < 0.0001$). The level sensor in the bioreactor tank became fouled with sludge and overestimated the liquid volume through day 283. Thus, the average hydraulic residence time was likely overestimated. The average hydraulic residence time for the GAC-fluidized AnMBR was 3.9±1.0 h (Figure 5.14), which is less than the performance objective of 20 h ($p < 0.0001$) and 65% less than the average hydraulic residence time for the gas-sparged AnMBR.

Biosolids Production

The volatile solids generation per unit mass loaded COD for each AnMBR system was calculated and compared to the performance objective of 0.2 g-VS/g-COD. The results were 0.074 and 0.13 g-VS/g-COD for the gas-sparged and GAC-fluidized AnMBR, respectively (Table 5.12). Both of these values met the performance objective. On the one hand, the value for the gas-sparged AnMBR may be low in part because of solids settling in the bioreactor and incomplete recovery. On the other hand, the greater solids residence time (60±27 d versus 7.7±4.2 d calculated for suspended/non-biofilm solids only [Figure 5.12 and Figure 5.15]) in the gas-sparged AnMBR could have led to a lower value via greater hydrolysis. The fixed solids recovery was low for both systems. Part of the low recovery for both systems was low precision of the solids analyses. When values for both systems are corrected based on the fixed solids recovery, the values (0.17 and 0.24 g-VS/g-COD) are similar to the performance objective (Table 5.12).

Membrane Flux

Operation of the gas-sparged AnMBR over the duration of the demonstration involved variation of several variables, including the HRT, wasting rate, associated bioreactor VSS concentration, UF permeation flux, and biogas blower flow rate and duty (i.e., percent of time the biogas blower was on when cycling). Operation of the GAC-fluidized AnMBR over the duration of the demonstration involved variation of several variables, including the HRT, wasting rate, bioreactor VSS concentration, and UF permeation flux. The purpose of the above variations was to optimize the AnMBR and meet all of the performance objectives.

The average net flux of the gas-sparged AnMBR for the entire demonstration, excluding periods of mechanical shutdown, was 7.6±1.6 LMH (Figure 5.35). This flux was significantly greater than the goal of 6 LMH ($p < 0.0001$). The maximum net flux was 14 LMH. The average net flux of the GAC-fluidized AnMBR for the entire demonstration, excluding periods of mechanical shutdown and COD supplementation, was 7.9±2.2 LMH (Figure 5.48). This flux was significantly greater than the goal of 6 LMH ($p < 0.0001$). The maximum net flux was 12 LMH.

While not a performance objective, an operational objective was to maintain the transmembrane pressure at less than 30 kPa to prevent irreversible fouling of the UF membranes. This operational objective was met most of but not all of the time in the gas-sparged AnMBR (Figure 5.35). The transmembrane pressure in the GAC-fluidized AnMBR was less than 30 kPa for the first 170 days and varied inconsistent thereafter (Figure 5.48).

Permeabilities in both AnMBR systems decreased over the duration of the demonstration. The initial permeabilities (corrected to 20°C) from days 1 to 60 were 280±110 and 200±60 LMH/bar in the gas-sparged and GAC-fluidized AnMBR, respectively (Figure 5.56). The final permeabilities were 49±25 and 24±13 LMH/bar, respectively (Figure 5.56).

Overall, the gas-sparged AnMBR ultrafiltration process demonstrated similar or greater permeability in the presence of elevated concentrations of solids and colloidal organics (Figure 5.55). However, both systems demonstrated instability (i.e., variable permeability over time), which was attributable not only to varying operational conditions and mechanical upsets but also to differences in membrane performance caused by the different methods of fouling management (i.e., variable biogas sparging versus constant GAC fluidization). Inconsistent maintenance cleaning also likely contributed to these instabilities.

Maintenance and Recovery Cleaning Frequency

Maintenance cleaning was initially conducted on an as-needed basis in response to TMP excursions rather than on a schedule. Maintenance cleaning frequencies for the gas-sparged and GAC-fluidized AnMBRs were 0.31 and 0.45 cleans/week, which is much less than the performance objective of ≤ 3 cleans/week (Figures 5.36 to 5.45 and 5.49 to 5.52). While this met the performance objective, inconsistent and insufficiently frequent maintenance cleaning likely contributed to decreased permeability over time in both systems. Recovery cleaning frequencies for the gas-sparged and GAC-fluidized AnMBRs were 1.5 and 2.0 cleans/year, which is also less than the performance objective (Figures 5.36 to 5.45 and 5.49 to 5.52). Therefore, an opportunity exists to increase ultrafiltration performance by increasing the cleaning frequency.

Wastewater Temperature

The intent of this performance objective is to demonstrate attainment of effectiveness at temperatures ≥ 10°C. The COD and BOD_5 removals in the gas-sparged AnMBR did not decrease with decreasing temperatures between 15 and 30°C (Figure 5.17c and Figure 5.20). The performance with respect to COD and BOD_5 removal below 15°C could not be evaluated because ambient wastewater temperatures did not go that low. COD and BOD_5 permeate concentrations did not increase as temperatures decreased between 15 and 30°C (Figures 5.18a, b and 5.22). In the GAC-fluidized AnMBR, COD and BOD_5 removals did not decrease (Figure 5.19c and Figure 5.20) and the permeate concentrations did not increase (Figures 5.19a, b, 5.22 and 5.23, and Table 5.11) as temperatures decreased between 15 and 30°C. The period of time when temperatures were between 10 and 15°C was concurrent with a process upset resulting from an inadvertent pump reversal. When non-upset data are evaluated, only three data points between 14.0 to 14.8°C exist, and they do not indicate a trend of changing performance with temperature (Figures 5.21 and 5.22, and Table 5.11). Therefore, insufficient data exist to evaluate performance of the GAC-fluidized AnMBR at temperatures <15°C.

Dissolved Methane Removal Rate

This performance objective is important with respect to the capital cost and replacement cost of gas-liquid membrane contactors for dissolved methane removal. The performance objective for methane flux was 0.5 g m^{-2} d^{-1}, and the observed flux was 6.5±1.8 g m^{-2} d^{-1} ($p < 0.0001$) (Figure 5.34). If two contactors were installed in series, thereby doubling the membrane area to achieve the 90% removal objective, the performance objective for flux would still be met.

Clinoptilolite Robustness

Robustness was quantified with respect to the variation on ammonia loading over multiple regeneration cycles. No decrease in the ammonia loading (i.e., per unit mass of clinoptilolite) over multiple sorption/regeneration cycles would indicate good robustness. Two regeneration cycles were conducted, and the loading decreased by 21 to 50% compared to the performance objective of 10% (Figure 5.65). The second regeneration did not result in further decreases in ammonia loading suggesting robustness after the initial sorption/regeneration cycle, but additional loading/regeneration cycles would be required to validate this hypothesis. Therefore, the conclusion was that the performance objective for robustness has not been met, but this conclusion is based on limited testing.

Total Phosphorus Removal Rate

The phosphorus removal rate by coagulation-flocculation was 53±12 mg L^{-1} d^{-1} (Section 5.7.15), which was less than the performance objective of 60 mg L^{-1} d^{-1} (p=0.052). This rate is based on the combined volume of the coagulation, flocculation, and sedimentation vessels. Further optimization may have resulted in the performance objective being met.

Ammonia Removal Rate

The ammonia removal rate prior to breakthrough was 4.4±0.9 g L^{-1} d^{-1} (Section 5.7.17) which is greater than the performance objective of 2 g L^{-1} d^{-1} (p=0.00063). A full-scale system would conceivable be designed in a lead-lag configuration to maximize loading (i.e., the lead bed would be run past breakthrough). In this case the overall removal rate would be less than the reported value.

Electrolysis

Electrolysis of the ammonia-laded regenerant solutions was conducted with GreenBox™ technology. Electrolysis was not observed with any of the six solutions (Section 5.7.17). It is believed that iron from upstream coagulation processes interfered negatively with the electrodes (Figure 5.62 and Table 5.18). Further studies on the linkage of clinoptilolite ion exchange with ammonia electrolysis will require non-iron based coagulants and/or a change in process order.

Safety

No OSHA-reportable safety events were incurred at Ft. Riley, substantiating the ability to safely design and operate an AnMBR system despite potentially hazardous concentrations of methane and hydrogen sulfide.

Ease of Use

The operator certification requirement for a full-scale AnMBR plant will depend on the specific requirements of the treatment plant permitting agency. During the upgrade of the Loch Sheldrake wastewater treatment plant in New York to add *aerobic* membrane bioreactors, the requirement increased from a Grade 3 to a Grade 4A operator license. This plant had conventional activated sludge and anaerobic digestors prior to the upgrade. This is just one example, and it cannot be extrapolated to other facilities.

6.2 QUALITATIVE PERFORMANCE OBJECTIVES

6.2.1 Compare Gas-Sparged and GAC-Fluidized AnMBRs

Direct comparisons between the gas-sparged and GAC-fluidized AnMBR systems were made throughout the demonstration and are described in detail in throughout Section 5.7 and in Section 6.1. The following general conclusions are based on the results of these comparisons:

Effectiveness

- Both systems were capable of meeting quantitative performance objectives for BOD_5 and COD; however, the GAC-fluidized AnMBR could attain lower effluent concentrations (Figure 5.22). This difference was attributable in part to lower influent concentrations for the GAC-fluidized AnMBR (Figure 5.21) but may have also been associated with differences in performance of fixed-film and suspended biological systems. The percent removals of BOD_5 and COD were greater in the gas-sparged AnMBR (Figure 5.20), but again, this was in part attributable to the greater influent concentrations. Neither system was capable of meeting the 10-mg/L BOD_5 metric for reuse. Primary sedimentation in addition to screening may have resulted in attainment of this metric on the basis of previous research (Dagnew et al. 2011, Dong et al. 2016, Shin et al. 2014).

- Other effectiveness criteria were either met or would likely be met with additional optimization (Table 3.1).

Net Energy Production Efficiency

- The GAC-fluidized AnMBR required less energy to operate than the gas-sparged AnMBR (Figure 5.80 and Figure 5.83). The energy consumption of the pilot-scale GAC-fluidized AnMBR was low because significant work had gone into minimizing head loss in the system over several years of research. Such was not the case with the gas-sparged AnMBR nor is it the case with full-scale fluidized bed reactors that are commercially available (Table 5.25). Energy-saving features in the GAC-fluidized AnMBR are recommended for use in future full-scale applications if energy efficiency is a project goal.

- Both systems demonstrated lower methane yields per unit COD removed at lower temperatures. The gas-sparged AnMBR and GAC-fluidized AnMBR systems had similar methane yields (Figure 5.30 and Figure 5.31) even though they had different SRTs (Figure 5.12 and Figure 5.15) had a greater methane yield than the GAC-fluidized AnMBR, especially at lower temperatures. These differences in yield with respect to temperature and process are likely associated with differences in hydrolysis at lower temperatures. In addition, differences in solids residence times contributed to differences in methane yield.

- While data available from this study was somewhat limited for low temperature operation, the data indicated that the methane yield per unit of COD removed was significantly lower at 15 to 20°C than at 25 to 30°C. Such lower yields have previously been demonstrated in a detailed completely-mixed anaerobic reactor study on digestion of primary municipal sludge (O'Rourke 1968). Experiments involved steady-state reactor operation over temperature ranges from 15 to 35°C and SRTs from 2.5 to 60 days. The methane yield at 60-d SRT was essentially the same for all reactors, except at 15°C, where the yield was only about 35% of the other reactor. Yields for all lower temperature reactors at lower SRTs were lower than at 35°C. For example, at 30-d SRT, methane yields at 25, 20, and 15°C were 95, 82, and 25%, respectively of those at 35°C. At 15-d SRT yields were 86, 45 and 18%, respectively, of those at 35°C. Neither methane formation by methanogens nor hydrolysis of cellulose and protein were the major factors reducing methane yields; the major factors was lipids and long-chain fatty acid decomposition – materials largely

associated with wastewater suspended material that if not biologically decomposed would be filtered out from the permeate by the membranes, leading to lower yields per unit mass of COD removed. This means that the yield of VS per unit of COD removed should in turn increase. Such lower yields may not be as serious if primary treatment is used because most fatty suspended materials are removed prior to AnMBR treatment.

- Considering the factors above, both systems were capable of being operated under energy-positive conditions and/or with net energy consumption less than that for conventional treatment (Figures 5.82, 5.84 and 5.85). Increased UF membrane flux promoted the likelihood of energy-positive operation.

Implementability

- Both AnMBR systems operated at similar organic loading rates (Figure 5.11 and Figure 5.14). The GAC-fluidized AnMBR was capable of performing at shorter hydraulic residence times than the gas-sparged AnMBR (Figure 5.11 and Figure 5.14). On the one hand, this result can be attributed to the advantages of fixed-film biological systems. On the other hand, the membrane performance of the gas-sparged AnMBr system was better and less likely to be subject to membrane failure in response to membrane abrasion by the GAC (Table 5.16, and Figures 5.57 and 5.58). Considering these relative attributes, a combined process involving a GAC-fluidized bioreactor and a gas-sparged UF membrane may be an ideal process configuration and warrants investigation (see Section 7).

- UF membrane permeability trends were similar in the two AnMBR systems with the GAC-fluidized AnMBR permeability being half that of the gas-fluidized AnMBR at the end of the demonstration (Figure 5.55 and Figure 5.56). The gas-sparged AnMBR had greater ability to decrease TMP and increase permeability via variation of biogas sparge flow rate (Figure 5.46 and Figure 5.55a).

- Biosolids production was less in the gas-sparged AnMBR (Table 5.12), but this could have resulted from either greater SRT and associated hydrolysis or an underestimated value resulting from inadequate bioreactor mixing. Therefore, further evaluation is required.

6.2.2 Assess System Performance with Respect to Temperature

- The effect of temperature on biological performance in both systems was evaluated in detail in Section 5.7.5, 5.7.9, and 5.7.10.

  - Both systems were capable of similar COD and BOD_5 removal (90±4% and 86±3% COD removal in the gas-sparged and GAC-fluidized AnMBRs, respectively; 89±5% BOD5 removal in both systems) between 15 and 30°C (Figure 5.20) over similar organic loading rates (1.3±0.5 and 1.4±0.5 kg-COD m^{-3} d^{-1} for the gas-sparged and GAC-fluidized AnMBRs, respectively). Performance evaluation at temperatures less than 15°C was not possible because of insufficiently low wastewater temperatures in the gas-sparged AnMBR and a process upset attributable to a pump reversal in the GAC-fluidized AnMBR.

- Total methane yield (i.e., gaseous plus dissolved) per unit removed COD was affected by temperature in both systems, with lower yields observed at lower temperatures (Figure 5.30 and Figure 5.31). The decreased yield at lower temperatures was likely associated with decreased hydrolysis and accumulation of organics in the bioreactor. At lower temperatures, the yield of the GAC-fluidized AnMBR was less than that of the gas-sparged AnMBR, possibly due to a shorter solids residence time for suspended solids (Figure 5.12 and Figure 5.15).

- UF membrane performance in both systems is evaluated in detail in Section 5.7.12, 5.7.13, and 5.7.14.

    - UF membrane permeability was normalized to 20°C to allow for comparison of membrane permeability independent of temperature changes. Typically, membrane permeability decreases with lower temperature because of water density and viscosity increases.

6.2.3 Characterize Gas Composition

Gas-sparged AnMBR biogas composition was analyzed and found to contain hydrogen sulfide and siloxanes in addition to methane, carbon dioxide, and nitrogen (Table 5.24). The hydrogen sulfide concentrations were particularly high because of the relatively high sulfate concentrations in Ft. Riley wastewater. Siloxanes were generally undetected or at low concentrations. Such may not be the case with other wastewater sources. Treatment of the biogas to remove hydrogen sulfide is necessary prior to conversion to combined heat and power (Evans et al. 2016, Jayaraman et al. 2015, Vandenburgh and Evans 2016). While iron sponge technology is often used, large-scale biofilters have been successfully demonstrated to be capable of removing hydrogen sulfide in a safer and more cost-effective manner (Polo et al. 2017, Woo et al. 2017).

6.2.4 Characterize Process Residuals

Biosolids and coagulation-flocculation-sedimentation sludge from the gas-sparged AnMBR process were characterized (Table 5.21 and Table 5.22) and compared to regulatory requirements for land application of biosolids (U.S. Government 2018). The biosolids met criteria for class B biosolids with respect to fecal coliforms and class A biosolids with respect to metals. It did not meet class A criteria with respect to concentrations of enteric viruses and *Salmonella*. Therefore, the biosolids meet class B requirements with respect to pathogens. Class A could be met if primary sedimentation and anaerobic digestion was added to the process. Such a process modification is discussed in Section 7.

Coagulation sludge contained phosphorus that has potential use as a fertilizer and contained appreciable phosphorus, sulfur, iron and aluminum (Table 5.22). Further studies would be necessary to determine whether the phosphorus and sulfur are agriculturally available, considering it was coagulated with iron and aluminum coagulants.

Dewatering of both residuals was evaluated (Table 5.23). The biosolids required more polymer for dewatering than the chemical sludge but was still capable of attaining a solids content of 16%.

6.2.5 Characterize Ammonia Sorbent Performance

Section 5.7.17 presented results on clinoptilolite performance and regeneration. While the sorbent was capable of removing ammonia, its loading over time varied possibly because of dissolved iron carryover from the coagulation process. Electrolysis of the regenerations solution was not successful, potentially for the same reason. Therefore, this process requires additional development and is not further evaluated with respect to cost in Section 7.

6.2.6 Characterize Membrane Performance

Sections 5.7.12 to 5.7.14 presented results on ultrafiltration membrane performance. Primary conclusions based on these results are:

- Permeability of both sets of membranes started high and then decreased by about ten-fold over the period of over one year of operation. However, permeability of the gas-sparged membranes was similar or greater than of the GAC-fluidized membranes even though concentrations of suspended solids and colloidal organics were much greater in the gas-sparged AnMBR.

- Maintenance cleaning in both systems was insufficient and contributed to the decreases in permeability.

- In the gas-sparged AnMBR, the pilot-scale sparging system design was not optimal and contributed to fouling.

- Increasing the biogas sparge rate in the gas-sparged AnMBR resulted in increased permeability, though at an increased energy cost. Such modification of permeability is not possible in the GAC-fluidized AnMBR system.

- Membrane foulants on the membranes included both organics (e.g., biofilm) and inorganics (clay-like materials likely associated with the wastewater influent). Primary sedimentation could reduce the amount of inorganic fouling of the membranes. In addition. the GAC-fluidized AnMBR membranes were coated with elemental carbon. The carbon may have deposited through the demonstration or following the upset condition, when GAC was ground in the recirculation pumps.

- Membrane abrasion was much greater in the GAC-fluidized AnMBR compared to gas-sparged AnMBR. The membrane lifetime in the gas-sparged AnMBR is estimated to be on the order of ten years or more based on historical operation of aerobic membrane bioreactors with the same membranes (Cote et al. 2012, Kubota Membrane Europe 2008). The GAC-fluidized AnMBR membranes are likely to have a much shorter lifetime based on observed abrasion in this and previous studies (Shin et al. 2016a, Shin et al. 2016b).

- These results suggest membrane performance in the gas-sparged AnMBR was more robust and flexible than in the GAC-fluidized AnMBR, though energy requirements for gas-sparging are greater than those for GAC-fluidization.

6.2.7 Conduct a Broad Lifecycle Assessment (LCA)

Refer to Section 7.4 for the LCA methods and results.

6.2.8 Characterize Treated Water with Respect to Various Water Reuse Alternatives

Treated water quality is summarized in Table 5.20. The data suggest the water is potentially suitable for surface water discharge, depending on local regulatory requirements and a variety of re-use opportunities, including toilet flushing, irrigation, dust suppression, etc. The treated water would require additional treatment for indirect potable reuse, such as ozone-biofiltration or full-advanced treatment using reverse osmosis (Sun et al. 2018, U.S. EPA and CDM Smith 2017, U.S. EPA et al. 2012).

6.2.9 Characterize Chlorine Demand

The chlorine demand was estimated to be 12 mg/L (Table 5.20). Though not a major cost driver (see Section 7), this demand is associated with the reducing nature of the AnMBR effluent. This demand could be reduced by post-treatment in various processes including aerobic biofilters and cascade aeration. Such processes would also be beneficial with respect to treatment of residual sulfide so as to reduce chemical coagulation costs and environmental impact (see Section 7).

6.2.10 Characterize Microbial Ecology

Sections 5.7.21 and 5.7.22 present detailed results on the microbial ecology of both AnMBR systems.

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7.0 COST AND LIFECYCLE ASSESSMENT

An assessment of capital, operating and lifecycle costs for various AnMBR process configurations compared to a conventional treatment process is presented in Sections 7.1 through 7.3. A simplified LCA of these processes is presented in Section 7.4.

7.1 COST MODEL

The cost model can be broadly divided into capital costs and operating costs. Capital cost elements are further sub-divided into direct and indirect costs. Direct cost elements include preliminary (screening, grit removal, and equalization where necessary), primary treatment (sedimentation/clarification), conventional secondary treatment (activated sludge), AnMBR secondary treatment (gas-sparged, GAC-fluidized and hybrid AnMBR configurations), phosphorus and sulfide removal by chemical coagulation and sedimentation, sludge and biogas management, dissolved methane removal, disinfection, yard piping, electrical, and instrumentation and controls (I&C). Indirect costs include taxes and fees, contractor overhead and profit, construction contingency, and engineering design services. Elements of the capital cost analysis are presented in Table 7.1. The primary source of information for costs was bid tabs from prior CDM Smith projects, which represent real construction costs for similar types facilities. This approach is different from previous approaches (Cashman et al. 2018, Cashman and Mosley 2016, Smith et al. 2014) that have relied on cost estimating software.

Table 7.1 Cost Model for Direct and Indirect Capital Costs.

Cost Element	Cost Type	Basis
Preliminary and primary treatment	Direct	Previous projects
Conventional secondary treatment	Direct	Previous projects
AnMBR secondary treatment	Direct	Demonstration results, previous projects, vendor quotes
Phosphorus and sulfide removal	Direct	Demonstration results, previous projects
Sludge and biogas management	Direct	Demonstration results, previous projects
Dissolved methane removal	Direct	Demonstration results, previous projects, vendor quotes
Disinfection	Direct	Demonstration results, previous projects
Electrical	Direct	20% of direct cost subtotal
Instrumentation and controls	Direct	5% of direct cost subtotal
Yard piping	Direct	Previous projects
Taxes and fees	Indirect	15% of total direct costs
Contractor overhead and profit	Indirect	15% of total direct costs, taxes and fees
Construction contingency	Indirect	25% of total direct costs, taxes and fees, and contractor overhead and profit
Engineering design services	Indirect	10% total direct costs, taxes and fees, contractor overhead and profit, and construction contingency

Operational costs include waste disposal, chemical purchases, membrane replacement, and power consumption. Labor and maintenance costs are expected to be similar for each scenario and are not included in this comparison. Operational cost elements are summarized in Table 7.2.

Table 7.2 Cost Model for Operating Costs Exclusive of Labor.

Cost Element	Basis
Waste disposal	Demonstration results, previous projects and engineering design calculations
Chemical use	Demonstration results, previous projects, engineering design calculations, and vendor supplied chemical costs
Membrane replacement	Demonstration results, vendor supplied data
Power use	Demonstration results, previous projects and engineering design calculations

Capital and annual operating costs for each scenario were combined for comparison into an overall lifecycle cost using a net present value analysis with a 20-year evaluation period and a 7% discount rate.

7.2 COST DRIVERS

Several important cost drivers must be considered for comparison between full-scale implementations of the AnMBR demonstration technologies and the conventional technology. These include the quantity of membranes required, chosen sulfide and phosphorus removal technology, dissolved methane removal technology, net energy production or consumption, and waste generation and disposition.

The quantity of membrane modules is a function of the design flux. For this alternatives analysis, three flux values were compared. Low flux (7.5 LMH) represents performance observed in the demonstration and results in more required membrane modules, which impacts costs associated with construction, membrane replacement, and membrane cleaning. Moderate flux (15 LMH) represents maximum performance that was observed in the demonstration and is hypothesized to have been sustainable if regular maintenance cleaning was conducted. High flux (30 LMH) is considered unrealistic today but may be achievable in the future with additional development. The conventional treatment alternative does not use membranes and, therefore, it does not carry these costs.

Incorporating coagulation and sedimentation for sulfide and phosphorus removal from treated AnMBR effluent adds capital costs that are not necessarily required for a conventional process, where coagulation with alum for phosphorus removal is assumed to occur within the primary clarifiers and secondary process. For the AnMBR alternatives, coagulation-flocculation-sedimentation technology was chosen and is based on demonstration results. This method utilized ferric chloride, ACH, and cationic polymer which were demonstrated in the gas-sparged AnMBR demonstration. As will be demonstrated, these chemicals – especially ACH – have a high cost and lifecycle impact. Therefore, alum which was tested briefly in the GAC-fluidized AnMBR demonstration was also evaluated.

Hollow-fiber membranes were evaluated for dissolved methane removal based on results from the-gas sparged AnMBR demonstration and based on the vendor's recommended full-scale design criteria. While the pressure drop across the membranes in the demonstration was low, full-scale designs will involve greater pressure drops and high energy requirements for pumping. Therefore, an alternative approach using vacuum degassing tanks was also evaluated. The two technologies carry different capital costs and energy requirements.

Net energy consumption was calculated based on the energy demands for each unit process, and energy produced from biogas combustion in cogeneration units. Energy costs from purchase of energy from the grid, or profit from sale of energy back to grid, were calculated based on a typical unit energy cost. The major differentiation in energy consumption between gas-sparged AnMBR and GAC-fluidized AnMBR is the energy required for gas sparging. Liquid pumping costs for the gas-sparged AnMBR were assumed to be equal to those for the GAC-fluidized AnMBR system. Two different temperature scenarios were also considered because methane yield (gaseous plus dissolved) in the demonstration was affected by temperature as a result of varying degrees of hydrolysis. Conventional activated sludge treatment requires significant energy for aeration of the secondary treatment bioreactors, which is not required for either anaerobic technology. Energy production is largely a function of temperature and COD removal.

Residual streams from each unit process include screenings and grit, biosolids, and solids associated with phosphorus and sulfide removal. Quantities of each unit were calculated and costs for processing and disposal of each residual stream were calculated based on processing equipment, chemical costs, transportation, and disposal fees. Screening and grit were assumed to be disposed in a landfill and biosolids and chemical coagulation solids beneficially reused via land application because their organic and nutrient content.

Several potential cost-drivers were not considered as part of this evaluation. This cost model assumes that the proposed full-scale treatment facilities are greenfield sites, and no consideration was given to costs or savings associated with upgrading existing facilities. Land cost and site work (i.e., grading) are highly site specific and were not considered. An influent pump station, effluent pump station, administration building, and laboratory spaces that are often associated with full-scale treatment plants were not included in this analysis. Site-specific phosphorus discharge limits may vary from what was assumed, which could result in additional required treatment equipment. Nitrogen removal was not considered for reasons discussed below.

7.3 COST ANALYSIS

This section presents a comparison of conventional aerobic treatment with various AnMBR process scenarios for a 5-million gallon per day (MGD). A 5-MGD plant was chosen because this is the minimum size for which cogeneration units are considered to be economically viable (Naik-Dhungel 2010). Seven AnMBR scenarios were considered and each scenario represents a different configuration of a full-scale treatment plant. In addition, each AnMBR scenario was evaluated at three different flux conditions and two temperature conditions. An eighth scenario represents conventional activated sludge treatment with anaerobic digestion and is used as a baseline for comparison against the AnMBR scenarios. Supporting information is included in Appendix G.

7.3.1 Basis of Design

The characteristics of medium strength wastewater are summarized in Table 7.3 (Tchobanoglous et al. 2014). The target effluent quality parameters used to develop the design are based on typical secondary treatment requirements for domestic wastewater and are provided in Table 7.4. Nitrogen removal using the clinoptilolite nitrogen removal system was not included in this analysis because the electrolysis system did not work, apparently because of iron fouling. This process will be evaluated further as part of Environmental Security Technology Certification Program (ESTCP) project ER-201728. Nitrification will likely occur in the conventional activated sludge scenario; however, the relative impacts of discharged nitrogen species in the conventional and AnMBR alternatives were not evaluated.

Table 7.3 Average Characteristics for Medium Strength Municipal Wastewater.

Parameter	Value		
Average Daily Flow	5 MGD = 18,950 m^3/day		
Peak Wet Weather Flow	15 MGD = 56,800 m^3/day		
High Wastewater Temperature	25-30°C		
Low Wastewater Temperature	15-20°C		
Influent Constituents	Average Concentration (mg/L)	Average Day Loading (lb/d)	Max Month Loading (lb/d)
COD	430	17,930	23,130
BOD_5	190	7,920	10,220
TSS	210	8,760	11,480
TKN	40	1,670	1,890
NH_3-N	25	1,040	1,280
Total Phosphorus	7	290	330
Sulfate (as SO_4)	30	1,250	1,250

Table 7.4 Effluent Quality Requirements.

Parameter	Value
COD	60 mg/L
Carbonaceous BOD_5	30 mg/L
TSS	30 mg/L
NH_3-N	Not applicable
NO_3-N + NO_2-N	Not applicable
Total Phosphorus	1 mg/L
Sulfide	0.1 mg/L
Dissolved Methane	90% removal
E. coli	200 CFU/100 mL

Seven AnMBR process scenarios and one conventional process scenario were evaluated. Scenarios 1 and 2 represent what was evaluated in this demonstration. Scenario 3 is a hybrid of Scenarios 1 and 2 based on recommendations of this study. Scenarios 4 through 6 are equivalent to Scenarios 1 through 3 but include primary sedimentation and anaerobic digestion of the sedimentation sludge. Scenario 7 is identical to Scenario 6 but includes an alternative method of dissolved methane removal, as discussed below. Scenario 8 is conventional treatment. These scenarios are summarized below. The main process units included in each treatment scenario are shown in Table 7.5. Process flow diagrams for each of these scenarios are included in Appendix G.

Table 7.5 Main Process Units Included in Each Scenario.

Included Technology	Scenario							
	1-Gas-Sparged	2-GAC Fluidized	3-Hybrid	4–P+Gas-Sparged	5–P+GAC-Fluidized	6-P+Hybrid	7–P+Hybrid+AltCH4	8 - Conventional
Coarse Screens with Washer/Compactor	X	X	X	X	X	X	X	X
Grit Removal	X	X	X	X	X	X	X	X
Fine Screening with Washer/Compactor	X	X	X	X	X	X	X	
Equalization	X	X	X	X	X	X	X	
Primary Sedimentation				X	X	X	X	X
Suspended Growth Aerobic Bioreactor								X
Secondary Clarification								X
Suspended Growth Anaerobic Reactor	X			X				
GAC-Fluidized Bed Bioreactor		X	X		X	X	X	
Gas-Sparged UF Membranes	X		X	X		X	X	
GAC-Fluidized UF Membranes		X			X			
Anaerobic Digester				X	X	X	X	X
Coagulation and Flocculation for P and S Removal	X	X	X	X	X	X	X	X
Sludge Thickening and Dewatering	X	X	X	X	X	X	X	X
Sludge Lime Stabilization	X	X	X					
Dissolved Methane Removal - Membranes	X	X	X	X	X	X		
Dissolved Methane Removal - Vacuum Flash Tank							X	
External Biogas Storage	X	X	X	X	X	X	X	X
Biogas Conditioning, H_2S and Moisture Removal	X	X	X	X	X	X	X	X
Combined Heat and Power Engine Generator	X	X	X	X	X	X	X	X
Disinfection - Sodium Hypochlorite	X	X	X	X	X	X	X	X

- Scenario 1 - Gas-sparged AnMBR demonstration configuration including vacuum-operated, hollow-fiber, gas-liquid contactor for dissolved methane removal and coagulation-flocculation-sedimentation for sulfide and phosphorus removal, (abbreviated as gas-sparged).
- Scenario 2 - GAC-fluidized AnMBR demonstration configuration including vacuum- operated, hollow-fiber, gas-liquid contactor for dissolved methane removal and coagulation-flocculation-sedimentation for sulfide and phosphorus removal, (GAC-fluidized).
- Scenario 3 - Hybrid, GAC-fluidized bed bioreactor with gas-sparged UF membranes including vacuum-operated, hollow-fiber, gas-liquid contactor for dissolved methane removal and coagulation-flocculation-sedimentation for sulfide and phosphorus removal, (Hybrid).
- Scenario 4 – Scenario 1 plus primary sedimentation and anaerobic digestion, (P + Gas-sparged).
- Scenario 5 – Scenario 2 plus primary sedimentation and anaerobic digestion, (P + GAC-fluidized).
- Scenario 6 – Scenario 3 plus primary sedimentation and anaerobic digestion, (P + Hybrid).
- Scenario 7 – Scenario 6 with a vacuum degasser for dissolved methane removal instead of a hollow-fiber contactor, (P + Hybrid + AltCH4).
- Scenario 8 - Conventional activated sludge treatment with anaerobic digestion of biosolids, (Conventional).

Scenarios one through seven were each evaluated at low, medium, and high flux (7.5, 15, and 30 LMH, respectively) and at low and high temperatures (<20°C and >25°C, respectively). The temperatures affected methane yield and used observed yields presented in Section 5. A basis of design and cost analysis was performed for each scenario at each flux and temperature. The following subsections present the basis of design for the main process units.

Preliminary Treatment

Preliminary treatment consists of screening and grit removal. Coarse screens and grit removal are common to all scenarios and are intended to remove large debris and grit that could damage downstream equipment. Fine screening was chosen for membrane scenarios to protect the membranes and prevent fouling. Equalization is provided to account for peak flows to the AnMBR. A summary of preliminary treatment design criteria is provided in Table 7.6.

Table 7.6 Preliminary Treatment Basis of Design.

Parameter	Unit	Anaerobic MBR Alternatives without Primary Sedimentation	Anaerobic MBR Alternatives with Primary Sedimentation	Conventional Activated Sludge Alternative
Coarse Screening				
Screen Type	-	Multiple-Rake Mechanical Bar Screen		
Number of Screens	-	2		
Screen Opening Size	mm	6		
Screenings Handling	-	Washer/Compactor Screw Auger, Screenings to Landfill		
Motor HP, Each Train	HP	10		
Grit Removal				
Type	-	Stacked Tray Vortex System		
Number of Trains	-	2		
Removal Efficiency	%	> 95% Removal of Grit Larger than 75 microns		
Grit Handling	-	Inclined Screw Grit Washer/Classifier, Grit to Landfill		
Motor HP, Each Train	HP	20 HP		
Fine Screening				
Screen Type	-	Center Flow Perforated Plate		None
Number of Screens	-	2	2	
Screen Opening Size	mm	1	2	
Screenings Handling	-	Washer/Compactor Screw Auger, Screenings to Landfill		
Motor HP, Each Train	HP	10		
Peak Flow Equalization				
Type	-	One Open Concrete Tank		None
Total Volume	gal	1,000,000		
Tank Dimensions, Each	-	70-ft Diameter by 18-ft Side Water Depth		
Mixing Power	HP	15		
EQ Return Pump Capacity	gpm	700		
EQ Return Pump Motor	HP	15		

Primary Clarification

Primary clarification removes suspended solids from the raw wastewater influent by gravity sedimentation. The resulting sludge is sent to anaerobic digesters for co-digestion with residuals generated in the secondary process. The design criteria used for primary clarifiers incorporated in Scenarios 4 through 8 are included in Table 7.7. Effluent from the primary clarifiers is then sent to biological treatment. Table 7.8 provides a summary of primary effluent loads and sludge quantities.

Table 7.7 Primary Clarification Design Criteria.

Parameter	Unit	Criteria
Primary Clarifiers		
Type	-	Circular Center Feed Type, Concrete Tanks
Design Peak Flow	MGD	10
Surface Overflow Rate at Peak Flow	gpd/sf	1,800
Number Tanks	-	2
Diameter, each Tank	ft	60
Side Water Depth	ft	14
Sludge Collection Motor Size	HP	1.0
Primary Sludge Pumping		
Number Sludge Pumps	-	Two
Pump Flow Capacity	gpm	200
Pump Motor Size	HP	15

Table 7.8 Primary Effluent Loads and Primary Sludge Quantities.

Constituents	% Removal	Average Concentration (mg/L)	Average Day Loading (lb/d)	Max Month Loading (lb/d)
Primary Effluent				
Chemical Oxygen Demand (COD)	35%	280	11,655	15,030
Biochemical Oxygen Demand, 5-day (BOD_5)	35%	120	5,150	6,645
TSS	60%	85	3,500	4,590
TKN	0%	40	1,670	1,890
NH3-N	0%	25	1,040	1,280
Total Phosphorus	40%	4.2	175	200
Sulfate	0%	30	1,250	1,250
Primary Sludge				
Sludge Quantity	dry lb/day	5,250		6,890
Typical Solids Content	%	3%		

Anaerobic Membrane Bioreactors

Full scale design for each of the demonstration technologies includes an anaerobic bioreactor and a membrane bioreactor. General process design parameters for the anaerobic bioreactor are provided in Table 7.9. The design criteria used for the suspended growth (Scenarios 1 and 4) and GAC-fluidized bioreactors (Scenarios 2, 3, 5, 6, and 7) are provided in Table 7.10. The membrane bioreactors associated with each chosen flux were sized to accommodate the required number of membrane modules for each flux condition. The design basis used for the membrane bioreactors is provided in Table 7.11.

Conventional Activated Sludge Process

The conventional activated sludge system (Scenario 8) was designed with primary sedimentation, an aerated bioreactor, secondary clarifiers, and chemical phosphorus removal within the secondary treatment process. The design basis for the conventional activated sludge system is provided in Table 7.12.

Table 7.9 Anaerobic Treatment Overall Basis of Design.

Parameter	Units	Gas-Sparged AnMBR	GAC-Fluidized AnMBR
Combined Liquid HRT at Average Flow	h	11	3.9
Organic Loading Rate, without Primary Sedimentation	kg-COD/m^3/d	0.94	2.7
Organic Loading Rate, with Primary Sedimentation	kg-COD/m^3/d	0.52	1.7
SRT	d	60	sSRT = 11
MLSS	mg/L	9,100	2,700
MLVSS	mg/L	7,100	1,800
Volatile Solids Production	kg-VS / kg-COD loaded	0.13[a]	0.13

[a] Actual solids production was 0.074 kg/kg but it is believed this is underestimated due to solids deposition in the reactor, so the yield from the GAC-fluidized pilot was used for full-scale design.

Table 7.10 Anaerobic Bioreactor Basis of Design.

Parameter	Units	Suspended Growth Bioreactor			GAC-Fluidized Bioreactor		
Design Net Flux	LMH	7.5	15	30	7.5	15	30
Reactor Active Volume	m^3	7,700	8,200	8,400	1,700	2,400	2,700
	gal	2,040,000	2,170,000	2,230,000	450,000	630,000	720,000
Type of Tanks	-	Two circular concrete tanks with fixed steel covers			Two circular concrete tanks with fixed steel covers		
Total Volume including Freeboard, each Tank	gal	1,274,400	1,353,400	1,392,800	280,800	392,200	447,900
Tank Dimensions, Each	-	79-ft dia x 35-ft tall	81-ft dia x 35-ft tall	82-ft dia x 35-ft tall	37-ft dia x 35-ft tall	44-ft dia x 35-ft tall	47-ft dia x 35-ft tall
Side Water Depth	ft	30			30		
HRT at Average Flow	h	9.8	10.4	10.7	2.7	3.8	4.3
GAC Type		NA			Calgon Filtrasorb 300 sieved to remove < 0.8 mm		
GAC Quantity	kg	NA			240,000	470,000	580,000
GAC Fluidization Velocity	m/h	NA			27		
Mixing Power, Each Tank	HP	10			10[a]		

[a] Mixing requirement of 0.1 HP per 1,000 cubic feet was assumed for a typical digester based on engineering judgement. For a fluidized bed reactor, the tank volume is smaller than a gas-sparged system, but additional energy will likely be required for fluidization.

Table 7.11 Membrane Bioreactor Basis of Design.

Parameter	Units	Gas-Sparged AnMBR			GAC-Fluidized AnMBR		
Design Net Flux[a]	LMH	7.5	15	30	7.5	15	30
Membrane Make	-	Suez					
Membrane Mode[a]	-	ZeeWeed 500d					
Membrane Type	-	0.04 µm PVDF on woven polyester					
Instantaneous Flux[a]	LMH	9.4	18.8	37.5	9.4	18.8	37.5
Number of Trains	-	8	4	2	16[b]	8[b]	4[b]
Number of Cassettes	-	75	40	20	150	80	40
Number of Modules	-	3,060	1,530	770	6,120	3,060	1,540
Membrane Area	m^2	105,264	52,632	26,488	105,264	52,632	26,488
Active MBR Volume including GAC	gallons	253,000	126,000	63,000	356,000	178,000	89,000
MBR Liquid HRT (empty bed)	h	1.2	0.6	0.3	0.27	0.13	0.07
MBR Power Requirement	kWh/d	6,600	3,700	2,200	3,600	2,200	1,400
GAC Type	-	NA			Calgon Filtrasorb 300 sieved to remove < 0.8 mm		
GAC Quantity	kg	NA			460,000	230,000	120,000
GAC Fluidization Velocity	m/h	NA			90 (empty bed)		
Membrane Cleaning Chemicals	-	500 mg/L NaOCl and 2000 mg/L citric acid; Citric acid may be acidified to pH ~ 2 with HCl					

[a] Based on use of membrane relaxation where the net flux = 80% of the instantaneous flux (8 minutes on, 2 minutes relax)

[b] GAC-fluidized bed reactors use the same membrane area as the gas-sparged AnMBR. However, twice the number of modules is required to accommodate the GAC.

Table 7.12 Conventional activated sludge basis of design.

Parameter	Unit	Criteria
BOD Removal Process Design		
Aerobic Solids Residence Time	d	10
Biological MLSS	mg/L	2,900
Net Biological Sludge Yield	lb TS / lb BODr	0.66
Chemical Phosphorus Removal		
Coagulant Dosing Point	-	Mixed liquor upstream of secondary clarifiers
Coagulant Type	-	48% aluminum sulfate
Coagulant Dose	mg/L as Al	3.5
Coagulant Volume	gal/d	600
No. Mixers	-	1
Mixer HP, Each	HP	15
Chemical MLSS	mg/L	700
Aerobic Bioreactor		
Number Tanks	-	2 plug flow basins with fine bubble diffuser grids
Total Aerobic Volume	gallons	1,500,000
Dimensions, Each Tank	-	140-ft x 40-ft
Side Water Depth	ft	18 ft
Aeration System		
Dissolved Oxygen Concentration	mg/L	1.5
Average Airflow Required	scfm	3,780
Peak Airflow Required	scfm	6,310
Number Blowers	-	3
Blower Capacity, Each	scfm	3,155
Motor Size, each Blower	HP	250 HP
Secondary Clarifiers		
Number Tanks	-	Four circular center feed type clarifiers
Diameter, Each Tank	ft	75-ft
Surface Overflow Rate at Peak Flow	gpd/sf	900
Side Water Depth	ft	15
Sludge Collection Motor, Each	HP	1.0
RAS Pumping		
Number Pumps	-	2
Flow Capacity, Each Pump	gpm	3,500
Pump Motor Size	HP	40
WAS Pumping		
Number Pumps	-	2
Pump Flow Capacity	gpm	700
Pump Motor Size	HP	10

Dissolved Methane Removal

Dissolved methane is removed from anaerobic effluents with vacuum-assisted, hollow-fiber membranes in Scenarios 1 through 6. The basis of design for membrane contactors for dissolved methane removal is provided in Table 7.13. For Scenario 7, vacuum flash tanks were considered as an alternative gas removal technology. The reason for this evaluation was because of the high head loss associated with full-scale membrane contactors, as discussed in Sections 7.3.2 and 7.3.3. The basis of design for the vacuum flash tanks is summarized in Table 7.14.

Table 7.13 Membrane Contactors for Dissolved Methane Removal Basis of Design.

Parameter	Unit	Dissolved Methane Removal from AnMBR Effluent
Membrane Contactor		
Make	-	3M Liqui-Cel
Model	-	14x28
Number Contactors	-	14 trains; 2 in series per train (28 total)
Flux	g $CH_4/m^2/d$	36[a]
Membrane Area	m^2	6,610
Pressure Loss	psi	26
Contactor Feed Pumps (MBR Permeate Pumps)		
Number Pumps	-	3
Pump Motor Size	HP	75
Vacuum-Assisted Gas Sweep		
Sweep Gas Type		Nitrogen gas (N_2)
Total Sweep Flow Rate	scfm	21
Sweep Gas Generator Type	-	Pressure swing adsorption
Sweep Gas Generator Motor Size	HP	20 hp for air compressor
Vacuum Pump Type	-	Liquid ring
Number Vacuum Pumps	-	Three
Total Vacuum Volume Flow	acfm	280
Vacuum Pump Pressure	mm Hg (abs)	100
Vacuum Pump Motor Size, Each	HP	15

[a] Based on modeling by 3M.

Table 7.14 Vacuum Flash Tank for Dissolved Methane Removal Basis of Design.

Parameter	Unit	Dissolved Methane Removal from AnMBR Effluent
Vacuum Degasser		
Make	-	Elgin vacuum degasser
Model	-	ESDG 1200
Number of Units	-	3
Vacuum Pump Horsepower	hp	5
Tank Headspace Vacuum	psi	12.3

Phosphorus and Sulfide Removal for AnMBR Scenarios

For the demonstration technologies, phosphorus and sulfide removal from the treated effluent was achieved with chemical precipitation and sedimentation. ACH, ferric chloride, and cationic polymer were evaluated on the basis of the results of the pilot study performed at Ft. Riley. A summary of the full-scale design criteria for the phosphorus and sulfide removal system is provided in Table 7.15 below. An alternative scenario was also considered for comparison purposes in which aluminum sulfate (alum) and cationic polymer were used. For this alternative it was assumed that the flocculation and sedimentation equipment would remain the same, but with an alum dose of 10 mg/L, and a polymer dose of 1 mg/L would be used.

Table 7.15 Phosphorus and Sulfide Removal Basis of Design.

Parameter	Unit	Criteria
Number of Trains	-	2
Design Flow, Per Train	MGD	5
Coagulant Type	-	40% Ferric Chloride, 58 mg/L as Fe; Aluminum Chlorohydrate, 16 mg/L as Al; Cationic Polymer, 0.6 mg/L
Rapid Mix		
Detention Time	sec	30
Volume, Per Train	gal	3,500
No. of Mixers, Each Train	-	1
Mixer Motor Size, Each	HP	15
Flocculation		
No. of Stages	-	3
Detention Time, Per Stage	min	10
Volume, per Stage, Each Train	gal	35,000 gallons
No. of Mixers, Each Train	-	3
Mixer Motor Size, Each	HP	2.0
Sedimentation		
Sedimentation Type	-	Inclined Plate Settlers
Tank Volume	gal	224,000
Loading Rate (Effective)	gpm/ft^2	0.3
Detention Time	min	65
Sludge Removal Mechanism	-	Chain-and-flight, 0.5 HP Drive

Disinfection

Final effluent disinfection for all full-scale design scenarios is achieved with sodium hypochlorite. The required dose for the anaerobic alternatives is based on chlorine demand data collected in the Ft. Riley pilot study. For the conventional activated sludge alternative, a chlorine demand and dose were chosen based on typical design values. A summary of the basis of design for the disinfection system is provided in Table 7.16. Note the higher chlorine demand measured at the Ft. Riley demonstration compared to a typical nitrifying conventional activated sludge process.

Table 7.16 Disinfection System Basis of Design.

Parameter	Unit	Anaerobic MBR Alternatives	Conventional Activated Sludge Alternatives
Disinfectant Type	-	12.5% Sodium Hypochlorite	12.5% Sodium Hypochlorite
Chlorine Demand	mg/L as Cl_2	12	8
Chlorine Dose	mg/L as Cl_2	15	12
Disinfectant Volume	gpd	600	480
Number of Chlorine Contact Tanks	-	2	2
Contact Time at Average Flow	minutes	40	60
Contact Time at Peak Flow	minutes	20	20
Design Peak Flow	MGD	10	15
Total Contact Tank Volume	gallons	138,000	208,000
Mixer HP	HP	5	5

Sludge Management

In Scenarios 1 through 3, secondary sludge is thickened on a gravity belt thickener and then is combined with the primary sludge and then stabilized with lime prior to dewatering. In Scenarios 4 through 8, primary and secondary biological sludge is anaerobically digested and does not require lime stabilization. Some degree of sludge thickening was assumed to be achieved in the primary clarifiers, while it was assumed that secondary sludge would be pumped to gravity belt thickeners for thickening to 6-7% solids. The resulting blend of primary sludge and thickened secondary sludge was assumed to reach a 5.5% thickness, which is a typical thickness for digester feed sludge because it has a reasonable viscosity for pumping to the digester and mixing within the digester.

Biological sludge from all scenarios is ultimately disposed of through land application as Class A biosolids. The design criteria for primary and secondary sludge management and stabilization are provided in Table 7.17.

Tertiary sludge (i.e., sludge generated from chemical precipitation of phosphorus and sulfide) is assumed to be suitable for land application. The dewatering characteristics of sludge from chemical precipitation during the Ft. Riley pilot study was used to develop the basis of design for the management of tertiary sludge and is presented in Table 7.18.

Table 7.17 Primary and Secondary Sludge Thickening, Dewatering, and Stabilization Design Criteria.

Parameter	Unit	Anaerobic MBR Alternatives without Primary Sedimentation	Anaerobic MBR Alternatives with Primary Sedimentation	Conventional Activated Sludge Alternative
Sludge Production				
Primary Sludge	dry lb/d TS	0	5,300	5,300
Secondary Sludge	dry lb/d TS	2,300	1,500	4,200
Total Sludge	dry lb/d TS	2,300	6,800	9,500
Secondary Sludge Thickening				
Type	-	One gravity belt thickener		
Belt Width	m	2 meters		
Motor Size	HP	10.0		
Thickened Secondary Sludge	%	6-7%		
Polymer Dose Rate	lb active / dry ton	8		
Polymer Required	lb active / d	9.3	6.1	17
Primary and Secondary Sludge Stabilization				
Type	-	Lime Addition	Mesophilic Digestion (20-day SRT)	
Lime Dose	tons/d	0.35	-	-
Lime Equipment Power	HP	30	-	-
Average Blended Sludge Feed	%	5.5	5.5	5.5
Digester Feed Volume	gal/d	-	14,760	20,583
Digester Volume	gallons	-	295,000	412,000
Number Digesters	-	-	1	1
Digester Dimensions	-	-	41-ft diameter x 35-ft high	48-ft diameter x 35-ft high
Digester Mixing Power, Each	HP	-	10	10
Volatile Solids Reduction	%	-	55%	55%
Stabilized Sludge	dry lb/d	3,030	3,050	5,090
Primary and Secondary Sludge Dewatering				
Type		One belt filter press		
Motor Size	HP	10	10	10
Polymer Required	lb active / d	21	27.5	46
Dewatered Cake Solids	%	20%	20%	20%
Dewatered Cake Quantity	wet tons/d	7.6	7.6	12.7

Table 7.18 Tertiary Sludge Management Design Criteria.

Parameter	Unit	Anaerobic MBR Alternatives without Primary Sedimentation	Anaerobic MBR Alternatives with Primary Sedimentation	Conventional Activated Sludge Alternative
Sludge Production				
Tertiary Sludge	dry lb/d TS	8,890		NA
Tertiary Sludge Content	%	3.0		NA
Sludge Thickening and Dewatering				
Type	-	Two 3-belt belt filter presses		NA – chemical sludge is removed with the secondary sludge
Total Connected Horsepower	HP	10		
Polymer Dose Rate	lb active / dry ton	18		
Polymer Required	lb active / d	80		
Dewatered Sludge Content	%	20%		

Biogas Treatment and Cogeneration

For all scenarios, biogas will be treated to remove sulfide prior to being used for heat and power generation in an engine generator. A packed media biotower will be used for sulfide removal (Polo et al. 2017, Woo et al. 2017). The characteristics of biogas from anaerobic bioreactors were determined based on biogas characteristics observed in the Ft. Riley pilot study. However, the influent sulfate concentration of the Fort Riley wastewater was observed to be approximately twice that of typical medium strength wastewater. Therefore, the biogas sulfide concentration for this evaluation was assumed to be half of what was observed in the pilot (i.e. 2500 mg/L instead of 5,000 mg/L). Anaerobic digester biogas characteristics were assumed based on typical design values. The biogas characteristics used in the full-scale design alternatives is presented in Table 7.19. The basis of design for biogas storage, treatment, and cogeneration is provided in Table 7.20.

Table 7.19 Biogas Characteristics.

Parameter	Value
Anaerobic Bioreactor Biogas	
Methane	68%
Nitrogen Gas	24%
Carbon Dioxide	6%
Hydrogen Sulfide	2,500 mg/m^3
Anaerobic Digester Biogas	
Methane	65%
Nitrogen Gas	< 1%
Carbon Dioxide	25%
Water Vapor at 40°C	6%
Hydrogen Sulfide	2,500 mg/m^3

Table 7.20 Biogas treatment and Cogeneration for Scenarios 1 Through 8.

Parameter	Unit	1 – Gas-Sparged	2 – GAC-Fluidized	3 – Hybrid	4 – P + Gas-Sparged	5 – P + GAC-Fluidized	6 – P + Hybrid	7 – P + Hybrid+ AltCH4	8 - Conventional
Biogas Production									
AnMBR Biogas Flow at > 25°C	scfm	32	34	33	21	22	22	22	0
AnMBR Methane Flow at > 25°C	scfm	22	23	23	14	15	15	15	0
AnMBR Biogas Flow at < 20°C	scfm	12	8	8	7	5	31	31	0
AnMBR Methane Flow at < 20°C	scfm	8	5	5	5	3	3	3	0
Dissolved Methane Recovery Total Gas Flow > 25°C	scfm	39	39	39	39	39	39	18	0
Dissolved Methane Recovery Methane Flow > 25°C	scfm	10	10	10	6	6	6	6	0
Dissolved Methane Recovery Total Gas Flow < 20°C	scfm	39	39	39	39	39	39	18	0
Dissolved Methane Recovery Methane Flow < 20°C	scfm	11	11	11	7	7	7	7	0
AnAD Biogas Flow	scfm	0	0	0	39	39	39	39	46
AnAD Methane Flow	scfm	0	0	0	25	25	25	25	30
Total Methane at > 25C	scfm	31	33	33	46	47	47	47	30
Total Methane at < 20C	scfm	19	16	16	38	36	36	36	30
Biological Desulfurization									
Type	-	One single-stage FRP tower with plastic media							
H_2S Removal Efficiency	%	>95%							
Air Supply Blower	HP	5.0							
Recirculation Pump	HP	5.0							
Combined Heat and Power									
Type	-	Engine-generator with heat recovery jacket							
Size	kW	400							

7.3.2 Cost Estimate

Capital costs were developed for each scenario and at each design membrane flux (Table 7.21). A summary of direct costs is shown graphically in Figure 7.1. The capital cost of conventional treatment was less than all AnMBR scenarios except at 15 and 30 LMH, where the hybrid (Scenario 3) was similar or less. At a moderate flux of 15 LMH, the capital costs for the gas-sparged, GAC-fluidized, and hybrid AnMBR Scenarios (1 through 3) were 28, 31, and 21% greater, respectively, than that for the conventional scenario. The GAC-fluidized AnMBR (scenarios 2 and 5) costs are based on an assumption that the membrane costs are the same as for the gas-sparged AnMBR. If the costs were greater, which is likely, then the cost for the GAC-fluidized AnMBR system would be greater than shown. Secondary treatment was the greatest cost component regardless of scenario or flux. When primary treatment is included (Scenarios 4 through 6), the costs are 34, 36, and 26% higher than conventional treatment, respectively. Scenario 7, which include primary sedimentation plus the hybrid AnMBR with alternative dissolved methane removal, is 24% high capital cost than conventional treatment. These results suggest that, with optimization, the hybrid AnMBR has the potential to be cost-competitive with conventional treatment. Consider also that conventional treatment has been in existence and optimized for many decades, whereas the AnMBR system for municipal treatment has never been built. Costs generally decrease with optimization.

Table 7.21 Direct Capital Costs.

Cost Component	Process Scenarios							
	1 – Gas-Sparged	2 – GAC-Fluidized	3 – Hybrid	4 – P + Gas-Sparged	5 – P + GAC-Fluidized	6 – P + Hybrid	7 – P + Hybrid+ AltCH4	8 - Conventional
Preliminary and Primary Treatment	$4,247,000	$4,247,000	$4,247,000	$5,697,000	$5,697,000	$5,697,000	$5,697,000	$3,040,000
Conventional Secondary Treatment	$0	$0	$0	$0	$0	$0	$0	$7,705,000
AnMBR Secondary Treatment (7.5 LMH)	$12,540,000	$15,380,000	$10,840,000	$12,540,000	$15,380,000	$10,840,000	$10,840,000	$0
AnMBR Secondary Treatment (15 LMH)	$8,420,000	$9,300,000	$6,900,000	$8,420,000	$9,300,000	$6,900,000	$6,900,000	$0
AnMBR Secondary Treatment (30 LMH)	$6,600,000	$6,600,000	$5,170,000	$6,600,000	$6,600,000	$5,170,000	$5,170,000	$0
Phosphorus and Sulfide Removal with Tertiary Sludge Dewatering	$4,654,000	$4,654,000	$4,654,000	$4,654,000	$4,654,000	$4,654,000	$4,654,000	$200,000
Primary & Biological Sludge Handling & Stabilization	$5,750,000	$5,750,000	$5,750,000	$5,640,000	$5,640,000	$5,640,000	$5,640,000	$5,780,000
Biogas Conditioning and CHP	$4,050,000	$4,050,000	$4,050,000	$4,050,000	$4,050,000	$4,050,000	$4,050,000	$4,050,000
Dissolved Methane Removal	$1,190,000	$1,190,000	$1,190,000	$1,190,000	$1,190,000	$1,190,000	$270,000	$0
Disinfection	$1,550,000	$1,550,000	$1,550,000	$1,550,000	$1,550,000	$1,550,000	$1,550,000	$1,950,000
Yard Piping	$2,000,000	$2,000,000	$2,000,000	$2,000,000	$2,000,000	$2,000,000	$2,000,000	$2,000,000

Note: Direct costs do not include associated costs for electrical (20% allowance) and instrumentation and control (5% allowance).

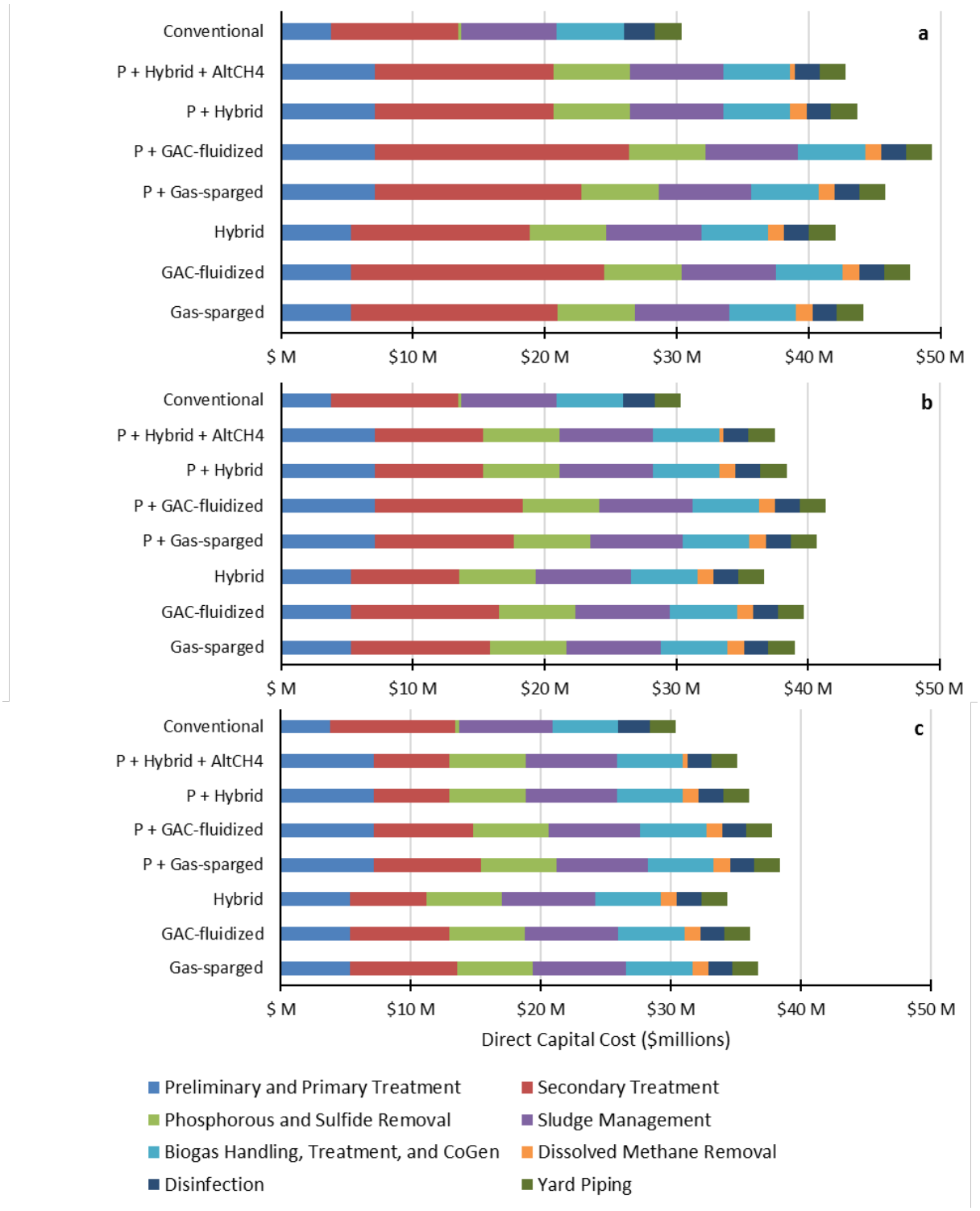


Figure 7.1 Direct Capital Costs for Conventional Treatment and Different AnMBR Process Configurations at Net Fluxes of 7.5 LMH (a), 15 LMH (b) and 30 LMH (c). P Denotes Primary Treatment.

AltCH4 denotes vacuum degassing process for dissolved methane removal. Indirect costs are a constant percentage of total direct cost as described in Table 7.1 and are not shown.

The operating costs for each scenario include waste disposal (i.e., landfilling of screening and grit and beneficial reuse of biosolids and chemical coagulation sludge), power, membrane replacement, and chemicals. Labor and maintenance costs are assumed to be constant across each scenario and, therefore, are not included in this analysis. Figure 7.2 shows operating costs for the high temperature scenarios (i.e., > 25°C) and Figure 7.3 shows operating costs for the low temperature scenarios (< 20°C). The primary difference between these alternative cost analyses is the amount of energy produced from biogas, which is represented as an energy cost. The energy shown in these graphs indicates net energy bought from the grid (a positive value) or sold back to the grid (a negative value). Use of the alternative dissolved methane removal process (scenarios 6) resulted in net energy-positive operation at fluxes of 15 and 30 LMH. However, energy efficiency was not the major driver with respect to overall operating costs of the AnMBR scenarios. Chemicals used for phosphorus and dissolved sulfide removal were the greatest operating cost by a significant margin. Sulfide removal is required from AnMBR permeate is required regardless of whether the effluent is discharge to a surface water (because it exerts an oxygen demand and upon oxidation and conversion to elemental sulfur will generate turbidity) or if it is further process for water reuse applications (because of the toxic and noxious odor-generating potential and corrosivity). Sulfide removal with coagulation was a major chemical cost driver and resulted in operating costs for all AnMBR scenarios being much greater than operating costs for conventional treatment. Membrane replacement costs were greater for the GAC-fluidized AnMBR scenarios (2 and 5) because of an assumed 5-year replacement frequency, which is conservative based on demonstration results and previous studies (Shin et al. 2016a, Shin et al. 2016b). The GAC-fluidized demonstration indicated it is possible the membranes would need to be replaced more frequently than every 5 years, which would further increase the cost. The membrane replacement frequency for the gas-sparged and hybrid systems was assumed to be 10 years based on previous studies with aerobic MBRs using the same or similar membranes (Cote et al. 2012, Kubota Membrane Europe 2008). The unit membrane cost for the gas-sparged and GAC-fluidized AnMBR systems was assumed to be equal, which may not be the case because of the lower membrane density in the GAC-fluidized AnMBR. If the unit membrane cost for the GAC-fluidized AnMBR system was greater than that for the gas-sparged AnMBR system, then the operating costs for the GAC-fluidized AnMBR would be greater.

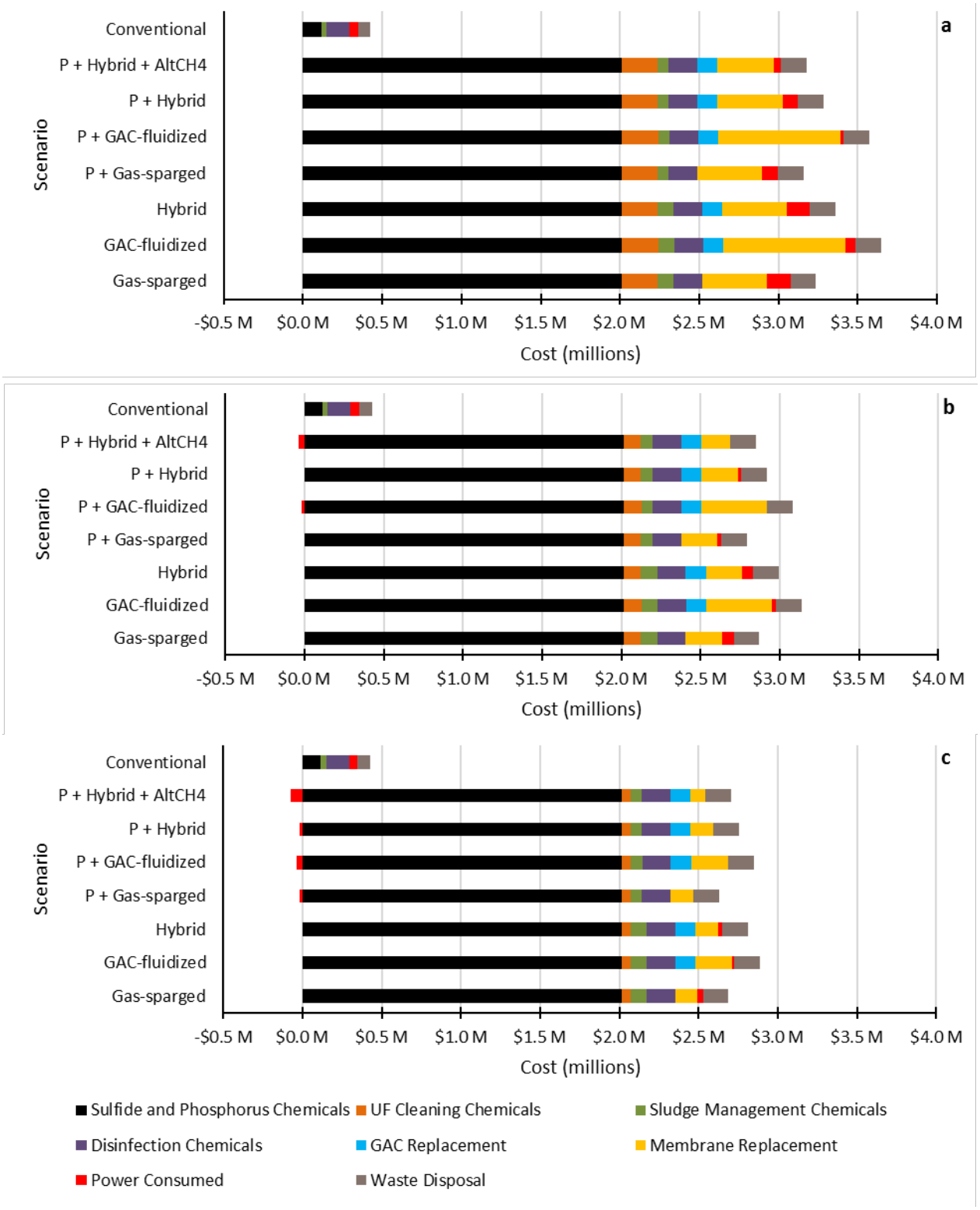


Figure 7.2 Annual Operating Costs Excluding Labor Maintenance at Temperatures > 25°C for Conventional Treatment and Different AnMBR Process Configurations at Net Fluxes of 7.5 LMH (a), 15 LMH (b), and 30 LMH (c).

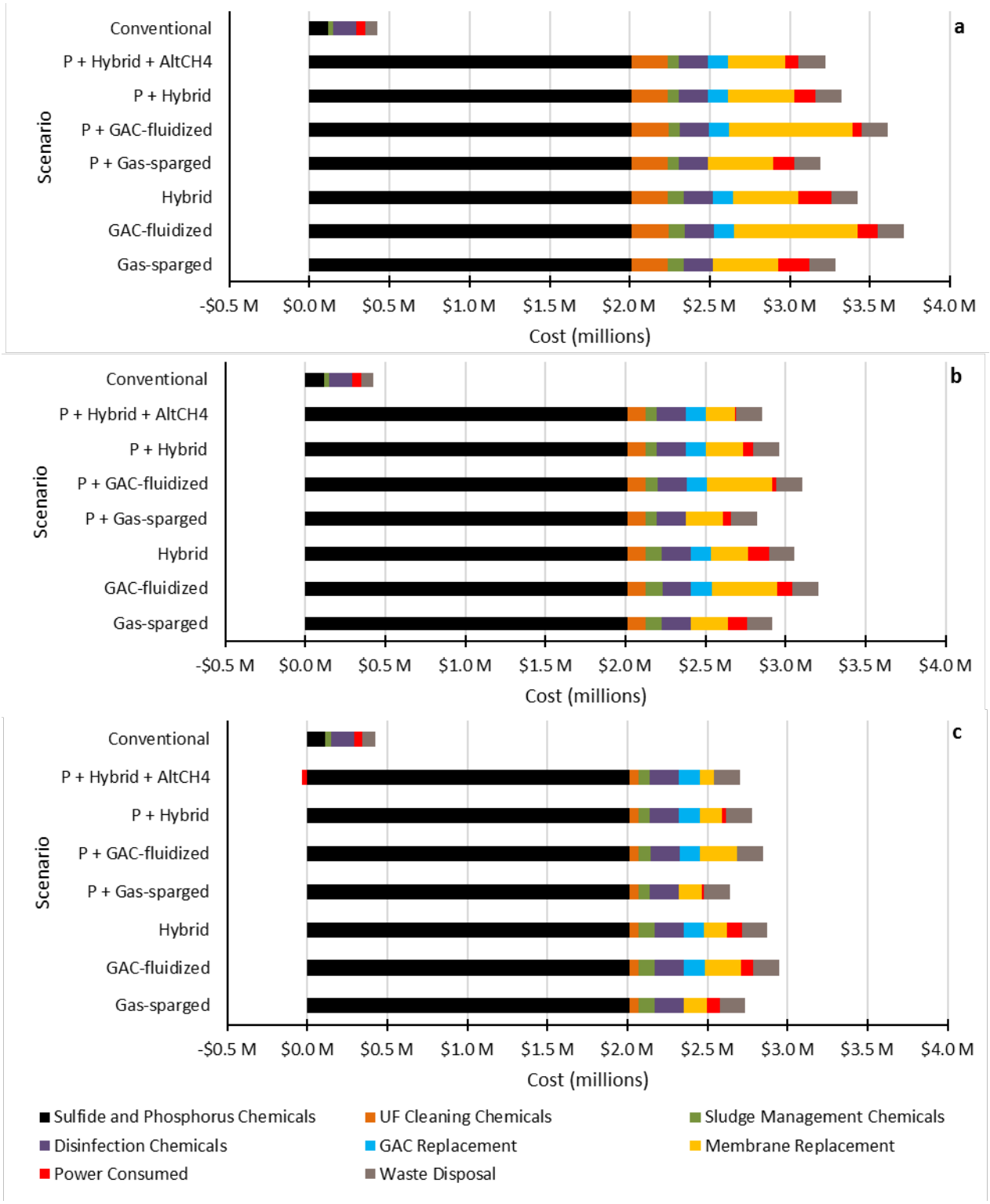


Figure 7.3 Annual Operating Costs Excluding Labor and Maintenance at Temperatures < 20°C for Conventional Treatment and Different AnMBR Process Configurations at Net Fluxes of 7.5 LMH (a), 15 LMH (b), and 30 LMH (c).

Total lifecycle cost was calculated assuming a 20-year lifecycle and a 7% discount rate for annual operating costs and combining with the capital cost. The lifecycle cost analysis results for high and low temperature conditions are presented in Figure 7.4 and Figure 7.5, respectively. Lifecycle costs were lowest for conventional treatment primarily because of the differences in operating costs. Comparison among the demonstration technologies shows that the GAC-fluidized bed AnMBR (Scenarios 2 and 5) is the most expensive, which is driven by more frequent membrane replacement. The overall lifecycle costs for gas-sparged AnMBR (Scenarios 1 and 4) and hybrid AnMBR (Scenarios 3 and 6) configurations are similar to the hybrid configuration resulting in a slightly lower lifecycle cost. Adding primary clarification ahead of the anaerobic treatment technologies (Scenarios 4, 5, and 6) results in slightly higher capital cost compared with Scenarios 1 through 3. However, the primary clarifier capital costs are partially offset by savings associated with higher energy production. The overall net present value analysis indicates that the lifecycle cost is lowest when primary clarification is not used.

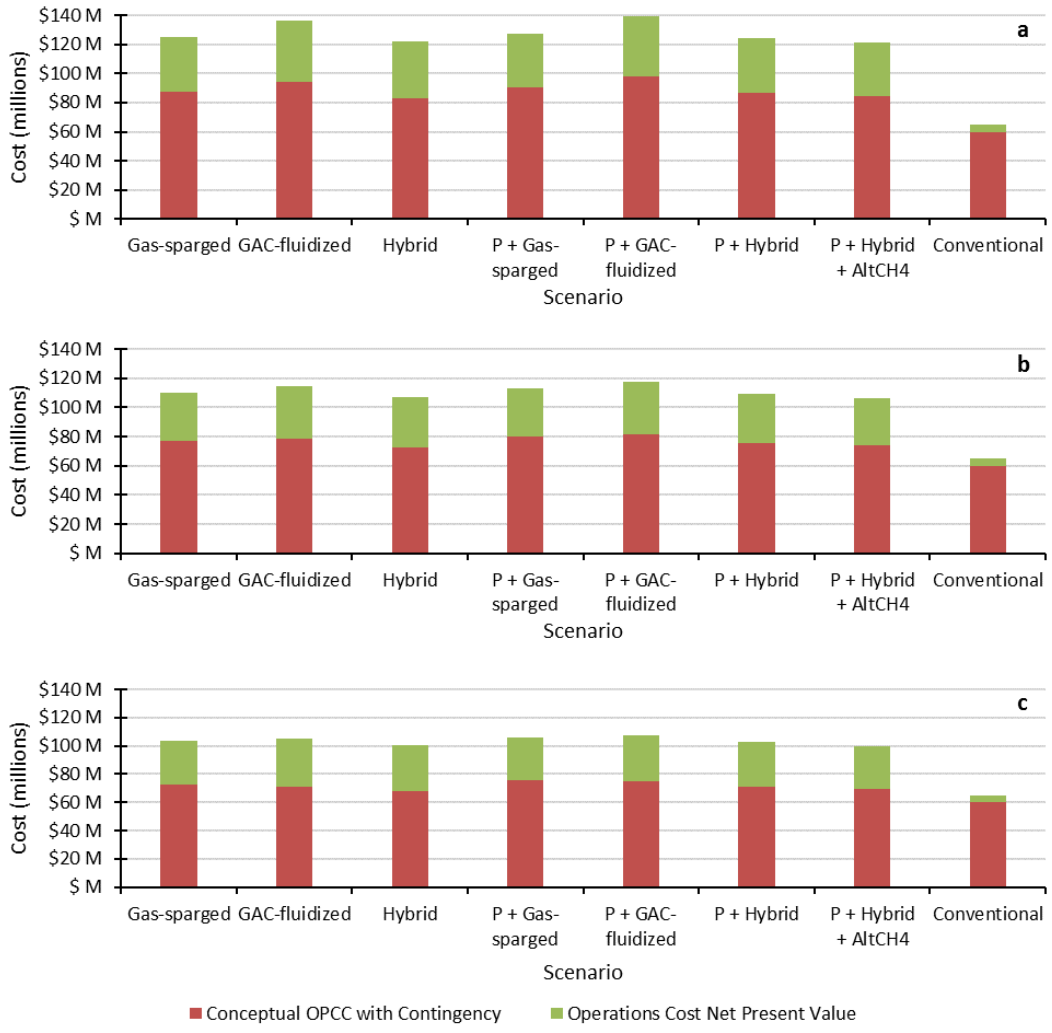


Figure 7.4 20-Year Lifecycle Costs Excluding Labor and Maintenance at Temperatures > 25°C for Conventional Treatment and Different AnMBR Process Configurations at Net Fluxes of 7.5 LMH (a), 15 LMH (b) and 30 LMH (c).

OPCC = opinion of probable construction cost.

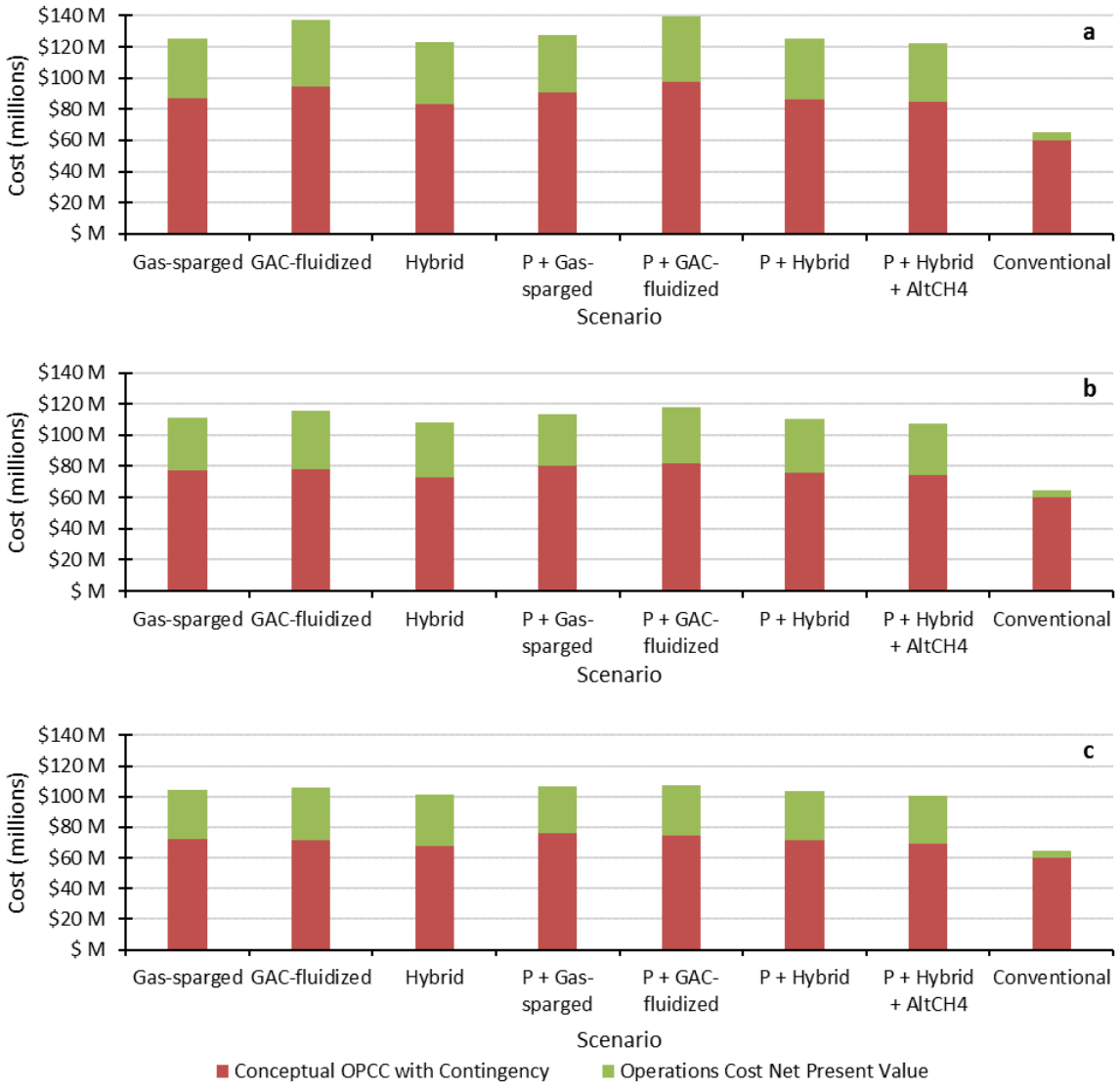


Figure 7.5 20-Year Lifecycle Costs Excluding Labor and Maintenance at Temperatures < 20°C for Conventional Treatment and Different AnMBR Process Configurations at Net Fluxes of 7.5 LMH (a), 15 LMH (b) and 30 LMH (c).

OPCC = opinion of probable construction cost.

7.3.3 Cost Estimate Discussion

The capital, operating, and lifecycle cost analysis leads to several conclusions. First and foremost, design flux for membrane systems has a strong effect on the overall cost of the system. The design flux directly correlates to the number of membrane modules required for the full-scale design and the cost of the membrane systems is the single largest contributor to overall capital cost. Furthermore, the operating costs associated with membrane replacement and membrane cleaning are directly related to the number of membrane modules.

Secondly, system temperature has minimal impact on overall cost of the system. Temperature impacts the quantity of methane generated, and therefore, the quantity of power produced. At higher temperatures, the operating costs of the system are slightly lower when compared with the low temperature alternatives. However, the overall role of power in the cost analysis is small compared to chemical and membrane replacement costs. Nevertheless, energy-positive or negative operation was dependent on the specific scenario, flux, and temperature (Figure 7.6).

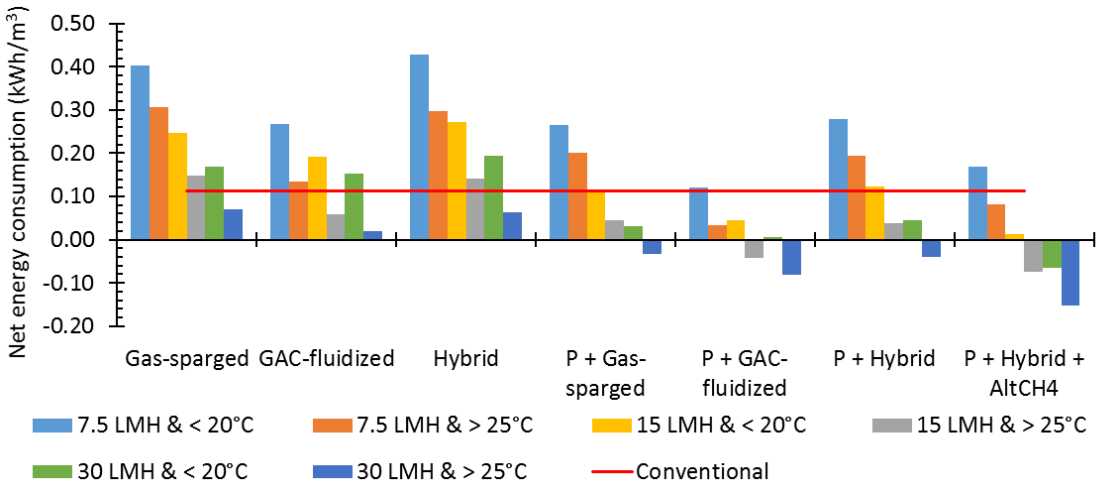


Figure 7.6 Net Energy Consumption for Different AnMBR Scenarios Compared to Conventional Treatment.

Use of a vacuum flash tank for dissolved methane removal (Scenario 7) results in lower capital costs compared with hollow-fiber cartridge membranes. Furthermore, operating costs are lower because the hollow-fiber cartridge membranes draw significant power to pump through the membrane systems. However, in general, the choice of dissolved methane removal technology had little impact on the overall economics of the system relative to other factors.

The AnMBR scenarios, in general, had greater operating costs when compared to conventional activated sludge treatment. The chemical costs associated with phosphorus and sulfide removal represent a significant portion of overall operating cost. The chemical mass used per unit volume water treated for all AnMBR scenarios was greater than conventional treatment even when alum was used instead of ferric chloride and ACH (Figure 7.7). The selection of coagulant and dose did, however, affect the relative mass of residuals generated by the AnMBR and conventional processes (Figure 7.8). The annual and lifecycle costs associated with chemical use is further illustrated in Figure 7.9 and Figure 7.10. Substitution of alum for ferric chloride and ACH greatly reduced the chemical cost. However, even when no coagulant was used, the chemical costs for the AnMBR scenarios were greater than those for conventional treatment because of the chemicals required to mitigate membrane fouling and the additional chlorine demand required for AnMBR effluent (as demonstrated at the Ft. Riley pilot). For example, the lifecycle cost for Scenario 7 with primary sedimentation, hybrid AnMBR, and alternative dissolved methane removal was 16% greater than that for conventional treatment. The lifecycle cost difference between Scenario 7 and Scenario 8 is primarily because of the costs for membrane replacement, membrane cleaning chemicals, and disinfection. Based on the above analysis, research into alternative processes for sulfide removal and more efficient membrane management is warranted.

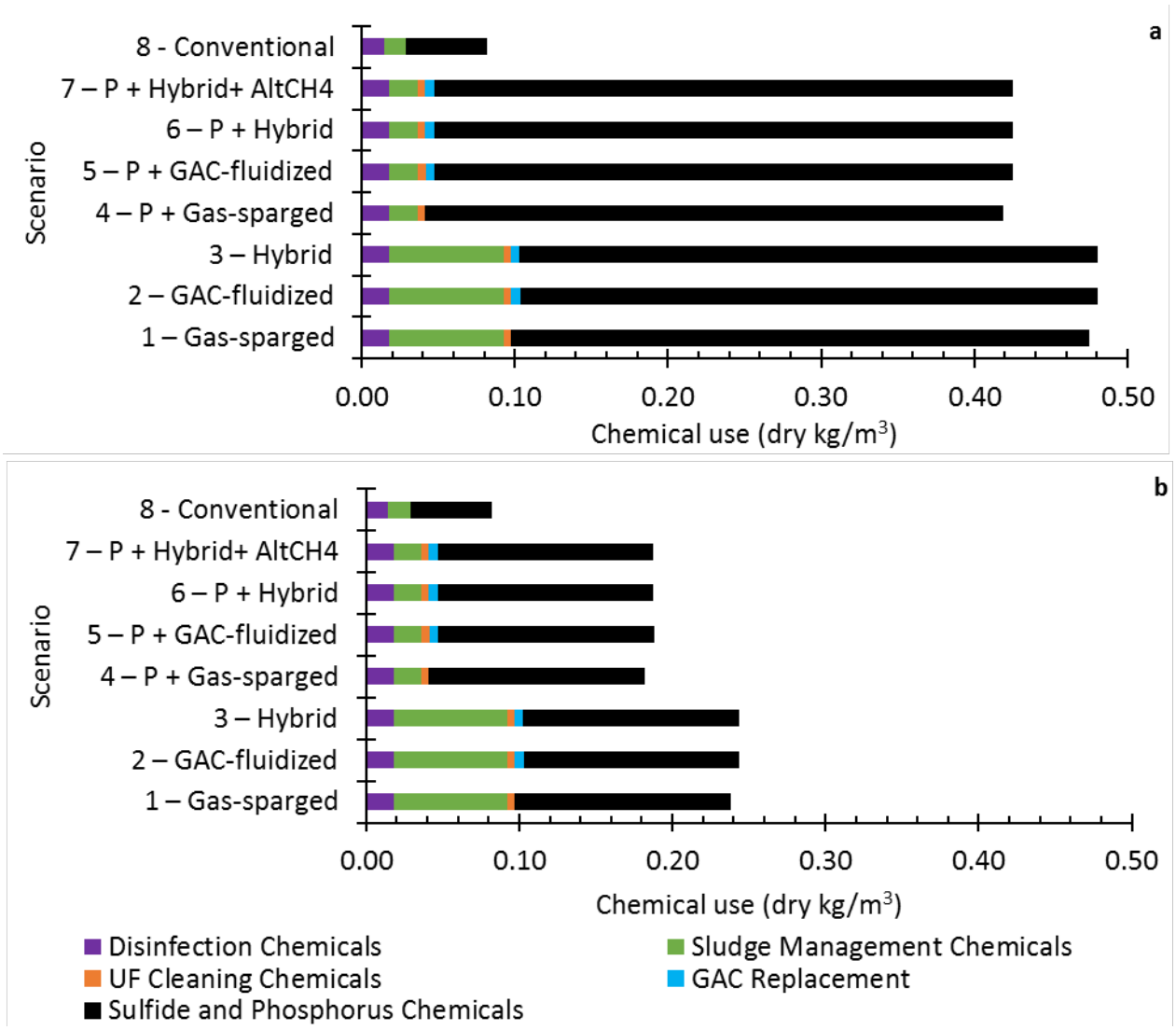


Figure 7.7 Total Chemical Use Per Unit Volume of Water Treatment for Different AnMBR Scenarios at 15 LMH Using Ferric Chloride and ACH (a) or Alum (b) for Phosphorus and Sulfide Removal in Comparison to Conventional Treatment.

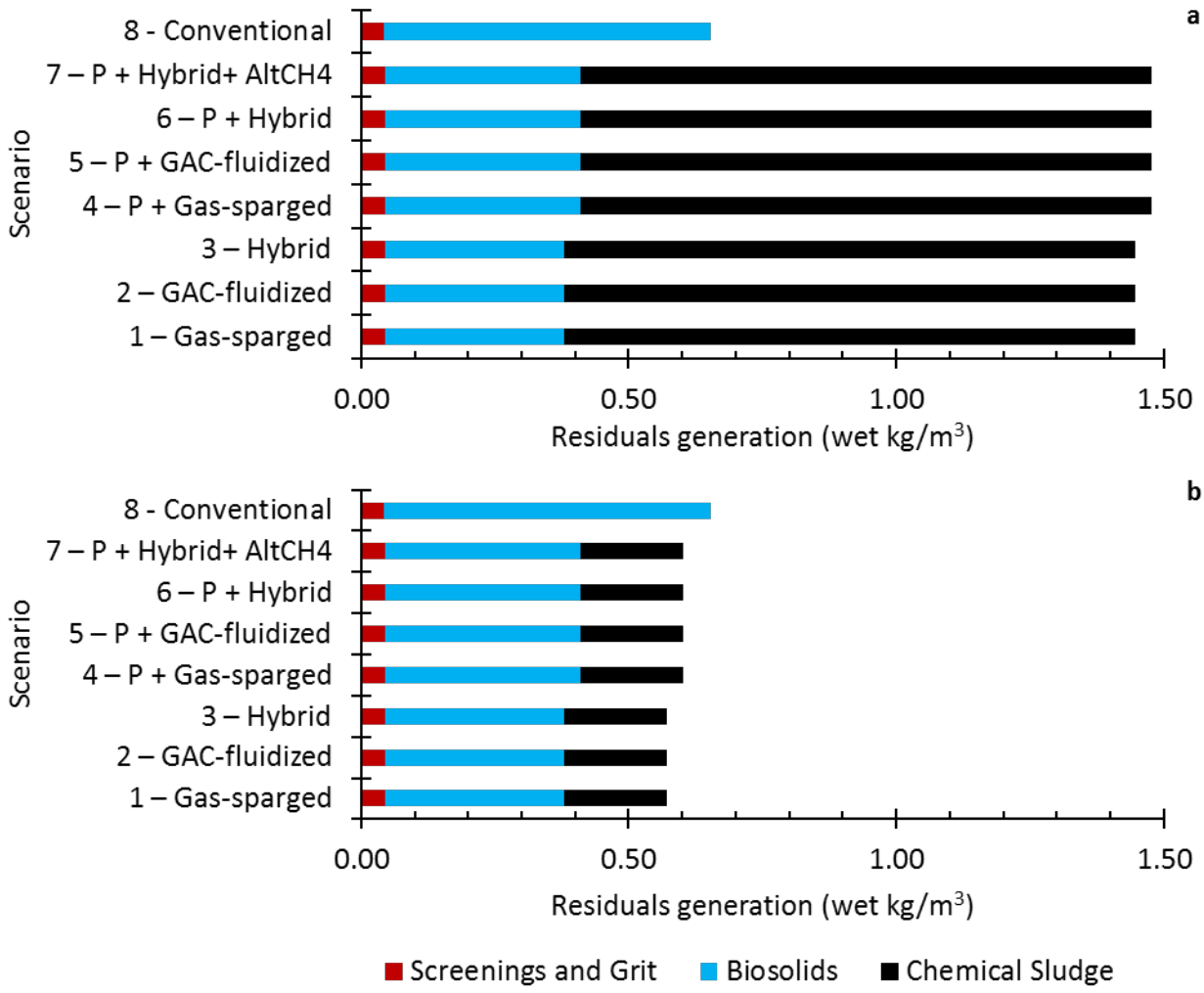


Figure 7.8 Total Solid Residuals Produced per Unit Volume of Water Treatment for Different AnMBR Scenarios at 15 LMH Using Ferric Chloride and ACH (a) or Alum (b) for Phosphorus and Sulfide Removal in Comparison to Conventional Treatment.

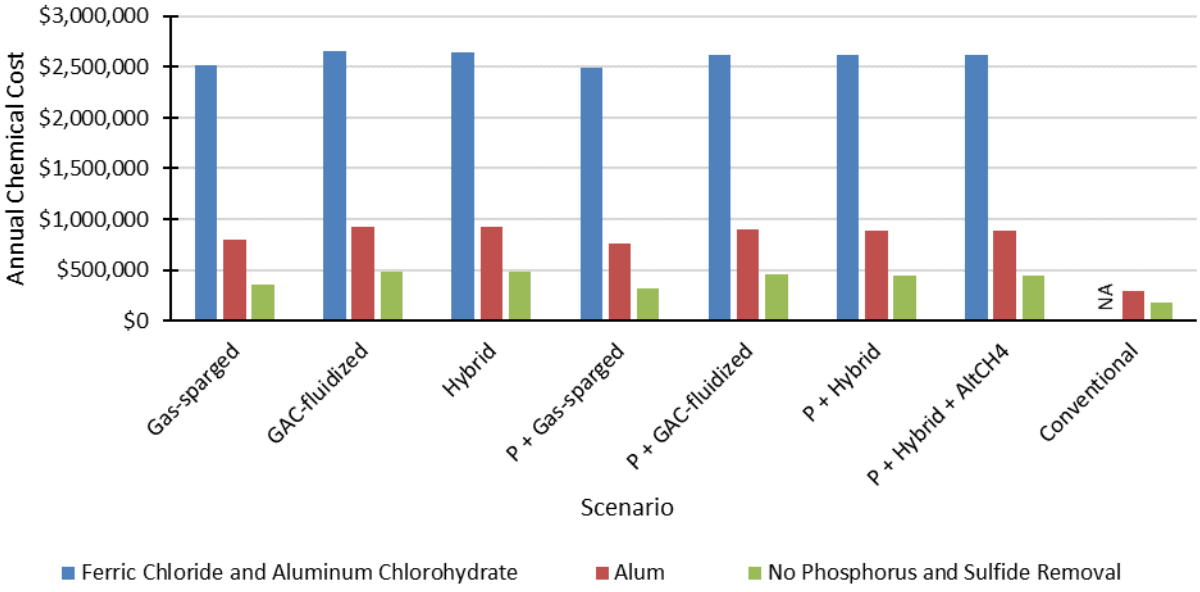


Figure 7.9 Comparison of Total Annual Chemical Costs Associated with Different Approaches for Phosphorus and Sulfide Removal at 15 LMH.

Total costs include chemicals for membrane cleaning and sludge management.

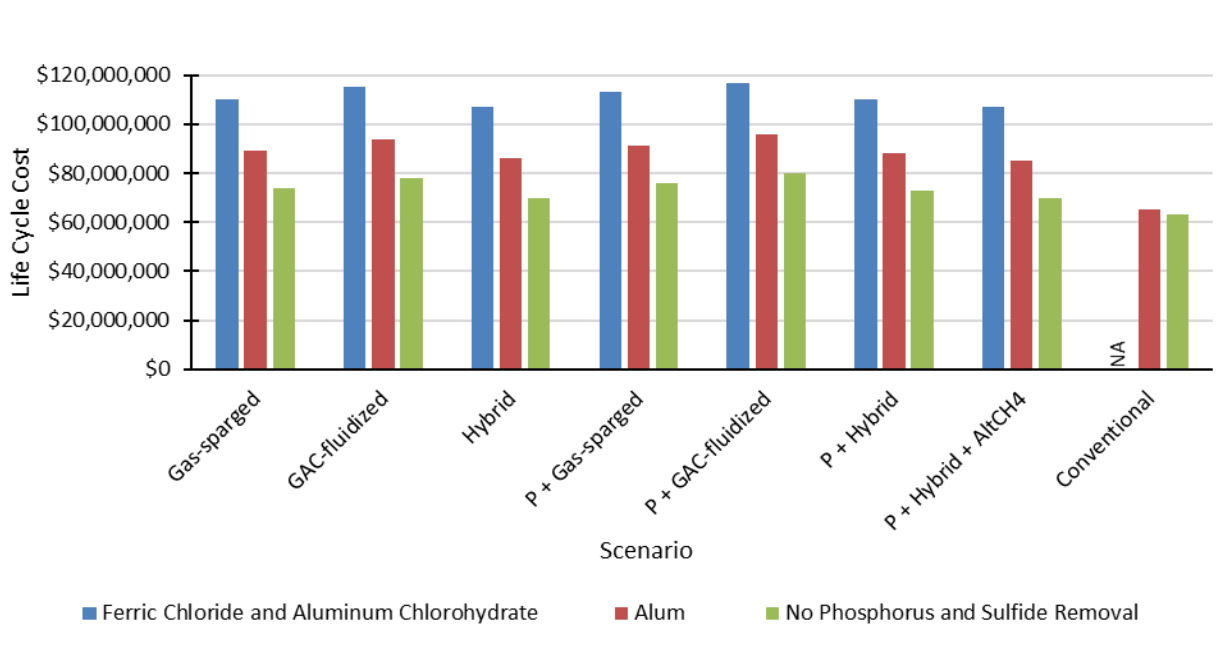


Figure 7.10 Comparison of Lifecycle Costs Associated with Different Approaches for Phosphorus and Sulfide Removal at 15 LMH and > 25°C.

Total costs include chemicals for membrane cleaning and sludge management.

One commonly used method of capital cost comparison wastewater treatment is the facility construction cost per gallon-per-day (gpd) of rated treatment capacity (on an annual average flow basis). This analysis was performed for all scenarios, and a summary is provided in Figure 7.11. Construction cost per gpd of treatment capacity for full-scale facilities is highly dependent on site-specific variables, including climate, site excavation conditions, hydraulic profile constraints, and the economic bidding climate. Based on CDM Smith's experience, conventional activated sludge treatment plants without tertiary treatment and without nutrient removal can range in construction cost from $4/gallon to costs exceeding $12/gallon. The low end of that range is possible for warm-weather plants with very few to no ventilated buildings and all pump stations located at grade, limited redundancy, and no on-site sludge processing. On the other hand, costs at the high end of the range are more typical for cold weather climates with ventilated and heated buildings, deeper structures and pump stations, and plants with extensive on-site sludge processing systems. Construction costs exceeding $12per gpd can be expected for plants requiring biological nutrient removal, which was not included in this analysis. The conventional activated sludge treatment capital cost of $10.50 per gpd presented in Figure 7.11 (which does not include engineering design services) is in the middle of the range for a typical conventional activated sludge plant. It is possible that the estimated costs for sludge handling, anaerobic digestion, and energy recovery for all alternatives (AnMBR and conventional) are higher than those presented here. However, these higher sludge handling costs would be similar for all alternatives and, thus, would not differentiate the alternatives.

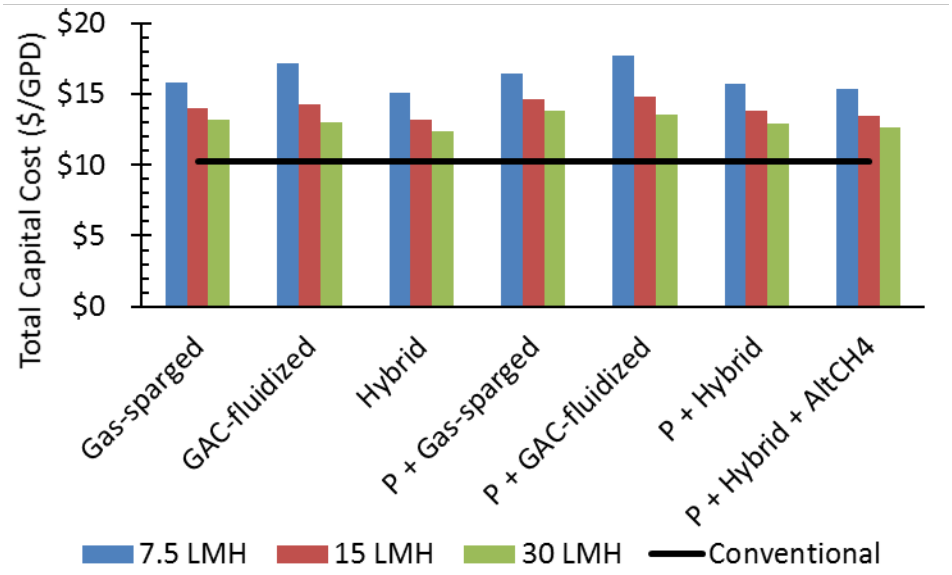


Figure 7.11 Total Capital Cost Including Direct and Indirect Costs Per Gallon-per-day Design Capacity.

The calculated operating cost per 1000-gallons as a function of flux and temperature for each scenario is shown in Figure 7.12. It should be noted that this cost does not include maintenance or labor costs, as described previously. While higher temperatures result in slightly lower operating costs due to excess energy produced in the form of methane, this additional energy is not significant when compared with the costs associated with chemical use. These results reinforce the conclusion that chemical costs for sulfide removal are a major factor leading to greater costs for AnMBR processes.

Previous studies (Cashman et al. 2018, Cashman and Mosley 2016, Khan et al. 2016, Pretel et al. 2016, Schoener et al. 2016, Smith et al. 2014) have not considered sulfide removal. As discussed in Section 7.4, chemical use also leads to greater environmental impacts. Demonstration of alternative sulfide removal technologies that are not as dependent on chemical use is needed. A biological process has been evaluated previously (Cai et al. 2017) and warrants further evaluation for treatment of AnMBR permeate because biological treatment has been used successfully to remove hydrogen sulfide from biogas at the full-scale (Woo et al. 2017).

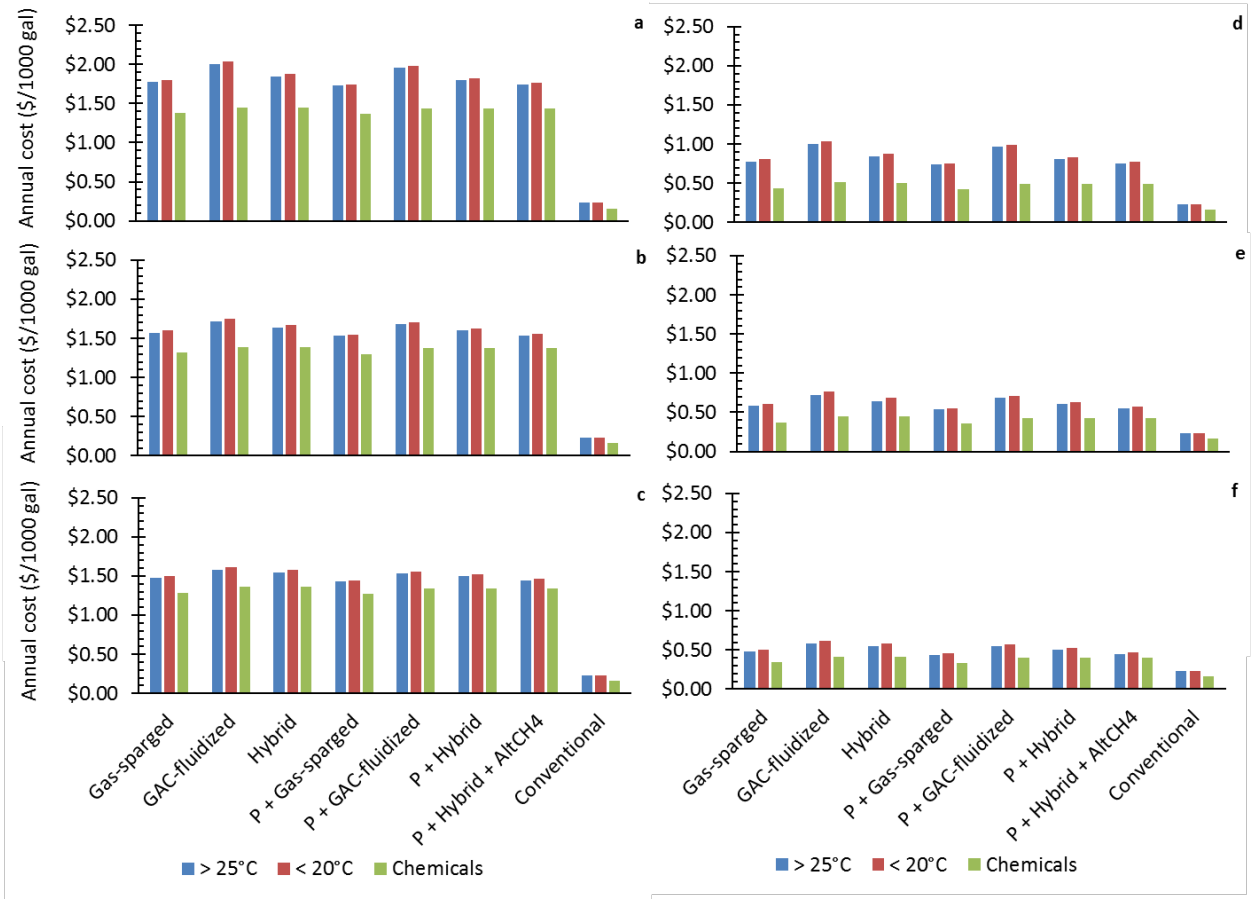


Figure 7.12 Operating Cost Per 1000-gallons for AnMBR Scenarios at 7.5 LMH (a,d), 15 LMH (b,e), and 30 LMH (c,f) and Conventional Treatment at Different Temperatures Compared to Chemical Cost (i.e., Membrane Cleaning, Sulfide and Phosphorus Removal, Sludge Management, Disinfection, and GAC Replacement) Based on Use of Ferric Chloride and ACH (a,b,c) or Alum (d,e,f). Maintenance and Labor Costs Are Not Included.

Summary

The AnMBR process has the potential to be cost-competitive with conventional treatment considering the possibility of energy-positive operation. The application of a hybrid process involving a GAC-fluidized bioreactor followed by a gas-sparged UF membrane process and a low-cost process for dissolved methane removal appears to be promising. Alternative methods for sulfide removal such as biological oxidation (Cai et al. 2017) should be evaluated because chemical coagulation is likely to be cost-prohibitive. Membrane replacement costs and chemical

costs for membrane cleaning also must be considered. The actual lifetime of UF membranes in an AnMBR is unknown; however gas-sparged UF membrane lifetime is expected to be ten years or more based on experience with aerobic membrane bioreactors using the same or similar membranes (Cote et al. 2012, Kubota Membrane Europe 2008). Chemical use for membrane maintenance and recovery cleaning should be considered and optimized. Implementation of the AnMBR process in warmer climates and on relatively strong wastewater streams can increase the potential for even more energy-positive operation and overall cost reduction. Finally, the AnMBR is a new process that has not had years of operational experience like conventional treatment processes. Therefore, it is not unexpected that AnMBR costs are greater than conventional treatment costs. The potential for cost reduction exists and can be realized through process implementation. Implementation on smaller distributed systems is a logical first step.

7.4 LIFECYCLE ASSESSMENT

The objective of the LCA is to identify components of each treatment technology process that contribute the most towards environmental impacts and provide recommendations for developing a sustainable treatment process. This section presents the LCA methodology, results, and findings.

7.4.1 Methodology

The functional unit is 5 MGD of treated wastewater on a daily operational basis (Cashman et al. 2018, Cashman and Mosley 2016, Smith et al. 2014). The water quality of the effluent was assumed to be the same for all processes and, therefore, was not considered in the LCA boundary. In addition, the construction and infrastructure of the treatment plant was not included in the LCA boundary, as previous studies have shown the operation stage of the plant as the primary environmental impact contributor (Smith et al. 2014). A process flow diagram showing the LCA boundary is shown in Figure 7.13.

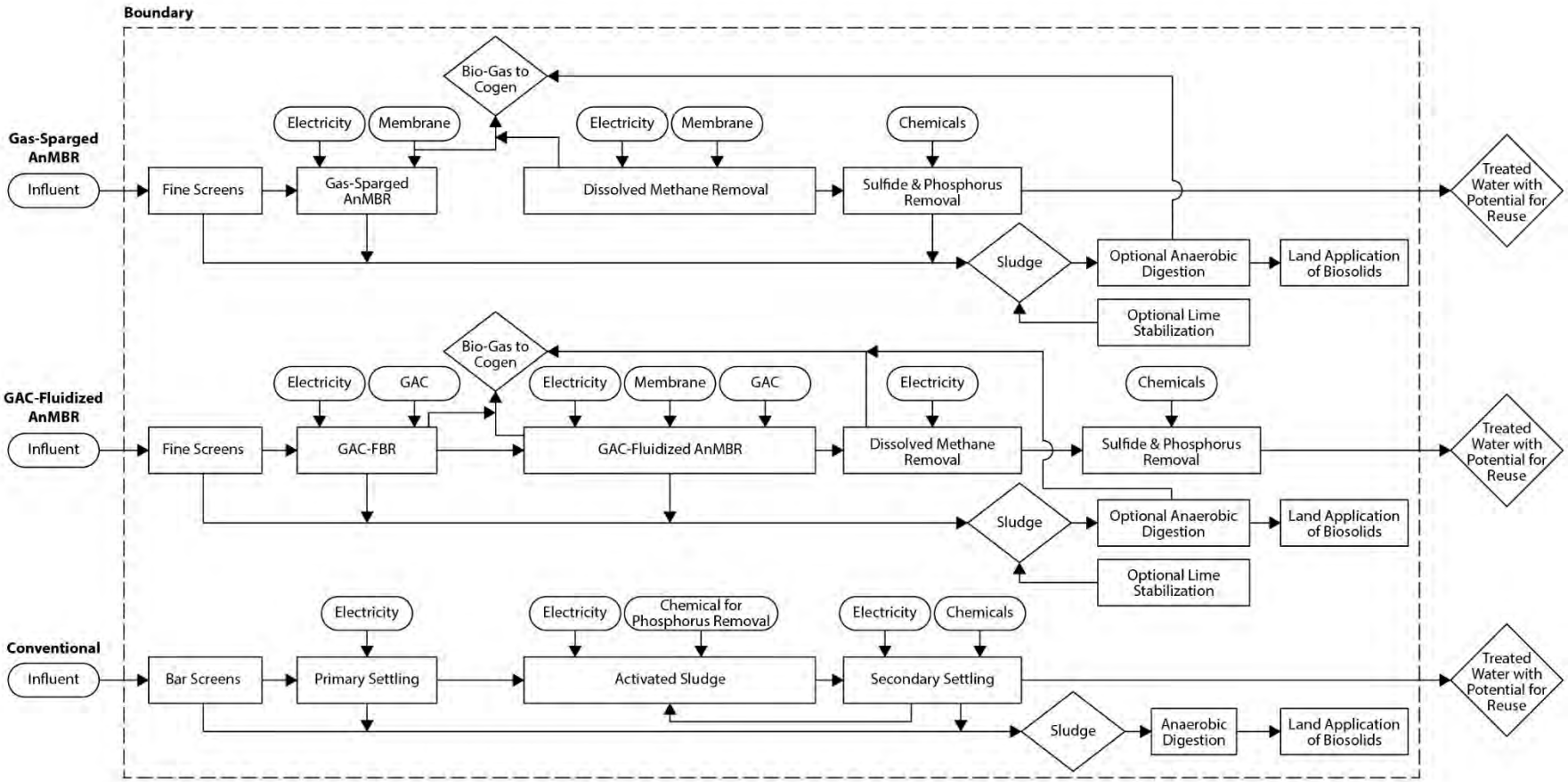


Figure 7.13 LCA Boundary.

The sustainability assessment considered consumption of raw materials and natural resources during materials acquisition, production, use stages, and end-of-life processes during plant operation. Appendix H presents the lifecycle inventory (LCI) and additional supporting information for the LCA. Primary data regarding energy and material consumption during each treatment process was compiled from engineering data and vendor specifications. Membrane modules were composed of polyvinyl chloride (PVC), polyester, and polypropylene. The membranes are composed of a thin coating of PVDF on a polyester matrix. PVDF is not available in the LCA database and comprises a very small percentage of the total mass of the membrane and, therefore, was not considered in the analysis. Polyester, PVC and polypropylene were included in the analysis. The polymer used for phosphorus removal as well as for sludge thickening was composed of polyacrylamide, kerosene (as surrogate for hydrotreated light petroleum distillates, which are listed as a component of the polyacrylamide emulsion polymer), and ultrapure water input parameters. Polyaluminum chloride (PACl) was used in the analysis to represent ACH (which is not listed in the ecoinvent LCA database).

Environmental impact offsets designated as "avoided products" were associated with energy production from biogas and methane recovery, elemental sulfur produced as a byproduct during biogas handling, and excess heat from biogas handling. An avoided product subtracts from the lifecycle environmental impact of the designated product.

All membrane materials were assumed to be recycled at the end of their useful life. Gravel and grit generated during primary treatment were assumed to be disposed of as inert material at a sanitary landfill. Biological and chemical sludge generated were assumed to be beneficially land applied. This scenario is similar to that conducted by others (Smith et al. 2014), which included electricity and diesel consumption and offsets of nitrogen and phosphorus as fertilizers.

LCI data for treatment system operation (e.g., production of chemicals, membrane materials) were based on average technology data from the ecoinvent lifecycle unit process database Version 3. The lifecycle impact assessment method used was the Tool for the Reduction and Assessment of Chemical and other Environmental Impacts (TRACI) Version 2.1 (Bare 2011, Bare et al. 2003), to facilitate comparison to previous studies (Cashman et al. 2018, Cashman and Mosley 2016, Smith et al. 2014). The TRACI environmental impact categories evaluated included: ozone depletion, global warming, smog, acidification, eutrophication, carcinogenics, non-carcinogenics, respiratory effects, ecotoxicity, and fossil fuel depletion.

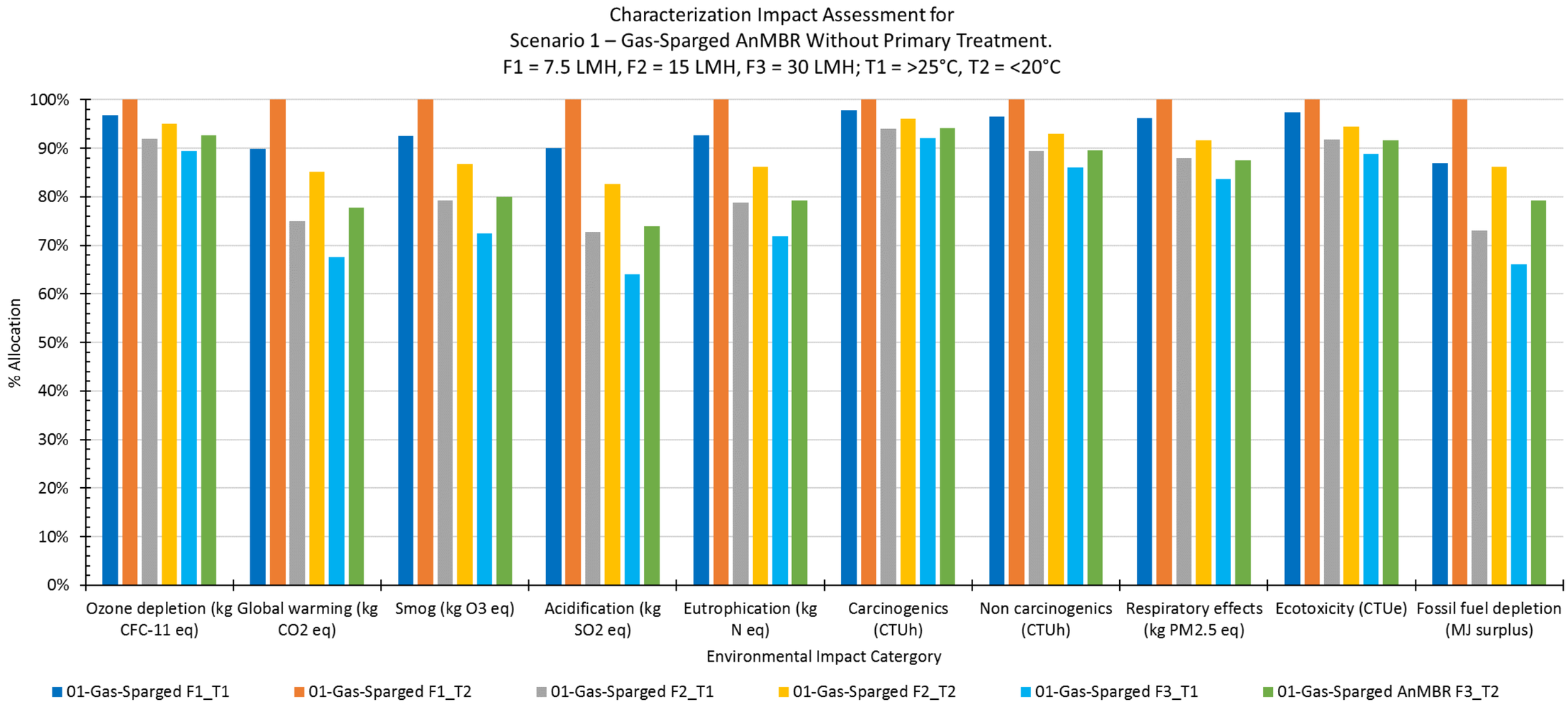
Two normalization analyses were performed: 1) one set of normalization factors (NF) using the EPA's TRACI 2.1 LCIA method (Bare 2011, Bare et al. 2003) for the United States region, which relate the impact scores to the average impact of a U.S. citizen per year; and 2) the second set of NFs using the conventional treatment process LCA outputs as conducted in similar studies (Smith et al. 2014).

Sensitivity analyses were performed to evaluate changes to environmental impact drivers from eliminating the nutrient removal process and substituting of aluminum sulfate (i.e., alum) for ferric chloride and PACl under the nutrient removal process.

7.4.2 Results: Individual Treatment Process Comparisons

For each of the seven AnMBR treatment processes assessed, six flux-temperature (7.5, 15, and 30 LMH; >25°C and <20°C) scenarios were evaluated. Figure 7.14 shows the characterization environmental impact assessment results for the gas-sparged AnMBR process without primary sedimentation (scenario 1) at each flux and temperature scenario. A characterization graph shows each flux and temperature scenario's relative contribution to environmental impact categories in relation to the scenario with the greatest contribution (highest score) per impact category set at 100%. Figures showing the characterization environmental impact assessment of the other AnMBR scenarios (i.e., 2 through 7) across varying flux and temperatures are provided in Appendix H. In general, as the flux increases (from 7.5 LMH to 30 LMH) and temperature increases (from <20°C to >25°C), overall contributions to environmental impacts decrease. The treatment process with least contributions to environmental impacts has a flux of 30 LMH and a temperature of >25°C.

Normalization offers reference situations of the pressure on the environment for each impact category. The reference situations evaluated in this study are environmental impacts relative to: 1) an average U.S. citizen per year (i.e., TRACI), and 2) the conventional treatment approach (Scenario 8). Normalized impact assessments were performed for each flux and temperature scenario, for each treatment process. The normalization impact assessment using the TRACI NFs indicates how much a treatment process contributes to a specific environmental impact category relative to the average impact of a US citizen per year. This assessment for the hybrid AnMBR process without primary sedimentation (Scenario 3) identified that all treatment processes, including conventional, had the greatest environmental impacts relative to an average US citizen per year for carcinogenics, followed by ecotoxicity, non-carcinogenics, and eutrophication. (Figure 7.15). The normalized impact assessment using NFs representative of the conventional treatment approach (scenario 8) identified that the hybrid AnMBR treatment process without primary sedimentation had 4 to 20 times the environmental impact as the conventional treatment scenario (Figure 7.16). Fossil fuel depletion was the greatest impact category. Figures showing the normalized environmental impact assessment of the other AnMBR treatment scenarios across varying flux and temperatures are provided in Appendix H and indicate support similar conclusions. As will be seen below, the main source of the environmental impacts is chemical consumption for sulfide removal.



Acronyms:

CTUe - Comparative Toxic Units for ecosystems
CTUh - Comparative Toxic Units for humans
kg CFC-11 eq - kilograms of chlorofluorocarbon-11 equivalent
kg CO2 eq - kilograms of carbon dioxide equivalent
kg N eq - kilograms of nitrogen equivalent
kg O3 eq - kilograms of ozone equivalent
kg PM2.5 eq - kilograms of fine particulate matter equivalent
kg SO2 eq - kilograms of sulfur dioxide equivalent
MJ Surplus - megajoule surplus

Figure 7.14 Relative Impact Assessment for Scenario 1 – Gas-sparged AnMBR Without Primary Treatment.

F1 = 7.5 LMH, F2 = 15 LMH, F3 = 30 LMH; T1 = >25°C, T2 = <20°C.

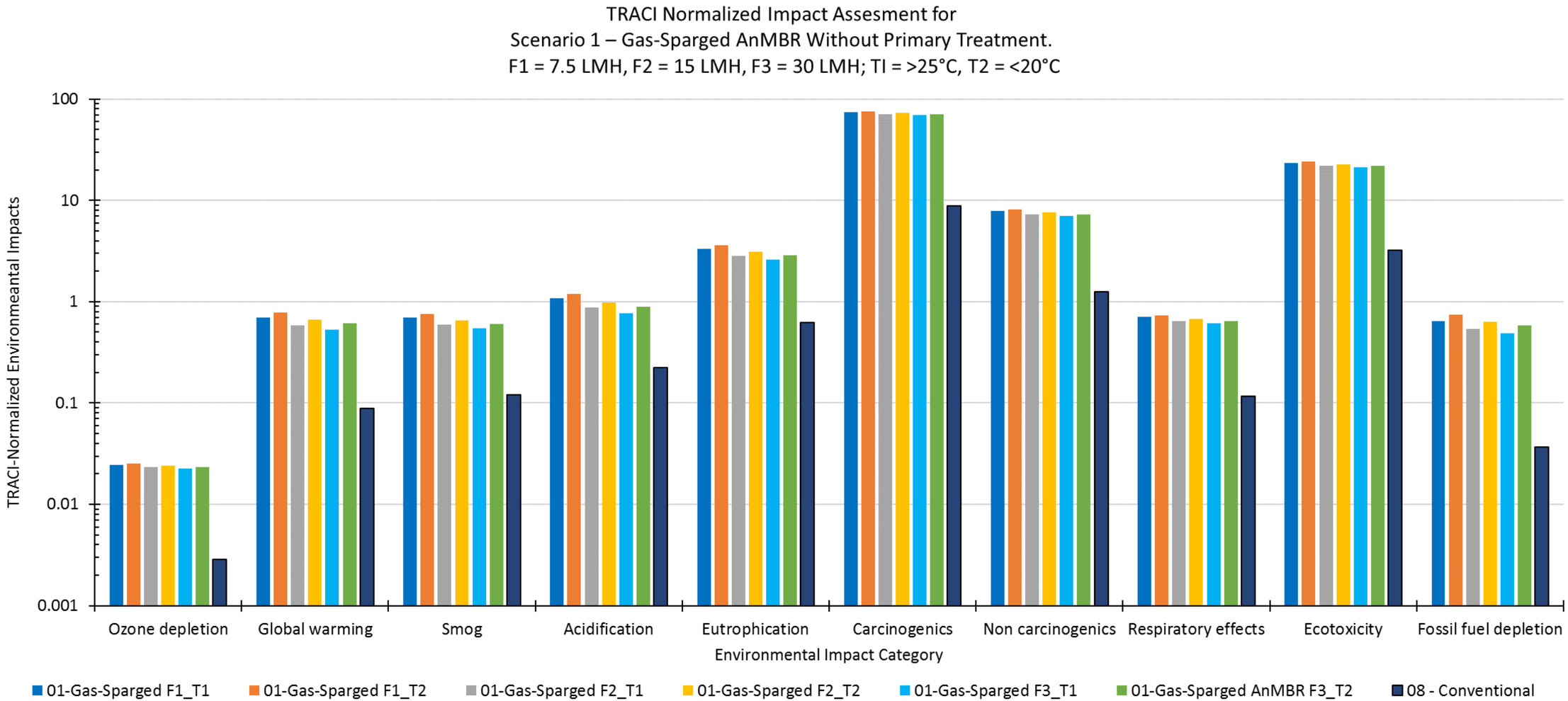


Figure 7.15 TRACI Normalized Impact Assessment for Scenario 3 – hybrid AnMBR.

F1 = 7.5 LMH, F2 = 15 LMH, F3 = 30 LMH; TI = >25°C, T2 = <20°C.

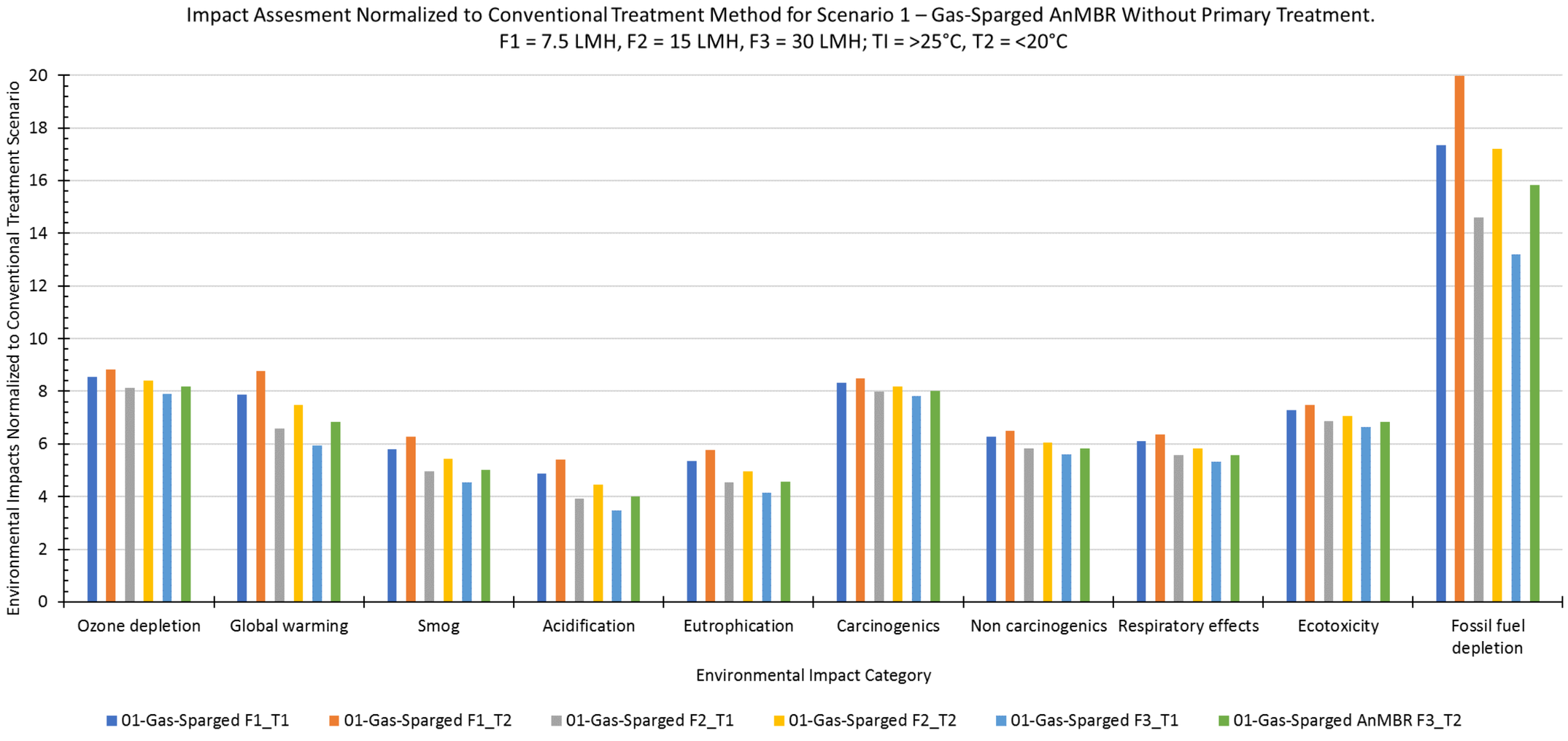


Figure 7.16 Impact Assessment Normalized to Conventional Treatment Method for Scenario 3 – hybrid AnMBR.

F1 = 7.5 LMH, F2 = 15 LMH, F3 = 30 LMH; TI = >25°C, T2 = <20°C.

To achieve a better understanding of the components of the treatment process that are major contributors to environmental impacts and thus resulting in greater contributions to impact categories in comparison to a conventional treatment approach, Sankey diagrams of the individual treatment processes were reviewed for carcinogenics, ecotoxicity, and global warming. These diagrams illustrate lifecycle outputs of a single impact category by using proportional arrow width as flow quantity. Red arrows indicate a negative environmental impact and green arrows indicate a positive environmental offset. Figure 7.17 through Figure 7.19 show the normalized environmental impact Sankey diagrams for the hybrid AnMBR process without primary sedimentation (Scenario 3) at 15 LMH and >25°C based on conventional treatment NFs presented in Figure 7.16.

The Sankey diagrams indicate that sulfur and phosphorus removal is the primary treatment process component contributing to greater carcinogenics, ecotoxicity, and global warming environmental impacts compared to a conventional treatment approach, followed by secondary treatment, dissolved methane, and disinfection for all treatment processes evaluated.

Environmental impact drivers from the sulfide and phosphorus removal component are PACl and ferric chloride, with a minor contribution from electricity consumption. Ferric chloride is a byproduct of steel pickling, and therefore, results in a smaller environmental footprint than raw material production of PACl. The environmental impact drivers from the secondary treatment component are primarily electricity, citric acid (i.e., for all environmental impacts except carcinogenics), and sodium hypochlorite. The primary environmental impact driver from the dissolved methane component is electricity and the primary environmental driver from the disinfection component is sodium hypochlorite. Additional environmental impact drivers were identified in the global warming Sankey diagram, including: water consumption during sulfide and phosphorus removal; GAC consumption during secondary treatment; and quicklime consumption during sludge management (see Appendix H).

Figure 7.20 shows the ecotoxicity characterization environmental impact Sankey diagram for the conventional treatment approach. The environmental impact drivers identified for the conventional treatment process were aluminum sulfate (i.e., alum) consumption during phosphorus removal, electricity consumption during secondary treatment, and sodium hypochlorite and water consumption during disinfection. The ecological impact for the conventional treatment process (3.55×10^4 CTUe) is much less than that for the hybrid AnMBR process (8.69×10^9 CTUe) because of the chemical requirement for sulfide removal.

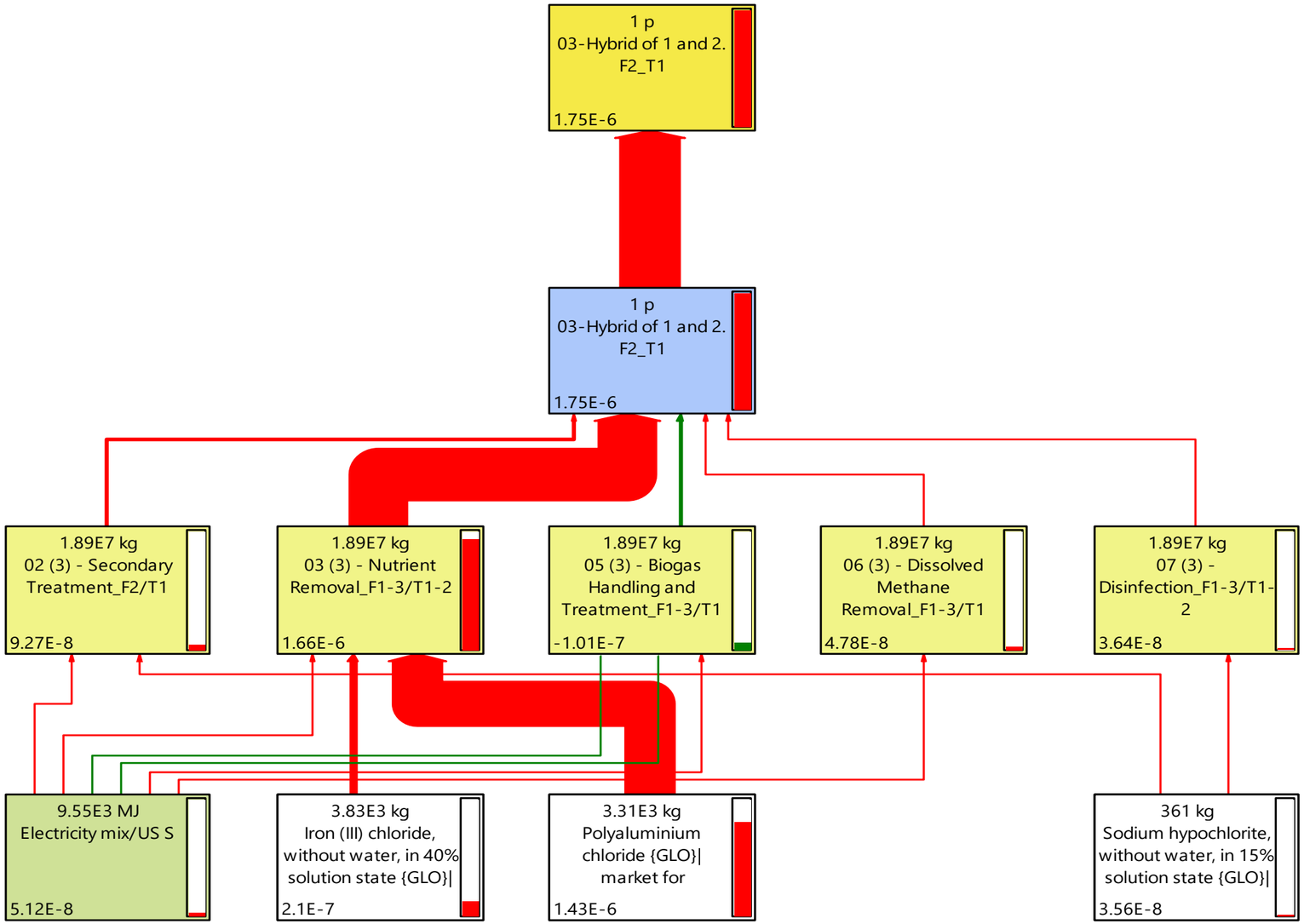


Figure 7.17 Carcinogenics (CTUh) Impact Assessment Normalized to Conventional Treatment Method.

Sankey diagram for Scenario 3 - hybrid AnMBR at 15 LMH and >25°C.

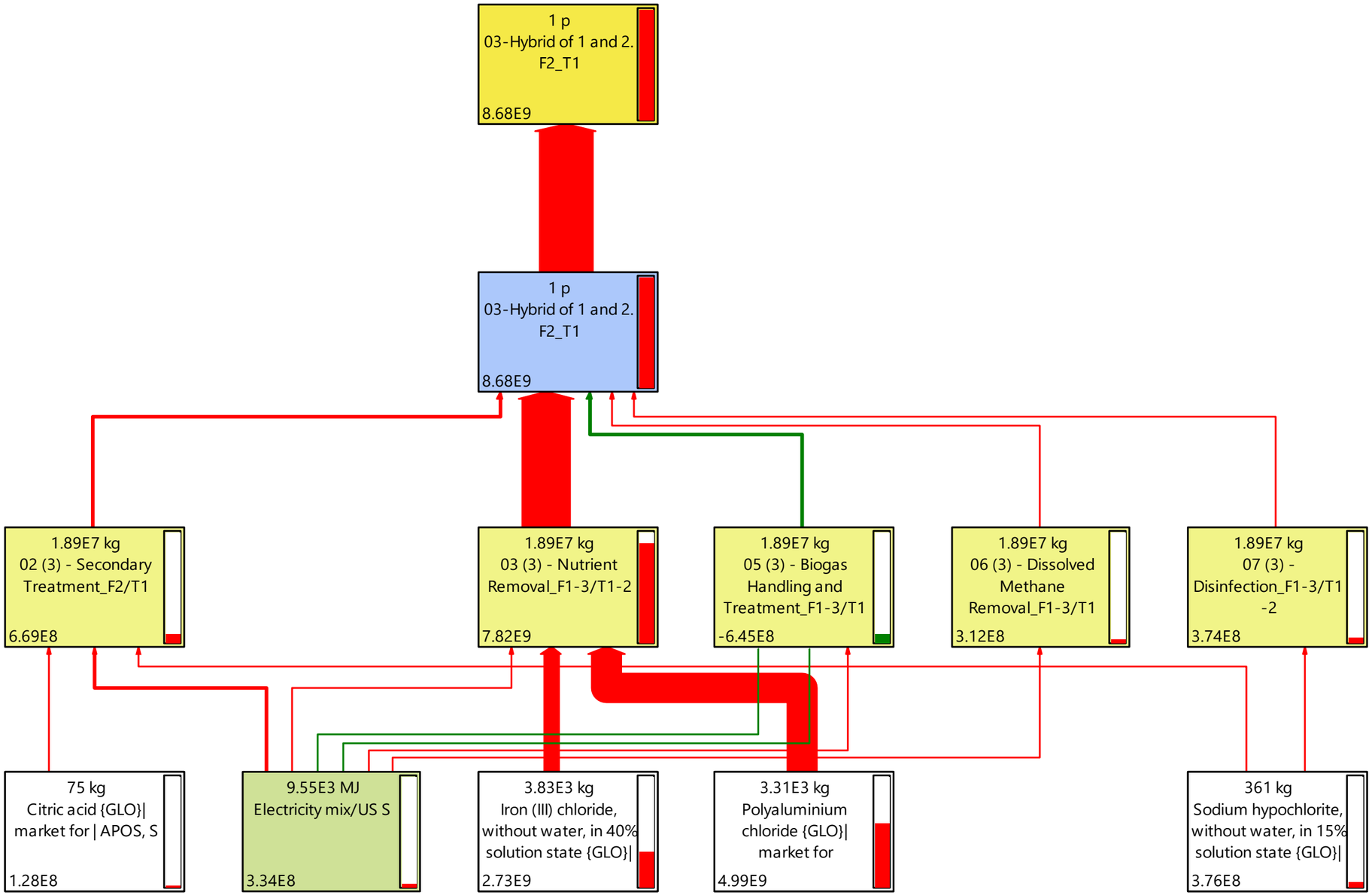


Figure 7.18 Ecotoxicity (CTUe) Impact Assessment Normalized to Conventional Treatment Method.

Sankey diagram for Scenario 3 - hybrid AnMBR at 15 LMH and >25°C.

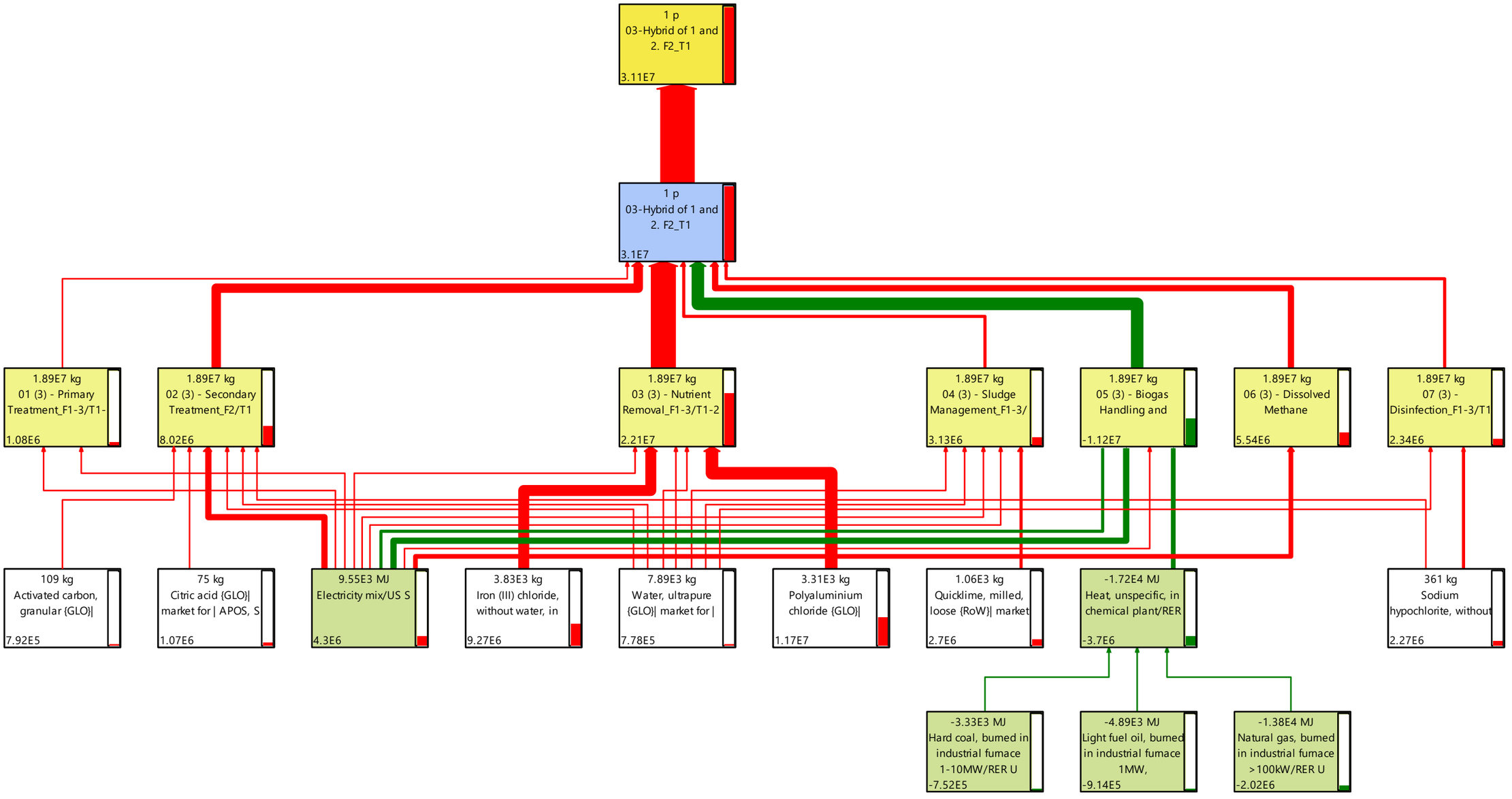


Figure 7.19 Global Warming (kg CO2 eq) Impact Assessment Normalized to Conventional Treatment Method.

Sankey diagram for Scenario 3 - hybrid AnMBR at 15 LMH and >25°C.

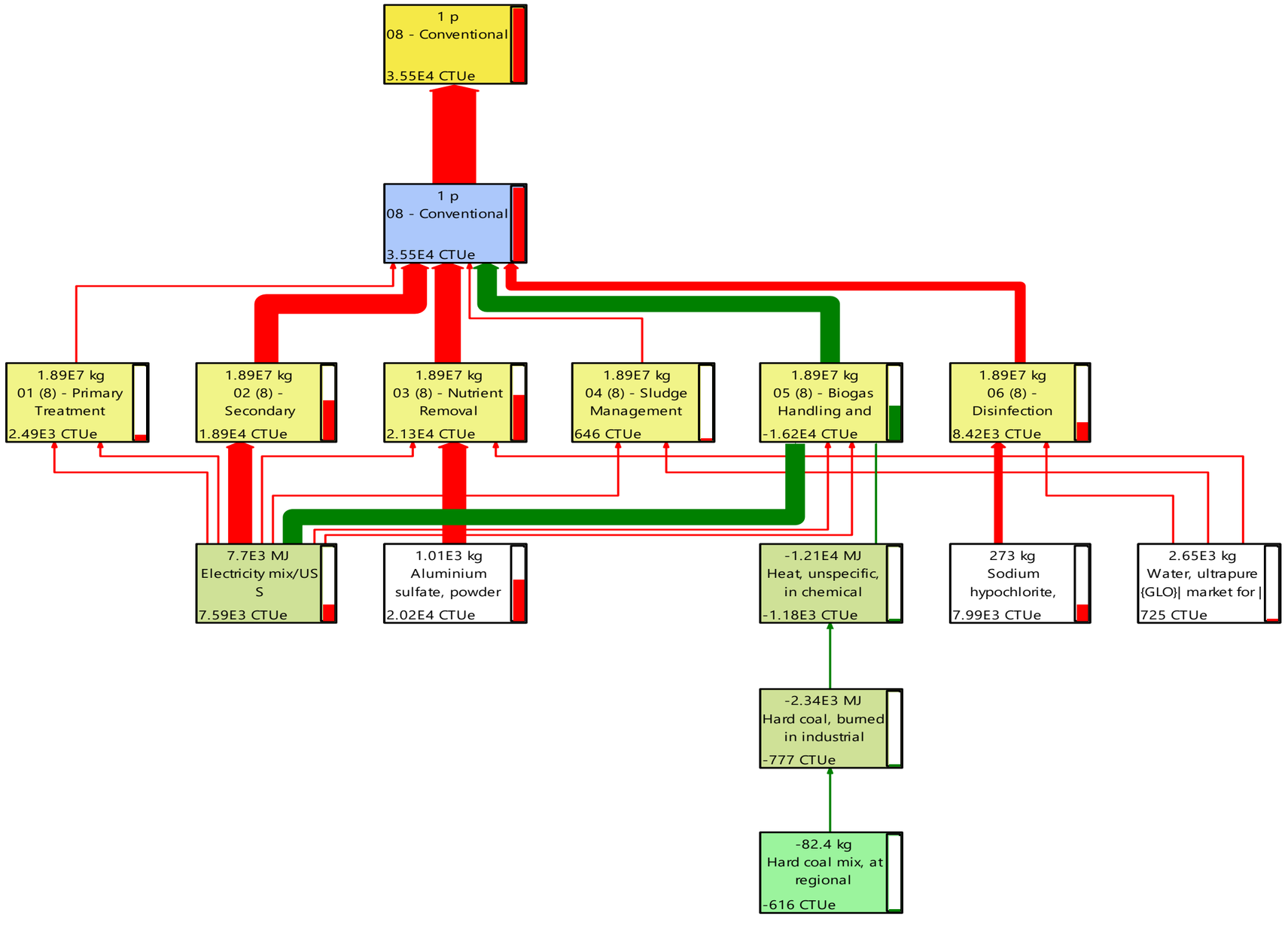


Figure 7.20 Ecotoxicity (CTUe) Characterization Impact Assessment Method.

Sankey diagram for Scenario 8 – conventional treatment.

7.4.3 Results: Flux and Temperature Scenario Technology Comparisons

For all the flux and temperature scenarios evaluated, the conventional treatment process had a significantly lower impact than the AnMBR treatment processes. This is primarily attributable to the differences in chemical and electricity consumption requirements. Figure 7.21 shows the characterization impact assessment for all AnMBR treatment scenarios at a flux 15 LMH and temperature of >25°C alongside the conventional scenario.

In general, integration of primary treatment (Scenarios 4 through 6) to both gas-sparged and GAC-fluidized AnMBR treatment processes reduces overall contributions to environmental impact categories. The GAC-fluidized AnMBR process (Scenarios 2 and 5) had less impact than the hybrid process (Scenarios 3 and 6) and the gas-sparged AnMBR process (Scenarios 1 and 4). As shown in Appendix H, changes in the flux and temperature resulted in minor increases and decreases in overall contributions to environmental impact categories for each treatment scenario. Characterization impact assessments comparing treatment scenarios for the other five flux/temperature conditions had similar results and are presented in Appendix H.

In summary,

- At a lower flux (7.5 LMH), for both temperature regimes (>20°C and >25°C), primary treatment with GAC-fluidized AnMBR process (Scenario 5) had the lowest overall environmental impact among the AnMBR treatment processes.
- At an intermediate flux (15 LMH), for both temperature regimes (>20°C and >25°C), primary treatment plus hybrid AnMBR plus vacuum degassing tank process (Scenario 7) had the lowest overall environmental impact among the AnMBR treatment processes.
- At a high flux (30 LMH), for both temperature regimes (>20°C and >25°C), primary treatment plus gas-sparged (Scenario 4) has a comparable overall lower environmental impact as the primary treatment plus hybrid AnMBR plus vacuum degassing tank process (Scenario 7).

The changes in total environmental impact contributions observed by the varying flux and temperature scenarios are primarily due to the differences in environmental impact offsets from electricity and heat generated in comparison to the total environmental impacts due to consumption of energy and materials (including chemicals) for a particular process operating at a specific flux and temperature. For example, with increasing flux the electricity consumption for gas-sparging decreases leading to a lower environmental impact.

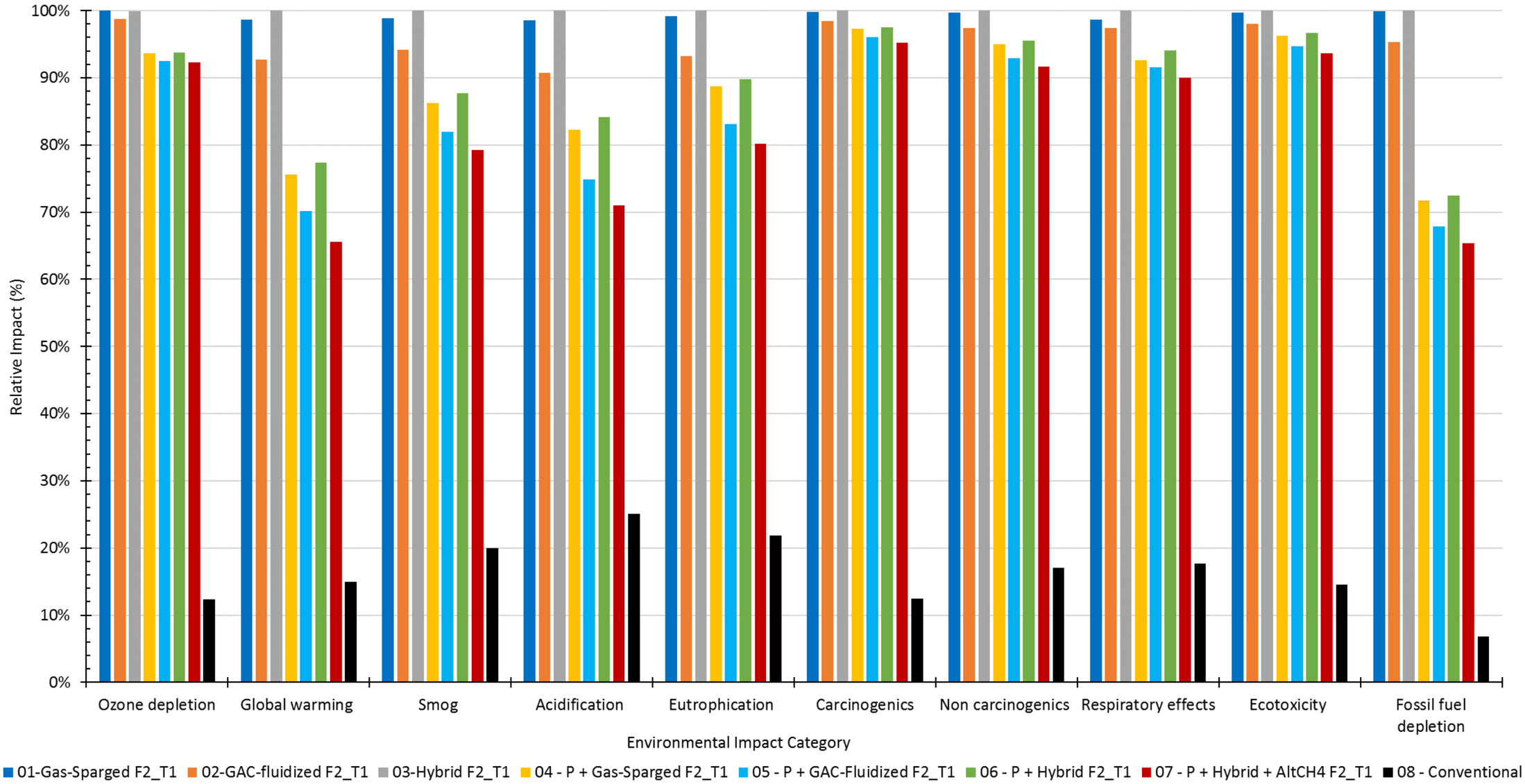


Figure 7.21 Characterization Impact Assessment of the AnMBR and Conventional Process Scenarios.

AnMBR processes are shown with 15 LMH (F1) and >25°C (T1).

7.4.4 Sensitivity Analysis of Phosphorus and Sulfide Removal

Figure 7.22 supports the above conclusions that chemical use for sulfide and phosphorus removal is the primary reason that all AnMBR scenarios, independent of flux and temperature, have greater environmental impacts across all impact categories. Eliminating the sulfide and phosphorus removal component from the treatment process resulted in more than a 70% reduction in all environmental impact categories for the seven AnMBR scenarios evaluated and in more than 24% reduction for the conventional process (Scenario 8). Furthermore, P + Hybrid + AltCH4 (Scenario 7) without nutrient removal had less impact across all categories than conventional treatment and resulted in an offset to global warming and acidification environmental impact categories. Fossil fuel depletion offsets were achieved by all processes that included primary treatment (Scenarios 4 through 7), GAC-fluidized (Scenario 2), and the conventional treatment process (Scenario 8). These offsets were achieved from biogas recovery and net energy consumption back to the grid. Greater offsets, including primary treatment (Scenarios 4 through 7), were observed at 30 LMH and > 25°C including the end points for global warming, smog (except Scenario 6), acidification, eutrophication (except Scenarios 5 and 6), and carcinogenics (except Scenarios 5 and 6), as well as a minor offset in non-carcinogenics for Scenario 7. Under this flux and temperature, all treatment scenarios resulted in offsets for fossil fuel depletion. While 30 LMH may not be realistic, the result indicates that greater flux leads to lesser environmental impact by the AnMBR process.

In general, replacing ferric chloride and PACl in the coagulation process with aluminum sulfate (alum) and reducing the use of polymer in the sludge thickening process resulted in nearly a 20% to 50% reduction across all environmental impact categories for the seven AnMBR scenarios (Figure 7.23). Fossil fuel impact was nearly eliminated in P + hybrid + AltCH_4 (scenario 7) when alum was used because of offsets that were achieved from biogas recovery and net energy consumption back to the grid. Fossil fuel impacts for scenarios 4 through 6 were less than or similar to the conventional scenario impact when alum was used for sulfide and phosphorus removal. Fossil fuel depletion offsets were achieved by all scenarios with primary treatment (Scenarios 4 through 7) at 30 LMH and > 25°C (see Appendix H). Impacts for other categories were greater for AnMBR scenarios than for the conventional scenario but less than the impacts when ferric chloride and PACl was used.

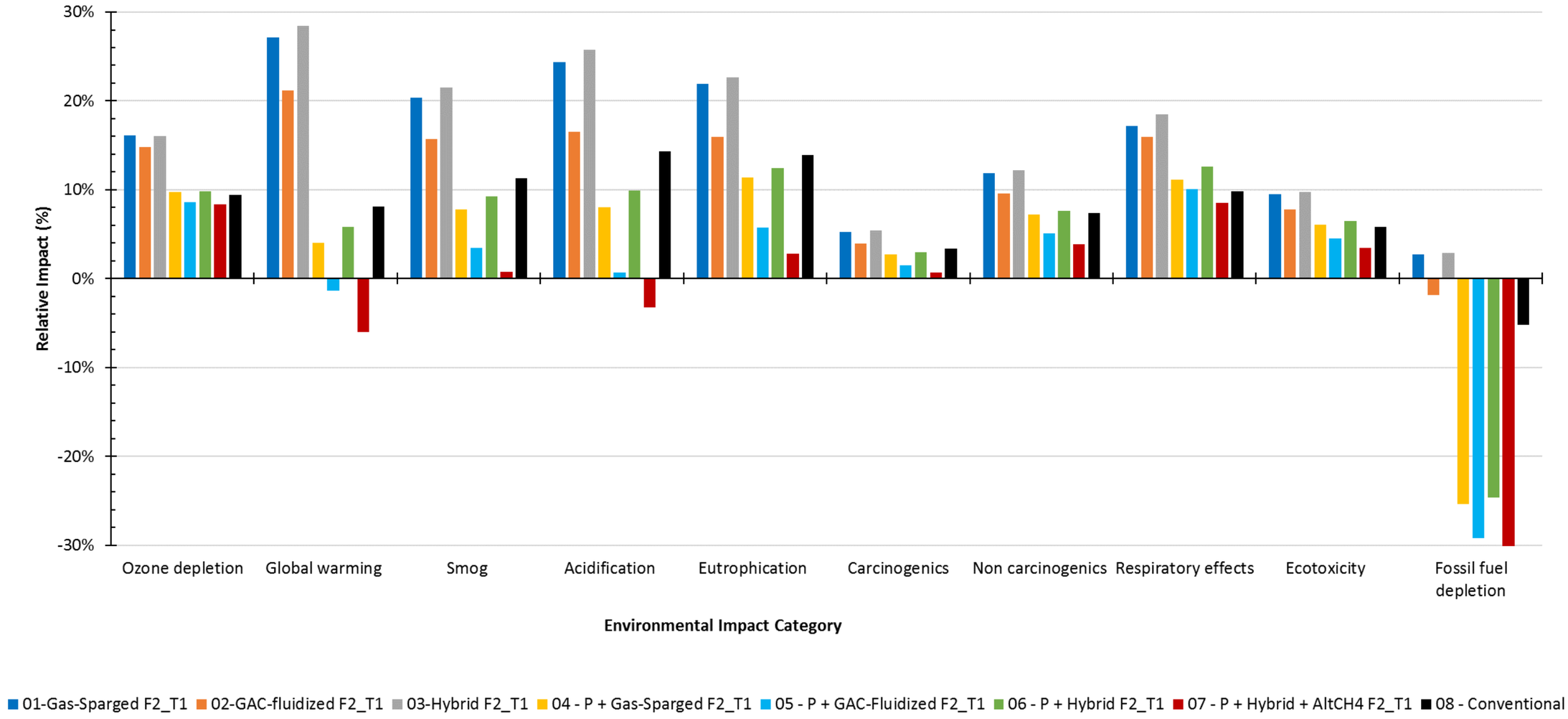


Figure 7.22 Relative Impacts of Scenarios without Sulfide and Phosphorus Removal at 15 LMH (F2) and >25°C (T1).

For all impact categories, impacts are relative to those for Scenarios 1 and 3 with sulfide and phosphorus removal which had relative impacts ranging from 99 to 100%.

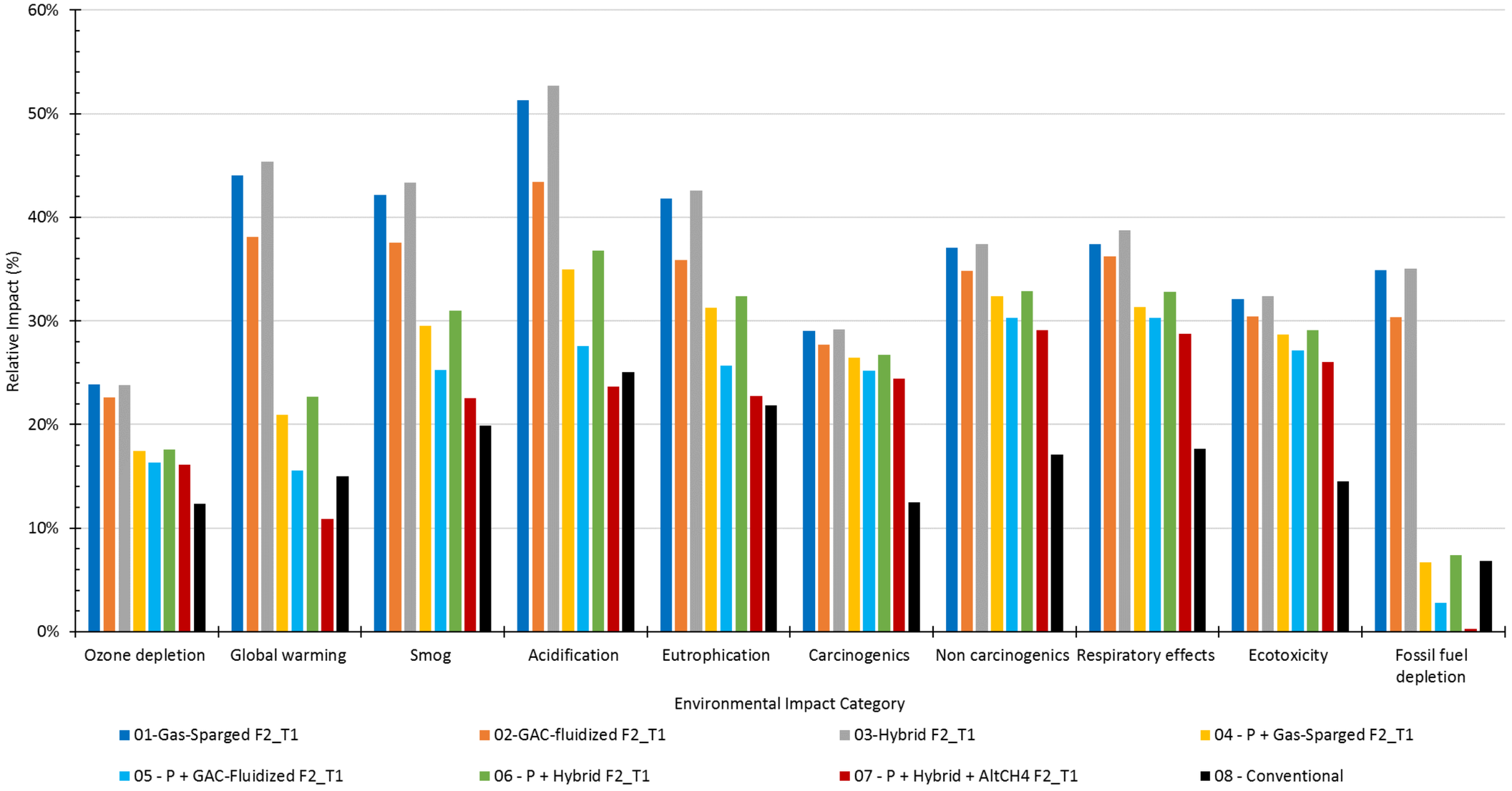


Figure 7.23 Characterization Impact Sensitivity with Respect to Sulfide and Phosphorus Removal Using Alum for Treatment Processes with 15 LMH (F2) and >25°C (T1).

For all impact categories, Impacts are relative to those for Scenarios 1 and 3 with sulfide and phosphorus removal which had relative impacts ranging from 99 to 100%.

7.4.5 Discussion: Comparison to Other Studies

Similar to previous studies (Cashman et al. 2018, Cashman and Mosley 2016, Smith et al. 2014), membrane materials and waste disposal were not identified as major environmental impact contributors. Smith et al. (2014) and this study's approach to the LCI for the membranes were slightly different, as PVDF is not included in the Ecoinvent V3.1 database. Neither approach appears to influence the overall LCA findings.

This study identified chemical consumption during the phosphorus and sulfide removal component as a major environmental impact contributor. The treatment process evaluated previously (Cashman et al. 2018, Cashman and Mosley 2016) also identified sodium hypochlorite use during chlorination as an environmental contributor. Smith et al. (2014) did not identify treatment chemicals as major contributors. The LCI for chemical consumption only consisted of PACl and citric acid, which was represented by a generic "organic chemical product" based on the available database inventory at the time of that study. In the current study, the chemical LCI was expanded to also include GAC (also considered by Cashman et al. [2018]), ferric chloride, aluminum sulfate (also considered by Cashman et al. [2018]), hydrotreated light petroleum distillates, and polyacrylamide.

This study attributed environmental impacts from treatment processes primarily to carcinogenics, ecotoxicity, and global warming. Cashman et al. and Smith et al. focused the evaluation of environmental impacts on contributions to global warming. This study identified chemical consumption during phosphorus and sulfide removal and disinfection components, and electricity consumption during secondary treatment and dissolved methane removal contributed the most towards global warming impacts. Smith et al. identified dissolved methane was the primary driver for global warming impacts, followed by electricity. Seventy-five percent of global warming impacts from Smith et al. AnMBR treatment process was from unrecovered dissolved methane released to the atmosphere. In this study, dissolved methane emitted to the atmosphere was not identified as a primary environmental impact driver because 90% was recovered. Smith et al. recommended dissolved methane management as a mitigation strategy. Cashman et al. identified heating of wastewater as the primary driver for global warming impacts, followed by electricity and chlorination. The current study did not consider heating of the wastewater.

To highlight the importance of evaluating contributions to global warming impacts, the costs borne by society from the total CO_{2eq} footprint were quantified by integrating the social cost of carbon (U.S. Government 2013). The costs borne by society represents financial implications to society for mitigation of climate change impacts. Figure 7.24 presents the costs borne by society for all treatment scenarios with a flux of 15 LMH and >25°C. Financial implications from the CO_{2eq} footprint for 20-year operation period were greater for AnMBR scenarios than the conventional scenario when ferric chloride and ACH was used for sulfide removal. When alum was used instead, the social cost for Scenario 7 is less than that for conventional Scenario 8. When no sulfide removal was conducted, all AnMBR scenarios that included primary sedimentation (i.e., Scenarios 4 through 7) have social costs less than the conventional scenario. These results support the conclusion that AnMBR treatment can be less environmentally impactful than conventional treatment.

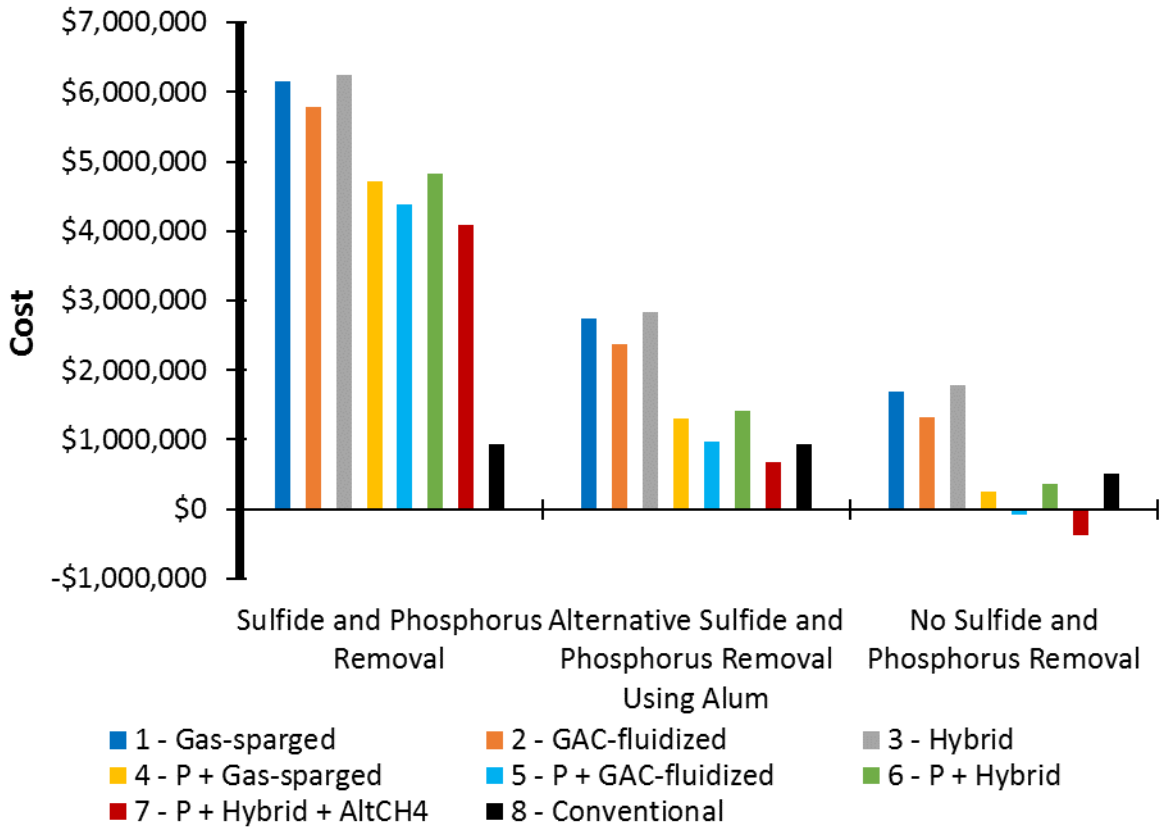


Figure 7.24 Costs Borne by Society (CO2eq) for Conventional Treatment and AnMBR Scenarios at 15 LMH and >25°C.

7.4.6 Discussion: Study Conclusions

A treatment process that integrates primary treatment and is operated at a higher flux and higher temperature resulted in a more sustainable outcome, in the context of environmental impact categories evaluated. As flux increased, environmental impact reductions were primarily observed for Scenario 4 – P + Gas-sparged AnMBR; primarily due to larger CO_{2eq} offsets from electricity and heat generated. Coupled with a higher temperature, this process had comparably low environmental impact contributions as Scenario 7 – P + Hybrid + AltCH4. In general, conventional treatment (Scenario 8) had the lowest overall environmental impact, followed by scenario 7 – P + Hybrid + AltCH4, when sulfide and phosphorus removal was conducted using chemical coagulation. The $CO2_{eq}$ offsets from electricity and heat generated had a strong influence on overall environmental impact contributions from an AnMBR process; however, the chemical use associated with sulfide and phosphorus removal process resulted in greater environmental impact compared to conventional treatment. The sensitivity analysis indicated that the sulfide and phosphorous removal component of the AnMBR treatment processes contributes at least 70% to overall environmental impact contributions, compared to at least 24% as a component of conventional treatment. PACl and ferric chloride consumption during sulfide and phosphorous removal are the primary environmental impact drivers. Substitution of these chemicals with alum mitigated a portion but not all of overall the environmental impact contributions when compared to conventional treatment.

Optimization of an AnMBR treatment process should consider integration of primary treatment, operation at a higher flux and temperature, biogas and heat recovery, use of a renewable energy source for grid electricity, and minimized consumption of sustainable chemicals. The LCA identified sulfide and phosphorus removal via chemical coagulation as an opportunity for optimization. Considering that sulfide is probably more of a driver of chemical use than phosphorus (and that phosphorus removal may not always be necessary), alternative methods such as biological sulfide oxidation (Cai et al. 2017) should be explored. Integration of alternative methods for sulfide removal alongside bioenergy recovery is necessary for developing an AnMBR treatment process that is more sustainable than a conventional treatment approach.

8.0 IMPLEMENTATION ISSUES

This section provides information that will aid in the future implementation of the AnMBR technology for sustainable wastewater treatment and resource recovery.

8.1 PROCESS CONFIGURATION

The results of this demonstration and economic analysis support use of primary sedimentation or domestic wastewater followed by a bioreactor and a gas-sparged UF membrane system. Inclusion of primary sedimentation in the process is projected to provide a greater potential for energy-neutral or energy-positive operation. In addition, the potential for membrane fouling – particularly by fats, oil and grease (FOG) – will be reduced.

The bioreactor may be either a suspended-growth bioreactor or GAC-fluidized bioreactor with the latter being preferable. The first-stage GAC-fluidized bioreactor was demonstrated to require a shorter HRT than the first-stage suspended-growth bioreactor. The GAC-fluidized bioreactor – being a fixed film system – will also be more resilient to process upsets.

The results of the demonstration indicate several reasons for using gas-sparged UF membranes, rather than GAC-fluidized UF membranes, downstream of the bioreactor. First, the membrane integrity was compromised by GAC-abrasion as has been observed previously (Shin et al. 2016a, Shin et al. 2016b), and the lifetime of these membranes would likely be short compared to greater than an estimated ten years for gas-sparged UF membranes (Cote et al. 2012, Kubota Membrane Europe 2008). Additionally, the GAC-fluidized UF membranes have half the membrane packing density per module compared to gas-sparged UF membranes. According to Suez, the majority of the manufacturing cost is associated with module fabrication and not membrane materials. Therefore, the capital cost of the GAC-fluidized UF membrane system is expected to be greater than that for a gas-sparged UF membrane system. Additionally, UF membrane modules for gas-sparged systems are commercially available whereas modules for GAC-fluidized operation are not. The operating cost is also expected to be greater because of membrane abrasion, shorter lifetime, and greater replacement frequency. Use of ceramic membranes can overcome the membrane integrity/replacement frequency issue (Aslam et al. 2017, Aslam et al. 2018) but currently have a high capital cost.

Dissolved methane removal using vacuum-operated membrane contactors was determined to have potential of removing 90% of dissolved methane, but the pressure loss through the contactors will result in high energy consumption. This energy consumption was not observed in the field demonstration because the contactors were operated at a low liquid flow rate. Full-scale designs would not practically use such a low flow rate. Therefore, alternative dissolved methane removal technologies, such as vacuum degasser (e.g., http://www.elginseparationsolutions.com/vacuum-degasser.html and www.degremont-technologies.com/Vacuum-Degassers), warrant evaluation. They have the potential for low-cost and low-energy consumption. While such a technology was not evaluated in this demonstration, Inha University has conducted laboratory batch studies with a two-stage vacuum degasser that demonstrated 94% dissolved methane removal at an operation condition of 0.06 bar and 4.2-min HRT with an energy requirement of 0.0068 kWh/m^3 (Kwon et al. 2006, Shin and Bae 2015).

Energy-neutral or -positive AnMBR operation was determined to be possible and control by several factors. These factors should be evaluated during process selection and design and include:

- Mechanical design and head loss – The pilot-scale GAC-fluidized AnMBR incorporated many design details to minimize head loss and energy consumption (see Section 5.7.24). These features are not commonly incorporated in mechanical design of today's wastewater treatment processes. Their incorporation will increase the potential for energy savings.

- UF membrane process configuration – The gas-sparged AnMBR required more energy than the GAC-fluidized AnMBR in part because of the added energy costs associated with compressible gas pumping. However, GAC-fluidization was concluded to have several drawbacks including short membrane lifetime and inability to control the intensity of membrane fouling control (i.e., by varying gas-sparge rate). Therefore, the gas-sparged UF configuration is recommended, but it must be designed and operated to balance membrane maintenance and energy consumption.

- UF flux – Greater UF flux resulted in lower energy consumption (in addition to lower capital cost) but increasing gas-sparging to achieve a greater UF flux can be counterproductive. Again, balancing membrane maintenance and energy consumption requires process optimization.

- Temperature – Increased temperatures led to increased total methane yield, likely a result of varying rates and extents of hydrolysis. The greater methane yield is desirable with respect to attainment of energy-neutral or -positive operation; however, the wastewater temperature is a function of geography and season and cannot be changed. Therefore, planning an AnMBR installation and setting energy efficiency goals should consider site location.

- Wastewater strength – Greater COD and BOD_5 concentrations resulted in greater rates of methane production. Local wastewater strength and variation through the day will control the ability to achieve energy-neutrality. Unlike temperature, wastewater strength is somewhat more controllable through supplementation with non-domestic wastewater sources. East Bay Municipal Utility District in California practices this in its food waste import program and operation of its anaerobic digesters. Such an approach with high-strength liquid wastes such as those from the food and beverage industry could be envisioned.

- Primary treatment – While not tested, engineering calculations indicated that primary sedimentation in combination with anaerobic digestion would result in greater methane production and more energy-efficient operation. Primary sedimentation may promote better effluent quality and decrease UF membrane fouling.

Sulfide must be removed prior to discharge or reuse. If it is not removed, it can lead to several problems including: 1) oxidization to sulfur ang fouling of process piping, 2) contribution to oxygen demand and generation of turbidity (from the generated elemental sulfur) upon discharge to surface water, and 3) toxicity and noxious odors precluding many reuse opportunities.

Phosphorus may need to be removed in the case of surface water discharge depending on local regulatory requirements. Coagulation-flocculation-sedimentation is a standard process and was demonstrated to be capable of sulfide and total phosphorus removal. Use of the sedimentation solids as a fertilizer is possible but requires further study to determine plant uptake. Chemical cost and environmental impact associated with sulfide removal were determined to be high (see Section 7). The coagulant doses were established based on limited optimization and likely could be reduced. Previous research on use of coagulation for removal of sulfide and phosphorus from AnMBR permeates indicate that lower doses of coagulants is possible (Lee et al. 2016, Yang and Bae 2014). Dosing iron salts into the bioreactor can also sometimes, but not always, improve performance with respect to UF permeability (Dong et al. 2015b, 2018, Lee et al. 2016) and may decrease overall costs. Alternative sulfide removal technologies, such as biological sulfide oxidation (Cai et al. 2017) and vacuum degassers, may also be effective and less expensive. Further research into cost-effective and sustainable technologies for sulfide and phosphorus removal is recommended.

Nitrogen removal requires further evaluation. Clinoptilolite was capable of removing ammonia in this demonstration, but the brine was not capable of being regenerated by electrolysis likely due to iron fouling. Placement of the ammonia removal process upstream of the coagulation process may obviate this issue but would need to be tested. Heat treatment has also been evaluated and has the potential to mitigate competition by other cations (Mun 2017). Use of regenerable clinoptilolite downstream of an AnMBR is being evaluated further in ESTCP project ER-201728. Other options for nitrogen removal have also been evaluated (McCarty 2018) and should be considered.

Water reuse is an option and may require additional treatment depending on the specific end use. Detailed discussion of water reuse can be found elsewhere (U.S. EPA and CDM Smith 2017, U.S. EPA et al. 2012).

8.2 END-USER CONSIDERATIONS

End-user considerations include cost, operability and potentially sustainability.

Cost

Capital and operating and maintenance costs, along with lifecycle cost and payback period, are of paramount concern. Most installations have existing wastewater treatment infrastructure, and justification is required for any capital expenditure. At an existing installation, installation of an AnMBR would likely involve replacement or retrofitting of an existing aerobic secondary treatment investment (i.e., oxidation ditch or activated sludge). For the purpose of comparability, the cost evaluation assumed installation of a new treatment system at a greenfield site. The analysis determined that capital costs for conventional treatment was lower than AnMBR scenarios primarily because of the cost associated with membranes. At a reasonable flux of 15 LMH, the capital costs for the gas-sparged and hybrid AnMBR scenarios (1 and 3) were 16 and 10% greater than that for the conventional scenario. An AnMBR system will require a smaller footprint than a conventional plant, and thus, land availability may justify increased capital expenditures. In addition, membrane costs may decrease in the future, as they have in the past. Operating cost was also lowest for conventional treatment primarily because of chemical costs associated with sulfide removal and membrane cleaning. This study demonstrated for the first time that sulfide removal

is an important cost driver and alternative methods of sulfide removal (e.g., biological sulfide oxidation and vacuum degassing) should be considered. The lifecycle costs for AnMBR systems were also greater than conventional treatment.

With respect to the DoD, the source of money must also be considered. For example, with the Navy, working capital funding (e.g., MILCON) is difficult to obtain and competes with other Navy activities. Another type of Navy funding is called Capital Improvements Projects. This is the type of funds that was obtained by the Naval Station Everett in Washington State when they required design and construction of a compensating ballast water (compwater) treatment system for over $1 million by the Navy Engineering and Expeditionary Warfare Center (EXWC).

Privatization must also be considered. Privatized wastewater facilities at DoD facilities will have little incentive to change the treatment process unless such an incentive is included in the contract with the operating company.

Operability

Operability includes various aspects, including plant reliability, permit compliance, and operator skill level and certification requirements. The plant must be reliable and capable of consistently meeting discharge requirements to remain in compliance with permits. AnMBRs have clearly not been in existence as long as oxidation ditch and activated sludge technologies. Therefore, a track record is not available to assess reliability. This demonstration indicated that upset conditions can occur, but such is the case at conventional treatment plants as well (Willmsen 2017). Further demonstrations of AnMBRs is necessary to provide such a track record of reliability.

Operator skill level and certification requirements associated with a plant's permit may be increased compared to a conventional plant. Such has been the case when conventional plants have been upgraded to *aerobic* MBRs or anaerobic digesters are installed at an existing facility. These requirements are not necessarily impediments but must be considered.

Sustainability

A lifecycle assessment demonstrated for the first time that sulfide (and phosphorus) removal from AnMBR permeate results in increased environmental impacts relative to conventional treatment. Chemical use associated with sulfide removal has a greater effect on environmental impact than other factors such as energy efficiency. If sulfide removal is not required, then the AnMBR systems can have fewer environmental impacts compared to conventional treatment. However, end-uses for AnMBR permeate where sulfide remains are anticipated to be limited because of toxicity, odor, and oxygen demand. Alternative non-chemical requiring methods of sulfide removal, such as biological oxidation and vacuum degassing, should be explored to reduce the environmental impact and cost associated with sulfide removal.

8.3 PROCUREMENT CONSIDERATIONS

Gas-sparged AnMBR systems are commercially available from various companies including Suez (www.suezwatertechnologies.com/products/anaerobic-mbr-technology). These companies typically offer the membrane systems but not the bioreactor systems. A suspended growth bioreactor may be

similar to an anaerobic digester, except it would not be heated. Many companies capable of designing and fabricating anaerobic digesters are readily available. GAC-fluidized bioreactors are commercially available from companies such as Envirogen (www.envirogen.com/pages/technologies/bioreactors/) but these are typically aerobic or anoxic and are not currently suitable for flammable biogas generation and collection. Anaerobic GAC-fluidized bioreactors have been installed for treatment of airport deicing/anti-icing runoff (Airport Cooperative Research Program 2013, Gibson 2002, Nelson 2017, Switzenbaum et al. 2001). In addition seven have been installed in Taiwan for treatment of industrial effluents (Cheng et al. 2015). These can be smaller-scale systems that may not be applicable for high flow rates, but can be used as a starting point for procurement of engineering and construction services.

Liqui-Cel gas-liquid contactors for dissolved gas removal are available through 3M (www.3m.com/3M/en_US/liquicel-us/). Vacuum degassers are commercially available for drilling and high-purity water production operations (e.g., www.elginseparationsolutions.com/vacuum-degasser.html and www.degremont-technologies.com/Vacuum-Degassers).

Use of vendor names is for informational purposes only and does not constitute SERDP-ESTCP endorsement.

8.4 POTENTIAL REGULATIONS

Current regulations for wastewater treatment and discharge that are applicable to existing wastewater treatment plants would also be applicable to AnMBR systems. The discharge from these plants is regulated primarily under the Clean Water Act. In addition, the following existing or future laws and regulations are applicable to federal agencies (Guy and Evans 2018).

Public Law 109-58 Energy Policy Act of 2005

- Title I: Energy efficiency.
  - Improved national energy efficiency encouraged through:
    - Statutory standards.
    - Requirements for federal action.
    - Incentives for voluntary improvements.
- Title II: Renewable energy.
  - Increase production and use.
  - Advance technology development.
  - Promote commercial development of renewable energy.

Public Law 110-140 Energy Independence and Security Act of 2007

- Greater energy independence / security for the United States (U.S.).
- Increase and develop clean renewable fuel production.
- Research and deploy greenhouse gas capture / storage options.
- Improve Federal Government energy performance.
- Increase U.S. energy security.

EO 13693 Planning for Federal Sustainability in the Next Decade (revoked by EO 13834)

- Federal agencies must:
  - Replace 25% of total building electric and thermal energy with renewable electric/alternative energy by 2025.
  - Install “appropriate green infrastructure features on federally owned property to help with stormwater and wastewater management”.

EO 13834 Efficient Federal Operations

- Reduce waste.
- Cut costs.
- Enhance infrastructure and operations resilience.
- Enable effective mission accomplishment.
- Reduce potable / non-potable water consumption.
- Comply with stormwater management requirements.
- Implement waste prevention / recycling measures.

Army Directive 2014-02 Net Zero Installations Policy.

- Reduce overall energy / water use.
- Implement energy recovery / cogeneration opportunities.
- Produce renewable energy onsite.
- Use water-efficient technology.
- Recycle and reuse water.
- Convert solid waste streams to resource values.

Army Directive 2017-17 Installation Energy and Water Security Policy.

- Secure critical missions.
  - Energy and water for 14 days.
- Sustain all missions.
  - Assured Access to Resource Supply.
    - Redundant / diverse sources.
    - Renewable energy and alternative water.
  - Reliable Infrastructure Condition.
    - Provides onsite energy and water storage.
    - Flexible and redundant distribution networks.
  - Reliably meet mission requirements.

The Navy follows guidelines set forth in Executive Order 13693 and the Army's Net Zero Challenge for water and energy conservation.

In addition to the above laws and regulations, codes must be considered as well, including the National Electrical Code (part of the National Fire Prevention Act) sections on electrical classification, which are applicable to the methane flammability in the AnMBR. Installations that already have anaerobic digesters in place will be familiar with these codes.

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APPENDIX B. GAS-SPARGED ANMBR OPERATIONS AND MAINTENANCE MANUAL AND DESIGN DRAWINGS

Operations and Maintenance Manual

Gas-Sparged Anaerobic Membrane Bioreactor (AnMBR) for Sustainable Wastewater Treatment ESTCP Project No. ER-201434

September 2016

Table of Contents

1.0 Introduction 1
2.0 Project Background 1
3.0 AnMBR Demonstration System Overview 2
    3.1 Liquid Process Overview 3
    3.2 Gas Process Overview 4
    3.3 Solids Process Overview 4
4.0 Operation 4
5.0 Maintenance 4
6.0 Sampling Plan 10
7.0 Field Observations 10
8.0 Standard Operating Procedures 20
    8.1 Floor drains 20
    8.2 Heat Tracing 21
    8.3 Filling Water Column Vents 21
    8.4 Automatically Draining Condensate Traps 22
9.0 Health and Safety Plan 28
    9.1 Site Location 28
    9.2 Transportation of personnel and test samples 28
    9.3 Required personnel protective equipment (PPE) 28
    9.4 Gas exposure hazard and mobile monitors 28
    9.5 Exposure to pathogens 29
    9.6 Severe Weather preparedness 29
    9.7 Chemical Hazards: 30
    9.8 Physical Hazards: 30
    9.9 Mechanical, electrical and noise hazards: 30
    9.10 Fire: 30
    9.11 Radiological Hazards: 31
    9.12 Emergency Support: 31
    9.13 Hazardous Waste Disposal: 31
    9.14 Site Control: 31
    9.15 Safe Work Practices: 31
Appendices 32

List of Figures

Figure 1 – Picture of the site 1
Figure 2 – Installation of trailer 2
Figure 3 – Hazardous Area of trailer 3
Figure 4 – Non-Hazardous Area of trailer 3
Figure 5 – Floor Drain Valves 20
Figure 6 – Pressure Relief Water Columns 21
Figure 7 – Condensate Trap (Collection Tank) 22

List of Tables

Table 1 – Demonstration System Components, Frequency and Maintenance 6
Table 1 – Demonstration System Components, Frequency and Maintenance (Continued) 8
Table 2 – 3 Month Start Up Sampling Schedule 12
Table 2 – 3 Month Start Up Sampling Schedule (Continued) 14
Table 3 – 12 Month Operation Sampling Schedule 16
Table 3 – 12 Month Operation Sampling Schedule (Continued) 18
Table 4 – Field Observations Checklist 24
Table 4 – Field Observations Checklist (Continued) 26

Appendices

Appendix A – Standard Operating Procedures
Appendix B – Intuitech Operation and Maintenance Manual
Appendix C – Frontier Operation and Maintenance Manual
Appendix D – Forms
Appendix E – Chemical Safety Data Sheets
Appendix F – CDM Smith Health and Safety Plan

1.0 Introduction

This O&M Manual is to aid in operation and maintenance of the Gas Sparged Anaerobic Membrane Bioreactor (AnMBR). This is a demonstration plant commissioned at Fort Riley, Kansas. The Gas Sparged AnMBR plant will be treating municipal wastewater collected from Fort Riley. The purpose of this demonstration plant is to study the effectiveness of Gas Sparged AnMBR at treating Municipal Wastewater to reuse standards and to the potential to make the process energy-neutral. Proper operation and maintenance of the plant is critical to the success of the study. This document is to be referenced for all processes and equipment associated with the plant.

2.0 Project Background

The Gas Sparged AnMBR demonstration plant is located next to the Camp Forsyth Pump Station of the Fort Riley Army Base in Kansas. The demonstration plant will pump 720 gallons per day out of the pump station wet well. The sludge reject and demonstration plant effluent will both drain back into the wet well. The various modification to the process operation will be made throughout the 15 month demonstration to determine what the optimum operating conditions are. Therefore, documentation of operational modifications are critical.

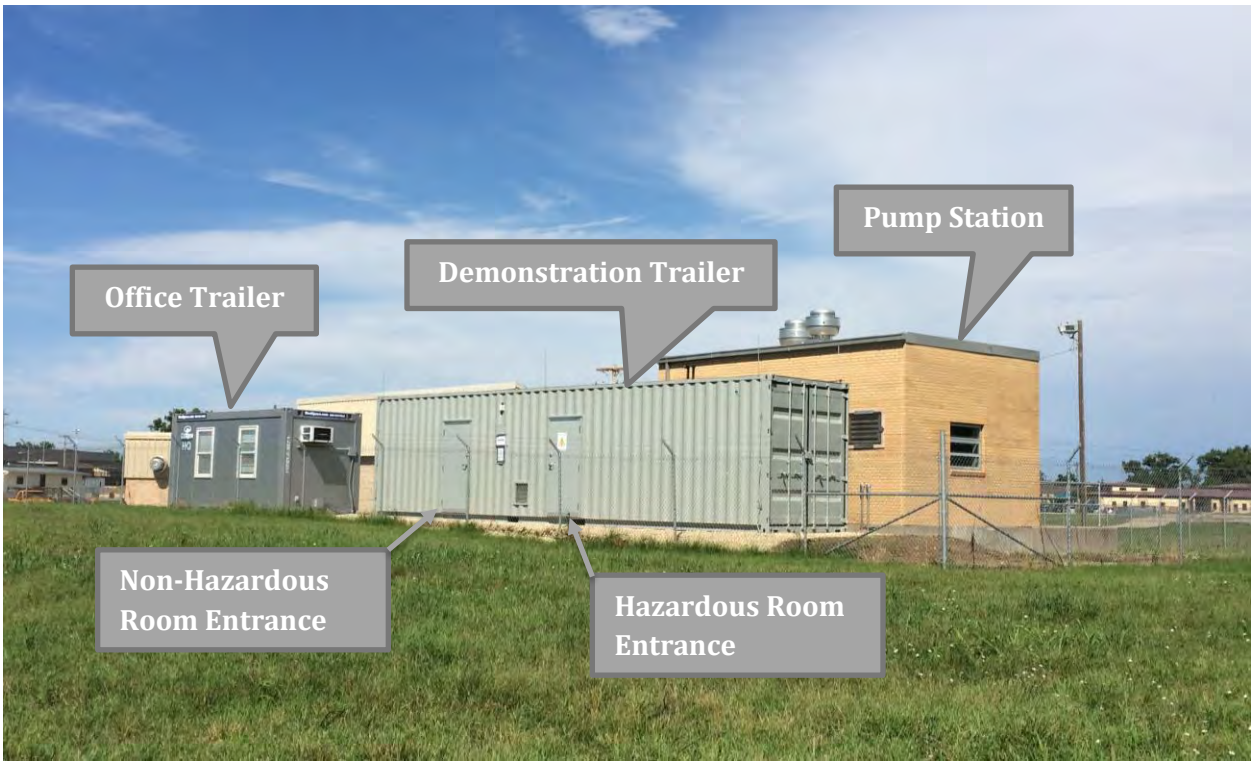

Figure 1 – Picture of the site

Objectives of demonstration:

- Demonstrate the effectiveness of AnMBR at treating screened domestic wastewater at temperatures above 10° C to produce high quality, re-usable water.
- Determine a lower applicable temperature limit for AnMBR technology that can be used to identify appropriate implementation sites.

- Demonstrate that AnMBR technology for domestic wastewater treatment can be operated in an energy-neutral manner.
- Demonstrate use of the technology in a treatment train that can effectively remove nitrogen and phosphorus nutrients (when necessary) in tandem with carbonaceous BOD5 and TSS.
- Demonstrate that hollow-fiber gas transfer membrane technology can effectively recover dissolved methane from AnMBR permeate.
- Demonstrate that the AnMBR minimizes sludge production and determine whether the sludge that is produced can be used beneficially as biosolids.
- Demonstrate that the AnMBR is a safe technology that is implementable at DoD installations and public utilities.

3.0 AnMBR Demonstration System Overview

The demonstration system that will be demonstrated consists of four main process unit, including:

Gas-sparged AnMBR for removal of chemical oxygen demand (COD) and total suspended solids (TSS);

- Hollow-fiber gas transfer membrane for removal of dissolved methane;
- A flocculation & sedimentation system for removal of sulfide and phosphorus; and
- Ion exchange (IX) system for removal of ammonia.

Refer to process and instrumentation diagram in design drawings set and the Technology Demonstration Plan for detailed system overview. Also, see **Figures 2, 3 and 4** for pictures of the demonstration plant.

Figure 2 – Installation of trailer

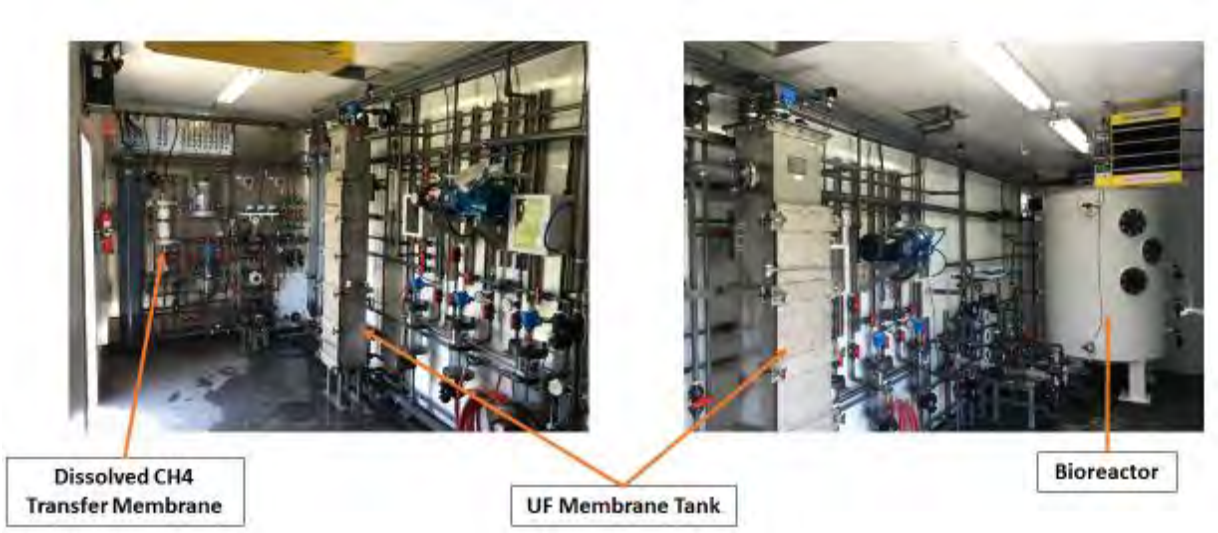

Figure 3 – Hazardous Area of trailer

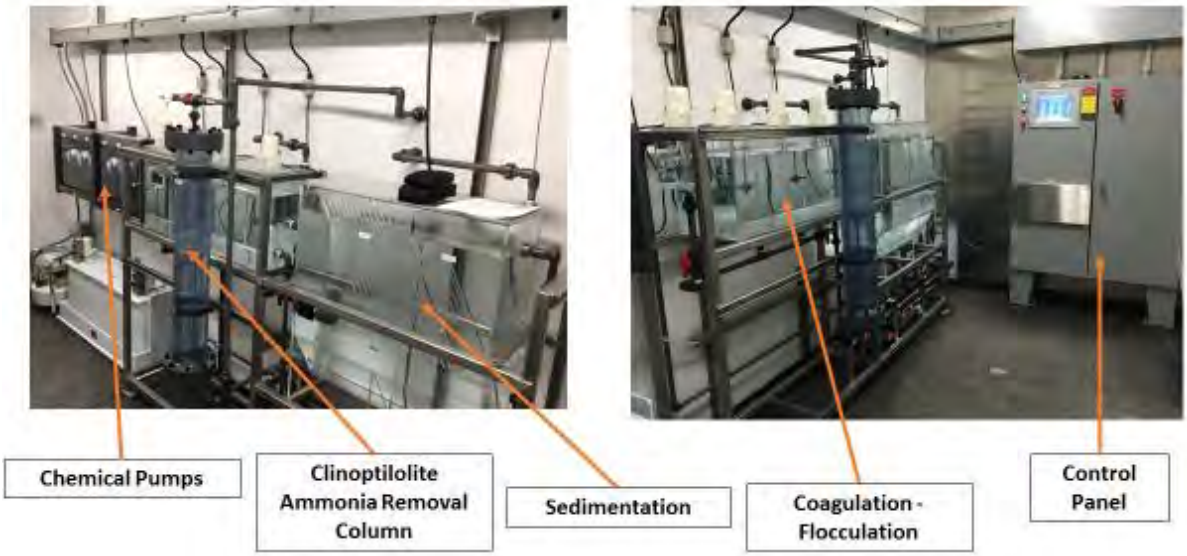

Figure 4 – Non-Hazardous Area of trailer

3.1 Liquid Process Overview

The raw sewage will be screened at the pump station and then pumped to the bioreactor.

A waste activated sludge (WAS) and mix pump will keep the Bioreactor mixed and waste sludge from the Bioreactor after a specified solids retention time. The recirculation pump will pump sludge from the Bioreactor through Membrane Tank and bring the membrane reject back to the Bioreactor. The Membrane Tank houses the ultra-filtration (UF) fiber membranes. A permeate pump will pull water out of the sludge and pump it to the hollow-fiber gas transfer membrane. The hollow fiber gas transfer membrane permeate will contain gas, and a vacuum pump will be attached to the gas side of the membrane to aid in pulling the dissolved methane out of solution. The liquid reject of this pump will then go to a rapid mix basin where coagulant and flocculant will be added to aid in coagulation and flocculation of remaining solids in the effluent. There are three flocculation basins that can be modified to operate in three different configurations. From the flocculation basins the effluent will go to a sedimentation basin where the solids will settle out. The clarified effluent will be pumped through an ion-exchange column before going back to the wet well.

3.2 Gas Process Overview

Biogas production occurs in two main locations within the process: the primary reactor and the secondary membrane reactor. Some of the gas produced in the headspace of the primary bioreactor will be used to sparge the membranes in the secondary bioreactor. The gas used for sparging will be cycled back to the primary reactor. Dissolved gas in the bioreactor permeate from the secondary reactor will be pulled out of solution in the hollow fiber gas contact membrane. A vacuum pump will be connected on the permeate side of the membrane to achieve this. The gas from the primary reactor headspace and the gas pulled out of the permeate will be combined together and then analyzed for flow rate, methane and oxygen content. These two gas streams can be analyzed individually by adjusting appropriate valve positions. Excess gas will be vented.

3.3 Solids Process Overview

Solids from the bioreactor will be recirculated through the Bioreactor and the Membrane Tank. When the TSS gets above a certain set point in the Bioreactor, the WAS/Mix pumps will waste some of the sludge in the Bioreactor back to the pump station wet well. Sludge will also be wasted after a specified solids retention time has passed. The solids from clarification will drain back to the pump station wet well.

4.0 Operation

The operation of the AnMBR trailer could be executed by the operator using the Human Machine Interface (HMI) installed by Intuitech. The HMI is located in the non-hazardous section of the lab trailer. The operation can be carried out either under automatic mode or under manual mode, when a certain segment of the operation can be controlled by the user, at which the automatic sequence of steps run by the HMI are not executed. The automatic sequence of operation executed by the HMI. The operation of the strainer at the influent end of the process trailer is also controlled by the HMI. The three major sequence matrices executed by the HMI are:

1. Membrane Sequence matrix – These steps constitute the normal operation of the AnMBR which also includes membrane sparging with the biogas at a periodic pre-determined time interval.

2. Recovery clean matrix – The steps here are executed to reverse fouling on the surfaces of the secondary reactor membrane module. Probably not part of everyday operation of the AnMBR, and will be executed on a need-basis.

3. Strainer sequence matrix – The intent of this sequence is to produce influent wastewater input from the wet well at the pumping station on site to the primary reactor.

Any or all of these operations can be performed under auto-, semi-auto, or manual mode. The details for operating under each mode is described in detail in the Intuitech O&M manual.

5.0 Maintenance

Several components of the demonstration system require periodic maintenance. The components of the system that require maintenance, the required maintenance, and the frequency that each activity needs to be performed is summarized in **Table 1**. Photos of the demonstration trailer showing the

location of these components are included in Section 3. The Maintenance Schedule chart shall be used for the duration of operation of the AnMBR trailer. Maintenance Log forms are included in Appendix C.

Table 1 – Demonstration System Components, Frequency and Maintenance

Equipment Name	Activity	Procedure	Weekly	Semi-Monthly	Monthly	Quarterly	Yearly	As-Needed
Progressive Cavity Pumps (Recric Pump, WAS/Mix Pump, IX Pump)	Clean Exterior	NA			X			
	Coupling Inspection	Intuitech O&M Manual, Maintenance.2.A				X		
	Coupling Replacement	Intuitech O&M Manual, Maintenance.2.A						X
	Stator Replacement	Intuitech O&M Manual, Maintenance.2.A						X
Biogas Sparge Blower	Check Pump for Leaks	Diaphragm-Gas Sampling Pumps.8			X			
	Check Connections for Leak	Diaphragm-Gas Sampling Pumps.8			X			
	Clean Exterior	Diaphragm-Gas Sampling Pumps.8				X		
Gas Transfer Membrane Contactor Blower	Check blower for leaks	NA	X					
	Check connections for leaks	NA	X					
	Check inlet filter	Airtech Blower Manual.5			X			
	Clean inlet filter	Airtech Blower Manual.5		X				
	Replace inlet filter	Airtech Blower Manual.5						X
	Clean Exterior	Airtech Blower Manual.5				X		
Ultra Filtration Fiber Membrane	Maintenance Clean	Demonstration Plan Appendix C		X				
	Recovery Clean	Demonstration Plan Appendix C						X
	Check for leaks in Fibers	NA						X
	Take Sample Fiber	NA				X		
	Clean Exterior	NA						X
Hollow Fiber Gas Contact Membrane	Clean Exterior	NA						X
	Clear Condinstation from Membrane	Refer to O&M Appendix C						X
Peristaltic Pumps	Cleaning	Intuitech O&M Manual, Maintenance.2.F.1			X			
	Tubing Inspection	NA	X					
	Tubing Replacement	Intuitech O&M Manual, Maintenance.2.F.2			X			
	Calibration	Intuitech O&M Manual, Maintenance.2.F.2			X			
	Calibration Check	NA	X					
Air Compressor	Compressor Air Filter Inspection	Intuitech O&M Manual, Maintenance.2.B.1				X		
	Oil Level Check	Intuitech O&M Manual, Maintenance.2.B.2			X			
	Oil Replacement	Intuitech O&M Manual, Maintenance.2.B.2					X	
	Air Prep Module Inspection	Intuitech O&M Manual, Maintenance.2.C				X		
	Air Prep Module Filter Replacement	Intuitech O&M Manual, Maintenance.2.C						X
Turbidimeter	Cleaning	NA			X			
	Calibration	Intuitech O&M Manual, Maintenance.2.E			X			
	Calibration Check	NA			X			
pH Meter	Cleaning	NA			X			
	Sensor Buffer Replacement	Intuitech O&M Manual, Maintenance.2.D				X		
	Calibration	Intuitech O&M Manual, Maintenance.2.D	X					
	Calibration Check	NA	X					

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Table 1 – Demonstration System Components, Frequency and Maintenance (Continued)

Equipment Name	Activity	Procedure	Weekly	Semi-Monthly	Monthly	Quarterly	Yearly	As-Needed
Biogas Analyzer	Calibration	Biogas Analyzer O&M Manual		X				
	Analyzer Flow Check	Biogas Analyzer O&M Manual	X					
	Analyzer Condensate Drain	NA	X					
	Replacement of Oxygen Sensor	Biogas Analyzer O&M Manual						X
	Analyzer Filter Inspection	Biogas Analyzer O&M Manual	X					
Feed Pump	Clean Exterior	NA			X			
	Coupling Inspection	Moyno Compact C O&M Manual				X		
	Coupling Replacement	Moyno Compact C O&M Manual						X
	Stator Replacement	Moyno Compact C O&M Manual						X
Permeate Pump	Clean Exterior	NA			X			
	Coupling Inspection	Intuitech O&M Manual, Maintenance.2.A				X		
	Coupling Replacement	Intuitech O&M Manual, Maintenance.2.A						X
	Stator Replacement	Intuitech O&M Manual, Maintenance.2.A						X
Strainer	Check Actuator Shaft Seal for Leaks	Eaton Model DCF400 O&M Manual	X					
	Check cleaning disc for excessive wear	Eaton Model DCF400 O&M Manual			X			
	Check inside of filter element for excessive wear	Eaton Model DCF400 O&M Manual			X			
	Inspect Actuator assembly	Eaton Model DCF400 O&M Manual					X	
Pressure Relief Vents	Water Level Check	NA	X					
	Fill	NA						X
Heat Tracing	Turn On/Off	NA						X

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6.0 Sampling Plan

A comprehensive sampling and analysis plan will be implemented during the startup and continuous optimization phases of the demonstration. The sampling locations, analytes, and sampling frequencies, are provided in **Tables 2 and 3** for the three-month startup phase and 12-month continuous optimization phase, respectively. Sample collection and analysis will be performed in accordance with attached table which specifies analytical methods, sample containers, preservatives, hold times, and required sample volumes. Analyses will be conducted by Kansas State University or contract laboratories to which Kansas State University will ship samples to, using standard methods identified in the attached tables. Quality assurance (QA)/quality control (QC) plan will be in place.

Samples will be grab samples collected by field personnel, with the exception of the samples collected during the baseline characterization described in Section 5.3 of the Technology Demonstration Plan, which will be collected with an auto-sampler.

COD, BOD_5, and total organic carbon (TOC) are determined according to Standard Methods. To eliminate the effect of hydrogen sulfide and dissolved methane on COD, BOD_5, and TOC measurements, all samples except influents will be purged with air for 10 min. For soluble COD, samples are filtered through 1.2-µm Whatman filter paper. Periodic samples will also be filtered with 0.2-µm and 0.45-µm filters to quantify presence of different colloidal fractions.

VFAs will be measured by Kansas State University (KSU) using a high performance liquid chromatograph (HPLC) equipped with an Aminex HPX-87H column and photo diode array and refractive index detectors as described previously by Dr. Parameswaran's research group.

7.0 Field Observations

There are several field observations that need to be recorded on a regular basis by the same team performing the sampling and maintenance described in Sections 5 and 6. These observations include and may not be limited to:

1. Readings on pressure gauge, temperature gauges, flow meters, water quality indicators, etc.
2. Water level in various process units (e.g. pressure relief vents, condensate traps, etc.)
3. Temperature and weather conditions at sampling
4. Physical conditions of the trailer – any signs of damage or wear/tear
5. General cleanliness of the trailer – both hazardous and non-hazardous sides as well as the analytical lab trailer.
6. Safety of the trailer – ensuring it is adequately locked with access limited only to approved personnel.
7. Measurement of key analytical parameters, as identified in the demonstration plan, that should be measured on site (in the field)

Recording of occurrences at the plant should be recorded on the forms contained in Appendix C. The various forms and their purpose are as follows:

1. Field Observation Checklist: This form should be filled out every time someone goes to the plant, the purpose is to identify where someone in the process is not operating as expected.

2. Event Log: This is a form to document events that happened at the plant that would not be recorded in the field observation check list or on the maintenance log forms.

3. Maintenance Logs: There are six (6) maintenance forms based on frequency of the maintenance actions. These forms should be filled in anytime the maintenance actions are performed.

4. HMI Forms: These forms are to document changes that are made to the control processes through the HMI.

Table 2 – 3 Month Start Up Sampling Schedule

Types	Liquid							Solids			Membranes		Gas		
Description	**Raw Influent**	**Strained Influent**	**Mixed Liquor**	**Membrane Permeate**	**De-gassed Permeate**	**IX Column Influent**	**IX Column Effluent**	**WAS**	**Sed Tank Sludge**	**IX Media**	**UF Membrane**	**Gas Transfer Membrane**	**Bioprocess Tank Exhaust**	**Permeate Off-Gas**	**Combined Gas Exhaust**
Area	**Feed Pump**	**WAS/Mix Pump**	**Bioprocess Tank**	**Permeate Pump**	**Gas Transfer Membrane**	**Sedimentation Tank**	**IX Column**	**WAS/Mix Pump**	**Sedimentation Tank**	**IX Column**	**UF Membrane**	**Gas Transfer Membrane**	**Permeate Pump**	**Permeate Pump**	**Permeate Pump**
Sample Valve Number	**SV 1000**	**SV 1100**	**SV 1201, 02, 03**	**SV 1311**	**SV 1521**	**SV 1650**	**SV 1722**	**SV 1455**	**SV 1640**	**N/A**	**N/A**	**N/A**	**SV 1212**	**SV 1545**	**SV 1235**
Aqueous Samples															
pH		S	C	S	S	S	S								
ORP				W	W	W	W								
Total COD	M	S		S		M	M								
1.2 µm filtered COD															
0.45 µm filtered COD															
0.2 µm filtered COD															
Total BOD_5	M	S		S		M	M								
DOC															
TOC															
Volatile Fatty Acids (VFAs)				S											
Alkalinity				S	W										
Hardness				W	W										
Specific Conductivity				W	W										
TDS				W	W										
Total Nitrogen[2]	M	W		W											
TKN[3]	M	W		W											
NH_3-N	M	M		S		M	S								
NO_3															
NO_2															
Sulfate	M	M		W											
Sulfide	M	M		W	W	W									
Total Phosphorus	M	M		W		W									
Dissolved Fe						W									
TSS	M	S	S	S		S	S								
VSS	M	S	S	S		S	S								
FSS	M	S	S	S		S	S								
Turbidity				S		S	S								
Dissolved CH_4				W	W										
Chlorine Demand							M								
E. coli and Total Coliforms[2]															

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Table 2 – 3 Month Start Up Sampling Schedule (Continued)

Types	Liquid							Solids			Membranes		Gas		
Description	**Raw Influent**	**Strained Influent**	**Mixed Liquor**	**Membrane Permeate**	**De-gassed Permeate**	**IX Column Influent**	**IX Column Effluent**	**WAS**	**Sed Tank Sludge**	**IX Media**	**UF Membrane**	**Gas Transfer Membrane**	**Bioprocess Tank Exhaust**	**Permeate Off-Gas**	**Combined Gas Exhaust**
Area	**Feed Pump**	**WAS/Mix Pump**	**Bioprocess Tank**	**Permeate Pump**	**Gas Transfer Membrane**	**Sedimentation Tank**	**IX Column**	**WAS/Mix Pump**	**Sedimentation Tank**	**IX Column**	**UF Membrane**	**Gas Transfer Membrane**	**Permeate Pump**	**Permeate Pump**	**Permeate Pump**
Sample Valve Number	**SV 1000**	**SV 1100**	**SV 1201, 02, 03**	**SV 1311**	**SV 1521**	**SV 1650**	**SV 1722**	**SV 1455**	**SV 1640**	**N/A**	**N/A**	**N/A**	**SV 1212**	**SV 1545**	**SV 1235**
Sludge Samples															
TS								M	M						
VS								M	M						
FS								M	M						
TP									M						
Sulfide									M						
Fe (total)									M						
RCRA Metals (As, Ba, Cd, Cr, Pb, Hg, Se, Ag)															
Capillary Suction Time															
Dewaterability															
E. coli and Total Coliforms															
Media Samples															
NH_3-N										R					
Gas Samples															
CH_4													C	C	C
CH_4, CO_2, N_2, O_2															
Siloxanes[2]															
H_2S													Q	Q	
Membrane Analyses and Samples															
Membrane Autopsy															
EPS			Q								Q				
Microbial Ecology															
DNA Sequencing and qPCR		Q	Q								Q				

Notes

S - Semiweekly (i.e., twice/week)
W - Weekly
B - Bimonthly (i.e., twice/month)
M - Monthly
Q - Quarterly

C - Continuously
X - Post membrane recovery clean
R - After each IX media replacement
E - End of demonstration
A - Samples collected in refrigerated ISCO sampler every 2 hours for 1 week to determine temporal variation.

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Table 3 – 12 Month Operation Sampling Schedule

Types	Liquid							Solids			Membranes		Gas		
Description	**Raw Influent**	**Strained Influent**	**Mixed Liquor**	**Membrane Permeate**	**De-gassed Permeate**	**IX Column Influent**	**IX Column Effluent**	**WAS**	**Sed Tank Sludge**	**IX Media**	**UF Membrane**	**Gas Transfer Membrane**	**Bioprocess Tank Exhaust**	**Permeate Off-Gas**	**Combined Gas Exhaust**
Area	**Feed Pump**	**WAS/Mix Pump**	**Bioprocess Tank**	**Permeate Pump**	**Gas Transfer Membrane**	**Sedimentation Tank**	**IX Column**	**WAS/Mix Pump**	**Sedimentation Tank**	**IX Column**	**UF Membrane**	**Gas Transfer Membrane**	**Permeate Pump**	**Permeate Pump**	**Permeate Pump**
Sample Valve Number	**SV 1000**	**SV 1100**	**SV 1201, 02, 03**	**SV 1311**	**SV 1521**	**SV 1650**	**SV 1722**	**SV 1455**	**SV 1640**	**N/A**	**N/A**	**N/A**	**SV 1212**	**SV 1545**	**SV 1235**
Aqueous Samples															
pH		W	C	W	W	W	W								
ORP				W	W	W	W								
Total COD	M	W		W		M	M								
1.2 µm filtered COD	Q	Q	Q												
0.45 µm filtered COD	Q	Q	Q												
0.2 µm filtered COD	Q	Q	Q												
Total BOD_5	M	W		W		M	M								
DOC							M								
TOC							M								
Volatile Fatty Acids (VFAs)				W											
Alkalinity				W	W		M								
Hardness				W	W		M								
Specific Conductivity				W	W		M								
TDS				W	W		M								
Total Nitrogen[2]	M	W		W			M								
TKN[3]	M	W		W			M								
NH_3-N	M	M		W		M	W								
NO_3							M								
NO_2							M								
Sulfate	M	M		W											
Sulfide	M	M		W	W	W	M								
Total Phosphorus	M	M		W		W	M								
Dissolved Fe						W	M								
TSS	M	W	W	W		W	W								
VSS	M	W	W	W		W	W								
FSS	M	W	W	W		W	W								
Turbidity				W		W	W								
Dissolved CH_4				B	B										
Chlorine Demand							M								
E. coli and Total Coliforms[2]								Q							

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Table 3 – 12 Month Operation Sampling Schedule (Continued)

Types	Liquid							Solids			Membranes		Gas		
Description	**Raw Influent**	**Strained Influent**	**Mixed Liquor**	**Membrane Permeate**	**De-gassed Permeate**	**IX Column Influent**	**IX Column Effluent**	**WAS**	**Sed Tank Sludge**	**IX Media**	**UF Membrane**	**Gas Transfer Membrane**	**Bioprocess Tank Exhaust**	**Permeate Off-Gas**	**Combined Gas Exhaust**
Area	**Feed Pump**	**WAS/Mix Pump**	**Bioprocess Tank**	**Permeate Pump**	**Gas Transfer Membrane**	**Sedimentation Tank**	**IX Column**	**WAS/Mix Pump**	**Sedimentation Tank**	**IX Column**	**UF Membrane**	**Gas Transfer Membrane**	**Permeate Pump**	**Permeate Pump**	**Permeate Pump**
Sample Valve Number	**SV 1000**	**SV 1100**	**SV 1201, 02, 03**	**SV 1311**	**SV 1521**	**SV 1650**	**SV 1722**	**SV 1455**	**SV 1640**	**N/A**	**N/A**	**N/A**	**SV 1212**	**SV 1545**	**SV 1235**
Sludge Samples															
TS								M	M						
VS								M	M						
FS								M	M						
TP									M						
Sulfide									M						
Fe (total)									M						
RCRA Metals (As, Ba, Cd, Cr, Pb, Hg, Se, Ag)								Q	Q						
Capillary Suction Time								Q	Q						
Dewaterability								Q	Q						
Part 503 Biosolids Analyses								Q	Q						
Media Samples															
NH_3-N										R					
Gas Samples															
CH_4													C	C	C
CH_4, CO_2, N_2, O_2													Q	Q	
Siloxanes[2]													Q	Q	
H_2S													Q	Q	
Membrane Analyses and Samples															
Membrane Autopsy											E	E			
EPS			Q								Q				
Microbial Ecology															
DNA Sequencing and qPCR		Q	Q								Q				

Notes

S - Semiweekly (i.e., twice/week)
W - Weekly
B - Bimonthly (i.e., twice/month)
M - Monthly
Q - Quarterly

C - Continuously
X - Post membrane recovery clean
R - After each IX media replacement
E - End of demonstration
A - Samples collected in refrigerated ISCO sampler every 2 hours for 1 week to determine temporal variation.

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Table 4 below summarizes the filed observations that need to be made on a regular basis. For each observation, the observation location and corresponding instrument number is listed along with the typical range that the observation should fall within. As the observations are made, they should be recorded on Table 4. The observed value should be compared to the typical value. If the observed value is outside the typical range, the operator should troubleshoot to determine why the observed value is out of range and make operational adjustments as needed.

8.0 Standard Operating Procedures

The subsequent sections describe operating procedures that will be performed frequently as standard operation of the demonstration plant. More detailed procedures for operations that require special consideration can be found in Appendix A.

8.1 Floor drains

The floor drains empty into a pipe that goes to the outside of the trailer. There is a valve on each of these pipes. The valve should be normally closed because there is no barrier between the wet well and the floor drains. The lack of barrier creates a potential of hazardous gases to enter the trailer from the wet well. If there is water buildup in the trailer, the valves will need to be opened to drain the water. After draining the water, the valve needs to be closed. **Figure 5** shows where the floor drain valves are located. There are two floor drains in the hazardous room on the trailer, and one in the non-hazardous area.

Figure 5 – Floor Drain Valves

8.2 Heat Tracing

Heat tracing cables are installed in three locations on the demonstration trailer:

1. The flame arrestors on top of the trailer,
2. The exterior/above ground portion of the raw influent pipe, and
3. The aboveground/exterior portion of the floor drain piping, potable water piping, and process drain piping.

The purpose of the heat trace cables is to prevent the liquid inside these pipes from freezing. These cables are powered powered either with the circuit breaker in distribution panel 1100 or with power cables connected to outdoor outlets. During the summer time the heat tracing is not needed, so the power cables will be unplugged. During the winter time, the circuit breaker should be on and the power cables should be plugged in to activate the heat tracing cables.

8.3 Filling Water Column Vents

In the event of pressure build up in the primary reactor, secondary membrane reactor, or in the permeate section of the process trailer, a mechanism to relieve this pressure has been built in through the water column vents. The biogas from the primary reactor passes through the first water column, after which it is used for membrane sparging and proceeds through the process flow. The second and third water column vents are designed to release the high pressure build up in the primary and secondary reactors, respectively. The water displacement from these two vents is a clear indication of a pressure buildup. The water level in all these vents need to be maintained at the marked level on the column, and can be filled manually with the water hose conveniently located within the hazardous section of the trailer. **Figures 6** show the details of the water column vents.

Figure 6 – Pressure Relief Water Columns

8.4 Automatically Draining Condensate Traps

There are actuated valves on the condensate traps (collection tanks). If the water level in the trap is above the normal max level, the automatic valve will open to drain the trap. Valve 1549 on collection tank 1540 will need to be opened manually to drain. If the tanks do not drain, then the operator should troubleshoot to figure out why the trap did not drain automatically (e.g. residue buildup on the level instrument, faulty automated valve, etc.) and make corrective actions. **Figure 7** shows a picture of a condensate trap.

Figure 7 – Condensate Trap (Collection Tank)

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Table 4 – Field Observations Checklist

Field Observations Checklist					
Area	**Equipment No.**	**Observation**	**Observation Location/ Instrument Number**	**Observed Value**	**Notes**
Floor of Hazardous Room	N/A	Water on the floor? Source of leak? Yes/No	Hazardous Room		
Bioprocess Tank	Tank 1200	Headspace Pressure, PSI	PI 1200		
		Sludge Color Normal? Yes/No	Observe Thru Windows		
Recirculation & WAS/Mix Pump Area	Pump 1100 (Influent)	Discharge Flow, GPM	FIT 1100		
	Pump 1430 (Recirc)	Discharge Flow, GPM	FIT 1430		
	Pump 1440 (WAS/Mix)	Discharge Flow, GPM	FIT 1440		
Biogas Sparge Pump	Pump 1410	Suction Pressure, PSI	PI 1413		
		Discharge Pressure, PSI	PI 1423		
		Discharge Flow, LPM	FIT 1410		
		Condensate Trap Water Level (Suction)	Tank 1410		
		Condensate Trap Water Level (Discharge)	Tank 1420		
Effluent Gas Flow Meter	FIT 1230	Flow, LPM	FIT 1230		
		Condensate Trap Water Level	Tank 1220		
Membrane Tank	Tank 1300	Pressure, PSI	PI 1300		
		Sparge Gas Flow RH, CFM	FI 1425		
		Sparge Gas Flow LH, CFM	FI 1426		
Pressure Relief Columns	Tank 1210, 1240, 1330	Water Column Level	Tank 1210		
		Water Column Level	Tank 1240		
		Water Column Level	Tank 1330		
Permeate Pump	Pump 1310	Discharge Flow, GPM	FIT 1310		
		Suction Pressure, PSI	PI 1310		
Vacuum Pump	Pump 1540	Suction Pressure, in Hg	PI 1540		
		Condensate Trap Water Level	Tank 1540		
Gas Transfer Membrane	Contactor 1500	Liquid Inlet Pressure, PSI	PI 1511		
		Gas Inlet Pressure, in Hg	PI 1530		
		Gas Flow, CFM	FI 1530		
CIP/Backpulse Tank	Tank 1320	Water Level	Tank 1320		
Non-Hazardous Room	N/A	Water on the floor? Source of Leak? Yes/No	Room, Chemical Storage Area		
Ambient Gas Monitor	AIT 1010, HSIT 1010	Methane Concentration, %LEL	AIT 1010		
		H2S Concentration, PPM	HSIT 1010		
Rapid Mix/Flocculation Basin	Basin 1620, 31, 32, 33	Mixer On/Off	Mixer 1620		
		Mixer On/Off	Mixer 1631		
		Mixer On/Off	Mixer 1632		
		Mixer On/Off	Mixer 1633		
		Water Level	Basin 1620		
		Water Level	Basin 1631		
		Water Level	Basin 1632		
		Water Level	Basin 1633		

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Table 4 – Field Observations Checklist (Continued)

Field Observations Checklist					
Area	**Equipment No.**	**Observation**	**Observation Location/ Instrument Number**	**Observed Value**	**Notes**
IX Column	Vessel 1720	Media Height	Vessel 1720		
IX Column Pump	Pump 1710	Discharge Pressure, PSI	PI 1710		
		Flow, GPM	FI 1710		
Sedimentation Tank	Basin 1640, 1650	Water Level	Basin 1650		
		Sludge Level	Basin 1640		
Chemical Storage & Metering	Pumps 1810, 20, 30, 40, 50	On/Off?	Pump 1810		
		On/Off?	Pump 1820		
		On/Off?	Pump 1830		
		On/Off?	Pump 1840		
		On/Off?	Pump 1850		
	Tanks 1810, 20, 30, 40, 50	Liquid Level	Tank 1810		
		Liquid Level	Tank 1820		
		Liquid Level	Tank 1830		
		Liquid Level	Tank 1840		
		Liquid Level	Tank 1850		
Chemical Storage & Metering	Mixer 1810, 1820	On/Off?	Mixer 1810		
		On/Off?	Mixer 1820		
Air Compressor	Compressor 1910	Filter Element Pop-Up Indicator	Air Prep Module 1910		
		Pressure Indicator, PSI	Air Prep Module 1910		
Thermostat	N/A	Room Temp	N/A		
Gas Analyzer	AIT 1231, 32, N/A, N/A	% O2	AIT 1231		
		% CH4	AIT 1232		
		Gas Analyzer Pressure, PSI	Inside Gas Analyzer		
		Condenstation in trap or stainless steel valve? Yes/No	Inside Gas Analyzer		
Nitrogen Gas Cylindar	N/A	Pressure in Tank, PSI	Regulator on Cylinder		
Spec Gas Cylinder	N/A	Pressure in Tank, PSI	Regulator on Cylinder		
Pump Station	Pump 1100 (Feed)	Check for water leaks on the assoicated piping	Floor		
Pump Station	Strainer	Check for water leaks or air leaks on associated lines	Floor and Piping		
Feed Pump	N/A	Pressure, PSI	Pressure Gauge by Feed Pump		
Strainer	N/A	Pressure, PSI	Pressure Gauge by Strainer		

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9.0 Health and Safety Plan

In addition to the health and safety considerations in the subsequent sections, the CDM Smith Health and Safety plan can be found in Appendix F.

9.1 Site Location

The Camp Forsyth pump station within Ft. Riley will be the site where the demonstration scale trailer AnMBR unit will operate from. The site used to part of former wastewater treatment plant and is situated within an enclosure with parking facilities available.

9.2 Transportation of personnel and test samples

Student researchers and investigators from Kansas State University, Drs. Hutchinson and Parameswaran, will visit the demonstration site regularly. All members will need to obtain appropriate security clearance to enter Ft. Riley and then drive to the site. Chris Otto with the Directorate of Public Works – Environmental division in Ft. Riley will be the primary sponsor for all members working on the onsite demonstration facility to obtain badge access. The researchers will drive K-State owned vehicles from the university to the project site and back. The researchers will be required to possess drivers insurance and adequate and current documentation (such as valid driver's license) at all times.

9.3 Required personnel protective equipment (PPE)

Researchers and all workers on the trailer unit are required to either possess, or have access to Personnel Protective Equipment (PPE) – laboratory coats, eye goggles, and gloves that are chemical resistant. All personnel on the trailer unit are required to wear long pants and closed toed shoes/boots. Ear plugs will be available, should the researchers need to access noisy machinery within the trailer. The PPE should be worn not just during sampling events alone, but every time that a researcher/operator is in the pilot trailer unit. The PPE can be removed once off the facility and need not be worn during transportation, unless moving a hazardous chemical from one point to another.

9.4 Gas exposure hazard and mobile monitors

Exposure to flammable and harmful gases, namely, Methane and Hydrogen Sulfide, can occur in a portion of the trailer unit that houses the primary and secondary anaerobic membrane bioreactors.

Methane:

A key ingredient of the produced biogas is Methane (CH_4). By itself, it is an odorless gas with a lower explosion level (LEL) of 4%. Ambient air monitoring meters for CH_4 are mounted in the hazardous section of the trailer. Should the level of methane within the trailer reach 10% of the LEL, the the system will automatically shut down and the alarm beacon will illuminate. All personnel should immediately evacuate the trailer and call 911.

Hydrogen Sulfide (H_2S):

Although not a major constituent of biogas from the AnMBR, H2S is both an explosive and toxic gas. At concentrations as low as 0.5 ppb, it is detected by the human nose and above 100 ppm, it paralyzes the olfactory nerve and impairs the ability to respond to the impending health hazard. Eye damage occurs at 50 ppm and concentrations higher than this can cause pulmonary edema. Apart from the

crippling health impacts, H_2S also has explosive potential with an LEL of 4% as well. OSHA (Occupational Safety and Health Administration) identifies a PEL of 10 ppm for H_2S and the TLV for H_2S as identified by ACGIH (American Conference of Governmental Industrial Hygienists) is 1 ppm. The ambient monitors for CH_4 and H_2S are located at a visible distance from the entry door for the hazardous section of the trailer to clearly indicate a hazardous situation prior to entry into the trailer. Moreover, personal H_2S monitors must be worn by the personnel and should enable early detection and alarm activation for evacuation procedures. All personnel intending to work on the trailer will be required to participate in H_2S awareness training courses online on a regular basis. The ambient H_2S monitor will shut down the trailer if the H_2S concentration reaches 5 ppm. If this occurs all personnel should evacuate the trailer and call 911.

9.5 Exposure to pathogens

Contact with wastewater and anaerobic sludge has a greater probability of occurrence during trailer operation by operators. Extreme care should be given to wearing PPE (gloves that are chemical resistant) and immediate steps should be taken to clean up accidental spills of wastewater or sludge by washing hands thoroughly with antibacterial soap. All KSU operators will have obtained adequate safety training, including Blood Borne Pathogens training from Environmental Health & Safety division at the University.

9.6 Severe Weather preparedness

In case of a tornado:

1. All occupants in the trailer unit should know where to go in case of a tornado or severe weather. In the event of a tornado, the sirens will sound a steady three-minute blast when there is need to take cover. Sirens are intended to alert personnel outside the building. For those inside buildings, an alert will be sent to personnel in every building via the telephone. Each department head should prepare a plan on how personnel will be advised of the weather emergency.

2. In general, you should:

    a. Get and stay indoors during the storm.

    b. Go to the interior hallways on the lowest level of the building.

    c. Stay away from windows, doors, outside walls and protect your head.

    d. Listen for improved weather conditions on a local radio or television station.

3. After the severe weather emergency has passed, faculty or staff should notify the proper emergency personnel of any damages or injuries by calling 911. All university related injuries or illnesses must be reported through Accidental Injury Forms, located in the departmental office, as per the Policy and Procedures Manual.

Heat Stress:

The possibility of a heat-related injury at the trailer site exists, especially during the summer months. All demonstration participants are encouraged to be attentive and responsive to signs of heat-induced illness. Heat stress symptoms include heat cramps, heat exhaustion, and heat stroke. Heat

stroke is the most serious condition and can be life-threatening. Some symptoms of heat-related injuries are pale clammy skin, sweating, headache, weakness, dizziness, and nausea. Signs of heat stroke include dry, hot, red skin, chills, and confusion. In the case of a suspected heat-related injury, try to cool the person down and contact medical help. Also, plan to take frequent breaks when there is extreme heat involved.

Insect and other animal stings/bites:

A potential for insect (honeybees, wasps) and nuisance from mosquitoes might occur in the vicinity of the trailer, during warm weather months especially. It is recommended that the participants have access to an approved brand of bug spray so they can keep these hazards at bay, along with adequate cleanliness in the work area to minimize vector attraction.

9.7 Chemical Hazards:

Prior to the start of demonstration, all participants will need to familiarize with the Material Safety Data Sheets (MSDS) for all the chemicals that will be used on trailer. This includes preservatives such as Sulfuric acid, Nitric acid, and chemical reagents such as Potassium Dichromate, Hydrochloric acid, Sodium Hypochlorite, Ferric Chloride, and Citric acid. Portable eye wash stations are located in each room of the trailer unit. All chemicals should be labeled.

9.8 Physical Hazards:

Physical hazards associated with field activities should be considered with utmost care. Dangers are posed by unseen obstacles, noise, heat, and poor illumination. Injuries may result from the following:

- Accidents due to slipping, tripping, or falling.
- Improper lifting techniques
- Moving or rotary parts of machines
- Improper maintenance of machinery

9.9 Mechanical, electrical and noise hazards:

Electrical cables present a potential tripping hazard. Cables should be placed in areas of low pedestrian travel. Hazard signals for low hanging electrical cables should be clearly posted so that possible direct contact could be avoided.

9.10 Fire:

The following steps should be taken to reduce the potential for fire during site activities:

- No smoking within 100 feet of any operating technology or the trailer
- Fire extinguishers will be maintained on-site.
- All personnel will be trained on the location of the portable fire extinguishers.
- The contact phone number for the fire department will be posted.

9.11 Radiological Hazards:

No radiation hazards should exist on the trailer demonstration site and should there be a need to include equipment/machinery that might emit radiation, detailed training and permits will be obtained, with the appropriate level of stringent precautions to avert any shortcomings to the participants or to the site itself.

9.12 Emergency Support:

The list of nearby hospital(s) with a roadmap of how to get there, will be posted on the trailer unit and will also be made available to the participants, and has already been disseminated through the demonstration plan document.

9.13 Hazardous Waste Disposal:

All hazardous waste generated at the demonstration scale trailer unit will be properly disposed according to the stipulations of the Environmental Health and Safety Officer. The participants will assist in this process by maintaining a record of the waste content concentration, and the usage of appropriate storage containers.

9.14 Site Control:

Access will be restricted to the primary participants identified by the project manager as necessary personnel to be on the trailer. The participants should take steps to ensure the equipment is secure before leaving the site on any given day or time.

9.15 Safe Work Practices:

Each company shall provide the required training and equipment for the participants to meet safe operating practices and procedures.

- Eating, drinking, chewing tobacco, and smoking will be permitted only in designated areas.
- No personnel will be allowed to do tasks alone in the hazardous or the non-hazardous sections of the trailer, other than sampling and work in the analytical lab trailer.
- PPE should always be enforced.

The Ft. Riley Fire Department has been given a tour of the facility and a copy of this Operations and Maintenance Manual. In the event of an emergency 911 should be called. If possible personnel should not work alone on-site. If personnel do need to work alone – they should notify a co-worker that they will be working at the site and notify them once again once they leave the site.

Appendices

Appendix A
Standard Operating Procedures

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Standard Operating Procedure for Draining Condensate from Hollow Fiber Membrane Contactor 1500

Authored by: Meagan Malloy 7/11/2016

Approved by:

Scope and Applicability

This SOP details procedures and safety considerations for recovering performance of the hollow fiber gas contact membrane at the US Army base Ft. Riley AnMBR Demonstration Plant. The procedure involves first positioning the valves so that the air will have to pass through the condensate trap. Next, position the valves to allow ambient air to flow through the inside of the hollow fibers. The ambient air will be sucked by the vacuum pump through the membrane and vaporize condensate that forms on the inside of the hollow fibers. When the condensate trap reaches its high level the drain valve will open allowing the collected water to flow back to the pump station wet well. The procedure is intended to outline how to recover performance of the membrane if there is condensate clogging the fibers.

Equipment

1. H2S gas meter
2. PPE described in HASP

Procedure for Recovering Performance of the Hollow Fiber Gas Contact Membrane

1. Put H2S monitor on the collar of your shirt.
2. Put PPE on.
3. One the HMI, manually turn the ventilation fan to full speed and ensure there are not high gas alarms going off.
4. Once process area is safe, ensure gas-line valves are positioned according to the table below (and sketches at end of document).

Valve	Position
DV-1541	Open
DV-1542	Open
DV-1543	Closed
DV-1530	Open
PV-1530	Open

5. Adjust the vacuum pump setting as well as DV and PV 1530 valve positioning to maintain the flow rate through the membrane of 7 scfm.
6. Allow ambient air to flow through the hollow fibers for 30 secs.
7. Return valves to normal operating position.

Valve	Position
DV-1541	Open

Valve	Position
DV-1542	Open
DV-1543	Closed
DV-1530	Closed
PV-1530	Closed

8. Check performance of the membrane contactor.
9. If performance hasn't been recovered, repeat steps 1 through 4 while incrementally increasing the amount of time ambient air flows through the membrane in step 3 until the membrane has reached a satisfactory amount of performance.
10. When finished return valves to normal operating position as described in step 7.

Figure 1 – The air filter that the ambient air will pass through before entering the membrane.

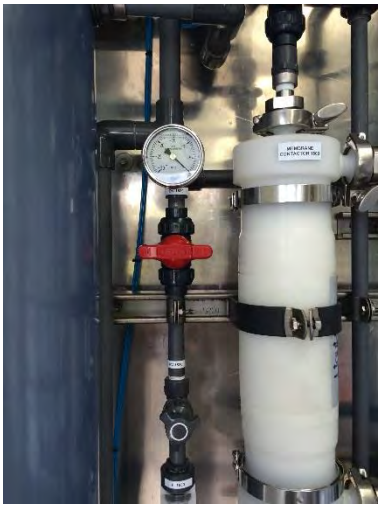

Figure 2 – Pressure gauge of the intake of ambient air next to the hollow fiber membrane.

Figure 3 – Hollow fiber membrane with respect to the vacuum pump and the condensate trap.

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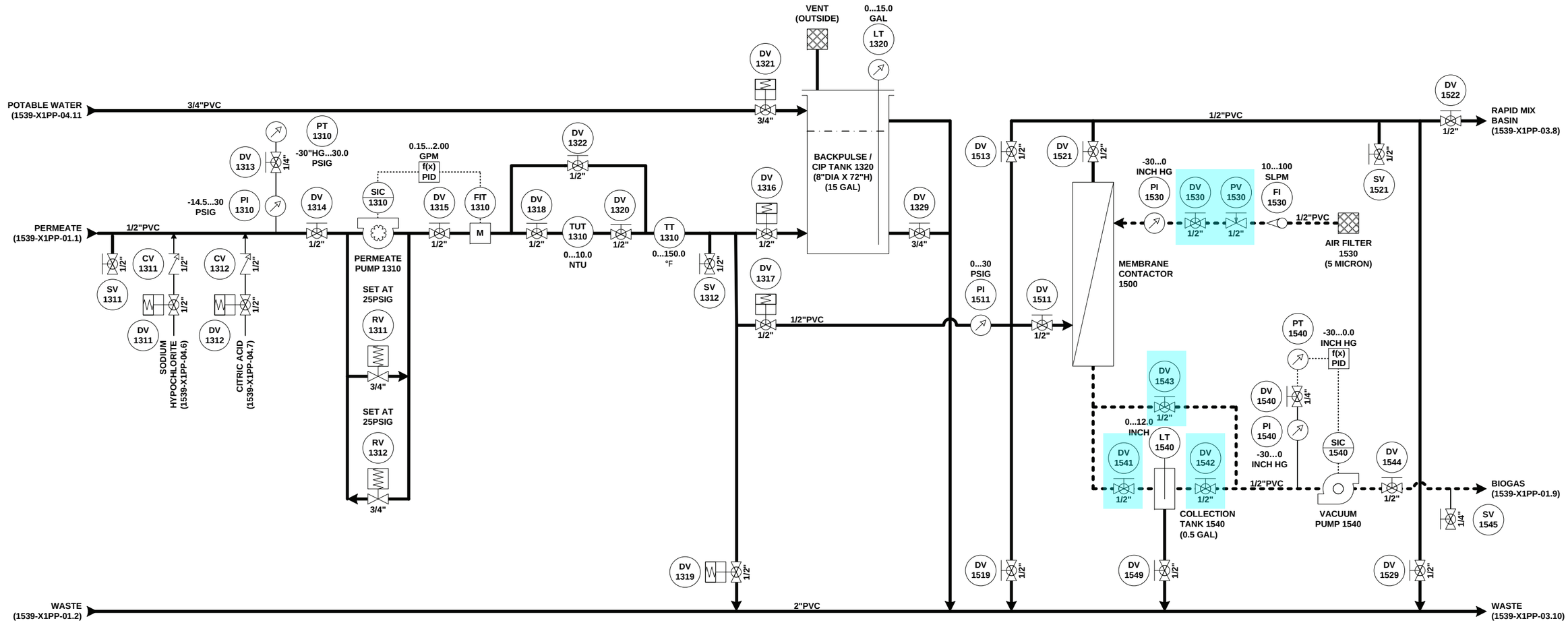

REV	DATE	BY	DESCRIPTION
1	01-04-16	EJH	MADE NUMEROUS CHANGES & ADDITIONS AFTER 12-29-15 TELECONFERENCE.
2	01-13-16	CDP	ADDED RV PRESSURE LIMIT, CHANGED LIT TAGS TO LT, REMOVED DV-1320, CHANGED FLOW METER RANGE
3	04-01-16	CLR	ADD DV-1544, DV-1318, DV-1320, DV-1322
4	06-07-16	CLR	ADD SV-1545, MOVE TT-1310, PI-1310, AND PI-1540

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FRAC: ± 1/16 0.XX: ± 0.01

ANGLES: ± 1° 0.XXX: ± 0.005

TITLE: **ANAEROBIC MBR PILOT PLANT PROCESS & INSTRUMENTATION DIAGRAM (2 OF 4)**

CLIENT: CDM SMITH	PROJECT: 1539
DRAWN BY: EJH	DRAWN DATE: 12-17-15
DRAWING NAME: 1539-X1PP-02.VSD	P.O.:
SCALE: NONE	REVISION: 4

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Standard Operating Procedure for Bioreactor Seeding

Authored by: Meagan Malloy 7/13/2016

Approved by:

Scope and Applicability

This SOP details procedures and safety considerations for seeding digested sludge to the pilot-scale Digester at the US Army base Ft. Riley AnMBR Demonstration Plant. The procedure involves first replacing the top sight plate on the Bioreactor with a valve and 4in camlock fitting. Then, position the valves to isolate the Bioreactor and the Membrane Tank from the rest of system. Next, fill the Bioreactor and Membrane Tank to the top with water. Then, allow the Bioreactor and Membrane Tank to drain while simultaneously filling the two tanks with Nitrogen gas. Digested sludge can then be fed into the Bioreactor through the camlock fitting. When the Bioreactor has 370 gallons of sludge, the digested sludge feed pump can be turned off. The recirculation pump can be used to fill the bioreactor with digested sludge to the elevation of the Mixed Liquor pipe. When sludge level equilibrium has been reached between Bioreactor and the Membrane tank, the recirculation pump can be turned off and the sight glass replaced. The procedure is intended to address safety considerations associated with liquid containing hydrogen sulfide, dissolved methane, and bacteria; and gas containing hydrogen sulfide and flammable concentrations of methane.

Safety/Hazards

Digested sludge contains hydrogen sulfide, dissolved methane, and potentially pathogenic bacteria. The dissolved gases can be released as vapors during mixing. Precautions must be taken to avoid dermal contact or ingestion of digester liquid; and inhalation of released vapors. The amount of dissolved methane (about 10 mg/L at 37 °C in equilibrium with 60% methane in the digester headspace) is not high enough to create vapor concentrations in the mix tank above the LEL of 5% for methane. The digester is also located in a class 1, division 1 process room which is explosion proof. Personal protective equipment to be used shall include but is not limited to safety glasses, close toed shoes, nitrile gloves, and an H2S gas meter. These items are discussed further in the Health and Safety Plan (HASP). Specific use of these items is discussed in the procedures below.

Equipment

1. H2S gas meter
2. PPE described in HASP
3. Portable centrifugal pump
4. Digested sludge
5. Two 275 Gallon totes
6. Fittings and hose to connect totes to pump
7. Hoses with cam-lock fittings to connect pump to Bioreactor
8. 6” flange connected to a ball valve and 4” cam lock

9. Bucket to catch excess sludge when switching hoses, and replacing sight glass
10. Explosion proof flashlight
11. Potable water and hose
12. Bucket
13. Floor squeegee
14. Operational control system for the process

Procedure for Digester Seeding

1. Put H2S monitor on the collar of your shirt.
2. Put PPE on.
3. On the HMI, turn the Ventilation Fan to manual mode and set the speed to 100%
4. On the HMI, turn the process to offline.
5. Drain the Bioreactor to be below the top sight glass (below a tank volume of 350 gallons). Replace the top sight glass with a 6" flange connected to a ball valve, and a 4" cam lock connection. Tighten flange bolts in a star pattern. Make sure the ball valve is closed.
6. Fill tanks 1210, 1240, and 1330 to their fill lines with Potable water.
7. Check position of hand valves to ensure that the Bioreactor and Membrane tank are isolated.
8. Open DV-1308, DV-1921, and DV-1924 to begin filling the Bioreactor and Membrane tank with potable water. The potable water is pressurized to 100psi so the valves do not need to be fully opened. The Bioreactor has a full volume of 470 gallons. The Membrane tank has a full volume of approximately 30 gallons. The levels can be monitored on the HMI screen.
9. Monitor the pressure relief in Columns 1210, 1240, and 1330 to ensure the tanks are not being over pressurized.
10. The HMI will alarm when the Bioreactor is above 380 gallons, and the Membrane tank will alarm when the volume is 28 gallons. This is expected and should not be cause for stopping the process. High pressure alarms are also a possibility, monitor the pressure so that the high pressure is not sustained. Adjust potable water valves as necessary.
11. When the Bioreactor and Membrane tank are filled with water, close DV-1921 and DV-1924.
12. Refill pressure relief columns if needed.
13. Check that Nitrogen Regulator is set to a discharge pressure of approximately 10psi.
14. Open DV-1251
15. Open DV-1209 and DV-1409
16. Monitor level of the Bioreactor and the Membrane Tank until empty. The HMI will not say when the level has reacted Zero. The lowest level that the HMI will say for the Bioreactor is 15 gallons, and the Membrane tank is 2 gallons. The Bioreactor level can be seen through the lowest sight glass using a flashlight. The pressure relief columns will indicate a slightly negative pressure in the tanks. This is okay, so long as it doesn't suck all the water into the tanks and allow ambient air in the system. Increase Nitrogen gas pressure if there seems to be an issue.
17. When the tanks are drained close their associated drain valves. When both tanks have been drained the nitrogen gas valve can be closed (DV-1251).

18. Connect tote with sludge to the portable centrifugal pump, connect the pump to the digester. Open the lid of the tote slightly so there are no pressure issues that could cause damage to the totes.
19. Open the ball valve and allow the hose to fill with sludge. When the hose is filled, turn the pump on.
20. Monitor the level of the Bioreactor on the HMI.
21. The level of the tank will level off when the pump can no longer overcome the head differential. At that point, turn the portable pump off and switch to the other tote. Then continue filling the Bioreactor to 370 gallons.
22. If the tank level becomes stagnant prior to the tank level reaching 370 gallons, then turn the portable pump off. Collect Samples. Fill the bioreactor to 370 with sewage using the feed pump. Turn the feed pump off when the tank level has reached 370 gallons.
23. Open Valves DV-1435 and DV-1436.
24. Turn the recirculation pump on and fill the Membrane tank with sludge until the level equalizes. The Mixed liquor pipe between the Membrane Tank and the Bioreactor will allow the levels to equalize.
25. Unlock the sludge hose from the cam lock fitting. Drain hose line back to the totes.
26. Check that the drain valves are open.
27. Check that the level of the bioreactor is slightly between 345 and 350 gallons. Then remove the temporary 6” flange and fittings and replace the sight glass. Use a container to catch excess sludge that spills when the flanges are exchanged. Tighten the bolts in a star pattern.
28. Open Floor drain valves. Hose down any spills. Use the squeegee to get excess water on the floor to the drains. After the cleaning is complete, close the floor drain valves.
29. Drain excess sludge from totes to the wetwell.
30. Open Feed Flow valve DV-1209
31. Check hand valves are set as they should be for production.
32. Return process to Auto-Production mode on the HMI.

Figures

Figure 1 - 6inch flange with valve and Cam Lock connection

Figure 2 - Top sight glass

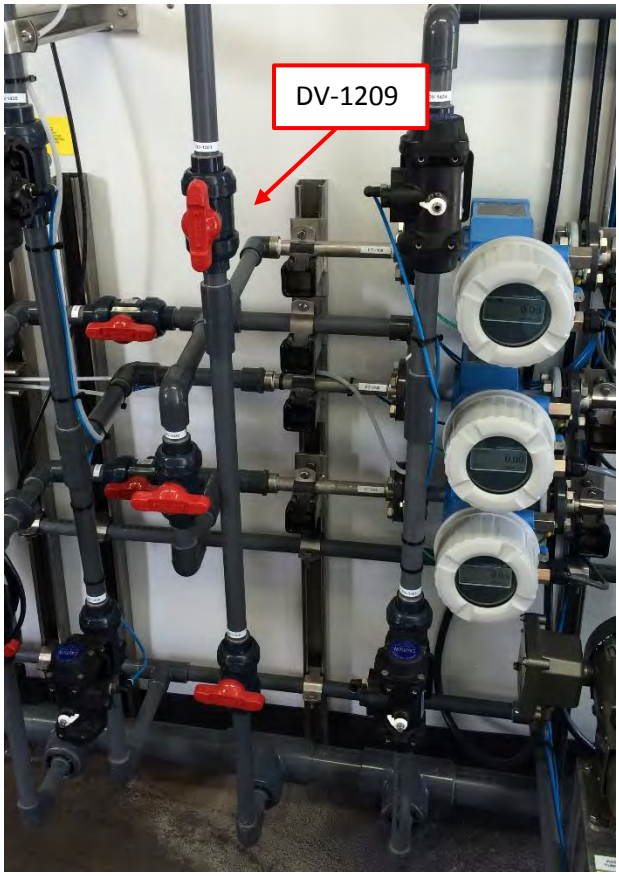

Figure 3 - Feed Flow Pipe and Valves

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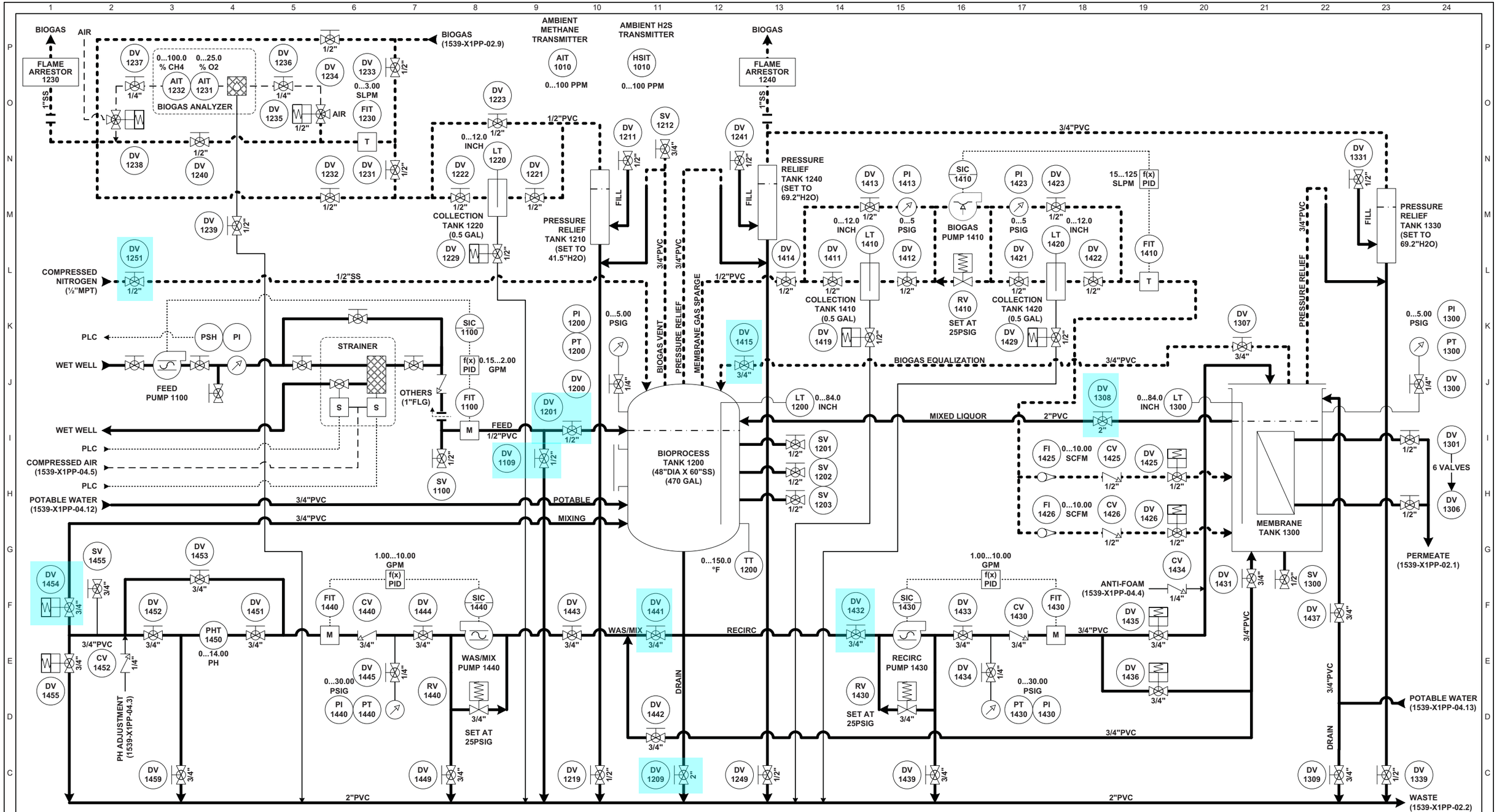

REV	DATE	BY	DESCRIPTION
1	01-04-16	EJH	MADE NUMEROUS CHANGES & ADDITIONS AFTER 12-29-15 TELECONFERENCE.
2	01-13-16	CDP	COMBINED LINES INTO MEMBRANE TANK 1300, ADDED RV PRESSURE LIMIT, CHANGED LIT TAGS TO LT, CHANGED FLOW METER RANGES
3	04-01-16	CLR	ADD DV-1238, DV-1414, DV-1415, DV-1437, DV-1538, SV-1212, AND AMBIENT GAS TRANSMITTERS. MOVED SV-1455, DV-1431.
4			

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FRAC: ± 1/16 0.XX: ± 0.01

ANGLES: ± 1° 0.XXX: ± 0.005

TITLE: ANAEROBIC MBR PILOT PLANT
PROCESS & INSTRUMENTATION DIAGRAM (1 OF 4)

CLIENT: CDM SMITH	PROJECT: 1539
DRAWN BY: EJH	DRAWN DATE: 12-17-15
DRAWING NAME: 1539-X1PP-01.VSD	P.O.:
SCALE: NONE	REVISION: 3

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Standard Operating Procedure for Exchanging Zeolite

Authored by: Meagan Malloy 7/20/2016

Approved by:

Scope and Applicability

This SOP details procedures and safety considerations for removing zeolite from the ion exchange column and replacing with new and/or regenerated Zeolite at the pilot-scale Digester at the US Army base Ft. Riley AnMBR Demonstration Plant. Two people are necessary to complete this procedure. The procedure involves first bypassing and draining the column, and removing the short pieces of pipe and the top and bottom of the reactor. Next the top flange is removed. Then, while one person supports the column to keep it from tipping over, another loosens the straps that hold the column upright. When the straps have been removed, the column can be lowered, and the spent Zeolite dumped into a secondary container. Wash water will be necessary to extract all the spent Zeolite from the column. After the column has been washed out, it will be placed back onto the rack. The top flange and top and bottom piping pieces should be put in place to check the alignment of the column. When the column is aligned the bottom pipe can be tightened into place. Then remove the top pipe piece and flange, and fill the column with new/regenerated Zeolite. When the column is full replace the top flange and piece of pipe and tighten the unions. When the column is back in place and all the piping pieces tightened the effluent can be directed back to the column.

Safety/Hazards

The effluent that will pass through the Zeolite column will have sulfide in it so precautions against hydrogen sulfide gas should be taken. The column will be very heavy when it is full of the wet Zeolite, so take care when moving the column to dump out the spent Zeolite. Additionally, when filling the column up with new/regenerated Zeolite, there is the potential for a lot of dust which can impair vision and breathing ability. Personal protective equipment to be used shall include but is not limited to safety glasses, close toed shoes, and an H2S gas meter. These items are discussed further in the Health and Safety Plan (HASP). Specific use of these items is discussed in the procedures below.

Equipment

1. H2S gas meter
2. PPE described in HASP
3. Safety glasses or goggles
4. Dust mask
5. Two adjustable wrenches
6. One strap wrench

Procedure for Digester Seeding

1. Put H2S monitor on the collar of your shirt.

2. Put PPE on.
3. Turn the process off on the HMI.
4. Drain the column by opening valves DV-1721 and DV-1729
5. When the column is drained unscrew the union at DV-1721 and the union on the bottom side of the column. Remove the section of pipe on the bottom side of the column. There is pipe strap that will need to be removed when removing the piece of pipe.
6. Unscrew the union at DV-1722 and the union at the top of the column. Remove the top piece of pipe and the sample valve.
7. Unscrew the bolts on the top flange of the column.
8. Bring the column down.
    a. Undo bolts of the column straps.
    b. Second person to hold the column in place, the column will be very heavy.
    c. Carefully lower the column, be mindful of how heavy the column is. Do not set down directly on the bottom pipe.
9. Dump the spent Zeolite into a container. Use potable water to clean-out excess material from the column.
10. Place column back in place. Put the column straps back in place and tighten the bolts. Ensure that the straps are level, and flush with the column.
11. Attach bottom pipe for alignment.
12. Place top flange in place and top pipe to check alignment. Make necessary adjustments.
13. When aligned, remove the top pipe and the top flange.
14. Carefully fill the column with the new/regenerated Zeolite.
15. When the column is full replace the top flange. Tighten the bolts in a star pattern.
16. Replace the top pipe and sample port. Tighten the unions.
17. Open floor drain valve for the non-hazardous room.
18. Clean the floor.
19. Return operation to production.
20. Send spent Zeolite to be regenerated.

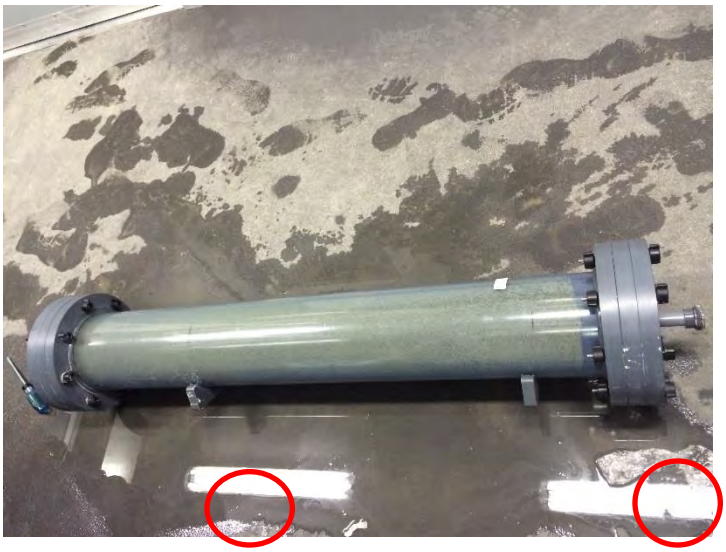

Figure 1 – Zeolite Column; circled in red are the pieces that sit into the equipment skid, which made alignment and support of the column possible.

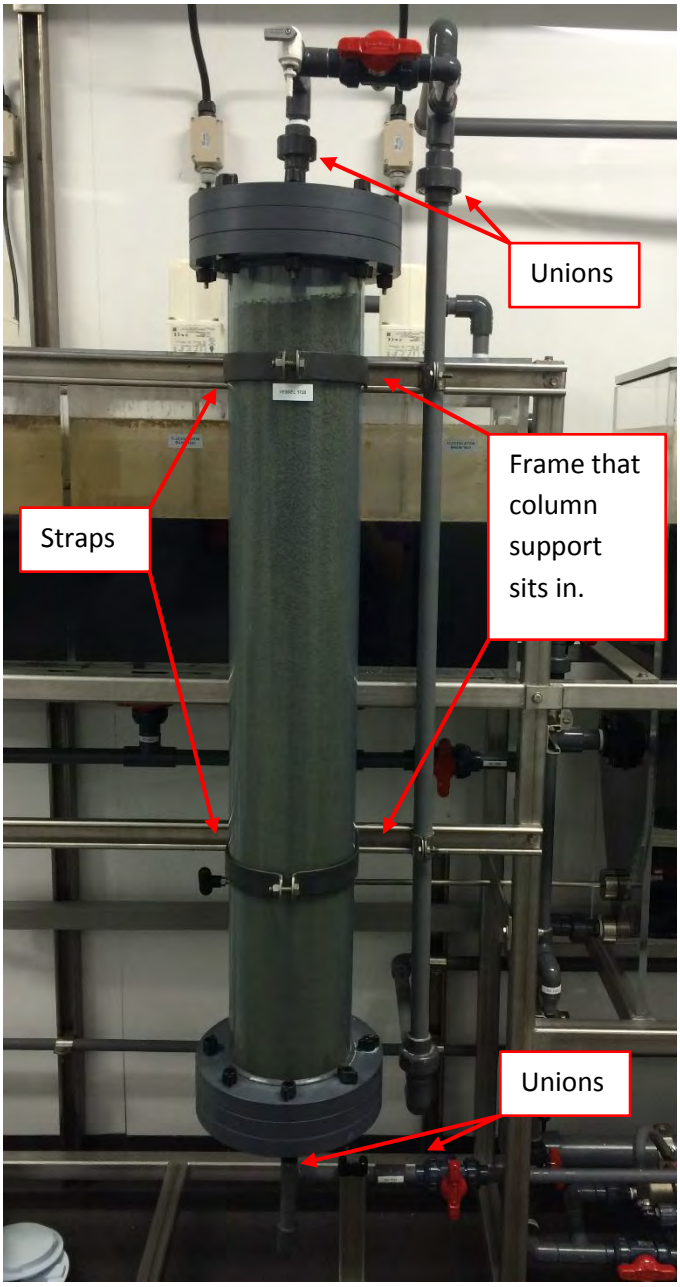

Figure 2 – Column with component call outs.

Standard Operating Procedure for cleaning the strainer

Authored by: Barrett Schmidt 7/22/2016

Approved by:

Scope and Applicability

This SOP details procedures and safety considerations for cleaning the strainer prior to feeding the pilot scale AnMBR at the US Army base in Ft. Riley. The strainer is located in the wet well building and is located immediately downstream of the feed pump. The procedure involves the manual dismantling of the strainer screen, after shutting down electric power to the strainer as well as compressed air supply that operates the actuator, and then dismantling the casing that houses the screens. This is followed by a thorough cleaning with wire brushes and water to remove fine debris that could be clogging the strainer pores.

Safety/Hazards

Raw wastewater can contain hydrogen sulfide, dissolved methane, and potentially pathogenic bacteria. The dissolved gases can be released as vapors during mixing. Precautions must be taken to avoid dermal contact or ingestion of the raw wastewater and inhalation of released vapors. Personal protective equipment to be used shall include but is not limited to safety glasses, close toed shoes, nitrile gloves, and an H2S gas meter. Rubber boots and an apron could be other essential items to prevent spills and splashes on clothing and skin. These items are discussed further in the Health and Safety Plan (HASP). Specific use of these items is discussed in the procedures below.

PPE

1. Rubber boots
2. Rubber apron
3. Lab coat
4. Rubber gloves
5. H2S monitor
6. Goggles

Equipment

1. Wire Brush
2. Bucket to catch strainer debris
3. Potable water and hose

Procedure for Cleaning the Strainer

1. Put on PPE
2. Manually turn the strainer off by turning the red knob on the power supply to the “off” position. (Figure 1)
3. Shut the air supply to the strainer off by turning the airline valves to the vertical positions.
4. Relieve any residual pressure in the system by applying pressure to the solenoid valves on either side of the power supply box until air flow stops.

5. Slowly loosen the three black knobs on top of the plunger casing. **Be sure to remove slowly as there may still be residual water pressure.
6. Take plunger out of casing and remove any debris with a wire brush
7. Inspect the plunger casing's rubber gasket for damage before putting the plunger back and closing the black knobs on top of the plunger casing. Hand tight so that no water will leak.
8. Return air supply valves to the open, horizontal, position. (Figure 2)
9. Turn the red knob back to the "on" position.

Figures

Figure 1 – Strainer power supply box

Figure 2 – Air supply valves in the “open” position

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Standard Operating Procedure for Checking Foam in the Primary Reactor/Membrane Tank

Authored by: Barrett Schmidt 7/26/2016

Approved by:

Scope and Applicability

This SOP details procedures and safety considerations for checking the pilot scale AnMBR at the US Army base in Ft. Riley for foam formation in the inspection valve installed on the biogas overflow line between the membrane tank and primary bioreactor. The procedure involves slowly opening a sample valve to visually observe foam in a long clear piece of tubing which is connected to the sampling valve and runs out of the trailer. If foam is present, it will become necessary to add a defoaming agent at the designated dosing rate, which will be determined each time depending upon the foaming intensity and jar testing**.**

Safety/Hazards

Raw wastewater can contain hydrogen sulfide, dissolved methane, and potentially pathogenic bacteria. The dissolved gases can be released as vapors during mixing. Precautions must be taken to avoid dermal contact or ingestion of the raw wastewater and inhalation of released vapors. Personal protective equipment to be used shall include but is not limited to safety glasses, close toed shoes, nitrile gloves, and an H2S gas meter. These items are discussed further in the Health and Safety Plan (HASP). Specific use of these items is discussed in the procedures below.

It is also important to note that the ventilation fan must be changed to 100% operational speed on the HMI, and the door to the hazardous location must be propped open before proceeding with this check.

PPE

1. Rubber gloves
2. H2S monitor
3. Goggles
4. Protective mask

Equipment

1. 10 foot long clear tubing
2. Step ladder to reach sample valve
3. Flashlight

Procedure for Checking for Foam

1. Put on H2S monitor
2. Put on remainder of PPE
3. At the HMI turn the air vent fan to 100% operational speed.
4. Prop open the door to the hazardous room.
5. Using the stepladder, attach 10 foot tube to the sample valve on the ***biogas recirculation pipe*** and run tubing outside of trailer.
6. Slowly open SV and watch the tubing for any signs of foam.
7. Return SV to the closed position and remove tubing.

8. Using the flashlight, attempt to locate any foam on the sludge surface in the bioreactor using the stepladder to see inside the uppermost viewport of the reactor.

Appendix B

Intuitech O&M Manual

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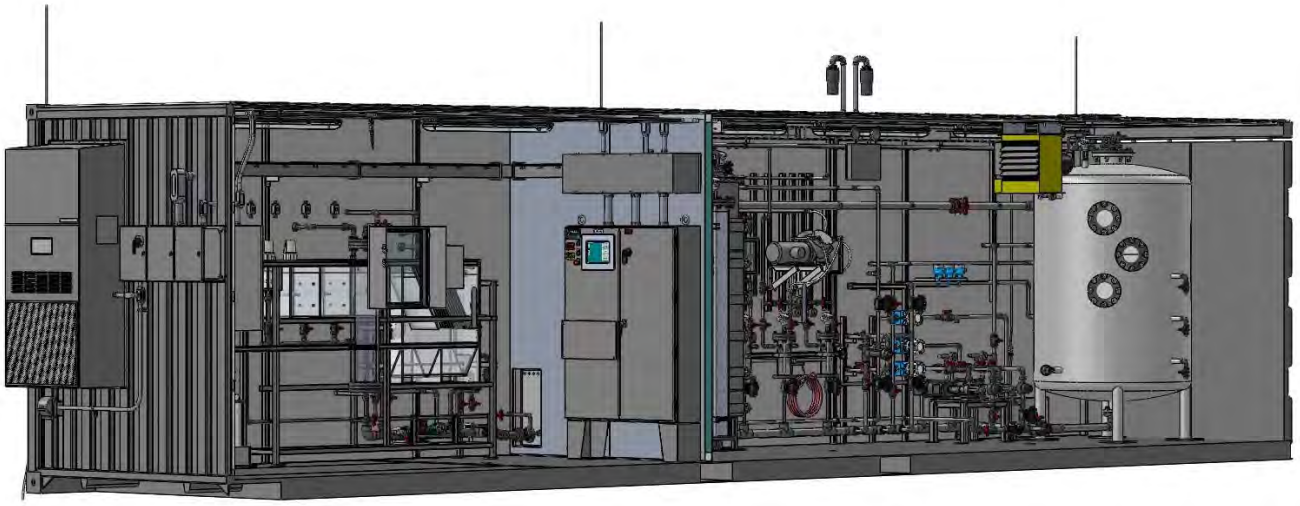
Standard Operating Procedures / Operations and Maintenance Manual

For

CDM Smith

Anaerobic Membrane Bioreactor (AnMBR) Pilot Plant



Release #4

Prepared By:

Intuitech®
"Intuitive Technology"
Process Equipment Manufacturing
Monitoring & Control Systems Integration

Project # 1539

September 23, 2016

TABLE OF CONTENTS

SPECIFICATIONS

1. Anaerobic membrane Bioreactor Pilot Plant 4
   A. Specifications 4
      1. General 4
      2. Instrumentation 4
      3. Physical 4
      4. Electrical 4

INSTALLATION

1. Un-packaging 5
2. Mechanical Inspection 5
   A. Initial Visual Inspection 5
   B. Leveling 5
   C. Component Mounting 5
   D. Piping Connections 5
3. Electrical Inspection 5
   A. Initial Visual Inspection 5
   B. Electrical Connections 6

OPERATION

1. Equipment Information 6
2. Operation Sequence 6
3. Sequence Matrix 7
4. Operation Interface 11
   A. General 11
   B. Manual Control Panel Operators 11
      1. Indicator Lights 11
      2. Push Buttons 11
      3. Main Disconnect 11
   C. Remote Indication Relay 11
      1. Remote Start Relay 11
      2. Remote Alarm Relay 12
      3. Remote Start Relay Override 12
   D. Human Machine Interface (HMI) 12
      1. Log In/Out Screen 12
   E. HMI Navigation Icons 14
      1. Overview Button 14
      2. Process Menu Button 14
      3. Trend Menu Button 14
      4. Alarms Button 14
      5. Settings Menu Button 14

6. Web Browser Button....15
7. Log In Button....15
8. Keypads....15
F. HMI Operation....16
1. Alarm Screens....16
2. Instrument Displays....16
3. Trending Screen and Pen Selection....17
4. Settings Menu Screens....18
5. Data Logging Screen....19
6. How to Collect Data Remotely from an Intuitech pilot Using Ultra VNC....20
7. Email Alarms Screen....21
8. Date/Time Screen....22
9. Overview Screen....23
10. Process Menu....25
11. Hazardous Location Process Control Screen....25
12. Non-Hazardous Location Process Control Screen....26
13. Sequencing Controls....26
14. Sequencer Configuration....27
15. Valve Controls....28
16. PID Loop Control Screens....29
17. Pace Loop Control Screens....30
18. Coalescing Tank Configuration....33
19. Ventilation Fan Control....33
20. Strainer Sequence Configuration....34
21. Tank Mixers....34
22. Instrument Configuration....36
23. HMI Alarms and Conditions....36

STARTUP

1. Pre-Startup Procedures....44
A. Electrical Installation....44
B. Gravity Waste....44
C. Open Process Connections....44
D. Flow Control Options....44
1. Flocculation Basin Options....44
2. Direct Filtration Option....45
E. Pump Inspection....45
1. Feed Pumps....45
2. Startup Procedures....45

EQUIPMENT OPERATION

1. Standard Operation....46
A. On-Board Air Supply....46
B. Water Flow Meters....46

C. Pneumatic Valve Solenoids 46
D. Level Transmitters 47

SHUTDOWN

1. Shutdown Procedures 47
A. Disconnect Electrical Power 47
B. Disconnect Process Connections 47
2. Draining Equipment 47
3. Secure Loose Parts 47
4. Emergency Shutdown 47

MAINTENANCE

1. General 48
2. Maintainable Equipment 48
1. Pump head maintenance 48
2. Coupling maintenance 48
3. Stator maintenance 48
4. Pump Rotating Assembly Removal and Cleaning 49
B. Air Compressor (1910) 52
1. Air Filter 52
2. Compressor Oil 52
C. Air Preparation Assembly (1910) 52
1. Filter Element 52
D. pH Transmitter (PHT-1450) 53
1. Salt Bridge 53
2. Calibration 53
E. Turbidimeter Analyzer (TUT-1310) 53
1. Sensor Maintenance 53
2. Calibration 53
F. Peristaltic Chemical and Sample Pump Assemblies (1810, 1820, 1830, 1840, 1850) 53
1. General 54
2. Peristaltic tubing maintenance and troubleshooting 54
3. Maintenance Schedule 55

APPENDIX- A

1. O&M Drawing Release

SPECIFICATIONS

1. Anaerobic membrane Bioreactor Pilot Plant

A. Specifications

1. General

Raw Water Flow Rate:	0.15...2.0 gpm (0.57...7.57 L/min)
WAS/Mixing Flow Rate:	1.0...8.0 gpm (3.8...30.3 L/min)
Recirculation Flow Rate:	1.0...8.0 gpm (3.8...30.3 L/min)
Permeate Flow Rate:	0.15...2.0 gpm (0.57...7.57 L/min)
Biogas Sparge Flow:	50...125 SLPM
Ion Exchange Flow Rate :	0.15...1.4 gpm (0.57...5.3 L/min)

2. Instrumentation

Biogas Methane*	Bioprocess Tank Level*
Biogas Oxygen*	Bioprocess Tank Temperature*
Biogas Sparge Flow*	Bioprocess Tank Pressure*
Feed Flow Rate*	Membrane Tank Pressure*
WAS/Mixing Flow*	Membrane Tank Level*
WAS/Mixing Pressure*	Condensation Tank Levels (per tank)*
WAS/Mixing pH*	Ambient Methane*
Recirculation Flow*	Ambient Hydrogen Sulphide*
Recirculation Pressure*	Permeate Flow Rate*
Membrane Vacuum*	Permeate Pressure*
Backpulse/CIP Tank Level*	Permeate Temperature*
Ion Exchange Flow Rate*	Permeate Turbidity*

*Data logged

3. Physical

Assembled Dimensions:	114”H X 102”W X 496”L
Dry Weight:	Approx. 32,500 lbs.

4. Electrical

Phase:	3
Frequency:	60 Hz
Voltage:	480 VAC
Current:	150 A Max

INSTALLATION

1. Un-packaging

The AnMBR pilot was designed within an integrated shipping container. The membranes were removed and shipped in a box to prevent damage. The plywood pieces mounted to the top of the container are to be removed to allow installation of the flame arrestors and odor control media. A crane will be required to lift the container off of the shipping truck and for final positioning of the pilot module. Ensure the crane is rated to safely carry the weight of the equipment (approx. 32,500 lbs.).

2. Mechanical Inspection

A. Initial Visual Inspection

Carefully inspect the skid for mechanical damage to the container, vessels, piping, motors, and instruments that may have occurred during the shipping or positioning of the equipment.

B. Leveling

Verify that the equipment is level. Proper operation of the flocculation and sedimentation module is dependent on the system being fairly level. However, to facilitate draining, it may be desirable to drop the cargo door end approximately 1 inch. Level each corner to with one inch.

C. Component Mounting

Verify that all components and instruments are secure. These include pipe straps and instrument mounts.

D. Piping Connections

Verify that all PVC piping connections are secure. These include pipe straps, threaded unions, check valves, process valves, and sample valves. Confirm that the process piping connections are installed and tightened. Further confirm that the connections are in accurate alignment and free from any undue stress imposed by connecting piping.

WARNING: Stress imposed by improperly aligned field piping may damage equipment. Ensure all connecting piping is free of undue stress.

ATTENTION: When installing, take care that <u>all</u> o-rings are installed with their corresponding connections or the assembly will leak. O-rings within PVC unions are frequently missed.

3. Electrical Inspection

A. Initial Visual Inspection

Carefully inspect for mechanical damage to the control panels that may have occurred during shipping or installation of the equipment. Excessive vibration from shipping can cause electrical components within the control enclosures to snap off of the din rail and cause damage to other components.

B. Electrical Connections

- **Control Panel Wiring**
  Verify that all wires within the control panel are terminated. Vibration from shipping can cause conductors to come loose. Un-terminated wires can short to other components, conductors, or the enclosure wall and cause damage.
- **Customer Feeder Circuit Breaker**
  Identify the location of the customer feeder circuit breaker so it can be easily identified and locked-out when servicing of the pilot electrical system.

OPERATIONAL OVERVIEW

1. Equipment Information

The pilot module consists of a customer supplied feed pump and strainer, bioprocess tank, membrane tank, permeate pump, flocculation/ sedimentation system and ion exchange. Biogas sparging is accomplished using an electric diaphragm pump. All membrane cleaning is automated and can be operated manually by an operator, or automatically based on runtime. All pumps contain automatic PID flow control, while the membrane contactor vacuum pump is PID controlled based on pressure. The backwash and air scour flow rates are also automatically controlled using PID loops. The chemical pumps are automatically paced to their associated flow rates, while the pH adjustment pump can also be controlled to pH using PID loop. Other features include automatic data logging of key parameters, remote monitoring and control using a standard web browser, and email alarm notification (when web enabled).

With the exception of the manually actuated valves, the equipment is monitored and controlled by an HMI (Human Machine Interface). The HMI communicates with the on-board PLC (Programmable Logic Controller) which monitors and controls various instruments and components. In short, the operator monitors the equipment through the HMI, which interacts with the PLC, which in turn activates the various equipment components.

2. Operation Sequence

The equipment follows a sequence of operation as summarized in the Sequence Matrix. The sequence matrix depicts the portion of the control logic that energizes pumps, valves, and other components required for each step of the operation. The PLC advances from step to step based on either an elapsed time or a specific event. A thorough understanding of the sequence matrix is essential to properly understand the equipment's operation.

The sequence matrix defines step advance criteria for both the auto and manual modes of operation. Each step in the operation sequence has a number and description. The "field devices" section of the table shows which equipment components are activated in any given step. The "condition" columns define the events or time requirements for advancing from step to step. The "go to step" columns indicate which step the equipment will be advancing to after the conditions or time requirements have been met in the given step. The "flow" columns define which flow setpoint the PLC will attempt to maintain as it applies to each step. Finally, the legend defines terminology used in the matrix.

For example, when the equipment is running in “auto” mode it follows the “auto step advance”. The first step in the operation sequence is “0”. Step “0” is described as OFFLINE. The “field devices” section of the matrix indicates that during the OFFLINE step none of the equipment’s components are activated (all valves are closed, all pumps are off). The “auto step advance” column informs that the equipment will stay in step “0” until the conditions of EVENT 1 are met. The legend defines EVENT 1 as “system mode is in “auto” or in other words the equipment is switched to “auto” mode. When the equipment is switched to “auto” mode the conditions of EVENT 1 are met, the “auto step advance” criteria states that the equipment will advance to step “1”. Step “1” is described as PREPRODUCTION - SPARGE (i.e. the initial start-up step). The “field devices” section defines which components are activated during the step. The equipment will continue in step “1” until the user defined step time has elapsed. Once the step time has expired, the “go to step” column states that the equipment will advance to step “2”. Step “2” is described as “PRE PRODUCTION - FLOW”. This is the final step before production.

During maintenance and recovery clean sequences the equipment will advance from step to step based on the elapsing of time limits as well as events. Once a clean sequence is started the equipment will continue through the entire sequence. **In Semi-Auto mode an operator can start, stop or interrupt the sequence in any step. Be aware that interrupting a cleaning sequence may foul the membrane or otherwise allow undesirable process or chemicals to bypass the membranes. The operator is responsible for all equipment operation when not in Auto mode.**

3. Sequence Matrix

MEMBRANE SEQUENCE MATRIX

STEP NUMBER	STEP DESCRIPTION	AUTO STEP ADVANCE		MANUAL STEP ADVANCE		FLOW							DEVICES																														
		CONDITION	GO TO STEP	CONDITION	GO TO STEP	FEED	PERMEATE / BACKPULSE	BIOGAS	RECIRCULATION	WAS / MIXING	MEMBRANE VACUUM	ION EXCHANGE	1 FEED PUMP 1100	2 1310 (FORWARD COMMAND) PERMEATE/BACKPULSE PUMP	3 1310 (REVERSE COMMAND) PERMEATE/BACKPULSE PUMP	4 BIOGAS SPARGE PUMP 1410	5 RECIRCULATION PUMP 1430	6 WAS/MIXING PUMP 1440	7 MEMBRANE VACUUM PUMP 1540	8 ION EXCHANGE PUMP 1710	9 PH ADJUSTMENT PUMP 1810	10 ANTI-FOAM PUMP 1820	11 COAGULANT FEED PUMP 1830	12 SODIUM HYPOCHLORITE PUMP 1840	13 CITRIC ACID PUMP 1850	14	15 COLLECTION TANK 1220 DRAIN VALVE DV-1228	16 INJECTION VALVE DV-1311 SODIUM HYPOCHLORITE	17 DV-1312 CITRIC ACID INJECTION VALVE	18 VALVE DV-1316 BACKPULSE/CIP TANK INLET	19 VALVE DV-1317 MEMBRANE CONTACTOR INLET	20 WATER INLET VALVE DV-1321 BACKPULSE/CIP TANK POTABLE	21 VALVE DV-1409 MEMBRANE TANK 1300 DRAIN	22 VALVE DV-1419 COLLECTION TANK 1410 DRAIN	23 UPPER IN-FT VALVE DV-1425 MEMBRANE GAS-SPARGE	24 LOWER IN-FT VALVE DV-1426 MEMBRANE GAS-SPARGE	25 VALVE DV-1429 COLLECTION TANK 1420 DRAIN	26 RECIRCULATION VALVE DV-1436	27 DV-1435 DEFOAM RECIRCULATION VALVE	28 1454 BIOPROCESS MIXING VALVE DV-	29 DV-1455 BIOPROCESS TO WASTE VALVE	30 DV-1441 WAS/MIXING PUMP INLET VALVE	31 DV-1442 MEMBRANE TO WASTE VALVE	32 MIXED LIQUOR VALVE DV-1308
0	OFFLINE	EVENT 1	1	EVENT 2	4,5,6,7,9,16																																						
1	PRE PRODUCTION - SPARGE	TIME	2	TIME	2	FLOW 1		FLOW 1	FLOW 1	FLOW 1	PRESSURE	FLOW 1	X			X	X	X	X		E		E				E				X	E		E	E	E	E	X		X		X		X
2	PRE PRODUCTION	TIME	3	TIME	3	FLOW 1	FLOW 1	FLOW 1	FLOW 1	FLOW 1	PRESSURE	FLOW 1	X	X		X	X	X	X		E		E				E			E	X	E		E	E	E	E	X		X		X		X
3	PRODUCTION	EVENT 3	4,5,6,7,9	EVENT 2	0,4,5,6,7,9	FLOW 1	FLOW 2	FLOW 1	FLOW 1	FLOW 1	PRESSURE	FLOW 1	X	X		X	X	X	X	X	E		E				E			E	X	E		E	E	E	E	X		X		X		X
4	RELAX	TIME	3	TIME	3	FLOW 1		FLOW 1	FLOW 1	FLOW1			X			X	X	X	X								E							E	E	E	E	X		X		X		X
5	DEFOAM	TIME	3	TIME	3	FLOW 1	FLOW 2	FLOW 1	FLOW 2	FLOW 1	PRESSURE	FLOW 1	X	X		X	X	X	X	X	E	X	E				E			E	X	E		E	E	E	E		X	X		X		X
6	W.A.S. TO WASTE	EVENT 4	3	EVENT 4	3	FLOW 1	FLOW 2	FLOW 1	FLOW 1	FLOW 2	PRESSURE	FLOW 1	X	X		X	X	X	X	X	E		E				E			E	X	E		E	E	E	E	X			X	X		X
7	BACKPULSE	TIME	8	TIME	8	FLOW 1	FLOW 3	FLOW 1	FLOW 1				X		X	X	X	X	X		E		E				E			X		E		E	E	E	E	X		X		X		X
8	BACKPULSE - RELAX	TIME	3	TIME	3	FLOW 1		FLOW 1	FLOW 1	FLOW 1			X			X	X	X	X		E		E				E							E	E	E	E	X		X		X		X
9	MAINTENANCE CLEAN - PERMEATE OFF 1	TIME	10	TIME	10			FLOW 1	FLOW 1	FLOW 1	PRESSURE					X	X	X	X		E						E							E	E	E	E	X		X		X		X
10	MAINTENANCE CLEAN - CHEM BACKPULSE 1	TIME*	11	TIME	11		FLOW 4			FLOW 1	PRESSURE					X			X	X		E				E	E				E			E			E			X		X		X
11	MAINTENANCE CLEAN - RELAX 1	TIME	12	TIME	12					FLOW 1	PRESSURE								X	X		E												E				E			X		X		X
12	MAINTENANCE CLEAN - CHEM BACKPULSE 2	TIME*	13	TIME	13		FLOW 5			FLOW 1	PRESSURE					X			X	X		E				E	E				E			E			E			X		X		X
13	MAINTENANCE CLEAN - RELAX 2	TIME	12,14	TIME	12,14					FLOW 1	PRESSURE								X	X		E												E				E			X		X		X
14	MAINTENANCE CLEAN - CLEAN BACKPULSE	TIME*	15	TIME	15		FLOW 6			FLOW 1	PRESSURE					X			X	X		E									X			E				E			X		X		X
15	MAINTENANCE CLEAN - PERMEATE OFF 2	TIME	3,9	TIME	0,9			FLOW 1		FLOW 1	PRESSURE						X		X	X		E												E	E	E	E			X		X		X
16																																												
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26																																												
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LEGEND	
X	OPEN OR RUNNING
E	ENABLED
TIME	TIME SETPOINT
FLOW	FLOW SETPOINT
EVENT 1	SYSTEM MODE IS AUTO
EVENT 2	SYSTEM MODE IS SEMI, AND OPERATOR PRESSES THE PRODUCTION, DEFOAM, WAS TO WASTE, RELAX/BACKPULSE, MAINTENANCE CLEAN OR RECOVERY CLEAN BUTTON.
EVENT 3	SYSTEM MODE IN AUTO AND THE RELAX, BACKPULSE, DEFOAM, WAS TO WASTE OR MAINTENANCE CLEAN IS CONFIGURED AND RUNTIME HAS EXCEEDED THE DEFINED LIMIT.
EVENT 4	PRE-DEFINED VOLUME HAS BEEN PUMPED TO WASTE.
EVENT 5	MEMBRANE TANK LEVEL IS LESS THAN CONFIGURED STEP LIMIT
EVENT 6	CONTINUE BACKPULSE-FILL / RELAX CYCLE BASED ON CONFIGURED TIME LIMIT UNTIL MEMBRANE TANK LEVEL IS GREATER THAN CONFIGURED STEP LIMIT
EVENT 7	MEMBRANE TANK LEVEL IS GREATER THAN CONFIGURED STEP LIMIT

* HIGH TANK LEVEL WILL ALSO ADVANCE STEP

RECOVERY CLEAN SEQUENCE MATRIX

STEP NUMBER	STEP DESCRIPTION	AUTO STEP ADVANCE		MANUAL STEP ADVANCE		FLOW						
		CONDITION	GO TO STEP	CONDITION	GO TO STEP	FEED	PERMEATE / BACKPULSE	BIOGAS	RECIRCULATION	WAS / MIXING	MEMBRANE VACUUM	ION EXCHANGE
0	OFFLINE	EVENT 1	1	EVENT 1	1							
1	R.C. - PERMEATE OFF	TIME	2	TIME	2			FLOW 1	FLOW 1	FLOW 1		
2	R.C.- MEMBRANE DRAIN 1	EVENT 2	3	EVENT 2	3							
3	R.C.- MEMBRANE FILL	EVENT 3	4	EVENT 3	4		FLOW 7			FLOW 1		
4	R.C.- BIOGAS SPARGE	TIME	5	TIME	5			FLOW 2		FLOW 1		
5	R.C.- MEMBRANE DRAIN TO WASTE 1	EVENT 2	6	EVENT 2	6					FLOW 1		
6	R.C.- CHEM BACKPULSE FILL 1	EVENT 4	7	EVENT 4	7		FLOW 7			FLOW 1		
7	R.C.- CLEAN BACKPULSE FILL 1	EVENT 5	8	EVENT 5	8		FLOW 7			FLOW 1		
8	R.C.- SOAK 1	TIME	9	TIME	9					FLOW 1		
9	R.C.- MEMBRANE DRAIN TO WASTE 2	EVENT 6	10	EVENT 6	10					FLOW 1		
10	R.C.- CHEM BACKPULSE FILL 2	EVENT 4	11	EVENT 4	11		FLOW 7			FLOW 1		
11	R.C.- CLEAN BACKPULSE FILL 2	EVENT 5	12	EVENT 5	12		FLOW 7			FLOW 1		
12	R.C.- SOAK 2	TIME	13	TIME	13					FLOW 1		
13	R.C.- MEMBRANE DRAIN TO WASTE 3	EVENT 6	14	EVENT 6	14					FLOW 1		
14	R.C.- PERMEATE FILL	EVENT 3	15	EVENT 7	15		FLOW 7			FLOW 1		
15	R.C.- SOAK	TIME	16	TIME	16					FLOW 1		
16	R.C.- MEMBRANE DRAIN TO WASTE 4	EVENT 2	0	EVENT 2	0					FLOW 1		
17												
18												
19												
20												
21												
22												
23												
24												
25												
26												
27												

FIELD DEVICES																																						
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
FEED PUMP 1100	1310 (FORWARD COMMAND) PERMEATE/BACKPULSE PUMP	1310 (REVERSE COMMAND) PERMEATE/BACKPULSE PUMP	BIOGAS SPARGE PUMP 1410	RECIRCULATION PUMP 1430	WAS/MIXING PUMP 1440	MEMBRANE VACUUM PUMP 1540	ION EXCHANGE PUMP 1710	PH ADJUSTMENT PUMP 1810	ANTI-FOAM PUMP 1820	COAGULANT FEED PUMP 1830	SODIUM HYPOCHLORITE PUMP 1840	CITRIC ACID PUMP 1850		COLLECTION TANK 1220 DRAIN VALVE DV-1229	SODIUM HYPOCHLORITE INJECTION VALVE DV-1311	CITRIC ACID INJECTION VALVE DV-1312	BACKPULSE/CIP TANK INLET VALVE DV-1316	MEMBRANE CONTACTOR INLET VALVE DV-1317	BACKPULSE/CIP TANK POTABLE WATER INLET VALVE DV-1321	MEMBRANE TANK 1300 DRAIN VALVE DV-1409	COLLECTION TANK 1410 DRAIN VALVE DV-1419	INLET VALVE DV-1425 MEMBRANE GAS-SPARGE UPPER	MEMBRANE GAS-SPARGE LOWER INLET VALVE DV-1426	COLLECTION TANK 1420 DRAIN VALVE DV-1429	RECIRCULATION VALVE DV-1436	DEFOAM RECIRCULATION VALVE DV-1435	BIOPROCESS MIXING VALVE DV-1454	BIOPROCESS TO WASTE VALVE DV-1455	WAS/MIXING PUMP INLET VALVE DV-1441	MEMBRANE TO WASTE VALVE DV-1442	MIXED LIQUOR VALVE DV-1308
			X	X	X			E						E					E		E	E	E	E			X		X		X								
					X									E					E		E			E			X		X	X								
		X			X			E						E			X		E		E			E			X		X								
			X		X			E						E					E		E	E	E	E			X		X								
					X			E						E					E	X	E			E			X		X								
		X			X			E			E	E		E	E	E	X		E		E			E			X		X								
		X			X			E						E			X		E		E			E			X		X								
					X			E						E					E	X	E			E			X		X								
		X			X			E			E	E		E	E	E	X		E		E			E			X		X								
		X			X			E						E			X		E		E			E			X		X								
					X			E						E					E		E			E			X		X								
		X			X			E						E			X		E	X	E			E			X		X								
		X			X			E						E			X		E		E			E			X		X								
			X		X			E			E	E		E	E	E	X		E		E			E			X		X								
					X			E						E					E		E			E			X		X								
		X			X			E						E			X		E	X	E			E			X		X								
					X			E						E			X		E		E			E			X		X								

LEGEND	
X	OPEN OR RUNNING
E	ENABLED
TIME	TIME SETPOINT
FLOW	FLOW SETPOINT
EVENT 1	SYSTEM MODE IS SEMI, AND OPERATOR PRESSES THE RECOVERY CLEAN BUTTON.
EVENT 2	MEMBRANE TANK LEVEL IS LESS THAN CONFIGURED STEP LIMIT
EVENT 3	MEMBRANE TANK LEVEL IS GREATER THAN CONFIGURED STEP LIMIT
EVENT 4	MEMBRANE TANK LEVEL IS REACHES 90%
EVENT 5	MEMBRANE TANK LEVEL IS REACHES 100%
EVENT 6	MEMBRANE TANK LEVEL IS LESS THAN CONFIGURED STEP LIMIT

STRAINER SEQUENCE MATRIX

STEP NUMBER	STEP DESCRIPTION	AUTO STEP ADVANCE		MANUAL STEP ADVANCE		FLOW	FIELD DEVICES									
							1	2	3	4	5	6	7	8	9	10
		CONDITION	GO TO STEP	CONDITION	GO TO STEP	FEED	FEED PUMP 1100		DCF STRAINER DISC EXTEND	DCF STRAINED PURGE VALVE						
0	NORMAL OPERATION	EVENT 1	1	EVENT 2	1	FLOW 1	X									
1	STRAINER - PRE FLOW	TIME	2	TIME	2	FLOW 2	X									
2	STRAINER - PLUNGER EXTEND	TIME	3	TIME	3	FLOW 2	X		X							
3	STRAINER - VALVE OPEN	TIME	4	TIME	4	FLOW 2	X		X	X						
4	STRAINER - PLUNGER RETRACT	TIME	0	TIME	0	FLOW 2	X									
5																
6																
7																
8																
9																
10																
11																
12																
13																

LEGEND	
X	OPEN OR RUNNING
TIME	TIME SETPOINT
FLOW	FLOW SETPOINT
EVENT 1	FEED PUMP RUNTIME HAS EXCEEDED THE DEFINED LIMIT
EVENT 2	SYSTEM IS IN OPERATION AND AN OPERATOR PRESSES THE FILTER STRAIN BUTTON

4. Operation Interface

With the exception of the manually actuated valves, the equipment is operated from the touch-screen HMI located on the front of the main control panel. The HMI monitors and controls the process by communicating with a PLC that in turn monitors and controls the automated components of the equipment. The HMI gathers data, annunciates alarms, displays historical and real-time trends and can be used to enter set points and adjust alarm limits.

A. General

The system is operated from the front of the control panel. The operating controls consist of:

- HMI
- Two indicator lights
- Emergency stop button
- Main disconnect switch

B. Manual Control Panel Operators

1. Indicator Lights

- RUNNING (Green) - indicates that the equipment is operating.
- ALARM (Red) - indicates that an alarm is present.

2. Push Buttons

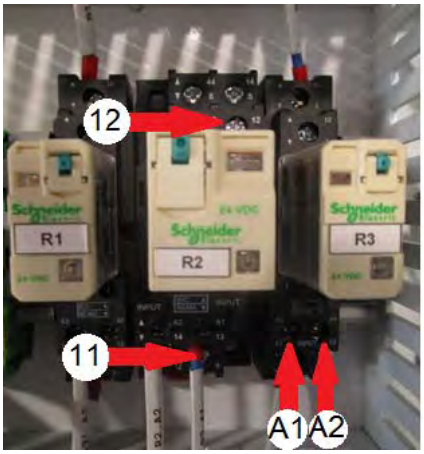
- EMERGENCY STOP- will stop all equipment operations. NOTE: Rotate clockwise to disengage or reset.

3. Main Disconnect

- DISCONNECT SWITCH - will disconnect main power to equipment.

C. Remote Indication Relay

Incorporated into the control panel are a few relays designed to provide alarm indication and control abilities to a remote SCADA system.



1. Remote Start Relay

The remote start relay is R3. This is a 24VDC relay. To attach a remote start command, connect 24VDC to terminals A1 and A2. When this circuit is powered, the equipment will begin service. Unlatching the coil will cause the system to shutdown. (See the HMI "Remote Start Command Screen" for information about the start delay.)

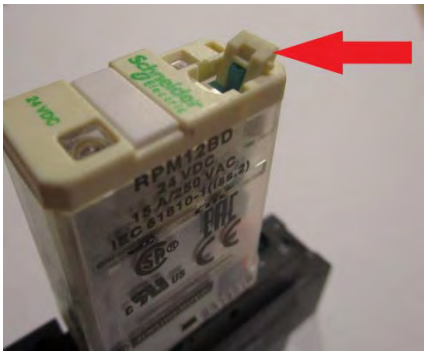
If remote start operation is desired, set the remote start delay to "AUTO". You can define a delay time between the start command and the actual sequence start. If no delay is needed, set the delay to 0 seconds and the sequencer will begin immediately upon a start command. The REMOTE START DELAY screen can be selected from the process menu and a similar screen will appear.

2. **Remote Alarm Relay**

   The remote alarm indication relay is labeled R2. This relay will open a set of dry contacts based on alarm conditions. The remote alarm relay coil will deactivate any time an alarm in annunciated. The coil is activated when there is not an alarm present (failsafe). On this relay, terminals 11 and 12 are the normally closed contacts. (The dry contacts are rated for up to 15A at 250 VAC.)

3. **Remote Start Relay Override**

   If you aren't going to be using a remote start signal from Relay R3, you will need to manually override the relay for normal system operation. Failure to manually override this relay will prevent the system from being able to run in AUTO. To override the relay, simply take your fingernail or a small screwdriver, slide it under the toggle for manual override, and flip it upwards as shown in picture.

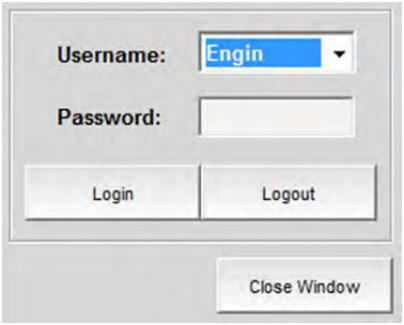


D. Human Machine Interface (HMI)

When the equipment is powered up, the HMI will display the following screen. It is necessary to log in with a username and password before system operation is possible.

1. **Log In/Out Screen**

   By selecting the Login icon, the login screen is displayed.

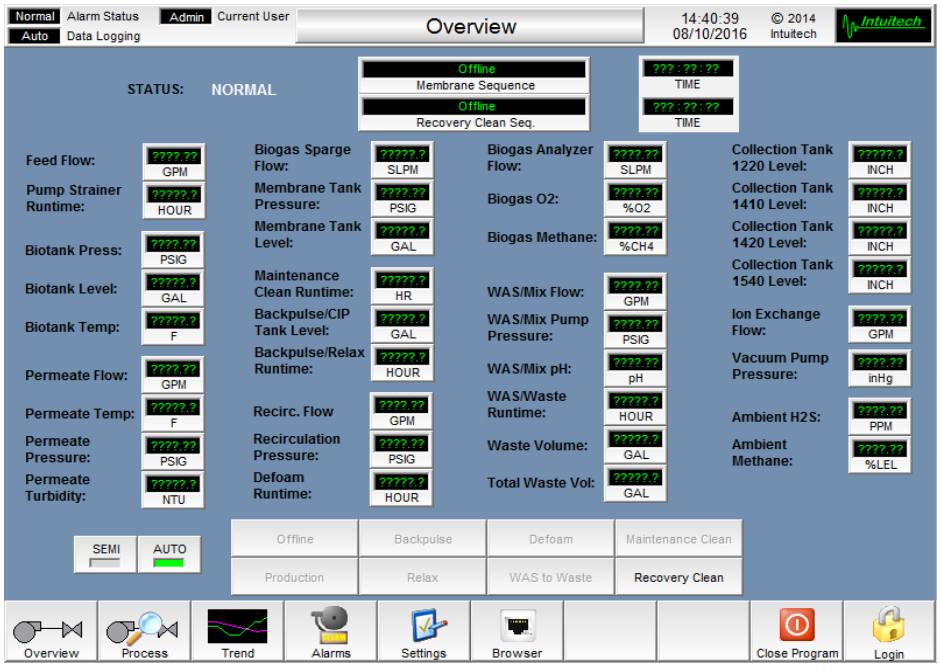


   Select the desired level of access (Administrator, Engineer, Operator, Guest, or View) from the drop-down box. Then, select the PASSWORD box and type the appropriate password. Select LOGIN when done. If your login is successful, the new login level will be displayed in the upper left corner of the screen. For security purposes, the passwords for each user level will not be printed in this manual. (Password information will be sent with the manual in a sealed envelope.) Select the LOGOUT button to return to the Guest level of access. Below are the five user levels and what functions each user has access to. Some activities may not be relevant for all HMI applications.

SECURITY LEVEL	USERNAME	PASSWORD
VIEW	VIEW	1234
OPERATOR	OPER	2953
ENGINEER	ENGIN	5212
ADMINISTRATOR	ADMIN	7398

HMI Security Level Access Permissions

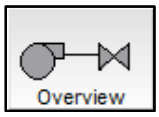
	Guest	View	Operator	Engineer	Administrator
View Login Screen	X	X	X	X	X
View Process Screens	X	X	X	X	X
View Trends		X	X	X	X
View Alarms		X	X	X	X
Reset Alarms			X	X	X
Control Pumps, Valves, Blowers, etc.			X	X	X
Modify Email Alarms Email Settings					X
Disable/Enable Email Alarms				X	X
Change Auto and Manual Setpoints			X	X	X
Initiate Sequencer Steps			X	X	X
Change Sequencer Step Times			X	X	X
Change PID Setpoints				X	X
Change PID Running Parameters				X	X
Change Alarm Limit Setpoints				X	X
Change Data Logging				X	X
Set Date and Time				X	X
Close Program					X



E. HMI Navigation Icons

The following navigation icon buttons displayed along the bottom of the screen throughout the HMI application provide the following functions:

1. Overview Button

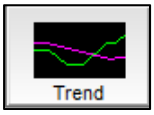


The overview screen displays the entire pilot process.

2. Process Menu Button

The monitoring and control of all automated system components is accessed through the process menu. Some of the process screens are monitoring only, some are control only, and some are for both monitoring and control of system components. For operational ease, the display of some instrument values may appear redundantly on two or more screens.

3. Trend Menu Button

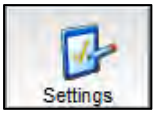


The trend menu allows the operator access to trending screens to analyze and view in a graphical format, the data coming from the system instruments.

4. Alarms Button

The alarm button is used to view the currently active alarms (Alarm Summary). The historical alarms screen (Alarm History) can be accessed from within the alarm summary.

5. Settings Menu Button



The system menu includes buttons to access data logging, e-mail alarms, and the miscellaneous screen. The miscellaneous screen is for setting and configuring various operational features.

6. Web Browser Button

The web browser button provides access to a built in web browser embedded into some instruments. Calibration and configuration can be performed through these screens.

7. Log In Button

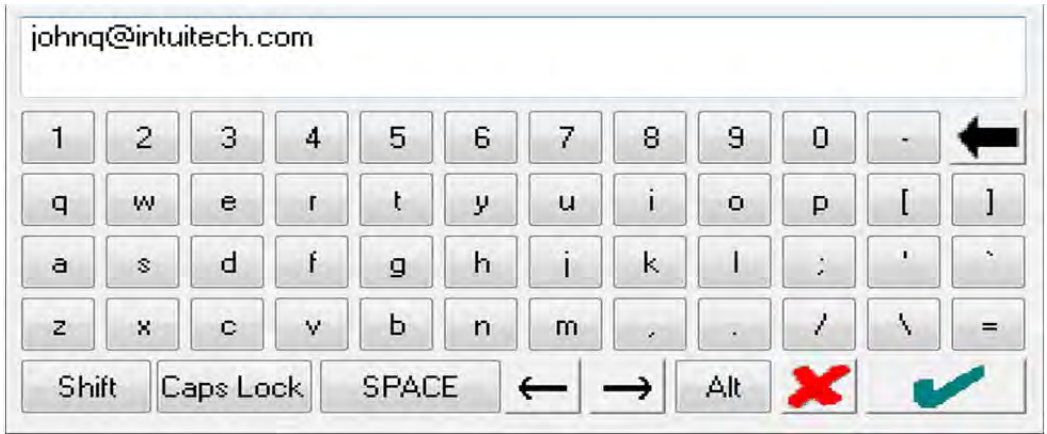
This icon displays a screen that allows the user to log in and out of different user levels. A password is required. Operators are required to log in with a username and password before system operation is possible.

This icon displays a screen that allows the user to log in and out of different user levels. A password is required. Operators are required to log in with a username and password before system operation is possible.

8. Keypads

There are two different keypads which can be selected by an operator. The simple keypad allows the operator to enter in numerical control values and other information.

NOTE: If the component has an operating range, it will be displayed at the bottom of the keypad - any value entered must fall within that range.

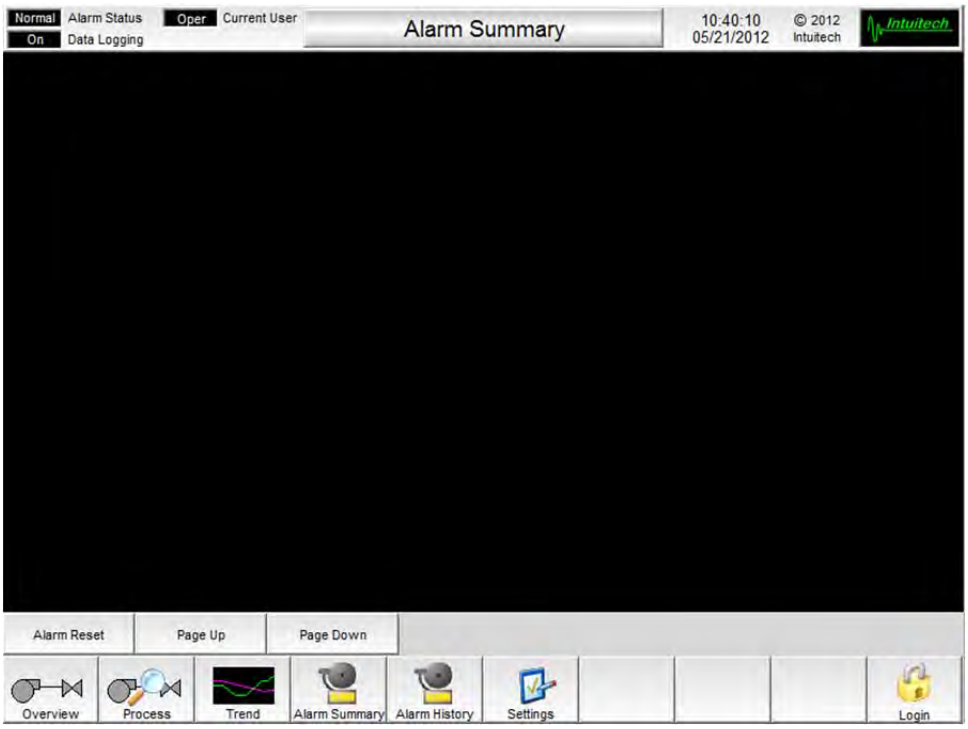


The full keypad is displayed anytime alpha-numeric characters are required. Each keypad is displayed when required.

F. HMI Operation

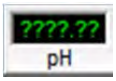
1. Alarm Screens

The date, time, and description of alarms will be displayed on the alarm screens. Once the conditions that triggered the alarm have been corrected, select the ALARM RESET button to acknowledge and reset all current alarms. Scroll through the alarms by selecting the PAGE UP and PAGE DOWN buttons on either of the alarm screens.



2. Instrument Displays

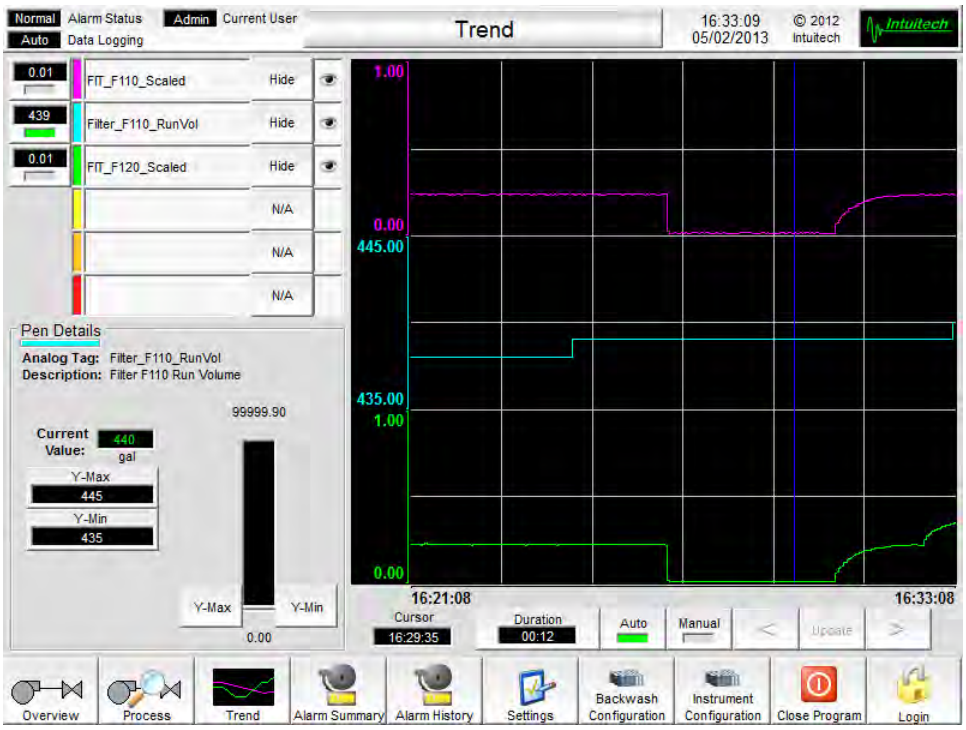
Each analog instrument has its own display screen. Access this screen by selecting the display button. Once selected, a similar screen will appear.



This screen will allow the user to set any high or low alarm limits associated with the instrument, as well as view a "quick-trend" of its recent activity. To add this analog signal to the main trending screen, simply press "Load" on one of the open Trend Pens.

3. Trending Screen and Pen Selection

The trend menu allows the operator access to the trending screens to analyze and view, in graphical/numerical format, the data coming from the system's instruments. When selected, a similar screen will be displayed



The time period displayed on the trending screen can be adjusted by selecting the desired time in hours and minutes on one of the TREND DURATION icons.

The AUTO selection allows users to view real time trends, while the MANUAL selection is for historical trends. An automatically updated trending screen will continually update itself. The manual update trending screens display a static "snap-shot" of information and will not automatically update.

If an analog signal is already selected, it will be displayed and can be manipulated from the upper-left corner of the trend screen. Each pen can either be viewed, or hidden using the VIEW/HIDE buttons. Once a pen is selected, the size of the Y-axis can be adjusted in the "Pen Details" section.

NOTE: In order to add a new analog signal to the trending screen, it must be activated from within its own display screen (as previously described).

Tap the screen at any point within the trend graph to move the vertical cursor (or select the < or > buttons to enact small moves). The color of the parameter at the top left of the screen corresponds with the color of the trend lines within the trending screen. The parameter value shown in the "Current Value" window, corresponds to the value on the graph at the position of the cursor.

4. Settings Menu Screens

The settings menu includes buttons to access data logging, e-mail alarms, and the date and time set screen.

5. Data Logging Screen

If the DATA LOGGING button is selected the following screen is displayed.
To operate data logging in automatic mode select the AUTO button. To set the interval at which the process parameters are recorded, activate the keypad by pressing the interval button and enter the desired interval (in seconds).

When in the automatic mode, the data-logging feature is only active when the system is active (i.e. data are only logged for equipment in operation).

To operate data logging in manual mode select the ON button. In manual mode data are collected whether the system is running or not.

Selecting the OFF button will disable all data logging.

Data is stored on a removable USB flash drive located on the front of the control panel door underneath the enclosure shelf. It is NOT necessary to open the control enclosure to access this drive. It is recommended that the HMI is shut down to remove the USB data drive. The data files can then be copied or moved from the USB flash drive to another computer for viewing. Data files are stored on the USB drive as .csv (comma separated variable) files, which can be opened with and saved as Microsoft® Excel™ (.xlsx) files. The .csv files contain data columns with integrated column headers. The first column in the .csv files correlates to the date and time the data were collected.

A second USB drive, located on the back of the HMI is used as a backup to the primary USB drive. This drive automatically logs data every five minutes. To gain access to this drive, the enclosure door will have to be opened. Disconnect power before opening the enclosure door to avoid potential electrical shock. There

are two USB “drives” plugged into the HMI. The red USB drive is the backup drive. The USB drive that is BLACK is the hard key for the software license. DO NOT REMOVE THE BLACK USB DRIVE as this will invalidate the software license.

ATTENTION: HOW MUCH DATA ARE YOU WILLING TO LOSE? Data should be retrieved and backed up on a separate computer regularly. How often this is performed should be based upon the amount of data loss you are willing to accept.

DANGER: Disconnect power to control panel before servicing to eliminate electrical shock and arc flash hazards.

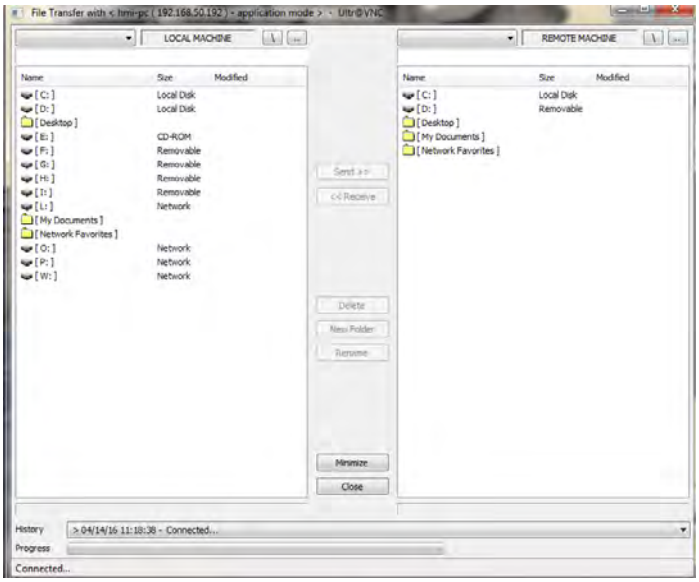
Once the USB flash drive is reconnected to the HMI, the data files will continue to append to the previously existing data (if files were copied to the computer in the previous step) or new files will be created (if the files were removed in the previous step).

When the size of the file exceeds the entered “High Alarm Limit” (in Mb), an alarm will be annunciated (indicating “Total Data File Size High”). Since large text files can become virtually unmanageable, it is recommended that the operator clears or moves the saved data in the data-logging file before they become larger than 30 Mb. If the file size becomes greater than the “Shutdown Limit”, an alarm will be activated indicating “Data Logging Stopped”. At this point the data logging feature will shut down.

6. How to Collect Data Remotely from an Intuitech pilot Using Ultra VNC

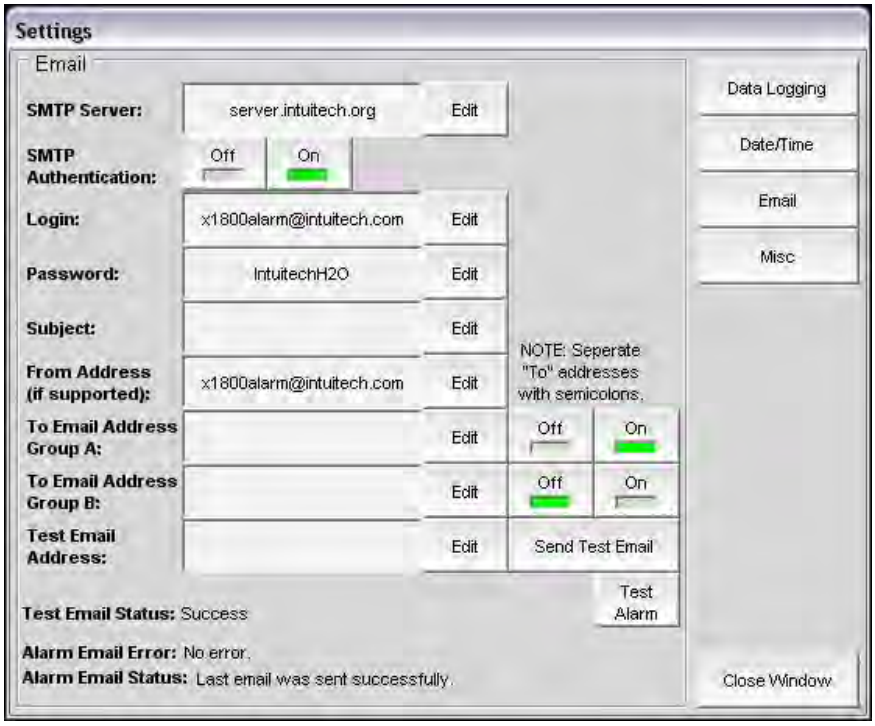
1) Log on to Ultra VNC using the instructions above. Open the file transfer screen by selecting the icon in the header bar.

2) The file transfer screen will show your local file path on the left (local Machine), and the Intuitech’ s pilot files (remote machine) on the right.



3) Data are stored on the [D:] drive of the remote machine. Double click the D: drive to view its contents. Then double click on the file location you wish to copy the files to on your local machine.
4) Highlight the data files you with the transfer and press “Receive”.
5) Once the data have been transferred, delete them from the pilot (remote machine). New files will be created.

7. Email Alarms Screen



When web enabled, the HMI has the ability to send all alarm notifications to specified email addresses. The email notifications include the time and date of the alarm as well as the message generated by the alarm.

Administrator login is required to view or modify the SMTP Server IP, SMTP Authentication, Username, Password, Mail from Address, and Mail to Address 1. Without administrator login, these fields will be displayed as asterisks and cannot be accessed.

At the time of this publication, the settings shown above are correct for proper email operation through the Intuitech mail server.

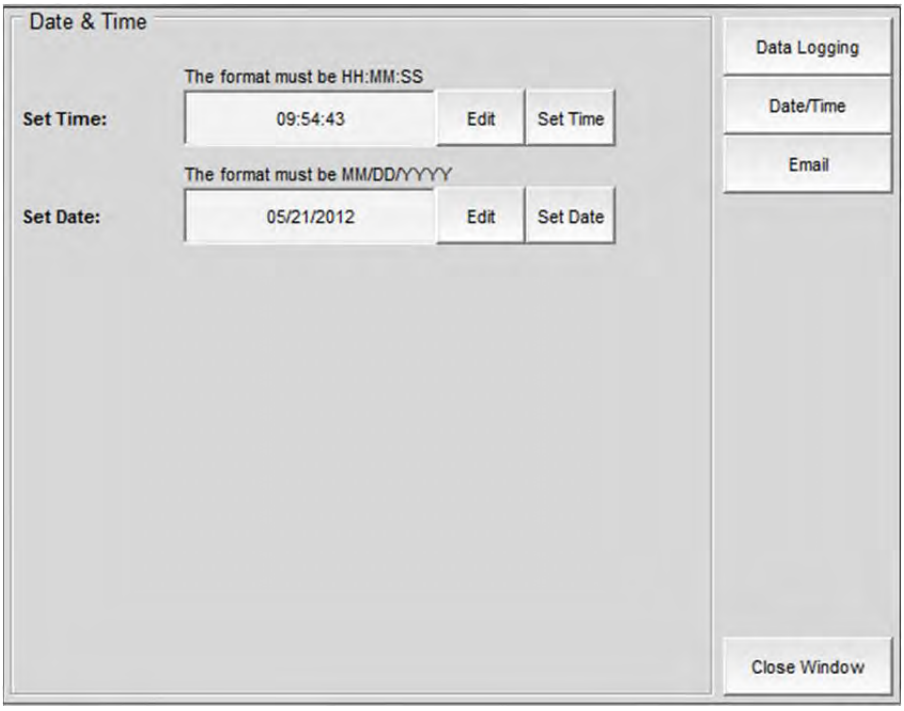
MAIL TO ADDRESS GROUP B
This field is identical to "Mail to Address Group A" except the administrator level of login is not required to modify the field. Specify any valid email address or multiple addresses separated by a semicolon (;). This can include cell phone email address (e.g. 8015551212@domain.com). Any alarms that occurred prior to email address changes (i.e. in the queue) will be sent using the old data. Messages are sent from the queue at 1-minute intervals.

TEST EMAIL
This field is provided to easily test the function of the email screen. Pressing the "Send Test Email" button will send a test email to the email address configured to its right. Pressing the "Test Alarm" button will generate a test alarm and send the email to everyone in Group A and Group B (as long as the group control is set to ON).

MAIL ERROR STATUS
This indicates the status of the last email attempt. If it reads "No error." then the last email was sent successfully. If other errors appear they will be similar to those most mail clients report when there is a failure. Please consult your network administrator if additional assistance is required.

8. Date/Time Screen

If the Date/Time button is selected the following screen is displayed.

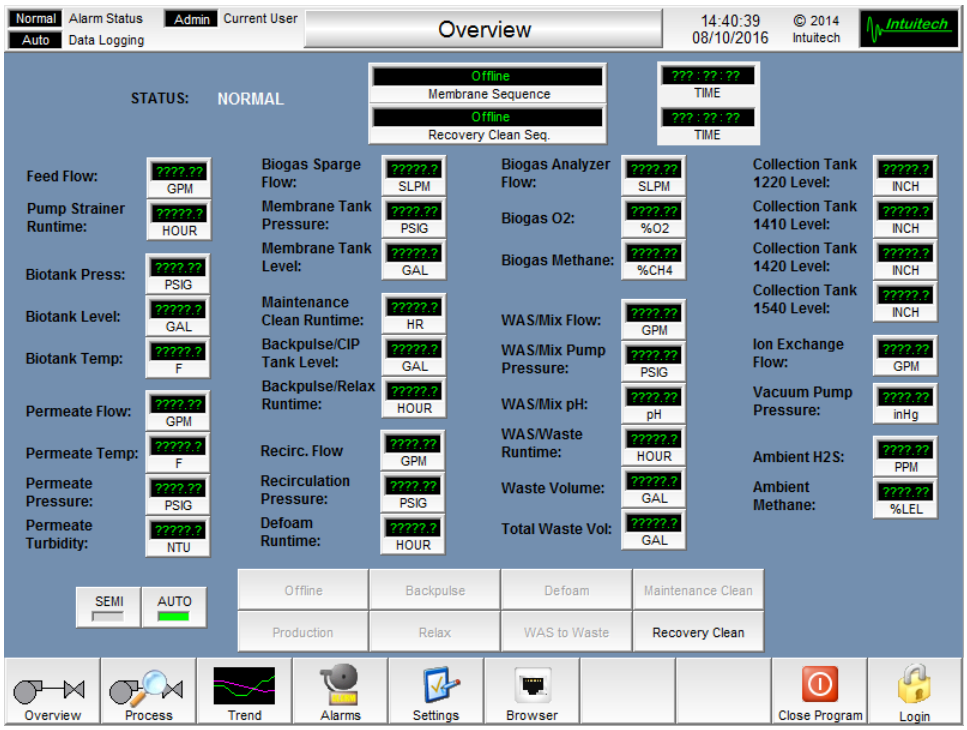


The SET TIME and SET DATE buttons are used to set the current time and date. Use "Edit" to enable the keypad and enter the proper time or date. Once the correct time has been entered, press "Set Time" to move that time into the HMI memory.

NOTE: Ensure that the time and date are entered in the exact format as displayed. Include the necessary symbols (i.e. colon and slash marks) when entering in the time and date or the entry will be rejected.

9. Overview Screen

When the OVERVIEW button is selected, a similar screen is displayed.



The screen displays an overview of data from the equipment process screens, along with control buttons for activating the sequencer. All instruments can be viewed from this screen. Alarm set-points can be found within the instrument display "buttons".

Selecting the SEMI buttons will enable the sequence control buttons (i.e. Production, Backpulse, Defoam, etc.).

In SEMI mode, following the manual step advance, if the Production button is pressed the pilot will begin the pre-production start-up, pressing the Relax or Maintenance Clean buttons will begin their respective processes, and pressing the Offline button will shut the pilot down. In semi mode, sequencing will not be initiated automatically, and the pilot will not re-enter service after a maintenance or recovery clean process.

Pressing the auto button (AUTO) will allow for fully automatic operation of the pilot (in accordance with the sequence matrix). When operating in auto mode backpulse, relax, defoam, WAS to waste and maintenance clean cycles are initiated based on their respective runtime triggers. The pilot will automatically re-enter production after any of these processes.

Refer to the sequence matrix for details of the sequencer operation.

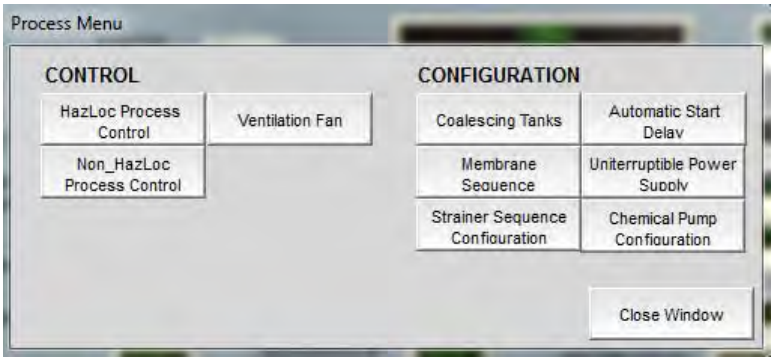
ATTENTION: In Semi-Auto mode an operator can start, stop or interrupt the sequence in any step. Be aware that interrupting a cleaning sequence may foul the membrane or otherwise allow undesirable process or chemicals to bypass the

membranes. The operator is responsible for all equipment operation when not in Auto mode.

NOTE: All alarm limits (including those used to initiate sequencer steps) are found within the display buttons for each processes runtime.

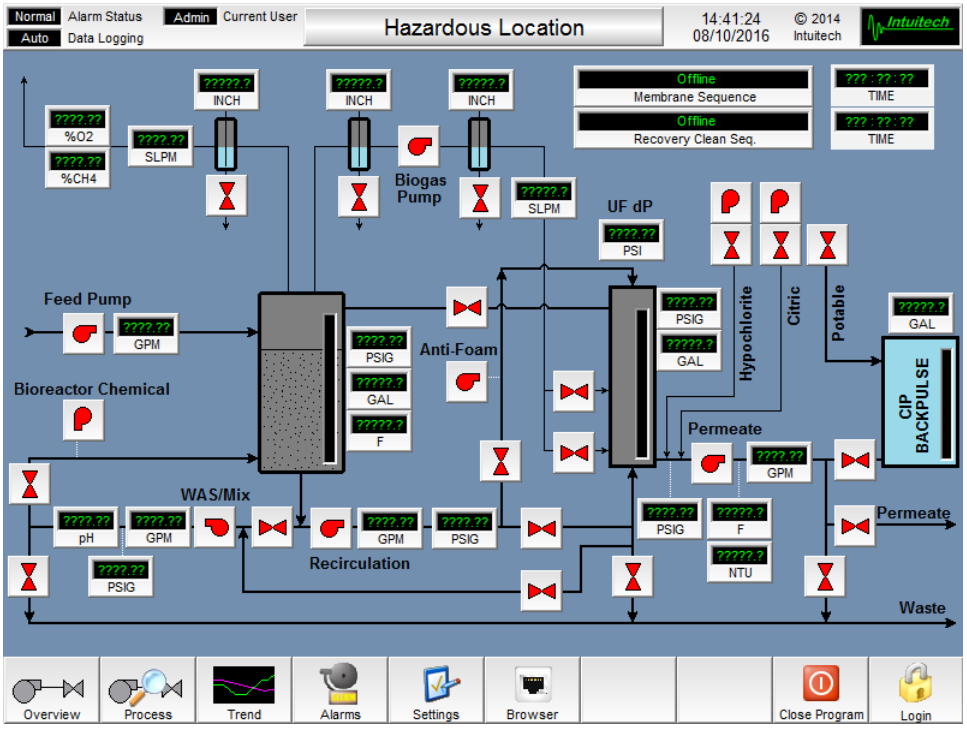
10. Process Menu

If the PROCESS button is selected, it will bring up the process menu, similar to the one shown. This screen provides acess to all of the process control and configuration screens.



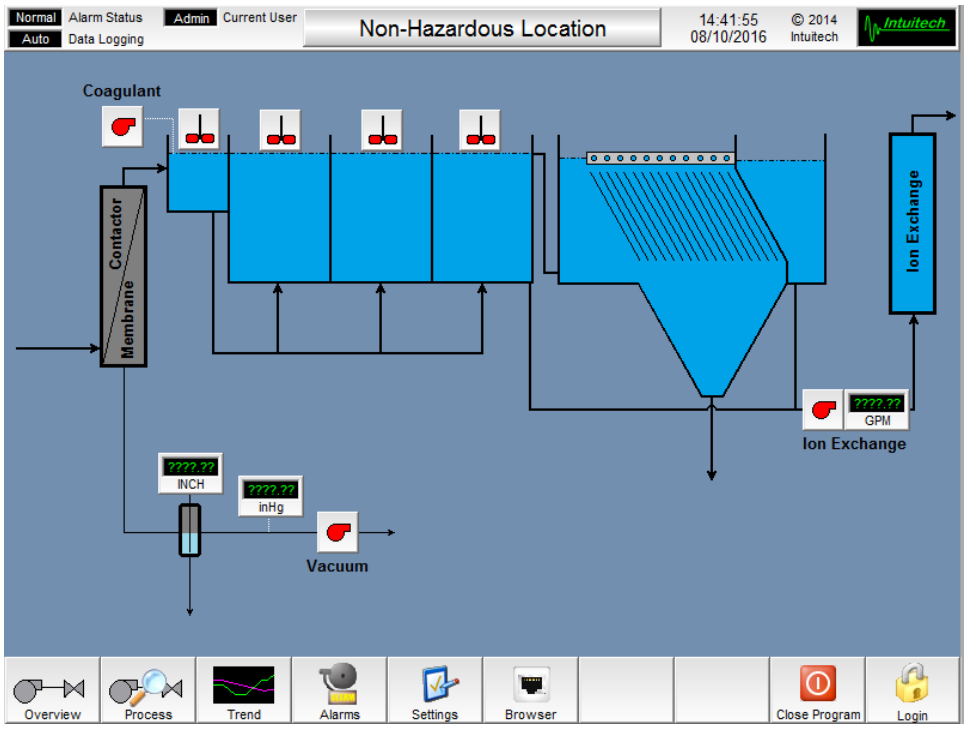
11. Hazardous Location Process Control Screen

If the HAZLOC PROCESS CONTROL button is selected, it will display a screen similar to the screen below. This screen allows control of all components located withing the hazardous (Class 1 Division 2, Group D) area.

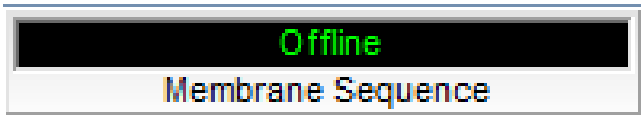


12. Non-Hazardous Location Process Control Screen

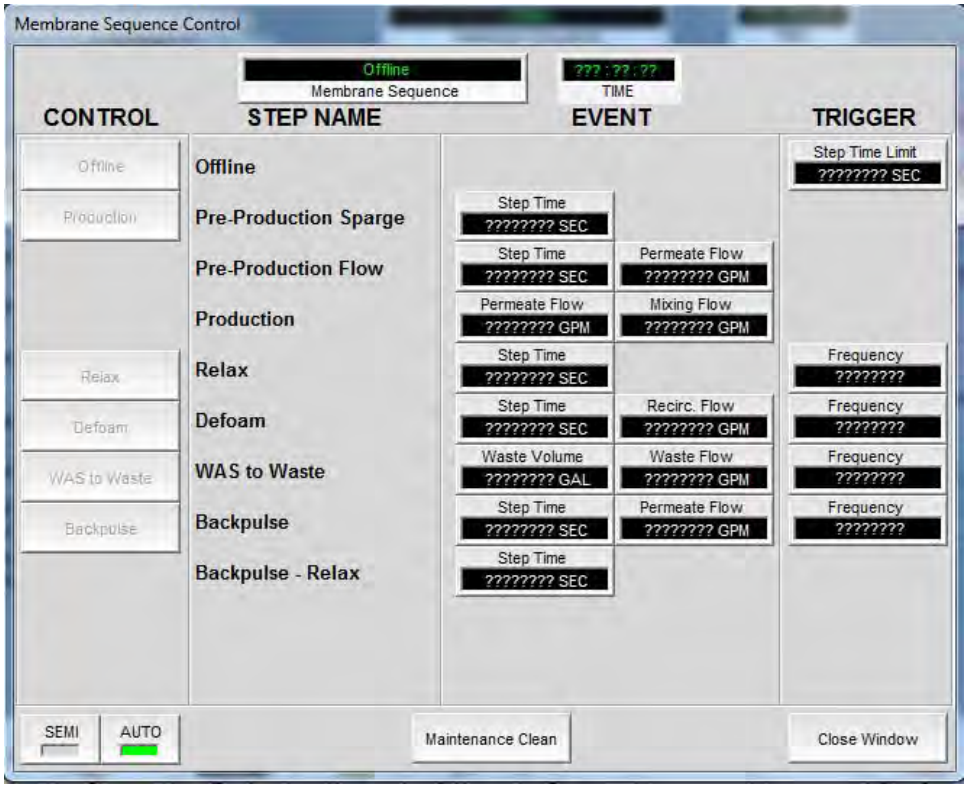
If the NON-HAZLOC PROCESS CONTROL button is selected, it will display a screen similar to the one below. This screen allows control of all components located in the non-hazardous area.



13. Sequencing Controls



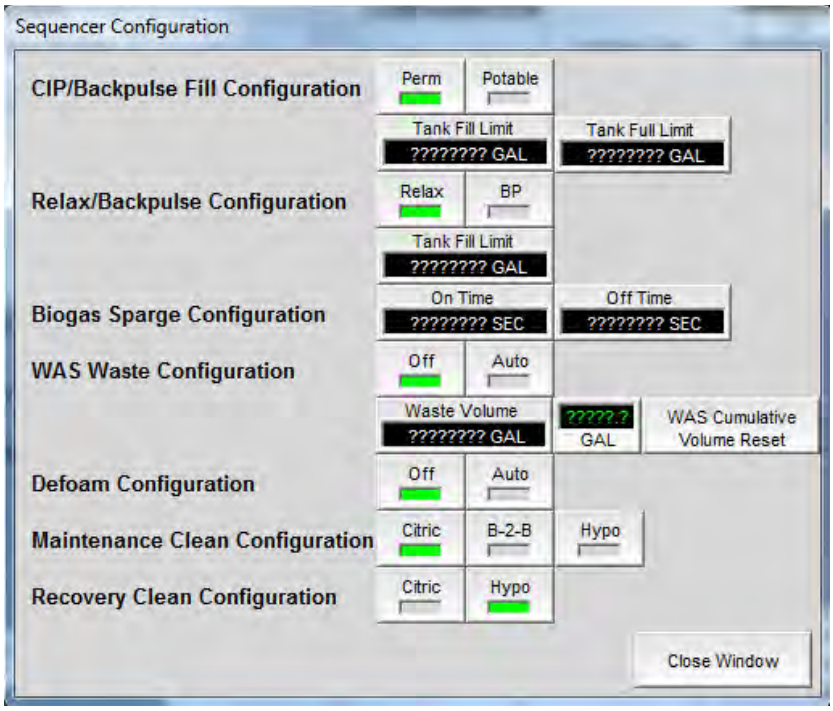
The sequencing controls are accessed by pressing one of the sequence buttons. Similar button exists for the feed pump strainer. If pressed, a screen similar to the one below is displayed.



Similar to the sequence matrix, this screen displays each of the steps included in the sequencing, listed in order, from the top-down. The step times, drain and fill levels, flow rates and step frequencies used throughout the pilot can be viewed and modified by pressing any of the EVENT or TRIGGER buttons. Similar screens exist for the Maintenance and Recovery Clean cycles.

14. Sequencer Configuration

If the sequencer button is selected, the following screen is displayed.

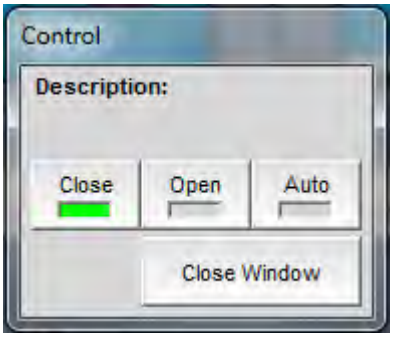


This screen contains the configuration parameters that determine how the membrane sequencing is controlled.

- CIP/Backpulse Fill Configuration: Define whether the backpulse tank is refilled with permeate or potable water. The Fill and Full limits determine when the tank will begin to fill and when the tank is considered full (respectively).
- Relax/Backpulse Configuration. The membrane will either run a permeate backpulse or a relax cycle based on the configured frequency. The tank fill limit is the point at which the backpulse will progress to the next step even if the configured step time has not elapsed.
- Biogas Sparge Configuration: The sparge time on and off is configured here.
- WAS Waste Configuration: Waste can be turned off or set to automatically waste based on the configured frequency. Waste Volume is the amount of process sent to waste each cycle. A cumulative waste volume is also displayed that is only reset manually.
- Defoam Configuration can be set to off or auto (based off a configured frequency).
- Maintenance Clean Configuration: The maintenance clean can be configured for citric acid, sodium hypochlorite, or “back-to-back” (a citric clean followed by a hypochlorite clean).

15. Valve Controls

If any valve control button is selected a similar screen is displayed.

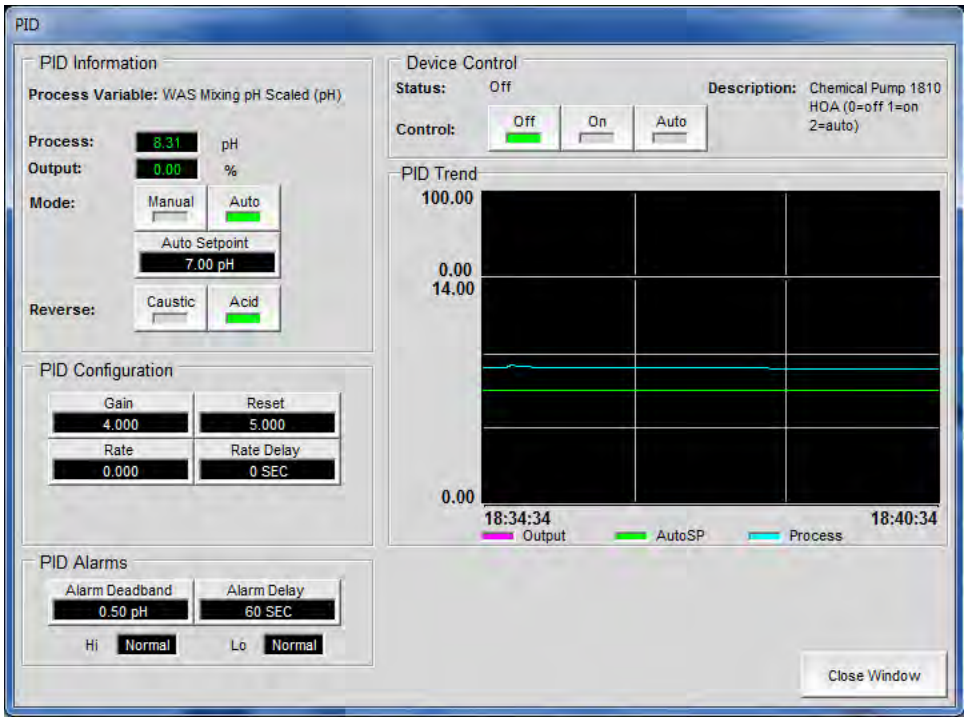


These control buttons designate what conditions open or close the valves. Pressing the AUTO control button will allow the valve to be

controlled by the sequencer (activated from the Overview Screen). Pressing the CLOSE or OPEN control buttons will actuate the valve independent of the sequencer.

16. PID Loop Control Screens

If any component (i.e. pump) using a PID control is selected, a similar screen is displayed.



NOTE: All module components which operate using PID control (listed below) will be controlled by a screen very similar to this one.

This screen displays important monitoring parameters, buttons for selecting control options, buttons for selecting auto or manual mode operation, and value input buttons for entering the auto and manual set-points.

The DEVICE CONTROL buttons (in the upper right corner) designate what conditions cause the pump to energize. Pressing the AUTO control button will allow the pump to be controlled automatically by the sequencer. Pressing the OFF or ON control buttons will energize or de-energize the pump manually, independent of the sequencer.

The MODE buttons (auto or manual) designate which setpoint the pump will maintain. When the mode is set to AUTO, the pump will seek the auto setpoint (using the PID control loop). When set to MANUAL, the pump will simply maintain the manual setpoint (a percentage of the pumps maximum flow, with no flow control).

The PID Configuration section contains the tuning parameters for the pump control. The gain, reset, and rate values function as the tuning parameters for the PID control loop. The Proportional–Integral–Derivative (PID) controller is a generic control loop feedback mechanism used to control equipment and maintain a setpoint. The PID controller attempts to correct for the discrepancy between a measured process variable and a desired setpoint by calculating and outputting a corrective action in order to adjust the process accordingly.

The PID controller calculation (algorithm) involves three separate parameters; the Proportional, the Integral and Derivative values (i.e. gain, reset, and rate, respectively). The Gain value determines the reaction to the current error, the Reset determines the reaction based on the sum of recent errors and the Rate determines the reaction based on the rate at which the error has been changing. A weighted sum of these three actions is used to adjust the process via a control element (such as the position of a control valve).

NOTE: The PID gain, reset, rate, and rate delay values for the pumps listed below are pre-tuned by the manufacturer and should not require further adjusting. Only qualified personnel should adjust values if it becomes necessary. Before adjusting, record the current values to use as a reference.

The PID ALARMS section contains the alarm deadband and alarm delay values, which define the conditions for the High and Low alarms. The alarm deadband delineates how much the process variable may vary before an alarm occurs. The alarm delay defines the time limit (in seconds) for how long that variable can remain out of range before an alarm occurs.

For example: Using a flow rate of 1.25 gpm, an alarm deadband value of 0.5 gpm and an alarm delay value of 60 seconds; if the flow rate fluctuates above 1.75 gpm or below 0.75 gpm for longer than 60 seconds, an alarm will occur.

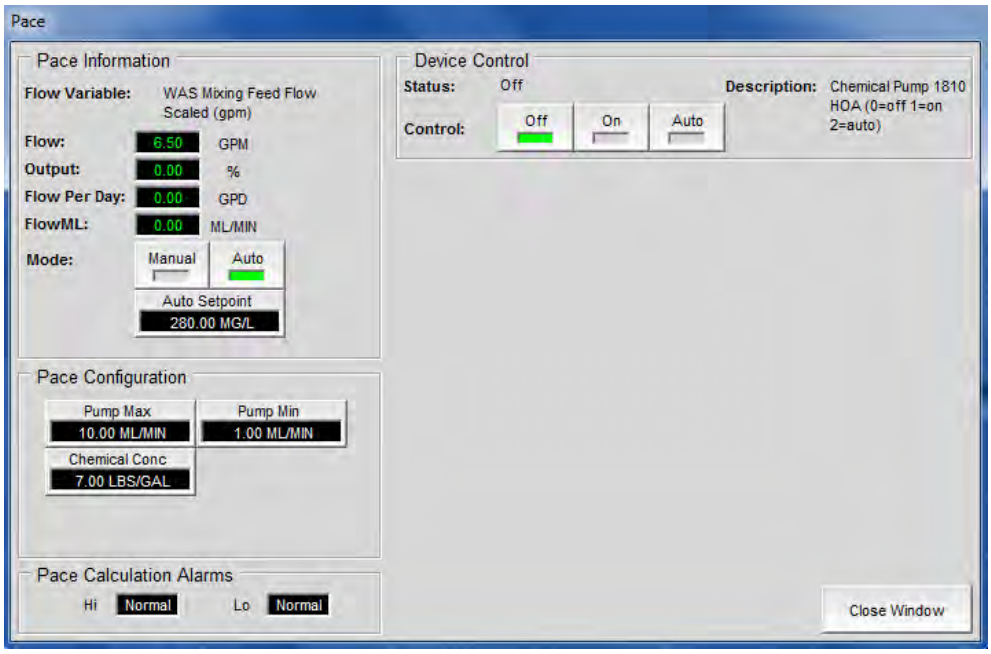
Similar screens exist for the following PID controlled components on the pilot:

- Feed Pump 1100
- Recirculation Pump 1430
- WAS/Mix Pump 1440
- Ion Exchange Pump 1710
- Permeate Pump 1310
- Biogas Pump 1410
- Vacuum Pump 1540
- Chemical Pump 1810

NOTE: The pH adjustment pump screen also includes buttons for selecting whether acid or caustic is being pumped to maintain pH. These buttons are not available on other PID loop screens.

17. Pace Loop Control Screens

If any component (i.e. chemical pump) using a Pace control is selected, a similar screen is displayed.



NOTE: All module components which operate using Pace control (listed below) will be controlled by a screen very similar to this one.
The screen displays monitoring parameters, control buttons, buttons for selecting auto or manual mode, auto and manual setpoint values, buttons for selecting which flow the pump will pace from (if applicable), along with; the solution concentration setpoint, and pump min/max set-points.

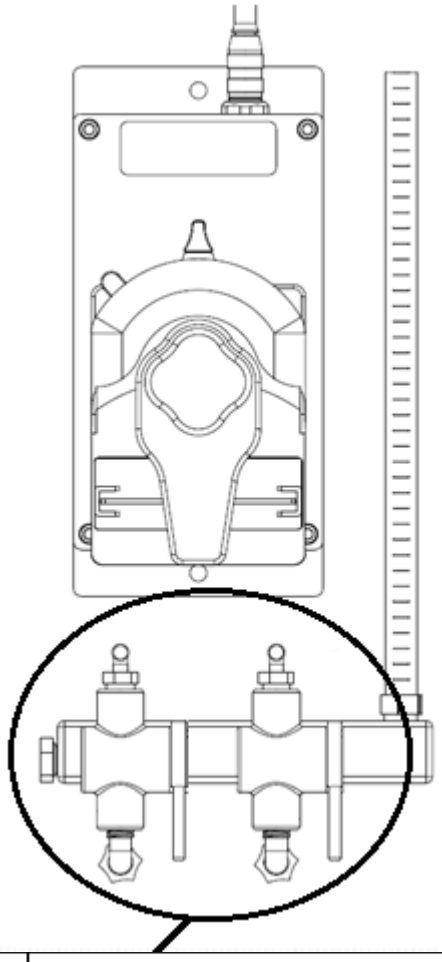
The Device Control buttons designate which conditions will cause the pump to energize. The Mode buttons designate which setpoint the pump will maintain.

NOTE: The auto setpoint is entered in units of milligrams of chemical, per liter of water (feed flow through the module).

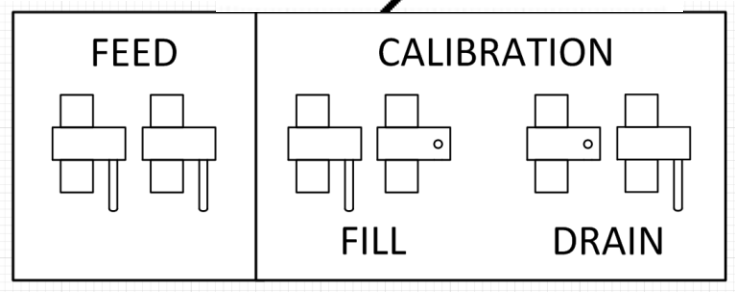
NOTE: The pH adjustment pump 1810 can be either run with PID or PACE control. When CHEMICAL PUMP CONFIGURATION, a similar screen will be displayed.

Pump 1810 is the only Chemical Pump with the option for PACE and PID control.

Pace Calibration:
To calibrate the pump for automatic operation in pace mode, the flow capacity of the pump must be measured and entered.
First, set the valve positions to FILL.
Next, switch the pump mode to manual by selecting the MAN button. To determine the pump's maximum flow, access the manual setpoint keypad and enter 100%. Press the ON control button and operate the pump until the graduated cylinder is full of the chemical to be dispensed (make a note of the current chemical level).
Next, set the valve positions to DRAIN and energize the pump for at 100% for 1 minute. After 1 minute of pumping, de-energize the pump and measure (in milliliters) the amount of chemical pumped from the graduated cylinder- enter this amount as the Pump Max setpoint. To determine the pump's minimum flow, repeat the process by operating the pump at the minimum manual setpoint percentage of 3% for one minute and measuring the chemical pumped. Enter this amount as the Pump Min setpoint. Repeat the process for each pump used.



Enter the solution concentration of the chemical being pumped (units are in pounds of chemical per gallon of solution). Once calibration is complete, set the valve positions back to FEED.



NOTE: If an auto dosing setpoint is entered which the equipment is not able to achieve, a "calculation high" or "calculation low" indication will appear.

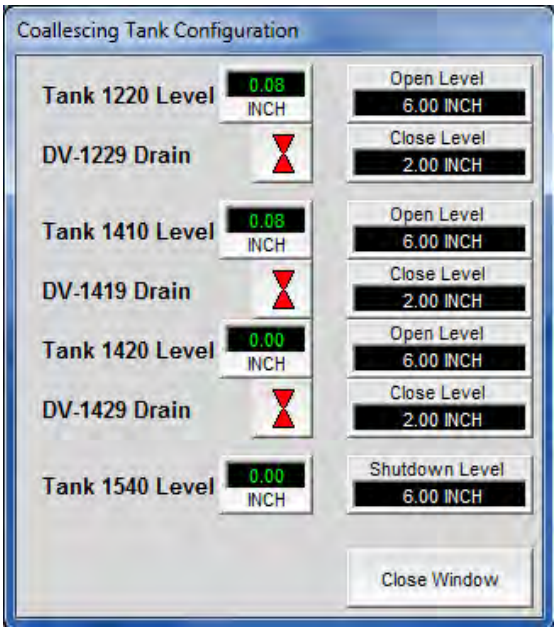
ATTENTION: If the chemical pump experiences a fault, the Pump Fault Alarm will be annunciated. **In addition to pressing the Alarm Reset button, it may be necessary to cycle power to the pump in order to clear the alarm.** This can be accomplished by simply removing the wiring connector at the top of the pump, then reconnecting it.

Similar screens exist for the following Pace controlled components on the pilot:

- Chemical Pump 1810
- Chemical Pump 1820
- Chemical Pump 1830
- Chemical Pump 1840
- Chemical Pump 1850

18. Coalescing Tank Configuration

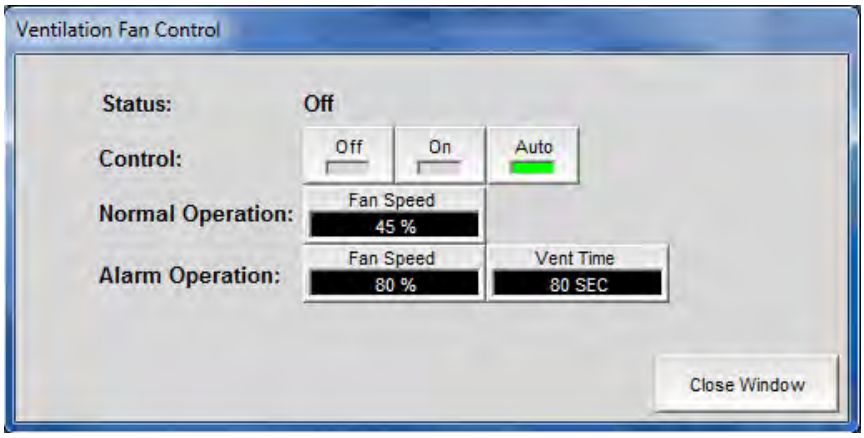
If the COALESCING TANKS button is selected, a similar screen will be displayed.



Each of these tanks have user defined setpoints which determin when the corresponding drain valve will open oand close. In addition, each drain valve can be manually opened or closed by selecting the valve button. If the Coalescing Tank 1540 level exceeds the user defined input for SHUTDOWN LEVEL, a shutdown alarm will be initiated.

19. Ventilation Fan Control

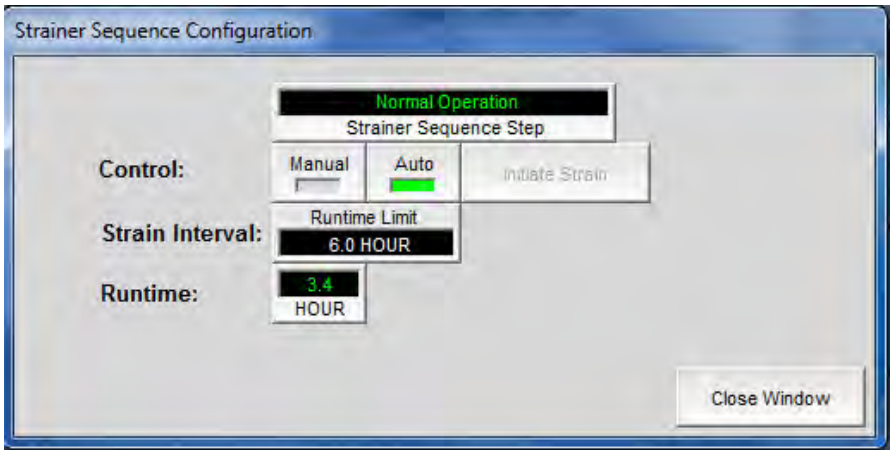
If the Ventilation Fan button is selected, a similar screen will be displayed.



When the control is set to AUTO, the fan will run at a user defined setpoint when an H2S or Methane alarm is triggered. Once the fan is in Alarm Operation, the fan speed and vent time will operate based on the above user defined setpoints. When set to ON, the fan will run at the "normal operation" speed unless an H2S or Methane Alarm is present. At that time the fan will change to "Alarm Operation". Setting the control to OFF will disable the vent fan.

20. Strainer Sequence Configuration

If the Strainer Sequence Configuration button is selected, a similar screen is displayed.



In MANUAL control, the strainer cycle can be initiated by the operator by pressing the INITIATE STRAIN button. When the control is in AUTO, a strain will be initiated based on the RUNTIME LIMIT.

21. Tank Mixers

If a mixer button is selected, a similar screen is displayed.

The screen displays important control options and monitoring parameters along with buttons for selecting options and modifying parameters.

The control buttons designate what conditions cause the mixer to energize. Pressing the AUTO control button will allow the mixer to be controlled automatically by the sequencer. Pressing the OFF or ON control buttons will energize or de-energize the mixer manually independent of the sequencer.

The auto setpoint designates the mixing gradient the mixer will maintain when energized under auto control.

The manual setpoint designates the percentage of the mixer's maximum RPM, which the mixer will maintain when energized under manual control.

The max and min RPM setpoints define the limits for the Calculation High and Calculation Low Alarms. They also function as the running parameters the PLC uses for determining and maintaining the gradient setpoint when operating in auto mode. Calibrating the mixer to existing conditions requires setting the min and max RPM setpoints.

NOTE: The mixers have been pre-configured at the factory, and should not require any additional changes to the RPM setpoints. If recalibration is necessary, follow the calibration procedure below.

To calibrate, first set the mixer to manual mode by pushing the MAN button and turning the control to ON. Next, access the manual setpoint keypad and set the mixer to 100%. Using a tachometer, count the number of rotations achieved in 1 minute. The number of rotations achieved at 100% in 1 minute equals the value for the SPEED MAX setpoint. Repeat the process by running the mixer at 8.33%

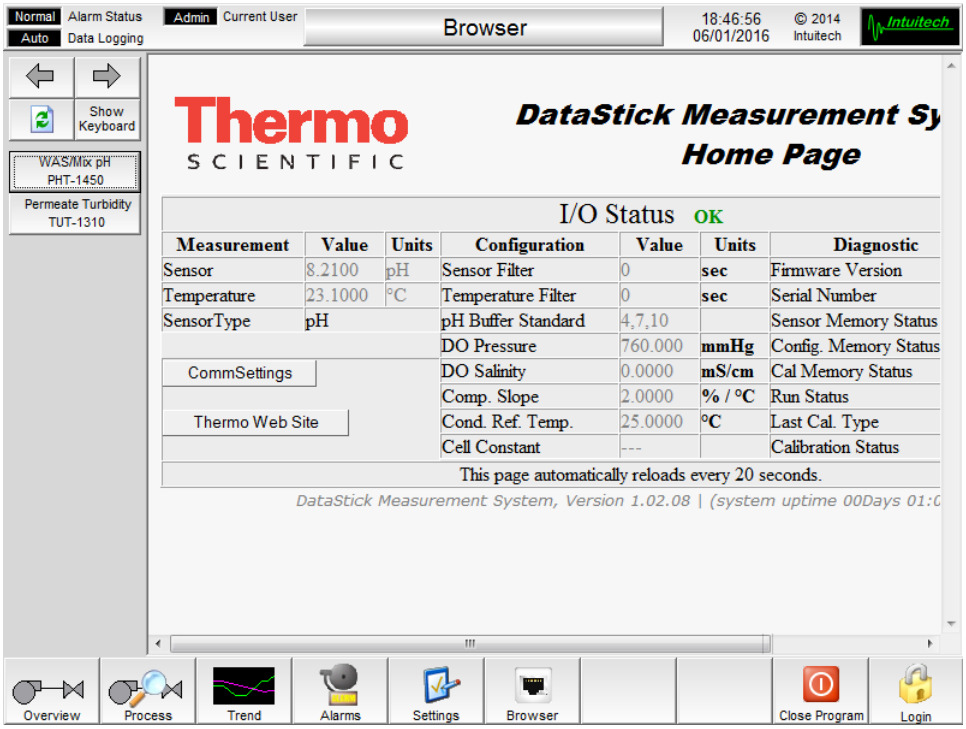
for one minute. The number of rotations achieved equals the SPEED MIN setpoint.

Once the speed limits are set, the auto setpoint can be entered in as a gradient with units of s-1 at which point the mixer is ready to run in auto mode. Repeat the process for each mixer.

NOTE: To avoid floc shearing, successive floc mixers are typically run at lower gradient values. Factors including runtime, flow rate, water quality, coagulants, and experience will dictate what the ratio between the three mixers should be.

22. Instrument Configuration

If the INSTRUMENT CONFIGURATION button is selected, the following screen is displayed.



The pH and turbidity sensors are equipped with an internal web browser page. To access that page, press one of the sensor buttons along the left edge of the screen. Instrument calibration is also accomplished through these screens. See Maintenance Section for more detailed information about calibration.

23. HMI Alarms and Conditions

All alarms generated by the equipment are summarized in this table. The "Message" column indicates the alarm text shown on the ALARM SUMMARY and ALARM HISTORY screens. The "Condition" column describes the logic that generates the alarm. The "Shutdown" column identifies whether the alarm will cause the pilot to shutdown.

Message	Condition	Shutdown
Ambient Hydrogen Sulphide Concentration High Alarm	Instrument value greater than specified limit for 30 seconds	X
Feed Pump Flow Transmitter Failed Alarm	No transmitter signal for 30 seconds	X
Biogas Flow Transmitter Failed Alarm	No transmitter signal for 30 seconds	X
Permeate Pump Flow Transmitter Failed Alarm	No transmitter signal for 30 seconds	X
Biogas Sparge Flow Transmitter Failed Alarm	No transmitter signal for 30 seconds	X
Ambient Methane Gas Concentration High Alarm	Instrument value greater than specified limit for 30 seconds	X
Backpulse CIP Tank Level Low Alarm	Tank level less than specified limit for 30 seconds	X
Bioprocess Tank Temperature Transmitter Failed Alarm	No transmitter signal for 30 seconds	
Bioprocess Tank 1200 Pressure Transmitter Failed Alarm	No transmitter signal for 30 seconds	
Membrane Tank 1300 Pressure Transmitter Failed Alarm	No transmitter signal for 30 seconds	
Permeate Pressure Transmitter Failed Alarm	No transmitter signal for 30 seconds	
Recirculation Pressure Transmitter Failed Alarm	No transmitter signal for 30 seconds	
WAS Mixing Pressure Transmitter Failed Alarm	No transmitter signal for 30 seconds	
Vacuum Pump 1540 Pressure Transmitter Failed Alarm	No transmitter signal for 30 seconds	X
Recirculation Flow Transmitter Failed Alarm	No transmitter signal for 30 seconds	X
WAS Mixing Flow Transmitter Failed Alarm	No transmitter signal for 30 seconds	X
Ion Exchange Flow Transmitter Failed Alarm	No transmitter signal for 30 seconds	
Bioprocess Tank Temperature Transmitter Failed Alarm	No transmitter signal for 30 seconds	
Permeate Turbidity Transmitter Failed Alarm	No transmitter signal for 30 seconds	
Ambient Hydrogen Sulphide Transmitter Failed Alarm	No transmitter signal for 30 seconds	X
Biogas Pump 1410 Failed Alarm	Device commanded to run but not running after 30 seconds	X
Condensation Tank 1220 Level Transmitter Failed Alarm	No transmitter signal for 30 seconds	X
Bioreactor Tank Level Transmitter Failed Alarm	No transmitter signal for 30 seconds	
Membrane Tank Level Transmitter Failed	No transmitter signal for 30 seconds	

Alarm		
Backpulse CIP Tank Level Transmitter Failed Alarm	No transmitter signal for 30 seconds	
Ambient Methane Gas Transmitter Failed Alarm	No transmitter signal for 30 seconds	X
Permeate Pump 1310 Failed Alarm	Device commanded to run but not running after 30 seconds	
Chemical Pump 1810 Fault Alarm	Chemical pump motor has experienced a fault **NOTE:** Cycle power to the chemical pump (by disconnecting wiring) to allow alarm reset.	
Chemical Pump 1820 Fault Alarm	Chemical pump motor has experienced a fault **NOTE:** Cycle power to the chemical pump (by disconnecting wiring) to allow alarm reset.	
Chemical Pump 1830 Fault Alarm	Chemical pump motor has experienced a fault **NOTE:** Cycle power to the chemical pump (by disconnecting wiring) to allow alarm reset.	
Chemical Pump 1840 Fault Alarm	Chemical pump motor has experienced a fault **NOTE:** Cycle power to the chemical pump (by disconnecting wiring) to allow alarm reset.	
Chemical Pump 1850 Fault Alarm	Chemical pump motor has experienced a fault **NOTE:** Cycle power to the chemical pump (by disconnecting wiring) to allow alarm reset.	
Feed Pump 1100 Flow Low Alarm	Value outside of defined deadband for the specified delay time	X
Feed Pump 1100 Flow High Alarm	Value outside of defined deadband for the specified delay time	
Feed Pump Pressure Switch High Alarm	Feed pump pressure greater than switching limit	X
Vacuum Pump 1540 Failed Alarm	Device commanded to run but not running after 30 seconds	X
Vacuum Pump 1540 Not in Auto Alarm	Control not in auto mode	
Vacuum Pump 1540 Pressure Low Alarm	Value outside of defined deadband for the specified delay time	X
Vacuum Pump 1540 Pressure High Alarm	Value outside of defined deadband for the specified delay time	X

Feed Pump 1100 Not in Auto Alarm	Control not in auto mode	
Permeate Pump 1310 Not in Auto Alarm	Control not in auto mode	
Permeate Pump 1310 Flow Low Alarm	Value outside of defined deadband for the specified delay time	X
Permeate Pump 1310 Flow High Alarm	Value outside of defined deadband for the specified delay time	
Condensate Collection Tank 1410 Drain Valve DV-1419 Open Too Long Alarm	Valve open for greater than specified time limit	X
Flocculation Mixer 3 Calculation Low Alarm	Mixer cannot attain entered auto setpoint	
Bioprocess Tank Temperature High Alarm	Value greater than specified limit for 30 seconds	
Bioprocess Tank Temperature Low Alarm	Value less than specified limit for 30 seconds	
Permeate Temperature Transmitter Failed Alarm	No transmitter signal for 30 seconds	
Permeate Temperature Low Alarm	Value less than specified limit for 30 seconds	
Permeate Turbidity High Alarm	Value greater than specified limit for 300 seconds	
Ion Exchange Pump 1710 Failed Alarm	Device commanded to run but not running after 30 seconds	X
Ion Exchange Pump 1710 Not in Auto Alarm	Control not in auto mode	
Ion Exchange Pump 1710 Flow Low Alarm	Value outside of defined deadband for the specified delay time	X
Ion Exchange Pump 1710 Flow High Alarm	Value outside of defined deadband for the specified delay time	
PLC Program Downloaded Alarm	New PLC program downloaded	X
Compressor Air Pressure Low Alarm	Air Compressor pressure less than 50 PSIG for 2 seconds	X
Rapid Mixer Calculation High Alarm	Mixer cannot attain entered auto setpoint	
Rapid Mixer Calculation Low Alarm	Mixer cannot attain entered auto setpoint	
Flocculation Mixer 1 Calculation High Alarm	Mixer cannot attain entered auto setpoint	
Flocculation Mixer 1 Calculation Low Alarm	Mixer cannot attain entered auto setpoint	
Flocculation Mixer 2 Calculation High Alarm	Mixer cannot attain entered auto setpoint	
Flocculation Mixer 2 Calculation Low Alarm	Mixer cannot attain entered auto setpoint	

Flocculation Mixer 3 Calculation High Alarm	Mixer cannot attain entered auto setpoint	
Flocculation Mixer 2 Failed Alarm	Device commanded to run but not running after 30 seconds	
Flocculation Mixer 3 Failed Alarm	Device commanded to run but not running after 30 seconds	
Biogas Pump 1410 Not in Auto Alarm	Control not in auto mode	
Biogas Pump 1410 Flow Low Alarm	Value outside of defined deadband for the specified delay time	X
Biogas Pump 1410 Flow High Alarm	Value outside of defined deadband for the specified delay time	
Feed Pump 1100 Failed Alarm	Device commanded to run but not running after 30 seconds	X
Recirculation Pump 1430 Failed Alarm	Device commanded to run but not running after 30 seconds	X
Recirculation Pump 1430 Flow Low Alarm	Value outside of defined deadband for the specified delay time	X
Recirculation Pump 1430 Flow High Alarm	Value outside of defined deadband for the specified delay time	
Chemical Cabinet 1 Leak Alarm	Leak detected inside chemical cabinet	X
Chemical Cabinet 2 Leak Alarm	Leak detected inside chemical cabinet	X
Biogas Methane Transmitter Failed Alarm	No transmitter signal for 30 seconds	
Condensation Collection Tank 1420 Level Transmitter Failed Alarm	No transmitter signal for 30 seconds	X
Condensation Collection Tank 1540 Level Transmitter Failed Alarm	No transmitter signal for 30 seconds	X
Biogas Oxygen Transmitter Failed Alarm	No transmitter signal for 30 seconds	
WAS Mixing pH Transmitter Failed Alarm	No transmitter signal for 30 seconds	
Condensate Collection Tank 1420 Drain Valve DV-1429 Open Too Long Alarm	Valve open for greater than specified time limit	X
Condensate Collection Tank 1220 Drain Valve DV-1229 Open Too Long Alarm	Valve open for greater than specified time limit	X
Condensation Collection Tank 1540 Level High Alarm	Value greater than specified limit for 30 seconds	X
Chemical Pump 1810 Calculation High Alarm	Pump cannot attain currently configured chemical dose	
Chemical Pump 1810 Calculation Low Alarm	Pump cannot attain currently configured chemical dose	
Chemical Pump 1820 Calculation High Alarm	Pump cannot attain currently configured chemical dose	

Chemical Pump 1820 Calculation Low Alarm	Pump cannot attain currently configured chemical dose	
Chemical Pump 1830 Calculation High Alarm	Pump cannot attain currently configured chemical dose	
Chemical Pump 1830 Calculation Low Alarm	Pump cannot attain currently configured chemical dose	
Chemical Pump 1840 Calculation High Alarm	Pump cannot attain currently configured chemical dose	
WAS/MIX Pump 1440 Flow Low Alarm	Value outside of defined deadband for the specified delay time	X
WAS/MIX Pump 1440 Flow High Alarm	Value outside of defined deadband for the specified delay time	
Permeate Pressure High Alarm	Value greater than specified limit for 30 seconds	X
Permeate Pressure Low Alarm	Value less than specified limit for 30 seconds	X
Bioprocess Tank 1200 Pressure High Alarm	Value greater than specified limit for 30 seconds	
Bioprocess Tank 1200 Pressure Low Alarm	Value less than specified limit for 30 seconds	
Membrane Tank 1300 Pressure High Alarm	Value greater than specified limit for 30 seconds	
Membrane Tank 1300 Pressure Low Alarm	Value less than specified limit for 30 seconds	
Recirculation Pressure High Alarm	Value greater than specified limit for 30 seconds	X
Recirculation Pressure Low Alarm	Value less than specified limit for 30 seconds	
WAS Mixing Pressure High Alarm	Value greater than specified limit for 30 seconds	X
WAS Mixing Pressure Low Alarm	Value less than specified limit for 30 seconds	
Bioreactor Tank Level High Alarm	Value greater than specified limit for 30 seconds	
Bioreactor Tank Level Low Alarm	Value less than specified limit for 30 seconds	
Membrane Tank Level High Alarm	Value greater than specified limit for 30 seconds	
Membrane Tank Level Low Alarm	Value less than specified limit for 30 seconds	
Biogas Oxygen Concentration High Alarm	Value greater than specified limit for 30 seconds	
Biogas Oxygen Concentration Low Alarm	Value less than specified limit for 30 seconds	

Biogas Methane Concentration High Alarm	Value greater than specified limit for 30 seconds	
Biogas Methane Concentration Low Alarm	Value less than specified limit for 30 seconds	
Hazardous Area Ventilation Fan Set to Off Alarm	Fan control set to off	
Biogas Transmitter Flow High Alarm	Value outside of defined deadband for the specified delay time	
Biogas Transmitter Flow Low Alarm	Value outside of defined deadband for the specified delay time	
Hazardous Area Ventilation Fan Failed Alarm	Device commanded to run but not running after 30 seconds	
PLC Power Failed Alarm	UPS Power Failed	
Rapid Mixer Failed Alarm	Device commanded to run but not running after 30 seconds	
Flocculation Mixer 1 Failed Alarm	Device commanded to run but not running after 30 seconds	
Emergency Stop Alarm	Emergency stop button depressed **NOTE:** Rotate button clockwise to release before resetting alarm.	X
Chemical Pump 1840 Calculation Low Alarm	Pump cannot attain currently configured chemical dose	
Chemical Pump 1850 Calculation High Alarm	Pump cannot attain currently configured chemical dose	
Chemical Pump 1850 Calculation Low Alarm	Pump cannot attain currently configured chemical dose	
Chemical Pump 1810 pH High Alarm	Value outside of defined deadband for the specified delay time	
Chemical Pump 1810 pH Low Alarm	Value outside of defined deadband for the specified delay time	
Power Supply Currently Operating in Battery Backup Mode Alarm	Main Power Failed	X
WAS/MIX Pump 1440 Failed Alarm	Device commanded to run but not running after 30 seconds	X
Power Supply Backup Capacitor Requires Replacement Alarm	UPS capacitor needs replacement in 2 months	
WAS Mixing pH High Alarm	Value outside of defined deadband for the specified delay time	
WAS Mixing pH Low Alarm	Value outside of defined deadband for the specified delay time	
WAS/Mixing Pump 1440 Not In Auto Alarm	Control not in auto mode	
Recirculation Pump 1430 Not in Auto Alarm	Control not in auto mode	
Strainer Not In Auto Alarm	Control not in auto mode	

Ventilation Fan Not In Auto Alarm	Control not in auto mode	

NOTE: Not in Auto Alarm: This alarm does not indicate an operational failure. It is simply an indicator to remind the operator that a given process is under manual control.

WARNING: Equipment protection is enabled only when control is in AUTO. Operator is responsible to protect equipment from damage when control is not in AUTO. Equipment not operating in auto is displayed on the alarm summary screen.

STARTUP

1. Pre-Startup Procedures

A. Electrical Installation

DANGER: All electrical connections shall be made by a qualified electrician.

B. Gravity Waste

Pumping to a line with excessive backpressure may cause instruments to back-flow or cause sputtering from weirs or overflows. If this behavior is seen, try decreasing the backpressure on the drain line.

ATTENTION: Do not connect process lines to field piping smaller than the sizes listed on drawings. Doing so may cause unpredictable equipment operation, backflow and possible flooding.

C. Open Process Connections

Open all process valves required for supply to the equipment. These are not the valves on the equipment but field valves that may need to be opened to supply water to the equipment.

D. Flow Control Options

1. Flocculation Basin Options

The equipment has the option to service water using one, two, or all three flocculation basins in operation at one time. To operate with only a single flocculation basin start by closing inlet valves DV-1631 and DV-1632. This will bypass flocculation basins 1631 and 1632. Next, use the plugs supplied with the system to plug the holes in the divider wall located between flocculation basin 1632 and 1633. This will restrict water from flowing backwards into the other flocculation basins. This will enable water to flow into flocculation basin 1633

.

To operate utilizing two flocculation basins, first close inlet valve DV-1631 and DV-1633. This will bypass flow to flocculation basin 1632. Use the rubber plugs to plug the holes in the divider wall between flocculation basins 1631 and 1632. Open inlet valve DV-1632. This will direct water flow into flocculation basin 1632 where it will continue into flocculation basin 1633.

To operate utilizing all three flocculation basins, open inlet flow valve DV-1631, close inlet valves 1632, 1633, and do not plug any holes between the basins. This will direct flow into flocculation basin 1631 then through the remaining two flocculation basins.

WARNING: All flocculation basins must be filled to the same level. Failure to follow these directions may lead to failure of the tank baffles.

The following chart may be used as a quick reference when configuring the equipment. It is also recommended to use the P&ID drawing as a reference whenever configuring flow through the equipment.

Number of Flocculation Basins Utilized	DV-1631	DV-1632	DV-1633	DV-1641	Divider Between 1632 &1633	Divider Between 1631 &1632
One Basin (1633)	X	X			X	
Two Basins (1632 & 1633)	X		X			X
Three Basins		X	X			
"X" denotes valve closed or basin plugged.						

2. Direct Filtration Option

The equipment has the option of bypassing the settling process in order to accommodate a direct filtration process. First, close valves DV-1632, DV-1633, and DV-1641. Open valve DV-1634. This will allow the flocculated water to bypass the Sedimentation Basin and flow directly into the suction side of the Ion Exchange Pump 1710.

E. Pump Inspection

1. Feed Pumps

Verify that each pump is aligned correctly and that the shaft rotates without binding.

WARNING: Do not run these pumps dry. Do not deadhead pumps for more than 30 seconds

2. Startup Procedures

A. Turn on main disconnect on the exterior of the container.
B. Turn on main disconnect on the PLC Panel
C. Log into HMI
D. Fill Bioprocess Tank 1200 using Feed Pump 1100 or by using the Potable Water Line. Open the Feed Pump control screen and set the MODE to manual. The Manual setpoint should be between 40% and 70%. Turn the Control to ON to begin filling the Bioprocess tank with water.
E. When the Bioprocess Tank is full, turn the Feed pump control to AUTO, and set all the open valves back to AUTO.
F. Next, open valves DV-1441 and DV-1454. Ensure the WAS/Mix pump 1440 has flooded suction and turn it on using the same method as with the feed pump.
G. Once steady flow is achieved, set all controls back to AUTO.
H. Fill the membrane tank. This is achieved by opening valves DV-1436 and DV-1308. Ensure the recirculation pump has flooded suction then turn it on using the same method as the previous pumps.
I. Once the membrane tank IS FULL, SET ALL CONTROLS BACK TO auto.

J. Fill the CIP Tank. Open DV-1314, DV-1315, DV-1318, DV-1320, and DV-1316. Ensure that the Permeate Pump has flooded suction then turn it on using the same method as previous pumps.
K. Fill the Floc Sed Tanks. To do this, leave all valves open as previously mentioned except for DV-1316. Close DV-1316 and open DV-1317 and DV-1513. Using the Permeate Pump again, you can now fill the Floc Sed Tanks. Open DV-1620, DV-1631, DV-1632, DV-1633, and DV-1641. This will allow the Floc Basins to fill as well as the Sedimentation Basin and Settled Water Basin. Close Floc Basin Valves as needed for single, double, or triple basin operation.
L. Fill the Ion Exchange Column. Open either DV-1634 or DV-1650 to flood the suction of Ion Exchange Pump 1710. Open DV-1712, DV-1721, and DV-1722 to fill the Ion Exchange Column. Close necessary hand valves on the Floc Sed for desired operation.
M. Using the red Utility Hose on the Potable Water Line, fill Pressure Relief Tanks 1210, 1241, and 1330 to the fill line on the tank. There is a hose attachment on each tank for ease of filling. Hand Valves DV-1211, DV-1241, and DV-1331 will need to be opened as well while filling. Once each tank is full, close the previously mentioned hand valves and coil the Potable Water Utility hose back up.
N. Ensure all pump control and alarm set-points are set at desired values (pump settings, alarm limits, sequence configurations, etc.)
O. Verify all required component controls to AUTO (feed, chemical, pumps, valves, etc.).
P. Verify that all necessary manual valves are open/closed for servicing water.
Q. You can now put the system into production by pressing the PRODUCTION button.

EQUIPMENT OPERATION

1. Standard Operation

A. On-Board Air Supply

The Pilot Module is equipped with a stand-alone air compressor. The air compressor (1910) is used exclusively for actuating the process valves and raw water strainer.

NOTE: If the air compressor pressure drops below 50 psig the pneumatic valves may no longer actuate properly and the pilot module will shut down. Pressure is displayed on PIT-1910 inside the panel.

B. Water Flow Meters

Each pump is equipped with a dedicated flow meter to measure water/gas flow in the process. Flow values are displayed on the flow meter display as well as the HMI. These flowmeters have been configured at the factory and no further adjustment or configuration should be necessary

C. Pneumatic Valve Solenoids

All pneumatic valves on the filter module are controlled using the air solenoid manifold inside the electrical enclosure. Each valve uses compressed air to open and an internal spring to close. In addition, each valve can be manually overridden from within the

electrical enclosure. To override a valve, insert a small flat-blade screwdriver into one of the blue actuator "buttons" (12 or 14) and rotate it 90° clockwise. To release, simply rotate 90° counter-clockwise.

NOTE: Intuitech recommends that valves only be operated from the VALVES buttons in the HMI. This manual override should only be used if necessary. **Remember to disengage the override when finished.**

D. Level Transmitters

Water levels in the vessels are measured using the transmitters attached to the stainless steel rod located in the center of each vessel (guided wave radar type).

SHUTDOWN

1. Shutdown Procedures

A. Disconnect Electrical Power

All electrical connections are to be isolated and disconnected by qualified personnel.

B. Disconnect Process Connections

All process connections (water, chemical, etc.) should be isolated and disconnected by qualified personnel.

2. Draining Equipment

Drain all water from equipment before storage to prevent biological growth and freeze-damage. This includes draining all filter vessels, tanks, piping, pump housings, instruments, and opening all valves. Some unions and fittings may need to be loosened to ensure complete drainage.

NOTE: Use caution when manually opening pneumatic valves.

Replace Storage Caps on pH Probe. During periods of storage or transportation, the sensor cap should be filled with a pH buffer solution and placed over the sensor tip. **If the salt bridge is allowed to dry out the sensor will be destroyed.** If the sensor is to be stored for an extended period of time, the pH buffer solution in the sensor cap should be replaced every six months.

3. Secure Loose Parts

Any loose parts should be properly secured and stored with equipment.

4. Emergency Shutdown

Emergency shutdown should be accomplished using the emergency stop pushbutton. The emergency stop pushbutton is an electrical disconnect of all control signals, resulting in an immediate shutdown of all equipment. The emergency stop pushbutton can be pressed at any time.

MAINTENANCE

1. General

All maintainable equipment is listed below, along with suggested maintenance procedures and replacement parts. Replacement parts can be purchased through Intuitech, Inc. A suggested maintenance schedule is provided for components that can be maintained on a timetable. However, maintenance intervals are affected by factors such as environment, runtime, and water quality. **Operational experience is the most important factor when formulating a maintenance timetable.** The maintenance timetable in this manual is provided as a recommendation only, actual maintenance schedules will vary by application.

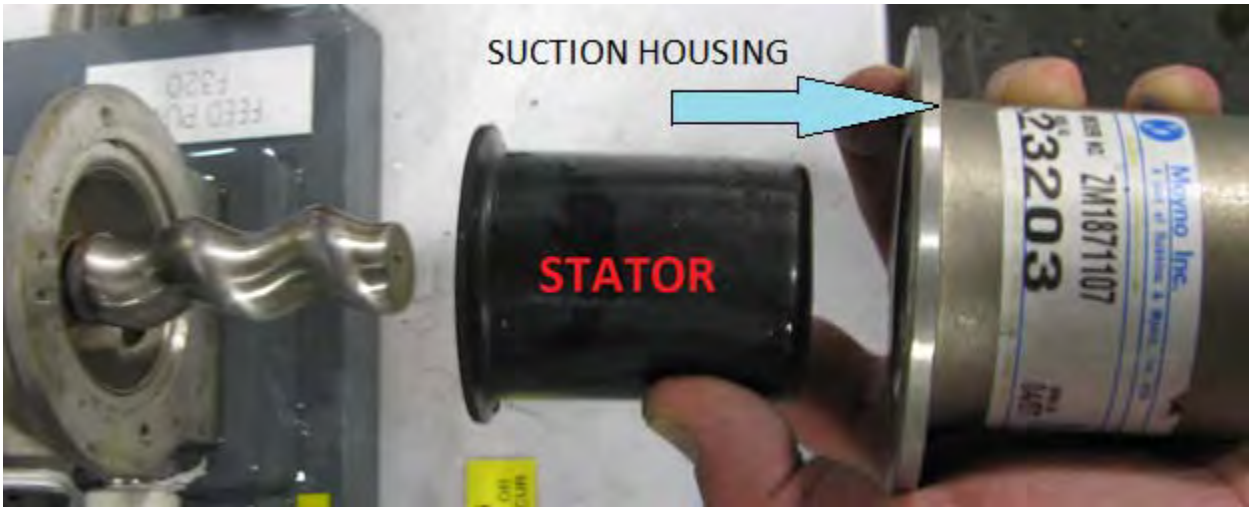
2. Maintainable Equipment

A. Progressive Cavity Pump Assemblies (WAS/Mixing, Recirculation, Ion Exchange)
Motor - Mfr: Baldor, PN: M7006A, Oriental Motor PN: BH162ST-A
Coupling - Mfr: Lovejoy, PN: 685144-10406, 685144-10480, 685144-10471, 685144-10406, 685144-65696.
Pump head - Mfr: Moyno, PN: 33304, 22002
Stator - Mfr: Moyno, PN: 330-6385-120, 330-6382-120
Maintenance information:

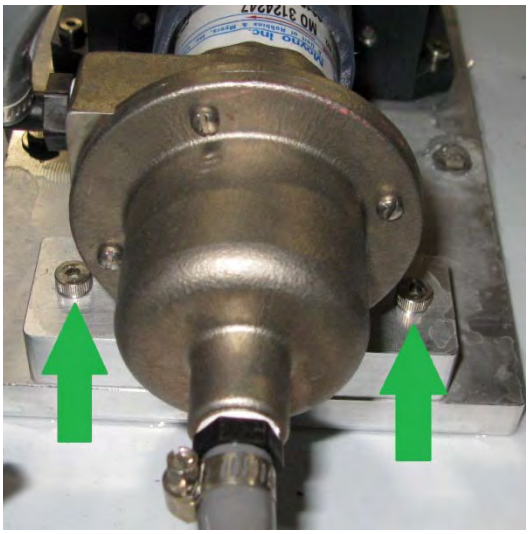
1. **Pump head maintenance**
   The progressive cavity pump assemblies require a minimum amount of maintenance. Maintenance includes routine cleaning with regular stator and coupling inspection. Although the pumps heads look different, the maintenance procedures are virtually identical for both pump types.
2. **Coupling maintenance**
   The rubber spider coupling connecting the two ends of the coupling assembly (between the pump head and motor) should be periodically checked for wear. Replacement is necessary if excessive slop or noise is observed between the pump and motor couplings, or if the spider coupling appears cracked or broken.
3. **Stator maintenance**

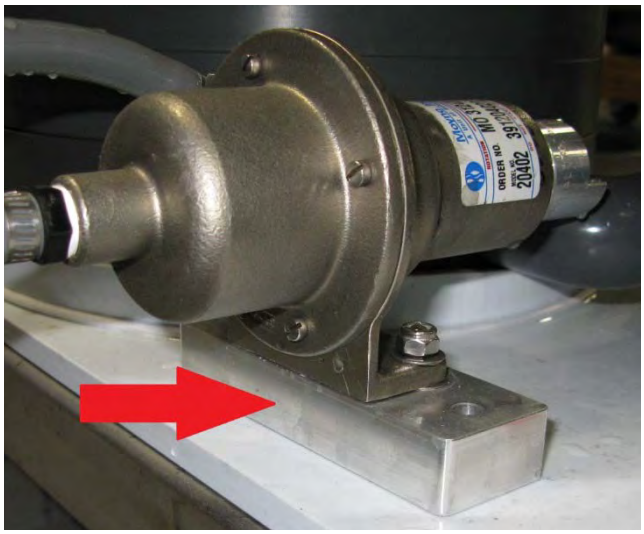
The progressive cavity pump stator may need to be replaced if the pump performance decreases. Several factors can affect stator life, including runtime, pump speed, water quality, etc. Over time the pump speed will increase to maintain the same flow rate. This is a sign the stator is wearing. If the pump cannot maintain the desired flow rate at a speed of 100%, then the stator should be replaced. Replace the stator by first removing the four screws holding the suction housing to the pump body (red arrows). Set suction housing aside. Slide old stator off the rotor and replace with new stator. Do not “unscrew” the old stator, or “screw” the new stator into place. Simply push or pull the stator straight on-

to or off-of the rotor. (Rotating the spiral pump shaft may cause it to loosen and become detached.) When installing the new stator make sure the edges of the stator seal up within the groove in the pump body. Replace screws.



4. **Pump Rotating Assembly Removal and Cleaning**
   Due to water quality and particulate matter, regular cleaning of the internal parts of the progressive cavity pump heads may be necessary. When removing or installing feed pumps, only remove the two screws indicated with green arrows. **Do not remove the base attached directly to the pump head (indicated with the red arrow) at any time.**





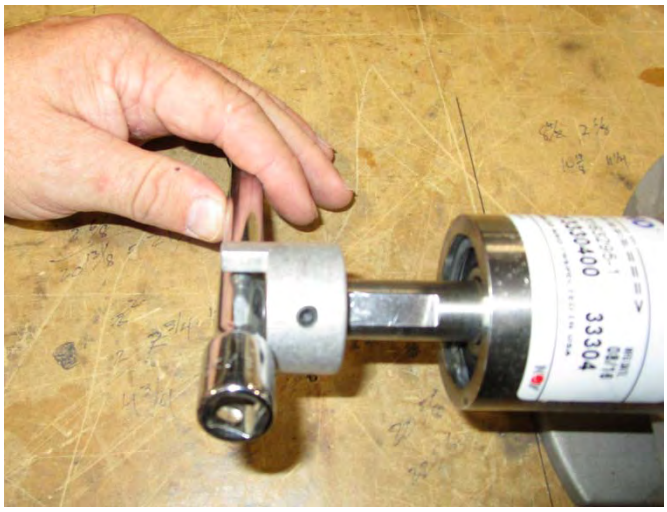
The following instructions are excerpts from the manufacturer's service manual after the stator removal instructions have been followed:

"**To Disassemble Mechanical Seal Models**
3. Remove rotor from flexible joint by turning counter-clockwise (RH thread).

4. Flexible joint can be removed from shaft by using a 3/16 inch allen wrench in end of joint and turn counter-clockwise.
5. Carefully slide mechanical seal off shaft. If any parts of mechanical seal are worn or broken, the complete seal assembly should be replaced. Seal Parts are matched together and are not interchangeable."

"**To Assemble Mechanical Seal Models**
3. Install Mechanical Seal using the following procedure:
   a. Clean and oil sealing surfaces using a clean light oil (not grease).
   Caution: Do not use oil on EPDM parts. Substitute glycerin or soap and water.
   b. Oil the outer surface of the seal seat, and push the assembly into the bore in the pump body, seating it firmly and squarely.
   c. After cleaning and oiling the shaft, slide the seal body along the shaft until it meets the seat seal.
   d. Install seal spring and spring retainer on shaft.
4. Thread flexible joint into shaft in a clockwise direction (RH thread).
5. Thread rotor onto flexible joint in a clockwise direction (RH thread)."

At this point, replace stator and pump housing as explained in step 3 in the Maintenance Section of this manual. With the potential frequency of removing the pump housing screws, it is recommended that **ANTI-SEIZE** be used on the screws to keep from galling and seizing. Below are pictures to aid in the disassembly, cleaning, and reassembly of the pump rotating assembly:



Rotate screw counter clockwise. Following the above manufacturers disassembly instructions should allow for the following parts to be removed.

The spring and spring seat are the most likely places to gather debris. Make sure these are well cleaned before re-assembly.

A small hook may be needed to remove the lower part of the mechanical seal. Be **EXTREMELY** careful when using a tool to remove the mechanical seal. If the ceramic part of the seal breaks, the entire assembly will need to be replaced.

.

<u>CAUTION</u>: If there are any questions when cleaning the pump, refer to the manufacturer's service manual or contact Intuitech technical support.

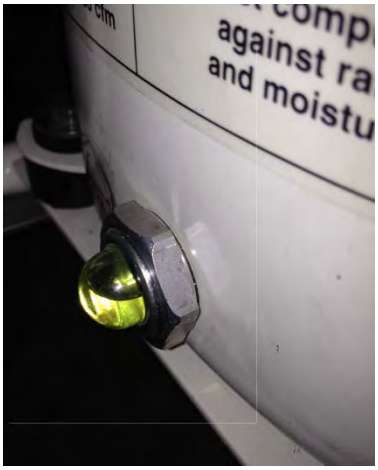
B. Air Compressor (1910)

Mfr: Werther International, PN: P 50-24 AL

Maintenance information:

1. **Air Filter**

   Inspect air filter periodically. Clean filter with soap and water as necessary. Squeeze excess moisture from filter and allow it to dry before re-installing. If filter becomes clogged or damaged, replace it. **NEVER** clean filter with a flammable liquid or solvent. Explosive vapors can accumulate in the air tank and cause an explosion, resulting in injury or death. **DO NOT** operate air compressor without an air filter.



2. **Compressor Oil**

   Inspect compressor oil level monthly. Oil level should fill half of the level sight dome. Top off as required. Entire oil volume should be replaced yearly. Manufacturer recommends draining oil by removing piston housing and dumping contents.

C. Air Preparation Assembly (1910)

Mfr: SMC, PN: CHS20-ND2-Z
AMG150C-N02BC
AM150C-N02C-T
AR20K-N02E-Z

Maintenance information:

1. **Filter Element**

   The SMC air prep assembly contains a filter replacement indication. If the red indicator pops

up and fills the clear window completely (red arrow) the filter element should be replaced.

D. pH Transmitter (PHT-1450)

Mfr: Thermo-Scientific, PN: PH21A1A2
Maintenance information:

1. **Salt Bridge**
   The pH transmitters do not require periodic maintenance. However, the sensor tip (salt bridge) must be kept moist at all times. **If the salt bridge is allowed to dry out the sensor will be destroyed.** During periods of long storage or transportation, the sensor cap should be filled with a pH buffer solution and placed over the sensor tip. **If the sensor is to be stored for an extended period of time, the pH buffer solution in the sensor cap should be replaced every six months.**
2. **Calibration**
   The calibration procedure for the pH sensors is identical to that of the turbidimeters. **See manufacturer's component manual on CD ROM for additional information.**

E. Turbidimeter Analyzer (TUT-1310)

Sensor – Mfr: Thermo-Scientific, PN: RT1173
Maintenance information:

1. **Sensor Maintenance**
   Frequency of required maintenance will depend on the installation, sample type, and water quality. Operational experience will dictate actual maintenance schedules.
2. **Calibration**
   The turbidimeter requires periodic calibration to ensure accurate measurements. Verification was performed at Intuitech before shipping, but calibration should be performed periodically in the field. Refer to the "Thermo Scientific Wide Range Turbidity Measurement System Manual" on CD ROM for field calibration details. Otherwise, the calibration procedure is the same as for the pH probe. To access the calibration screen, press the instrument configuration button. Once connected, the above screen will appear. To begin a calibration, simply click on the sensor value displayed, this will open the calibration screen. Then enter the value of the calibration standard and press "Set".

NOTE: The username is "aqa". The password is "aqa"

F. Peristaltic Chemical and Sample Pump Assemblies (1810, 1820, 1830, 1840, 1850)

Motor Mfr: Intuitech, PN: 5110-200

Pump head Mfr: Masterflex, PN: OE-77800-50
Maintenance information:

1. **General**

   Periodically inspect pump head for cleanliness. Use a mild detergent solution or 70% isopropyl alcohol only to clean the pump. **Do not immerse or use excess fluid.**

2. **Peristaltic tubing maintenance and troubleshooting**

   The peristaltic pump tubing may need to be replaced if the pump performance decreases. Several factors including run time, pump speed, and tubing pressure will determine how long the tubing will last. **If the pump cannot maintain the desired flow rate or the tubing begins to leak, then the tubing should be replaced.**

   Tube loading:

   1. Ensure the pump has been turned off. Do not attempt to change the tubing while the pump is rotating.
   2. To load tubing, open pump by moving the actuator lever to the far left (counterclockwise, if pump is mounted vertically - see Figures 1 and 2).
   3. Insert a loop of tubing into one open tubing retainer, then between the occlusion bed and the rollers and into the other tubing retainer (see figure 3).
   4. Position the tubing so that it seats firmly against the rollers and is centered on the length of the roller.
   5. While holding the tubing ends, move the actuator lever back to the far right (clockwise) position, as shown in Figure 1. The pump will automatically grip the tubing. Approximately 5 pounds of force must be applied to the actuator lever to fully close the pump and place the lever in its locked position. A similar amount of force is required to fully open the pump.
   6. Connect pump tubing to the correct chemical inlet and outlet connections.

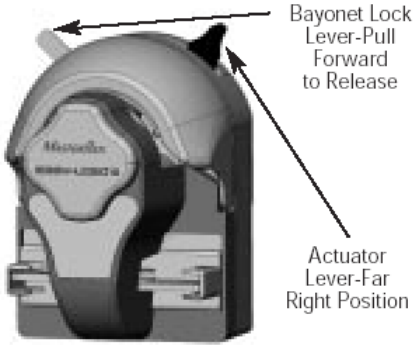


Figure 1
Fully Closed Position

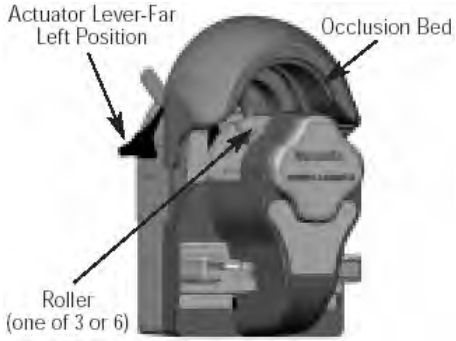


Figure 2
Fully Open Position

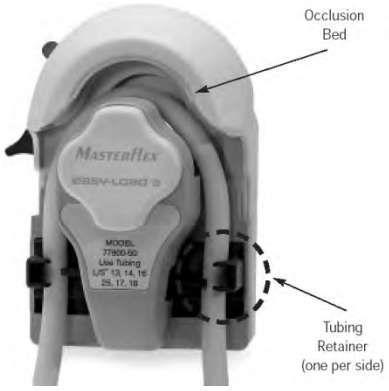


Figure 3
Tubing Path Through Pump - Loaded

NOTE: To unload tubing from the pump, turn off the drive. Then open the pump head by moving the actuator lever counterclockwise (left), as described above. The pump will open the tubing retainers and lift the tubing occlusion bed away from the tubing. Then remove the tubing from the pump.

WARNING: De-energize pump before servicing or injury may occur.

H. Enclosure Exhaust Vent Filter

Mfr: Stego, PN: 01801.0-00
Maintenance information:

1. **Filter mat cleaning:**
   The filter mat in the inlet / exhaust vent filters must be checked periodically. Depending on how clean the environment is that the filters are subjected to, more frequent cleaning may be necessary. To do this, pull off the inlet / exhaust vent hood which is secured by four snap clips. Remove the filter mat and beat or blow out with compressed air until clean. Re-install in reverse order of removal.

3. Maintenance Schedule

Component	Weekly	Monthly	Quarterly	Yearly
Progressive Cavity Pump Stator			X*	
Progressive Cavity Pump Coupling				X*
Peristaltic Pump Head & Tubing		X*		
Air Compressor Prep Equipment			X*	
Air Compressor Oil Replacement	X*			
Turbidimeter Cleaning	X*			X*

Enclosure Exhaust Vent Filter	X*			
Progressive Cavity Pump Internals	X*			
pH Sensor Buffer Replacement			X*	

*Or as necessary

APPENDIX- A

DRAWINGS

FOR

ANAEROBIC MBR PILOT PLANT
PROJECT 1539

FOR

O & M

RELEASE #3

AUGUST 5, 2016

DRAWING TITLE	DRAWING NAME	REVISION NUMBERS BY RELEASE									
		1	2	3	4	5	6	7	8	9	10
PROCESS & INSTRUMENTATION DIAGRAM SYMBOL LEGEND	0000-X1RL-01	0	0	0							
DEVICE TAG LEGEND	0000-X1RL-02	0	0	0							
ELECTRICAL SYMBOL LEGEND	0000-X1RL-03	0	0	0							
ANAEROBIC MBR PILOT PLANT - PROCESS & INSTRUMENTATION DIAGRAM (1OF 4)	1539-X1PP-01	4	4	5							
ANAEROBIC MBR PILOT PLANT - PROCESS & INSTRUMENTATION DIAGRAM (2 OF 4)	1539-X1PP-02	4	4	4							
ANAEROBIC MBR PILOT PLANT - PROCESS & INSTRUMENTATION DIAGRAM (3 OF 4)	1539-X1PP-03	4	4	4							
ANAEROBIC MBR PILOT PLANT - PROCESS & INSTRUMENTATION DIAGRAM (4 OF 4)	1539-X1PP-04	3	3	4							
ANAEROBIC MBR PILOT PLANT - SECTIONS - GENERAL ARRANGMENT	1539-10ML-01	2	2	2							
ANAEROBIC MBR PILOT PLANT - SECTION VIEWS A-A & B-B - GENERAL ARRANGEME	1539-10ML-02	2	2	3							
ANAEROBIC MBR PILOT PLANT - SECTION VIEWS D-D & E-E - GENERAL ARRANGEME	1539-10ML-03	2	2	2							
ANAEROBIC MBR PILOT PLANT - SECTION VIEWS F-F & G-G - GENERAL ARRANGEME	1539-10ML-04	2	2	2							
ANAEROBIC MBR PILOT PLANT - SECTION VIEWS C-C & BACK VIEW - GENERAL ARRA	1539-10ML-05	3	3	3							
ANAEROBIC MBR PILOT PLANT - CONTAINER END VIEWS - GENERAL ARRANGEMEN	1539-10ML-06	2	2	2							
ANAEROBIC MBR PILOT PLANT - ELECTRICAL CLASSIFICATION SEPERATION - GENER	1539-10ML-07	0	0	0							
ANAEROBIC MBR PILOT PLANT - LIGHTNING PROTECTION SYSTEM - FABRICATION	1539-10ML-08	1	1	1							
ANAEROBIC MBR PILOT PLANT - LIGHTNING PROTECTION - FABRICATION	1539-10MF-01	1	1	1							
ANAEROBIC MBR PILOT PLANT - CONTAINER FRONT - GENERAL ARRANGEMENT	1539-11ML-01	2	2	2							
ANAEROBIC MBR PILOT PLANT - CONTAINER BACK - GENERAL ARRANGEMENT	1539-11ML-02	2	2	2							
ANAEROBIC MBR PILOT PLANT - CENTER PARTITION - GENERAL ARRANGEMENT	1539-11ML-04	2	2	2							
ANAEROBIC MBR PILOT PLANT - CONTAINER FRONT - FABRICATION	1539-11MF-01	2	2	2							
ANAEROBIC MBR PILOT PLANT - CONTAINER BACK - FABRICATION	1539-11MF-02	3	3	3							
ANAEROBIC MBR PILOT PLANT - DISCONNECT PANEL - FABRICATION	1539-11MF-08	1	1	1							
ANAEROBIC MBR PILOT PLANT - POWER DISTRIBUTION - GENERAL ARRANGMENT	1539-11ML-05	0	0	0							
ANAEROBIC MBR PILOT PLANT - POWER DISTRIBUTION PANEL - FABRICATION	1539-11MF-09	0	0	0							
ANAEROBIC MBR PILOT PLANT - AC CONDUIT - FABRICATION	1539-11MF-34	0	0	0							
ANAEROBIC MBR PILOT PLANT - DC CONDUIT - FABRICATION	1539-11MF-35	0	0	0							
ANAEROBIC MBR PILOT PLANT - EXTERIOR CONDUIT - FABRICATION	1539-11MF-36	0	0	0							
ANAEROBIC MBR PILOT PLANT - CONTROL PANEL - FABRICATION	1539-11MF-10	1	1	1							
ANAEROBIC MBR PILOT PLANT - WIRE WAY - FABRICATION	1539-11MF-11	0	0	0							
ANAEROBIC MBR PILOT PLANT - DRAIN / WASTE PIPING - FABRICATION	1539-11MF-12	4	4	4							
ANAEROBIC MBR PILOT PLANT - MIXED LIQUOR - FABRICATION	1539-11MF-13	2	2	2							
ANAEROBIC MBR PILOT PLANT - RECIRCULATION PIPING - FABRICATION	1539-11MF-14	2	2	2							
ANAEROBIC MBR PILOT PLANT - MEMBRANE INFLUENT PIPING - FABRICATION	1539-11MF-15	2	2	3							
ANAEROBIC MBR PILOT PLANT - POTABLE WATER PIPING 1OF 2 - FABRICATION	1539-11MF-17	2	2	2							
ANAEROBIC MBR PILOT PLANT - POTABLE WATER PIPING 2 OF 2 - FABRICATION	1539-11MF-37	0	0	0							
ANAEROBIC MBR PILOT PLANT - RAW WATER PIPING - FABRICATION	1539-11MF-18	1	1	1							
ANAEROBIC MBR PILOT PLANT - VACUUM PUMP DISCHARGE PIPING - FABRICATION	1539-11MF-25	2	2	2							
ANAEROBIC MBR PILOT PLANT - BIOGAS EQUALIZATION PIPING - FABRICATION	1539-11MF-30	1	1	1							
ANAEROBIC MBR PILOT PLANT - COMPRESSED NITROGEN PIPING - FABRICATION	1539-11MF-31	2	2	2							
ANAEROBIC MBR PILOT PLANT - CONTAINER COMPRESSOR - FABRICATION	1539-11MF-19	1	1	1							
ANAEROBIC MBR PILOT PLANT - ELECTRICAL BULKHEAD PANEL - FABRICATION	1539-11MF-20	1	1	1							
ANAEROBIC MBR PILOT PLANT - PARTITION PROCESS CONNECTION PANEL - FABRIC	1539-11MF-21	2	2	2							
ANAEROBIC MBR PILOT PLANT - PROCESS CONNECTION PANEL - FABRICATION	1539-11MF-22	0	0	0							
ANAEROBIC MBR PILOT PLANT - ACCESS PORT COVER - FABRICATION	1539-11MF-27	0	0	0							
ANAEROBIC MBR PILOT PLANT - FLAME ARRESTOR / HATCH COVER - FABRICATION	1539-11MF-28	1	1	1							
ANAEROBIC MBR PILOT PLANT - HAZLOC HEATER - FABRICATION	1539-11MF-24	0	0	0							
ANAEROBIC MBR PILOT PLANT - BIOGAS ANALYZER - FABRICATION	1539-11MF-26	0	0	0							
ANAEROBIC MBR PILOT PLANT - WAS / MIX & RECIRC PRESSURE TRANSMITTER - FA	1539-11MF-29	0	0	0							
ANAEROBIC MBR PILOT PLANT - COLLECTION TANKS - GENERAL ARRANGMENT	1539-12ML-01	2	2	2							
ANAEROBIC MBR PILOT PLANT - PRESSURE VESSEL PIPING - GENERAL ARRANGMEN	1539-12ML-02	2	2	2							
ANAEROBIC MBR PILOT PLANT - BIOPROCESS TANK 1200 - FABRICATION	1539-12MF-01	0	0	0							
ANAEROBIC MBR PILOT PLANT - COLLECTION TANKS - FABRICATION	1539-12MF-07	0	0	0							
ANAEROBIC MBR PILOT PLANT - COLLECTION TANK 1220 - FABRICATION	1539-12MF-02	1	1	1							
ANAEROBIC MBR PILOT PLANT - PRESSURE RELIEF TANK 1210 - FABRICATION	1539-12MF-03	1	1	1							
ANAEROBIC MBR PILOT PLANT - PRESSURE RELIEF TANK 1240 - FABRICATION	1539-12MF-04	1	1	1							
ANAEROBIC MBR PILOT PLANT - BIOGAS FLOW TRANSMITTER - FABRICATION	1539-12MF-08	0	0	0							
ANAEROBIC MBR PILOT PLANT - MEMBRANE TANK 1300 - FABRICATION	1539-13MF-01	2	2	2							
ANAEROBIC MBR PILOT PLANT - PERMEATE PIPING - FABRICATION	1539-13MF-02	2	2	2							
ANAEROBIC MBR PILOT PLANT - MEMBRANE WIER PIPING - FABRICATION	1539-13MF-13	0	0	0							
ANAEROBIC MBR PILOT PLANT - PRESSURE RELIEF TANK 1330 - FABRICATION	1539-13MF-03	1	1	1							
ANAEROBIC MBR PILOT PLANT - BACKPULSE / CIP TANK 1320 - FABRICATION	1539-13MF-04	0	0	0							
ANAEROBIC MBR PILOT PLANT - PERMEATE PUMP PIPING 1OF 2 - FABRICATION	1539-13MF-05	2	2	2							
ANAEROBIC MBR PILOT PLANT - PERMEATE PUMP PIPING 2 OF 2 - FABRICATION	1539-13MF-06	0	0	0							
ANAEROBIC MBR PILOT PLANT - FLAME ARRESTOR PIPING - FABRICATION	1539-13MF-07	1	1	1							
ANAEROBIC MBR PILOT PLANT - BIOPROCESS TANK PRESSURE RELIEF PIPING - FAB	1539-13MF-08	1	1	1							
ANAEROBIC MBR PILOT PLANT - MAMBRANE TANK PRESSURE RELIEF PIPING - FAB	1539-13MF-09	1	1	1							
ANAEROBIC MBR PILOT PLANT - BIOGAS VENT PIPING - FABRICATION	1539-13MF-10	1	1	1							
ANAEROBIC MBR PILOT PLANT - BIOGAS EFFLUENT PIPING - FABRICATION	1539-13MF-11	1	1	1							
ANAEROBIC MBR PILOT PLANT - COLLECTION TANK 1410 - FABRICATION	1539-14MF-01	2	2	2							
ANAEROBIC MBR PILOT PLANT - COLLECTION TANK 1420 - FABRICATION	1539-14MF-02	1	1	1							
ANAEROBIC MBR PILOT PLANT - PUMP RACK PIPING 1OF 4 - FABRICATION	1539-14MF-03	5	5	5							

DRAWING TITLE	DRAWING NAME	REVISION NUMBERS BY RELEASE									
		1	2	3	4	5	6	7	8	9	10
ANAEROBIC MBR PILOT PLANT - PUMP RACK PIPING 2 OF 4 - FABRICATION	1539-14MF-04	3	3	3							
ANAEROBIC MBR PILOT PLANT - PUMP RACK PIPING 3 OF 4 - FABRICATION	1539-14MF-05	4	4	4							
ANAEROBIC MBR PILOT PLANT - PUMP RACK PIPING 4 OF 4 - FABRICATION	1539-14MF-06	2	2	2							
ANAEROBIC MBR PILOT PLANT - BIOGAS PUMP FLOW TRANSMITTER - FABRICATION	1539-14MF-11	0	0	0							
ANAEROBIC MBR PILOT PLANT - CONTAINER PARTITION PIPING - FABRICATION	1539-15ML-01	2	2	2							
ANAEROBIC MBR PILOT PLANT - COLLECTION TANK 1540 - FABRICATION	1539-15MF-01	1	1	1							
ANAEROBIC MBR PILOT PLANT - MEMBRANE CONTACTOR 1500 - FABRICATION	1539-15MF-02	1	1	1							
ANAEROBIC MBR PILOT PLANT - CIP PARTITION PIPING - FABRICATION	1539-15MF-03	1	1	1							
ANAEROBIC MBR PILOT PLANT - MEMBRANE GAS INLET PIPING - FABRICATION	1539-15MF-04	1	1	1							
ANAEROBIC MBR PILOT PLANT - BIOGAS PIPING - FABRICATION	1539-15MF-05	2	2	2							
ANAEROBIC MBR PILOT PLANT - CIP DRAIN PIPING - FABRICATION	1539-15MF-06	1	1	1							
ANAEROBIC MBR PILOT PLANT - BACKPULSE / CIP TANK VENT PIPING - FABRICATION	1539-15MF-07	1	1	1							
ANAEROBIC MBR PILOT PLANT - BACKPULSE / CIP TANK OVERFLOW PIPING - FABRIC	1539-15MF-09	0	0	0							
ANAEROBIC MBR PILOT PLANT - BIOGAS ANALYZER PIPING - FABRICATION	1539-15MF-08	3	3	3							
ANAEROBIC MBR PILOT PLANT - FLOCCULATION & SEDIMENTATION MODULE - GENE	1539-16ML-01	2	2	2							
ANAEROBIC MBR PILOT PLANT - FLOCCULATION & SEDIMENTATION MODULE ELEVA	1539-16ML-02	1	1	1							
ANAEROBIC MBR PILOT PLANT - FLOCCULATION TANKS - FABRICATION	1539-16MF-01	1	1	1							
ANAEROBIC MBR PILOT PLANT - FLOCCULATION TANKS - PARTS 1OF 3	1539-16MF-02	0	0	0							
ANAEROBIC MBR PILOT PLANT - FLOCCULATION TANKS - PARTS 2 OF 3	1539-16MF-03	1	1	1							
ANAEROBIC MBR PILOT PLANT - FLOCCULATION TANKS - PARTS 3 OF 3	1539-16MF-04	0	0	0							
ANAEROBIC MBR PILOT PLANT - SEDIMENTATION TANK - FABRICATION	1539-16MF-05	2	2	2							
ANAEROBIC MBR PILOT PLANT - SEDIMENTATION TANK - PARTS 1OF 3	1539-16MF-06	1	1	1							
ANAEROBIC MBR PILOT PLANT - SEDIMENTATION TANK - PARTS 2 OF 3	1539-16MF-07	1	1	1							
ANAEROBIC MBR PILOT PLANT - SEDIMENTATION TANK - PARTS 3 OF 3	1539-16MF-08	1	1	1							
ANAEROBIC MBR PILOT PLANT - FLOCCULATION TANK LID & MIXERS - FABRICATION	1539-16MF-10	2	2	2							
ANAEROBIC MBR PILOT PLANT - SEDIMENTATION TANK LID - FABRICATION	1539-16MF-11	1	1	1							
ANAEROBIC MBR PILOT PLANT - VESSEL 1710 - FABRICATION	1539-16MF-12	1	1	1							
ANAEROBIC MBR PILOT PLANT - ION EXCHANGE PUMP 1710 - FABRICATION	1539-16MF-13	0	0	0							
ANAEROBIC MBR PILOT PLANT - SETTLED WATER LAUNDER - FABRICATION	1539-16MF-22	0	0	0							
ANAEROBIC MBR PILOT PLANT - FLOCCULATION & SEDIMENTATION PIPING - FABRIC	1539-16ML-03	2	2	2							
ANAEROBIC MBR PILOT PLANT - FLOCCULATION / DRAIN & WASTE PIPING 1OF 2 - FA	1539-16MF-14	1	1	1							
ANAEROBIC MBR PILOT PLANT - FLOCCULATION / DRAIN & WASTE PIPING 2 OF 2 - FA	1539-16MF-15	0	0	0							
ANAEROBIC MBR PILOT PLANT - EFFLUENT FLOCCULATION PIPING - FABRICATION	1539-16MF-16	1	1	1							
ANAEROBIC MBR PILOT PLANT - ION EXCHANGE PUMP SUCTION PIPING - FABRICAT	1539-16MF-17	1	1	1							
ANAEROBIC MBR PILOT PLANT - ION EXCHANGE PUMP DISCHARGE PIPING - FABRIC	1539-16MF-18	1	1	1							
ANAEROBIC MBR PILOT PLANT - RAPID MIX INFLUENT PIPING - FABRICATION	1539-16MF-19	2	2	2							
ANAEROBIC MBR PILOT PLANT - EFFLUENT VESSEL PIPING - FABRICATION	1539-16MF-20	2	2	2							
ANAEROBIC MBR PILOT PLANT - CHEMICAL CONTAINMENT - GENERAL ARRANGMEI	1539-18ML-01	0	0	0							
ANAEROBIC MBR PILOT PLANT - CHEMICAL TANK - FABRICATION	1539-18MF-01	0	0	0							
ANAEROBIC MBR PILOT PLANT - CHEMICAL CONTAINMENT - FABRICATION	1539-18MF-02	0	0	0							
ANAEROBIC MBR PILOT PLANT - CHEMICAL CABINET - FABRICATION	1539-18MF-03	1	1	1							
ANAEROBIC MBR PILOT PLANT - ONE LINE DIAGRAM	1539-BOLD-10	4	4	4							
ANAEROBIC MBR PILOT PLANT - DISCONNECT PANEL - LAYOUT	1539-10EL-10	1	1	1							
ANAEROBIC MBR PILOT PLANT - DISCONNECT PANEL - MATERIALS LIST	1539-10EM-10	1	1	1							
ANAEROBIC MBR PILOT PLANT - DISCONNECT PANEL - POWER WIRING	1539-10EP-10	1	1	1							
ANAEROBIC MBR PILOT PLANT - DISCONNECT PANEL - HVAC WIRING	1539-10EP-11	0	0	0							
ANAEROBIC MBR PILOT PLANT - POWER DISTRIBUTION PANEL - LAYOUT	1539-11EL-10	2	2	2							
ANAEROBIC MBR PILOT PLANT - POWER DISTRIBUTION PANEL - MATERIALS LIST	1539-11EM-30	2	2	2							
ANAEROBIC MBR PILOT PLANT - POWER DISTRIBUTION PANEL - AC POWER WIRING	1539-11EP-10	4	4	4							
ANAEROBIC MBR PILOT PLANT - POWER DISTRIBUTION PANEL - AC POWER WIRING	1539-11EP-11	2	2	2							
ANAEROBIC MBR PILOT PLANT - CONTROL PANEL - LAYOUT	1539-12EL-10	3	3	3							
ANAEROBIC MBR PILOT PLANT - CONTROL PANEL - MATERIALS LIST	1539-12EM-30	3	3	4							
ANAEROBIC MBR PILOT PLANT - CONTROL PANEL - AC POWER WIRING 1OF 3	1539-12EP-10	3	4	4							
ANAEROBIC MBR PILOT PLANT - CONTROL PANEL - AC POWER WIRING 2 OF 3	1539-12EP-11	0	0	0							
ANAEROBIC MBR PILOT PLANT - CONTROL PANEL - AC POWER WIRING 2 OF 3	1539-12EP-12	3	3	3							
ANAEROBIC MBR PILOT PLANT - CONTROL PANEL - DC POWER WIRING 1OF 2	1539-12EP-20	2	2	2							
ANAEROBIC MBR PILOT PLANT - CONTROL PANEL - DC POWER WIRING 2 OF 2	1539-12EP-21	2	2	2							
ANAEROBIC MBR PILOT PLANT - CONTROL PANEL - AI1 INPUT WIRING 1OF 2	1539-12EC-10	4	4	4							
ANAEROBIC MBR PILOT PLANT - CONTROL PANEL - AI1 INPUT WIRING 2 OF 2	1539-12EC-11	3	3	3							
ANAEROBIC MBR PILOT PLANT - CONTROL PANEL - AI2 INPUT WIRING 1OF 2	1539-12EC-12	3	3	3							
ANAEROBIC MBR PILOT PLANT - CONTROL PANEL - AI2 INPUT WIRING 2 OF 2	1539-12EC-13	4	4	4							
ANAEROBIC MBR PILOT PLANT - CONTROL PANEL - AO1 OUTPUT WIRING	1539-12EC-20	1	1	1							
ANAEROBIC MBR PILOT PLANT - CONTROL PANEL - AO2 OUTPUT WIRING	1539-12EC-21	1	1	1							
ANAEROBIC MBR PILOT PLANT - CONTROL PANEL - AO3 OUTPUT WIRING	1539-12EC-22	2	2	2							
ANAEROBIC MBR PILOT PLANT - CONTROL PANEL - AO4 OUTPUT WIRING	1539-12EC-23	2	2	2							
ANAEROBIC MBR PILOT PLANT - CONTROL PANEL - AO5 OUTPUT WIRING	1539-12EC-24	3	3	3							
ANAEROBIC MBR PILOT PLANT - CONTROL PANEL - DIO1 INPUT WIRING 1OF 4	1539-12EC-50	1	1	1							
ANAEROBIC MBR PILOT PLANT - CONTROL PANEL - DIO1 INPUT WIRING 2 OF 4	1539-12EC-51	4	4	4							
ANAEROBIC MBR PILOT PLANT - CONTROL PANEL - DIO1 INPUT WIRING 3 OF 4	1539-12EC-52	2	2	2							
ANAEROBIC MBR PILOT PLANT - CONTROL PANEL - DIO1 INPUT WIRING 4 OF 4	1539-12EC-53	2	2	2							
ANAEROBIC MBR PILOT PLANT - CONTROL PANEL - DIO2 INPUT WIRING 1OF 4	1539-12EC-54	1	1	1							

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FRAC: ± 1/16 0.XX: ± 0.01

ANGLES: ± 1° 0.XXX: ± 0.005

TITLE: REVISION HISTORY

CLIENT: CDM SMITH	PROJECT: 1539
DRAWN BY: REM	DRAWN DATE: 12-17-15
DRAWING NAME: 1539-X6RR-01.VSD	P.O.:
SCALE: NONE	REVISION: 0

DRAWING TITLE	DRAWING NAME	REVISION NUMBERS BY RELEASE									
		1	2	3	4	5	6	7	8	9	10
ANAEROBIC MBR PILOT PLANT - CONTROL PANEL - DIO2 INPUT WIRING 2 OF 4	1539-12EC-55	3	3	3							
ANAEROBIC MBR PILOT PLANT - CONTROL PANEL - DIO2 INPUT WIRING 3 OF 4	1539-12EC-56	3	3	3							
ANAEROBIC MBR PILOT PLANT - CONTROL PANEL - DIO2 INPUT WIRING 4 OF 4	1539-12EC-57	1	1	1							
ANAEROBIC MBR PILOT PLANT - CONTROL PANEL - NETWORK DIAGRAM	1539-12ND-10	1	1	1							
ANAEROBIC MBR PILOT PLANT - CONTROL PANEL - PNEUMATIC SCHEMATIC 1 OF 2	1539-12NS-10	4	4	4							
ANAEROBIC MBR PILOT PLANT - CONTROL PANEL - PNEUMATIC SCHEMATIC 2 OF 2	1539-12NS-11	3	3	3							
ANAEROBIC MBR PILOT PLANT - FIELD CONNECTION PANEL - LAYOUT	1539-13EL-10	1	1	1							
ANAEROBIC MBR PILOT PLANT - FIELD CONNECTION PANEL - MATERIALS LIST	1539-13EM-30	2	2	2							
ANAEROBIC MBR PILOT PLANT - FIELD CONNECTION PANEL - POWER WIRING	1539-13EP-10	4	4	4							
ANAEROBIC MBR PILOT PLANT - NETWORK PANEL - LAYOUT	1539-14EL-10	0	0	0							
ANAEROBIC MBR PILOT PLANT - NETWORK PANEL - MATERIALS LIST	1539-14EM-30	1	1	1							
ANAEROBIC MBR PILOT PLANT - CHEMICAL MIXER - LAYOUT AND WIRING	1539-15EL-10	0	0	0							
ANAEROBIC MBR PILOT PLANT - CHEMICAL MIXER - MATERIALS LIST	1539-15EM-30	0	0	0							

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TITLE: REVISION HISTORY

CLIENT: CDM SMITH | PROJECT: 1539

DRAWN BY: REM | DRAWN DATE: 12-17-15

DRAWING NAME: 1539-X6RR-02.VSD | P.O.:

SCALE: NONE | REVISION: 0

DEVICE SYMBOLS

- FIELD-MOUNTED DEVICE
- PANEL-MOUNTED DEVICE
- DEVICE MOUNTED BEHIND PANEL
- PROGRAMMABLE OPERATOR INTERFACE (PANEL-MOUNTED)
- PROGRAMMABLE LOGIC CONTROLLER (MOUNTED BEHIND PANEL)

MISCELLANEOUS

- MINOR PROCESS LINE
- MAJOR PROCESS LINE
- ELECTRICAL SIGNAL
- WATER SURFACE
- MAJOR ARROW
- MINOR ARROW
- PROCESS VALUE POINT (??)
- DRAIN WITH AIR BREAK
- PROCESS BOUNDARY
- SO — CONDUIT SEAL-OFF

INSTRUMENTATION

- VARIABLE AREA FLOWMETER
- PADDLE WHEEL/ TURBINE FLOWMETER
- M — MAGNETIC FLOWMETER
- L — LAMINAR FLOWMETER
- VORTEX SHEDDING FLOWMETER
- T — THERMAL DISPERSION FLOWMETER
- ULTRASONIC LEVEL DEVICE
- OPTICAL DISTANCE TRANSMITTER
- FLOAT LEVEL DEVICE
- SIGHT LEVEL DEVICE
- GUIDED WAVE RADAR LEVEL DEVICE
- PRESSURE DEVICE
- CAPACITIVE LEVEL DEVICE

PROCESS EQUIPMENT

- M — ELECTRIC MIXER
- HEAT EXCHANGER
- HEATER
- STATIC MIXER
- PIPE WEIR WITH AIR BREAK
- EDUCTOR
- FILTER / STRAINER
- COALESCING FILTER
- ORIFICE PLATE
- RUPTURE DISK
- PRESSURE GAUGE ISOLATOR
- PIPE REDUCER
- FLOW THROUGH CELL

PUMPS/ BLOWERS

- BLOWER
- CENTRIFUGAL PUMP
- DIAPHRAGM PUMP
- FLEXIBLE IMPELLER PUMP
- GEAR PUMP
- PERISTALTIC PUMP
- PROGRESSIVE CAVITY PUMP
- ROTARY LOBE PUMP
- COMPRESSOR

CONTROL FUNCTIONS

- f(x) PID — PROPORTIONAL, INTEGRAL & DERIVATIVE
- f(x) PACE — FLOW PACING
- f(x) SUB — SUBTRACTION
- f(x) PWM — PULSE WIDTH MODULATION
- f(x) CALC — CALCULATION
- f(x) SEL — SELECTION
- f(x) SUM — SUMMATION
- f(x) MUX — MULTIPLEXER
- f(x) TRIM — TRIM
- f(x) LIM — SET POINT LIMITING

VALVES

- NEEDLE VALVE
- BUTTERFLY VALVE
- BALL VALVE
- CHECK VALVE
- GLOBE VALVE
- DIAPHRAGM VALVE
- GATE VALVE
- 3-WAY BALL VALVE
- 3-WAY GENERAL VALVE
- PLUG VALVE
- GENERAL VALVE
- AIR RELIEF VALVE
- VACUUM RELIEF VALVE
- PRESSURE / SAFETY RELIEF VALVE

CONTROL PHILOSOPHY

- SEQUENCER STEP
- DECISION
- OPERATOR INPUT
- PROCESS
- REFERENCE TO A DIFFERENT PAGE
- IF CONDITION IS TRUE CONTINUE

ACTUATORS

- PRESSURE REGULATING ACTUATOR
- AIR-TO-OPEN/ SPRING TO CLOSE ACTUATOR
- AIR-TO-OPEN/ AIR-TO-CLOSE ACTUATOR
- AIR-TO-CLOSE/ SPRING-TO-OPEN ACTUATOR
- M — ELECTRIC ACTUATOR
- S — SOLENOID ACTUATOR
- HAND ACTUATOR
- LEVEL ACTUATOR

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FRAC: ± 1/16 0.XX: ± 0.01

ANGLES: ± 1° 0.XXX: ± 0.005

TITLE: PROCESS & INSTRUMENTATION DIAGRAM SYMBOL LEGEND

CLIENT:

PROJECT:

DRAWN BY:

DRAWN DATE:

DRAWING NAME: 0000-XXRL-01.VSD

P.O.:

SCALE: NONE

REVISION: 0

INPUT DEVICE TAG PREFIXES						
PARAMETER	ELEMENT / SENSOR	INDICATOR	TRANSMITTER		SWITCH	
			BLIND	INDICATING	HIGH	LOW
AMMONIUM	AME	AMI	AMT	AMIT	AMSH	AMSL
ANALYTICAL (UNSPECIFIED)	AE	AI	AT	AIT	ASH	ASL
CHLORINE	CHE	CHI	CHT	CHIT	CHSH	CHSL
CONDUCTIVITY	CE	CI	CT	CIT	CSH	CSL
CURRENT	CUE	CUI	CUT	CUIT	CUSH	CUSL
DISSOLVED OXYGEN	DOE	DOI	DOT	DOIT	DOSH	DOSL
FLOW RATE	FE	FI	FT	FIT	FSH	FSL
FLOW TOTALIZER	FQE	FQI	FQT	FQIT	FQSH	FQSL
HARDNESS	HE	HI	HT	HIT	HSH	HSL
HYDROGEN SULFIDE	HSE	HSI	HST	HSIT	HSSH	HSSL
LEVEL	LE	LI	LT	LIT	LSH	LSL
NITROGEN	NE	NI	NT	NIT	NSH	NSL
ORP	ORE	ORI	ORT	ORIT	ORSH	ORSL
OXYGEN	OXE	OXI	OXT	OXIT	OXSH	OXSL
OZONE	OZE	OZI	OZT	OZIT	OZSH	OZSL
PARTICLE	PCE	PCI	PCT	PCIT	PCSH	PCSL
PH	PHE	PHI	PHT	PHIT	PHSH	PHSL
POWER	PWE	PWI	PWT	PWIT	PWSH	PWSL
POWER TOTALIZER	PWQE	PWQI	PWQT	PWQIT	PWQSH	PWQSL
PRESSURE	PE	PI	PT	PIT	PSH	PSL
PRESSURE DIFFERENTIAL	PDE	PDI	PDT	PDIT	PDSH	PDSL
RESISTIVITY	RE	RI	RT	RIT	RSH	RSL
RELATIVE HUMIDITY	RHE	RHI	RHT	RHIT	RHSH	RHSL
SPEED	SE	SI	ST	SIT	SSH	SSL
STREAMING CURRENT	SCE	SCI	SCT	SCIT	SCSH	SCSL
SUSPENDED SOLIDS	SSE	SSI	SST	SSIT	SSSH	SSSL
TEMPERATURE	TE	TI	TT	TIT	TSH	TSL
TIME TOTALIZER	TQE	TQI	TQT	TQIT	TQSH	TQSL
TOTAL ORGANIC CARBON	TCE	TCI	TCT	TCIT	TCSH	TCSL
TURBIDITY	TUE	TUI	TUT	TUIT	TUSH	TUSL
UV ABSORPTION OR TRANSMITTANCE	UVE	UVI	UVT	UVIT	UVSH	UVSL
VOLTAGE	VE	VI	VT	VIT	VSH	VSL
WEIGHT / FORCE	WE	WI	WT	WIT	WSH	WSL

ALARM DEVICE TAG PREFIXES		
PARAMETER	HIGH	LOW
AMMONIUM	AMAH	AMAL
ANALYTICAL (UNSPECIFIED)	AAH	AAL
CHLORINE	CHAH	CHAL
CONDUCTIVITY	CAH	CAL
CURRENT	CUAH	CUAL
DISSOLVED OXYGEN	DOAH	DOAL
FLOW RATE	FAH	FAL
FLOW TOTALIZER	FQAH	FQAL
HARDNESS	HAH	HAL
HYDROGEN SULFIDE	HSAH	HSAL
LEVEL	LAH	LAL
NITROGEN	NAH	NAL
OXYGEN	OXAH	OXAL
OZONE	OZAH	OZAL
PARTICLE	PCAH	PCAL
PH	PHAH	PHAL
POWER	PWAH	PWAL
POWER TOTALIZER	PWQAH	PWQAL
PRESSURE	PAH	PAL
PRESSURE DIFFERENTIAL	PDAH	PDAL
RESISTIVITY	RAH	RAL
RELATIVE HUMIDITY	RHAH	RHAL
SPEED	SAH	SAL
STREAMING CURRENT	SCAH	SCAL
SUSPENDED SOLIDS	SSAH	SSAL
TEMPERATURE	TAH	TAL
TIME TOTALIZER	TQAH	TQAL
TOTAL ORGANIC CARBON	TCAH	TCAL
TURBIDITY	TUAH	TUAL
UV ABSORPTION	UVAH	UVAL
VOLTAGE	VAH	VAL
WEIGHT / FORCE	WAH	WAL

OUTPUT DEVICE TAG PREFIXES	
DESCRIPTION	TAG
CHECK VALVE	CV
DISCRETE VALVE (OPEN/CLOSED)	DV
INJECTION VALVE	IV
PILOT VALVE	YV
PRESSURE REGULATOR	PR
PROPORTIONAL VALVE (MODULATING)	PV
RELIEF VALVE	RV
SAMPLE VALVE	SV

CONTROL DEVICE TAG PREFIXES	
DESCRIPTION	TAG
FLOW CONTROLLER	FC
FLOW INDICATING CONTROLLER	FIC
PRESSURE CONTROLLER	PC
PRESSURE INDICATING CONTROLLER	PIC
SPEED CONTROLLER	SC
SPEED INDICATING CONTROLLER (VFD)	SIC
TEMPERATURE CONTROLLER	TC
TEMPERATURE INDICATING CONTROLLER	TIC

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FRAC: ± 1/16 0.XX: ± 0.01

ANGLES: ± 1° 0.XXX: ± 0.005

TITLE: DEVICE TAG LEGEND

CLIENT: PROJECT:

DRAWN BY: DRAWN DATE:

DRAWING NAME: 0000-XXRL-02.VSD P.O.:

SCALE: NONE REVISION: 0

ELECTRICAL

- WIRING PROVIDED BY OTHERS
- INTERNAL WIRING OR COMPONENTS
- NON-WIRE JUMPERS
- STRANDED COPPER WIRE
- TWISTED PAIR CABLE WITH SHIELD & DRAIN
- MOLDED CABLE, M12, 4PIN, 22AWG
- SPECIAL CABLE
- INTEGRAL CABLE
- ETHERNET CABLE
- PANEL BOUNDARY
- DEVICE AND COMPONENT BOUNDARIES
- MOTOR (X HP)
- TRANSFORMER
- SHIELD
- PLUG CONNECTOR
- INLINE CONNECTOR (SPLICE, WIRE NUT, ETC)
- GROUND
- TERMINAL (X)
- COIL
- LIGHT WITH COLOR (C)
- CIRCUIT BREAKER
- FUSE
- NORMALLY OPEN CONTACT
- NORMALLY CLOSED CONTACT
- OVERLOAD RELAY
- SIGNAL POLE SWITCH
- PRESSURE SWITCH
- RESISTOR
- VARISTOR
- CAPACITOR
- HAND-OFF-AUTO SWITCH
- TWO POSITION SWITCH
- FLOW SWITCH
- LIQUID LEVEL SWITCH
- TEMPERATURE SWITCH
- NORMALLY OPEN PUSH-BUTTON
- NORMALLY CLOSED PUSH-BUTTON
- LINE REACTOR

REV	DATE	BY	DESCRIPTION
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FRAC: ± 1/16 0.XX: ± 0.01

ANGLES: ± 1° 0.XXX: ± 0.005

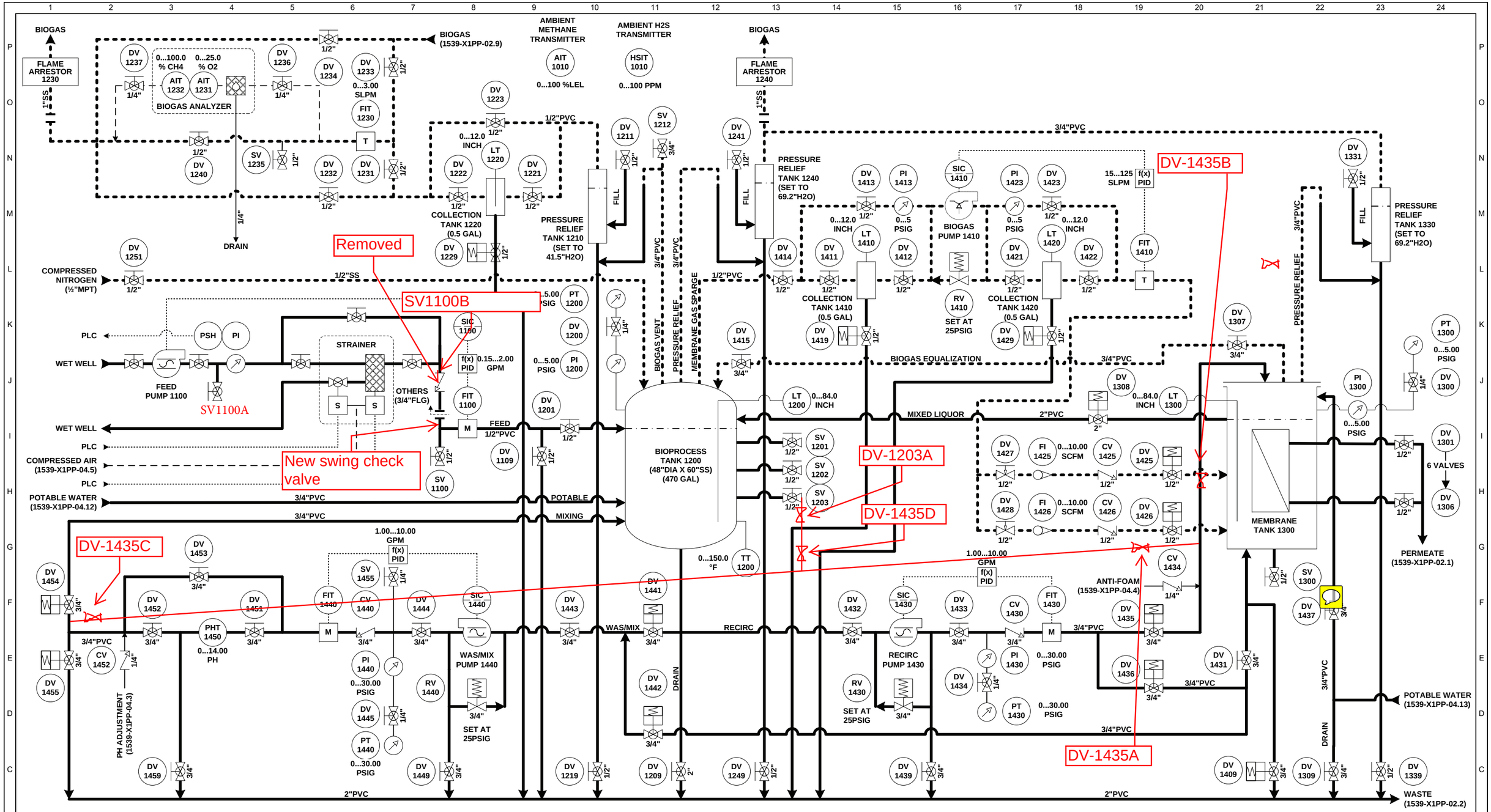
TITLE: ELECTRICAL SYMBOL LEGEND

CLIENT: PROJECT:

DRAWN BY: DRAWN DATE:

DRAWING NAME: 0000-XXRL-03.VSD P.O.:

SCALE: NONE REVISION: 0



REV	DATE	BY	DESCRIPTION
2	01-13-16	CDP	COMBINED LINES INTO MEMBRANE TANK 1300, ADDED RV PRESSURE LIMIT, CHANGED LIT TAGS TO LT, CHANGED FLOW METER RANGES
3	04-01-16	CLR	ADD DV-1238, DV-1414, DV-1415, DV-1437, DV-1538, SV-1212, AND AMBIENT GAS TRANSMITTERS. MOVED SV-1455, DV-1431.
4	06-07-16	CLR	ADD DV-1409, SV-1235, REMOVED DV-1238, DV-1235, COLLECTION TANK DRAINS ARE MAJOR LINE WEIGHT, PNEUMATIC ACTUATED VALVES DV-1441, DV-1442, DV-1308
5	08-05-16	CLR	ADD DV-1427 & DV-1428, CHANGE AIT-1010 TO % LEVEL

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ANGLES: ± 1° 0.XXX: ± 0.005

TITLE: ANAEROBIC MBR PILOT PLANT PROCESS & INSTRUMENTATION DIAGRAM (1 OF 4)

CLIENT: CDM SMITH | PROJECT: 1539

DRAWN BY: EJH | DRAWN DATE: 12-17-15

DRAWING NAME: 1539-X1PP-01.VSD | P.O.:

SCALE: NONE | REVISION: 5

Install new PI 1310

POTABLE WATER (1539-X1PP-04.11)
3/4"PVC
DV 1321
3/4"
VENT (OUTSIDE)
0...15.0 GAL
LT 1320
BACKPULSE / CIP TANK 1320 (8"DIA X 72"H) (15 GAL)
DV 1522
1/2"
RAPID MIX BASIN (1539-X1PP-03.8)
1/2"PVC

PERMEATE (1539-X1PP-01.1)
1/2"PVC
DV 1313
1/4"
PT 1310
-30"HG...30.0 PSIG
-14.5...30 PSIG
PI 1310
DV 1314
1/2"
SIC 1310
0.15...2.00 GPM
f(x) PID
DV 1315
1/2"
FIT 1310
M
DV 1322
1/2"
DV 1318
1/2"
TUT 1310
0...10.0 NTU
DV 1320
1/2"
TT 1310
0...150.0 °F
DV 1316
1/2"
DV 1329
3/4"
DV 1513
1/2"
DV 1521
1/2"
SV 1521
1/2"
-30...0 INCH HG
PI 1530
DV 1530
1/2"
PV 1530
1/2"
10...100 SLPM
FI 1530
1/2"PVC
AIR FILTER 1530 (5 MICRON)
MEMBRANE CONTACTOR 1500

SV 1311
1/2"
CV 1311
1/2"
DV 1311
1/2"
SODIUM HYPOCHLORITE (1539-X1PP-04.6)
CV 1312
1/2"
DV 1312
1/2"
CITRIC ACID (1539-X1PP-04.7)

PERMEATE PUMP 1310
SET AT 25PSIG
RV 1311
3/4"
SET AT 25PSIG
RV 1312
3/4"

SV 1312
1/2"
DV 1317
1/2"
1/2"PVC
0...30 PSIG
PI 1511
DV 1511
1/2"

PT 1540
-30...0.0 INCH HG
f(x) PID
DV 1543
1/2"
DV 1540
1/4"
PI 1540
-30...0 INCH HG
0...12.0 INCH
LT 1540
DV 1541
1/2"
DV 1542
1/2"
COLLECTION TANK 1540 (0.5 GAL)
SIC 1540
1/2"PVC
VACUUM PUMP 1540
DV 1544
1/2"
BIOGAS (1539-X1PP-01.9)
1/4"
SV 1545

DV 1319
1/2"
DV 1519
1/2"
DV 1549
1/2"
DV 1529
1/2"
Gauge 10

WASTE (1539-X1PP-01.2)
2"PVC
WASTE (1539-X1PP-03.10)

REV	DATE	BY	DESCRIPTION
1	01-04-16	EJH	MADE NUMEROUS CHANGES & ADDITIONS AFTER 12-29-15 TELECONFERENCE.
2	01-13-16	CDP	ADDED RV PRESSURE LIMIT, CHANGED LIT TAGS TO LT, REMOVED DV-1320, CHANGED FLOW METER RANGE
3	04-01-16	CLR	ADD DV-1544, DV-1318, DV-1320, DV-1322
4	06-07-16	CLR	ADD SV-1545, MOVE TT-1310, PI-1310, AND PI-1540

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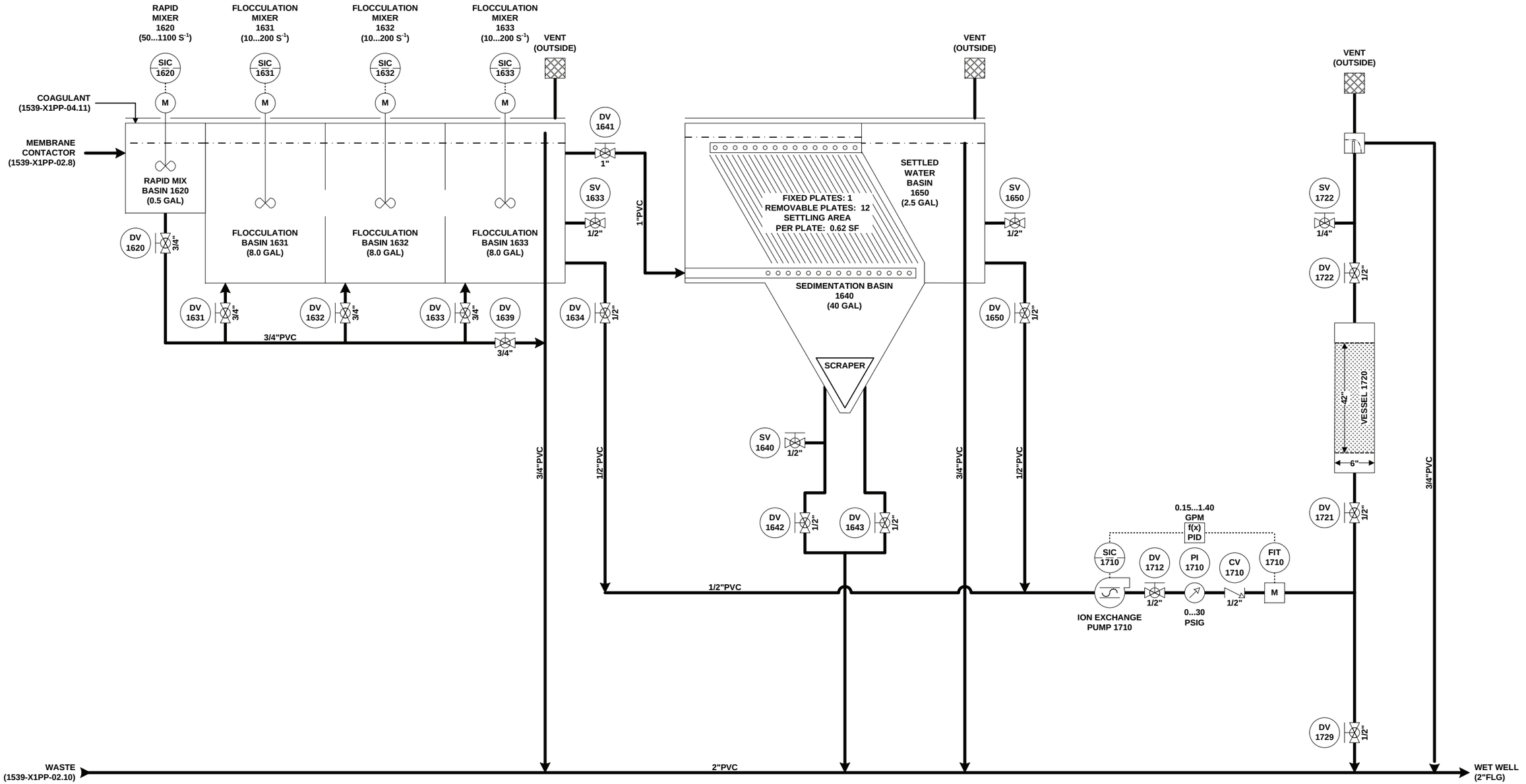
ANGLES: ± 1° 0.XXX: ± 0.005

TITLE: ANAEROBIC MBR PILOT PLANT
PROCESS & INSTRUMENTATION DIAGRAM (2 OF 4)

CLIENT: CDM SMITH | PROJECT: 1539
DRAWN BY: EJH | DRAWN DATE: 12-17-15
DRAWING NAME: 1539-X1PP-02.VSD | P.O.:
SCALE: NONE | REVISION: 4



REV	DATE	BY	DESCRIPTION
1	01-04-16	EJH	MADE NUMEROUS CHANGES & ADDITIONS AFTER 12-29-15 TELECONFERENCE.
2	01-15-16	CDP	CHANGED FLOW METER RANGE
3	04-19-16	CLR	REMOVED DV-1711 BEFORE EXCHANGE PUMP
4	06-06-16	CLR	DV-1641 TO 1", SV-1722 TO 1/4", MOVE DV-1721 TO VESSEL 1710, ION EXCHANGE PUMP 1700 TO 1710

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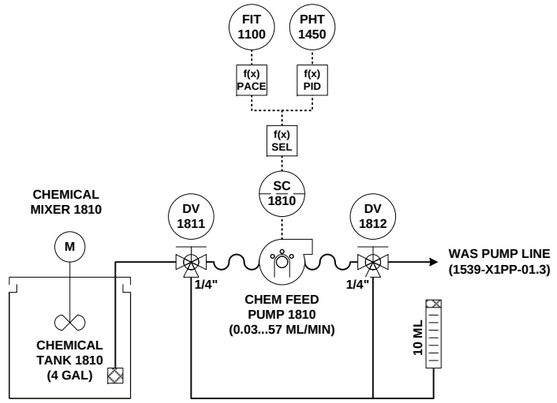
FRAC: ± 1/16 0.XX: ± 0.01

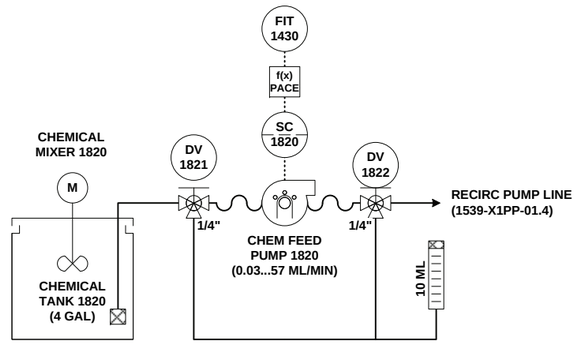
ANGLES: ± 1° 0.XXX: ± 0.005

TITLE: **ANAEROBIC MBR PILOT PLANT**
PROCESS & INSTRUMENTATION DIAGRAM (3 OF 4)

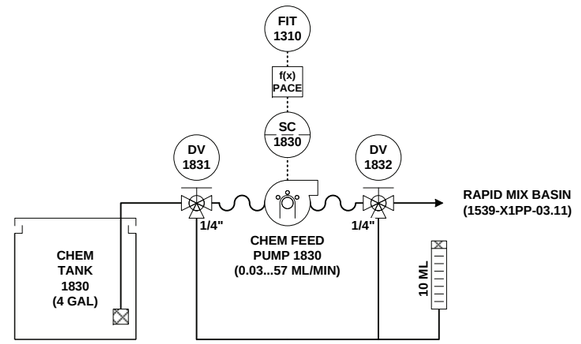
CLIENT: CDM SMITH	PROJECT: 1539
DRAWN BY: EJH	DRAWN DATE: 12-17-15
DRAWING NAME: 1539-X1PP-03.VSD	P.O.:
SCALE: NONE	REVISION: 4



BIOPROCESS TANK 1200 CHEMICAL PUMP



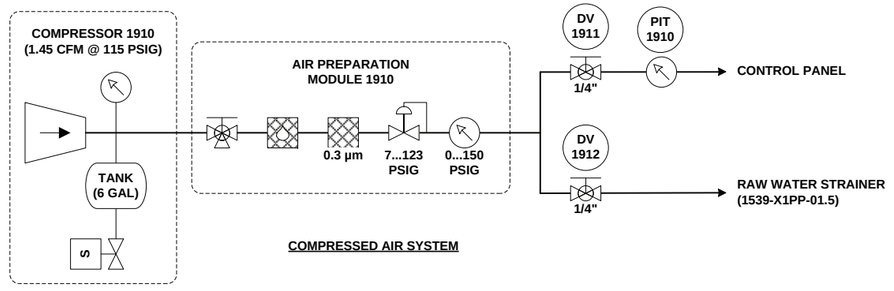
ANTI-FOAM SYSTEM



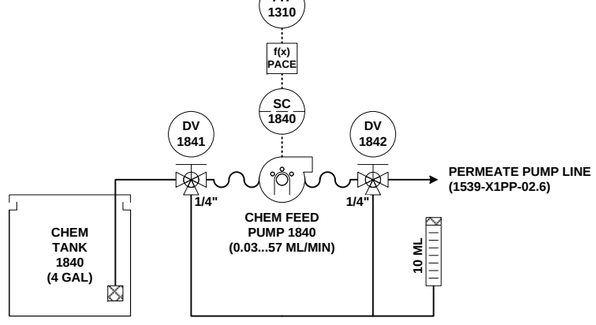
COAGULANT FEED SYSTEM

LSH 1801

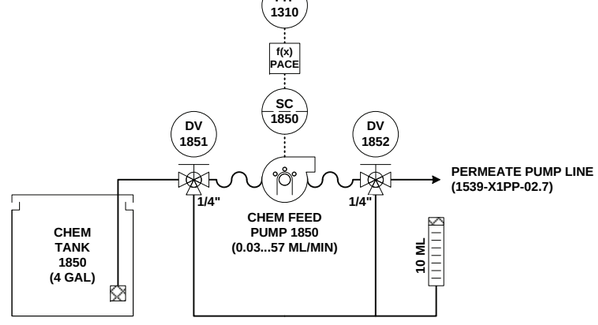
SECONDARY CONTAINMENT



COMPRESSED AIR SYSTEM



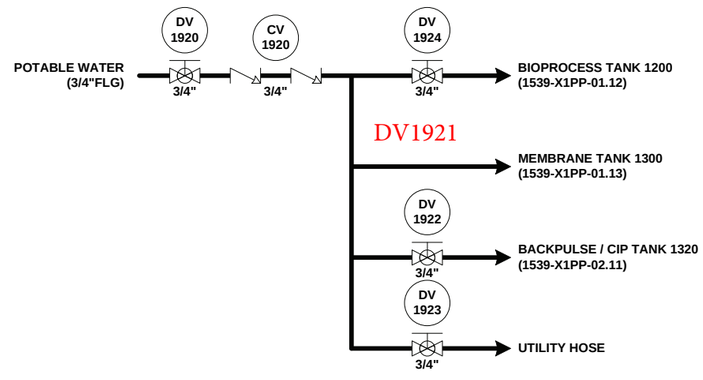
SODIUM HYPOCHLORITE FEED SYSTEM



CITRIC ACID FEED SYSTEM

LSH 1802

SECONDARY CONTAINMENT



UTILITY WATER SYSTEM

REV	DATE	BY	DESCRIPTION
1	1-4-16	EJH	MADE NUMEROUS CHANGES & ADDITIONS AFTER 12-29-15 TELECONFERENCE.
2	04-01-16	CLR	UPDATE TAG NAMES
3	06-06-16	CLR	ADD CHEMICAL MIXERS AND PIT-1910 TAG NAMES, REMOVED DV-1921
4	08-05-16	CLR	BIOPROCESS TANK CHEMICAL PUMP PACE TO FIT 1100

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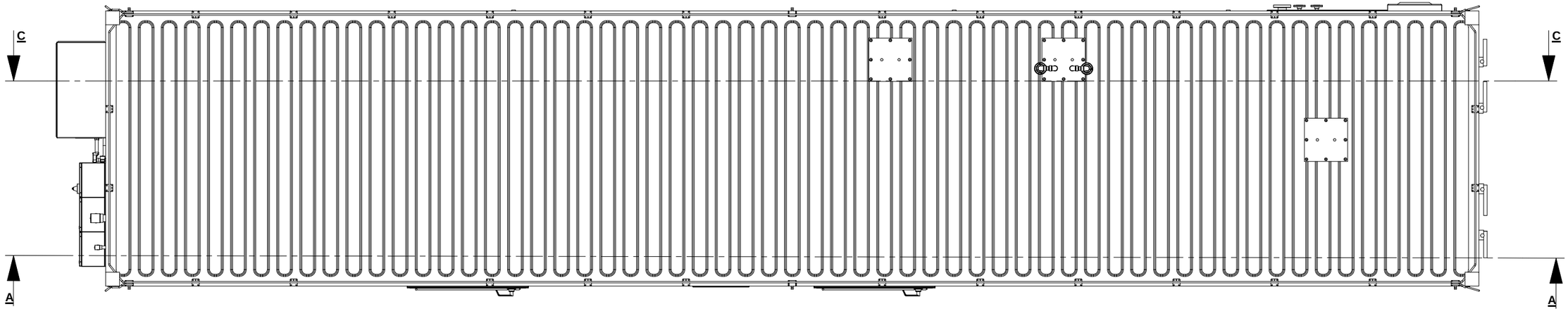
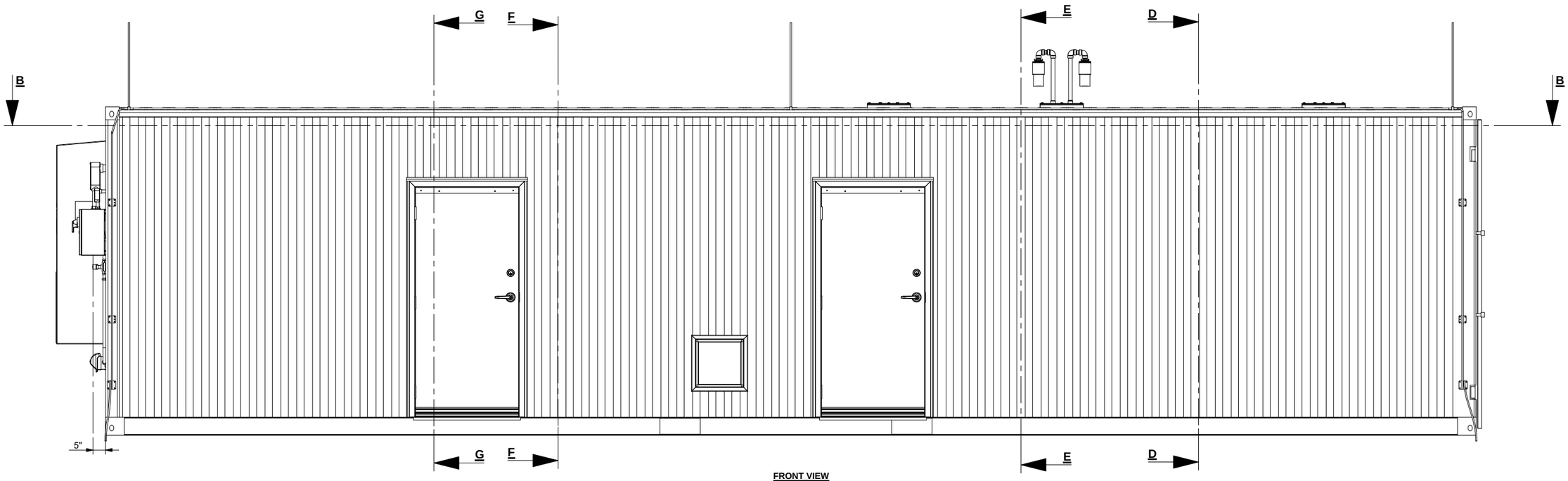
ANGLES: ± 1° 0.XXX: ± 0.005

TITLE: ANAEROBIC MBR PILOT PLANT
PROCESS & INSTRUMENTATION DIAGRAM (4 OF 4)

CLIENT: CDM SMITH	PROJECT: 1539
DRAWN BY: EJH	DRAWN DATE: 12-17-15
DRAWING NAME: 1539-X1PP-04.VSD	P.O.:
SCALE: NONE	REVISION: 4



TOP VIEW



FRONT VIEW

REV	DATE	BY	CHECKED	DESCRIPTION
1	05-03-16	AJB		UPDATED DRAWING TO SHOW MECHANICAL MODIFICATIONS
2	06-07-16	CLR		UPDATED DRAWING TO SHOW MECHANICAL MODIFICATIONS, CHANGE PLACEMENT OF AIR TERMINALS FOR LIGHTNING PROTECTION.
3				
4				

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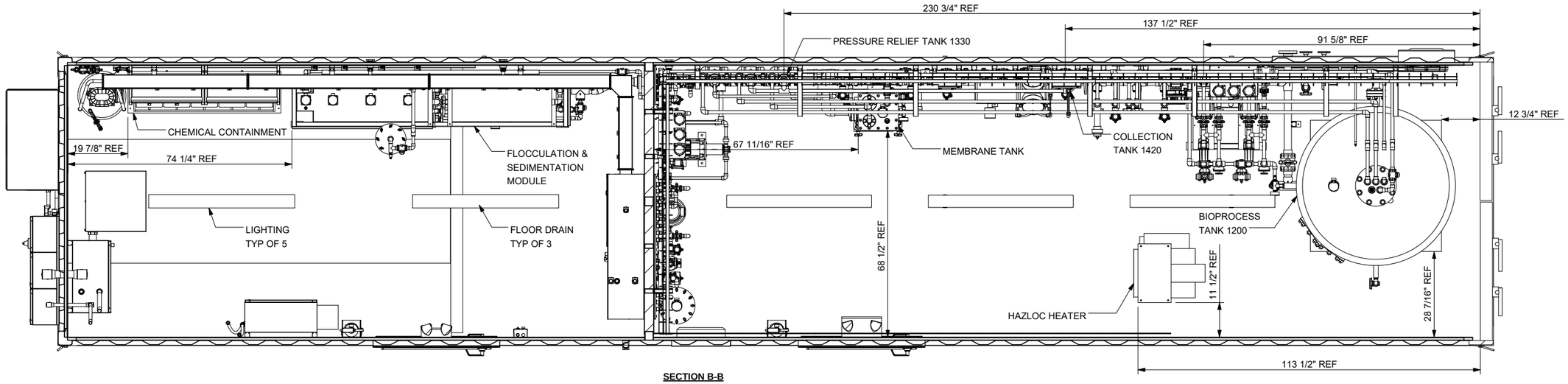
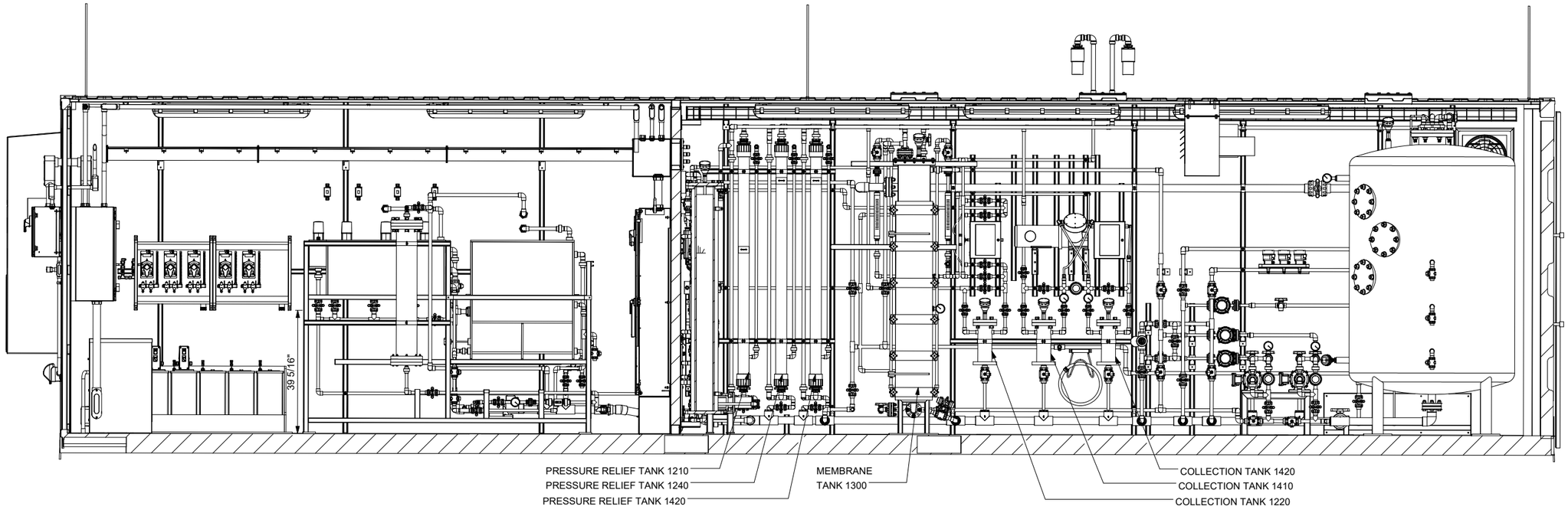
ANGLES: ±1° 0.XXX: ±0.005

TITLE: ANAEROBIC MBR PILOT PLANT SECTIONS - GENERAL ARRANGEMENT	
CLIENT: CDM SMITH	PROJECT: 1539
DRAWN BY: CLR	DRAWN DATE: 04-07-16
DRAWING NAME: 1539-10ML-01	P.O.:
SCALE: NONE	REVISION: 2



SECTION B-B



SECTION A-A

REV	DATE	BY	CHECKED	DESCRIPTION
1	05-03-16	AJB		UPDATED DRAWING TO SHOW ALL MECHANICAL MODIFICATIONS
2	06-07-16	CLR		UPDATED DRAWING TO SHOW ALL MECHANICAL MODIFICATIONS
3	08-05-16	CLR		UPDATE DRAWING TO SHOW ALL MECHANICAL MODIFICATIONS, ADD NEEDLE VALVES TO MEMBRANE TANK PIPING
4				

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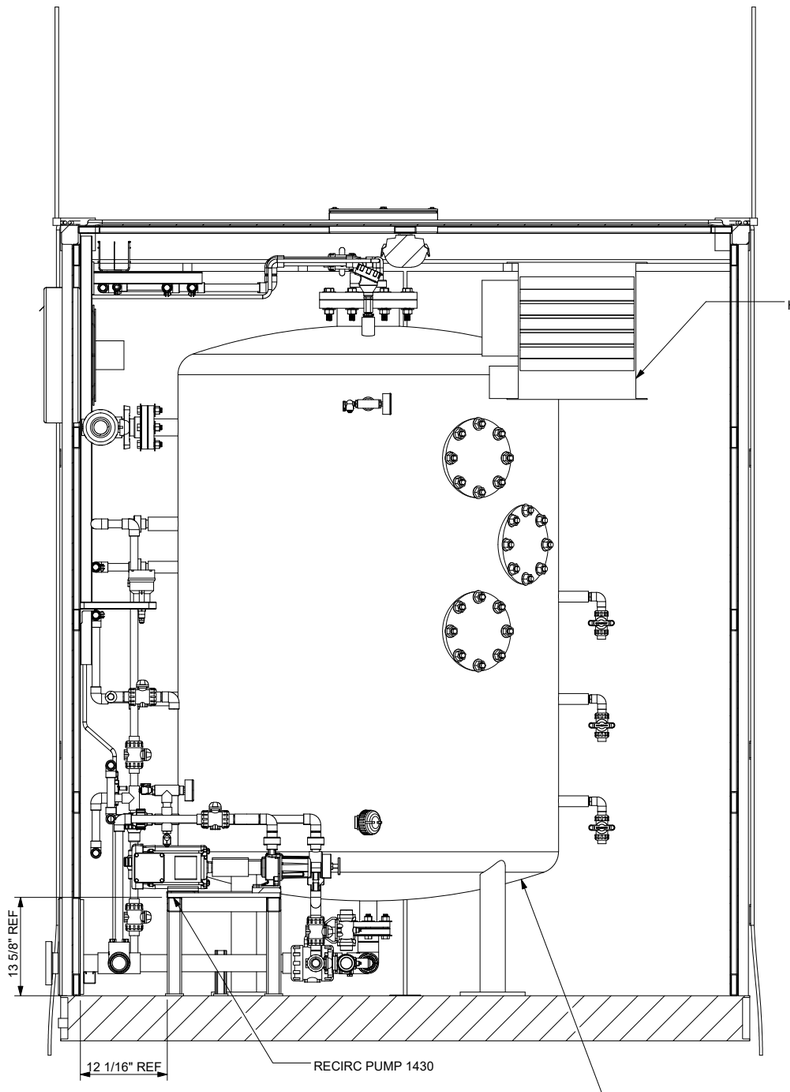
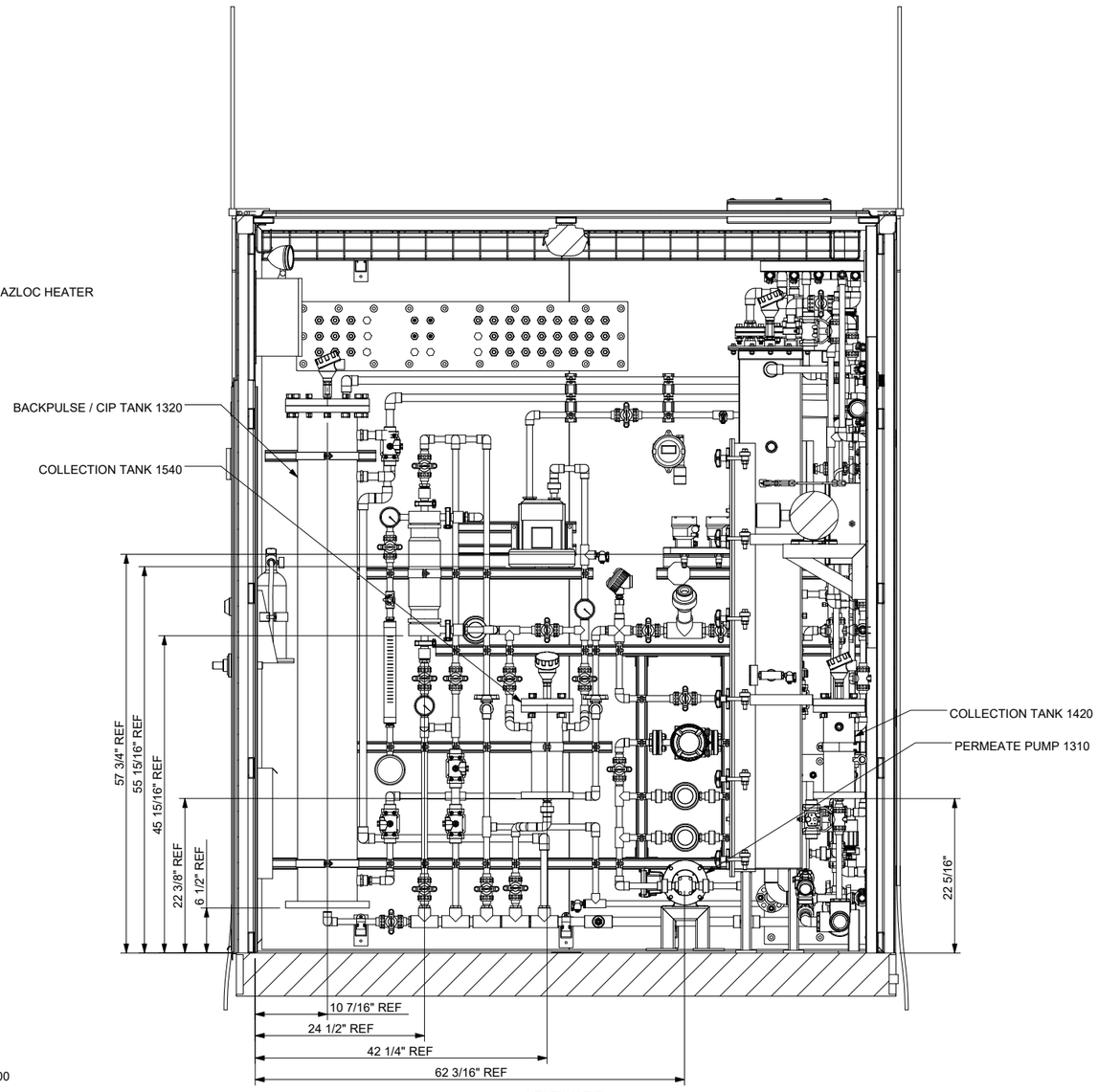
ANGLES: ±1° 0.XXX: ±0.005

TITLE: ANAEROBIC MBR PILOT PLANT
SECTION VIEWS A-A & B-B - GENERAL ARRANGEMENT

CLIENT: CDM SMITH	PROJECT: 1539
DRAWN BY: CLR	DRAWN DATE: 04-07-16
DRAWING NAME: 1539-10ML-02	P.O.:
SCALE: NONE	REVISION: 3



SECTION D-D



SECTION E-E

REV	DATE	BY	CHECKED	DESCRIPTION
1	05-03-16	AJB		UPDATED DRAWING TO SHOW ALL MECHANICAL MODIFICATIONS
2	06-06-16	CLR		UPDATED DRAWING TO SHOW ALL MECHANICAL MODIFICATIONS
3				
4				

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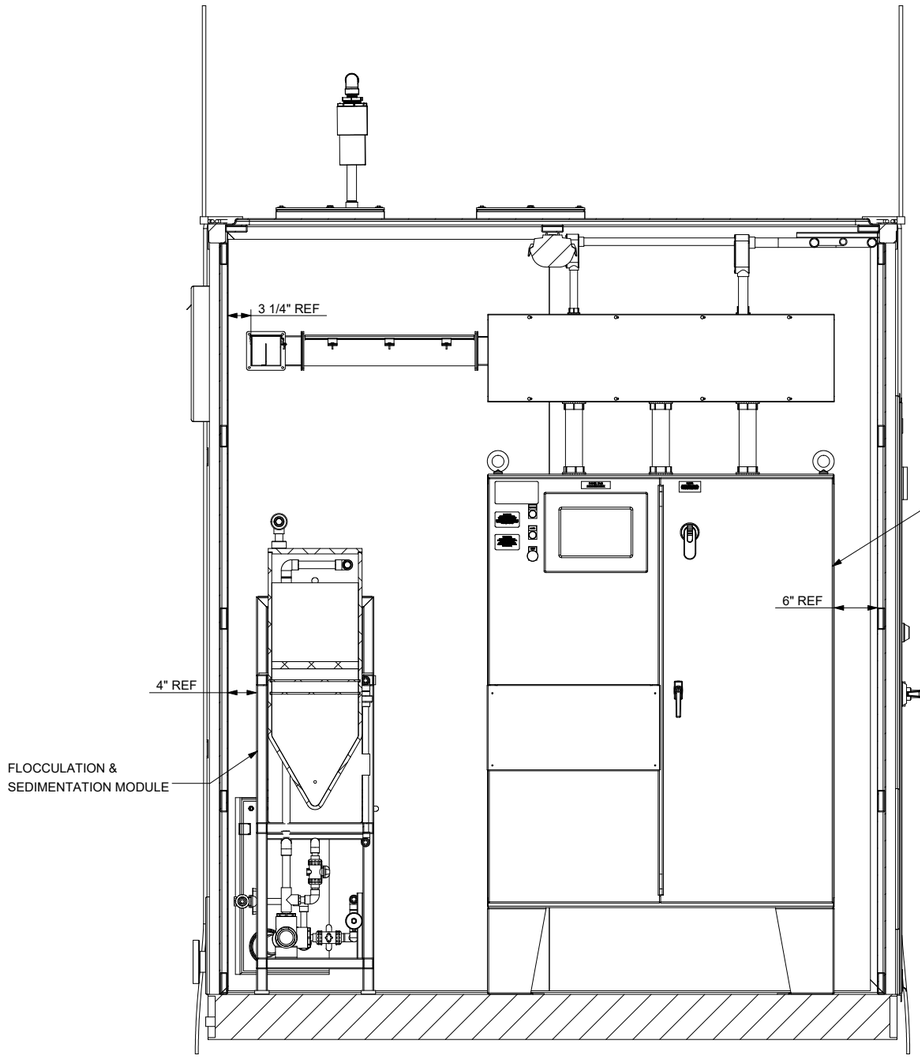
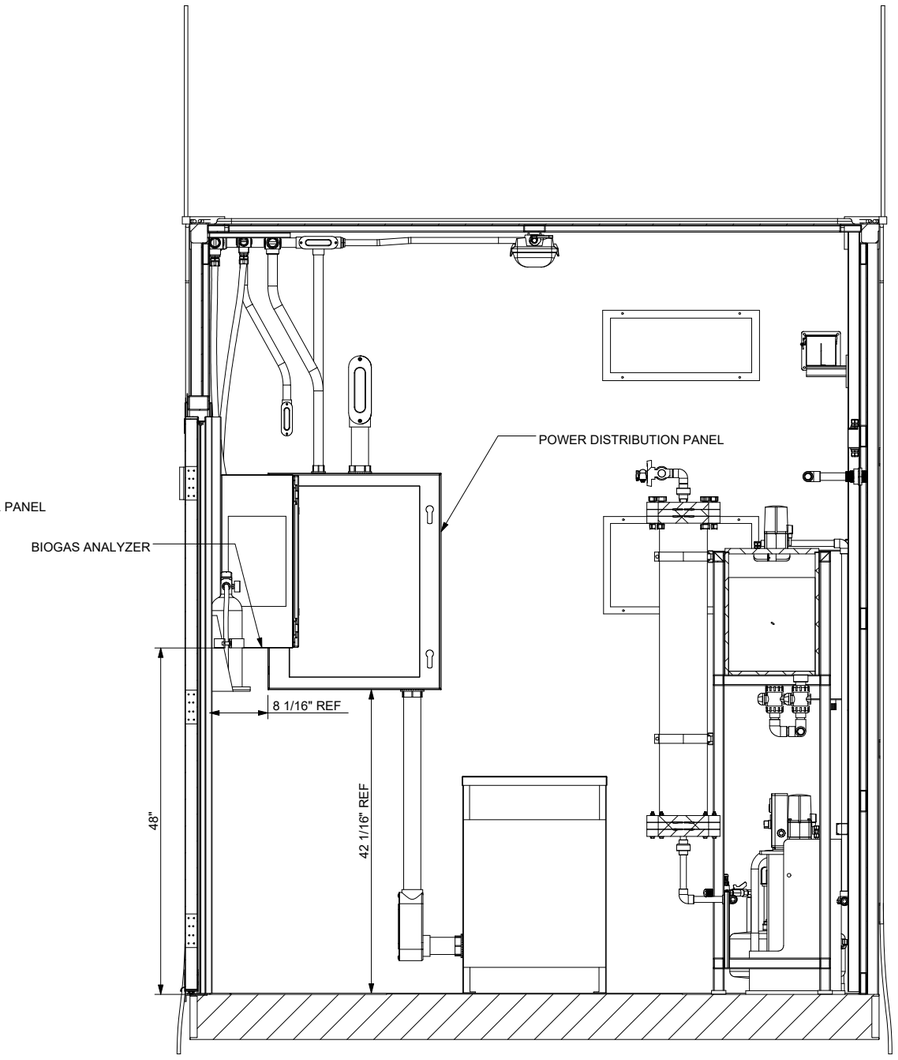
ANGLES: ±1° 0.XXX: ±0.005

TITLE: ANAEROBIC MBR PILOT PLANT
SECTION VIEWS D-D & E-E - GENERAL ARRANGEMENT

CLIENT: CDM SMITH
PROJECT: 1539
DRAWN BY: CLR
DRAWN DATE: 04-07-16
DRAWING NAME: 1539-10ML-03
P.O.:
SCALE: NONE
REVISION: 2



SECTION F-F



SECTION G-G

REV	DATE	BY	CHECKED	DESCRIPTION
1	05-03-16	AJB		UPDATED DRAWING TO SHOW ALL MECHANICAL MODIFICATIONS
2	06-07-16	CLR		UPDATED DRAWING TO SHOW ALL MECHANICAL MODIFICATIONS
3				
4				

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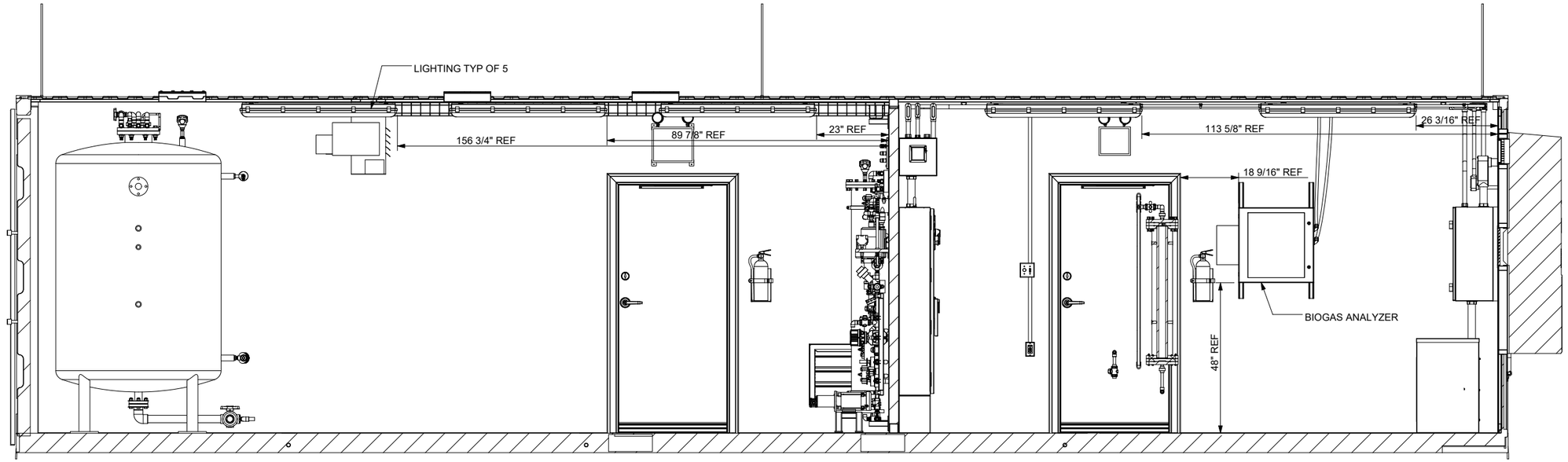
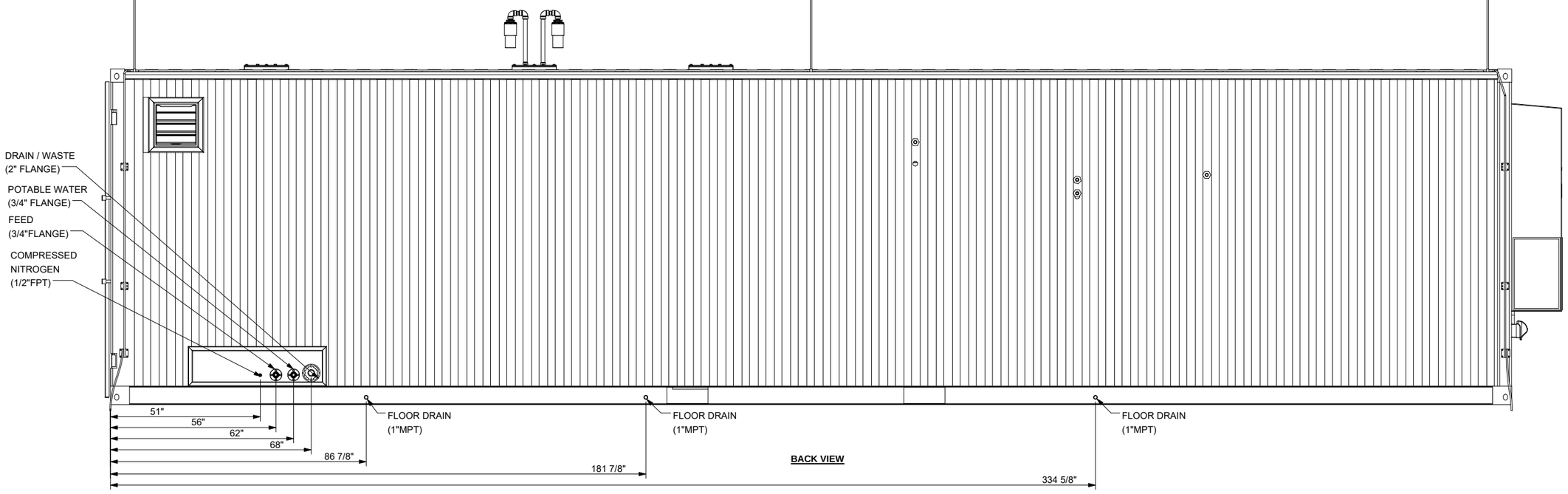
ANGLES: ±1° 0.XXX: ±0.005

TITLE: ANAEROBIC MBR PILOT PLANT
SECTION VIEWS F-F & G-G - GENERAL ARRANGEMENT

CLIENT: CDM SMITH	PROJECT: 1539
DRAWN BY: CLR	DRAWN DATE: 04-07-16
DRAWING NAME: 1539-10ML-04	P.O.:
SCALE: NONE	REVISION: 2



SECTION C-C



BACK VIEW

REV	DATE	BY	CHECKED	DESCRIPTION
1	05-03-16	AJB		UPDATED DRAWING TO SHOW ALL MECHANICAL MODIFICATIONS
2	05-10-16	AJB		ADDED PIPE CONNECTIONS FOR FLOOR DRAINS
3	06-07-16	CLR		UPDATED DRAWING TO SHOW ALL MECHANICAL MODIFICATIONS
4				

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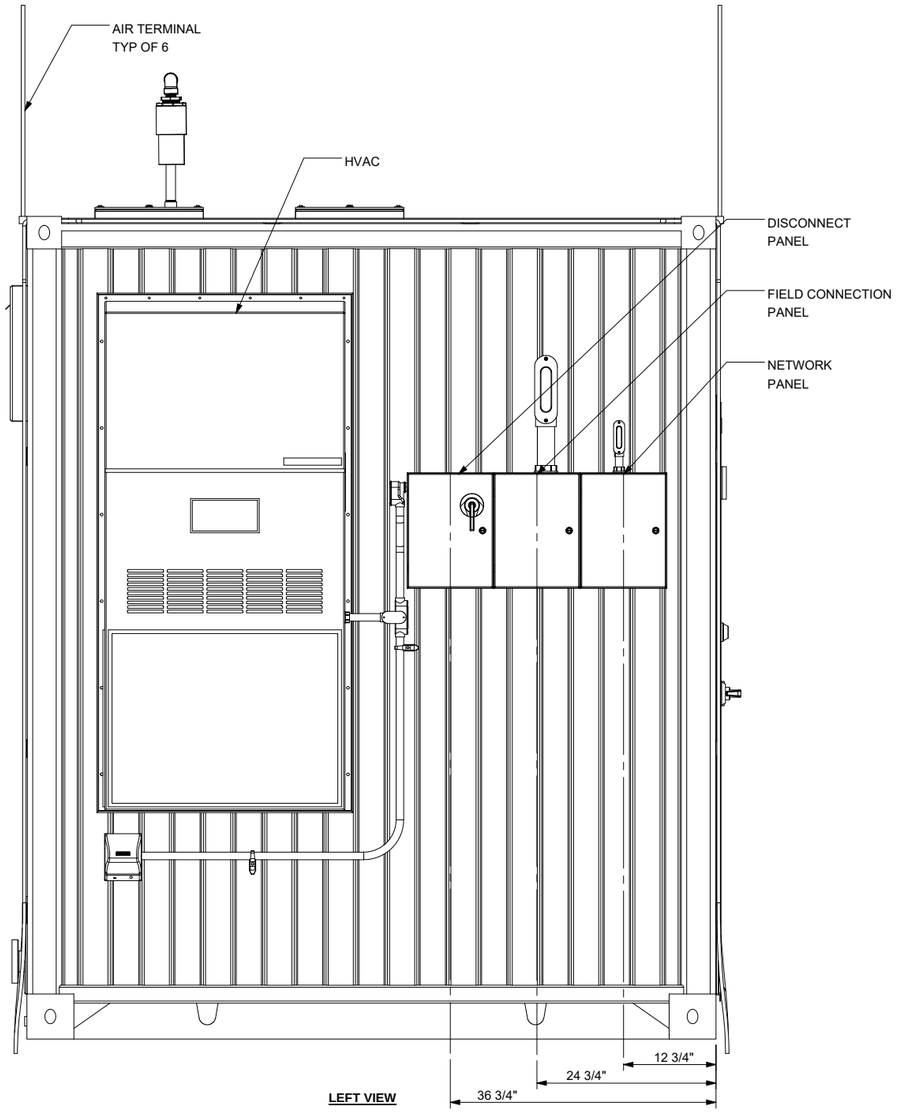
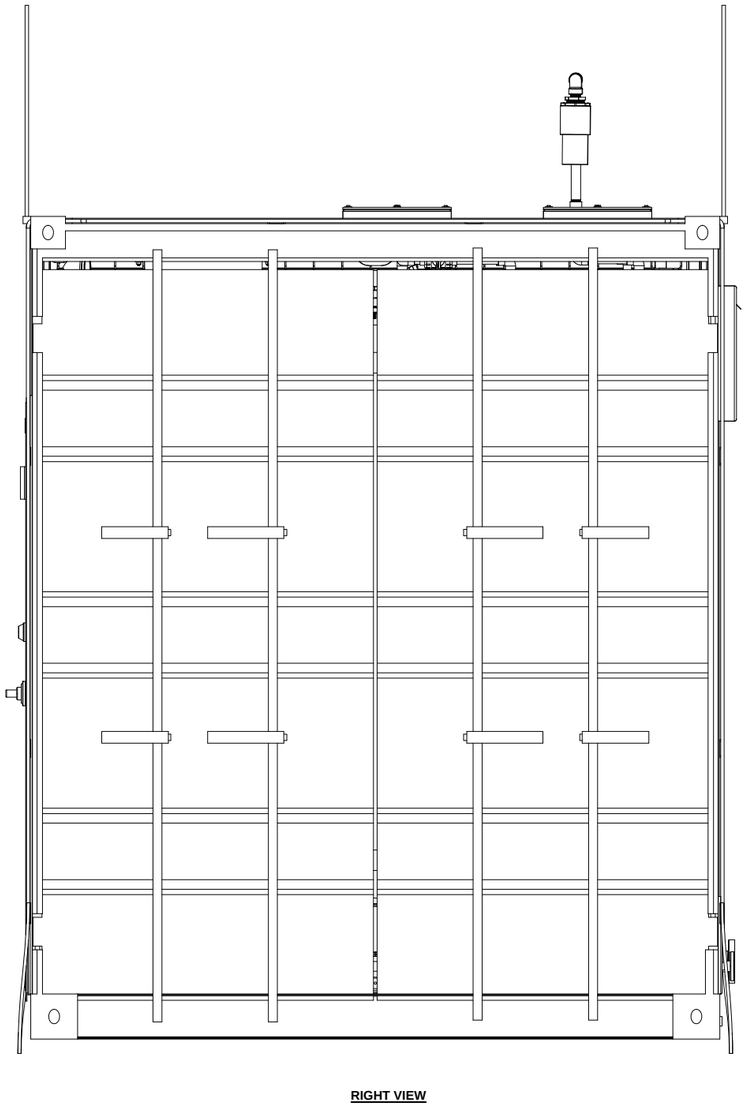
FRAC: ±1/16 0.XX: ±0.01
ANGLES: ±1° 0.XXX: ±0.005

TITLE: ANAEROBIC MBR PILOT PLANT
SECTION VIEW C-C & BACK VIEW - GENERAL ARRANGEMENT

CLIENT: CDM SMITH	PROJECT: 1539
DRAWN BY: CLR	DRAWN DATE: 04-07-16
DRAWING NAME: 1539-10ML-05	P.O.:
SCALE: NONE	REVISION: 3



LEFT VIEW



RIGHT VIEW

REV	DATE	BY	CHECKED	DESCRIPTION
1	05-03-16	AJB		UPDATED DRAWING TO SHOW ALL MECHANICAL MODIFICATIONS
2	06-06-16	CLR		UPDATE DRAWING TO SHOW MECHANICAL MODIFICATION, REPOSITION AIR TEMINALS
3				
4				

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FRAC: ±1/16 0.XX: ±0.01

ANGLES: ±1° 0.XXX: ±0.005

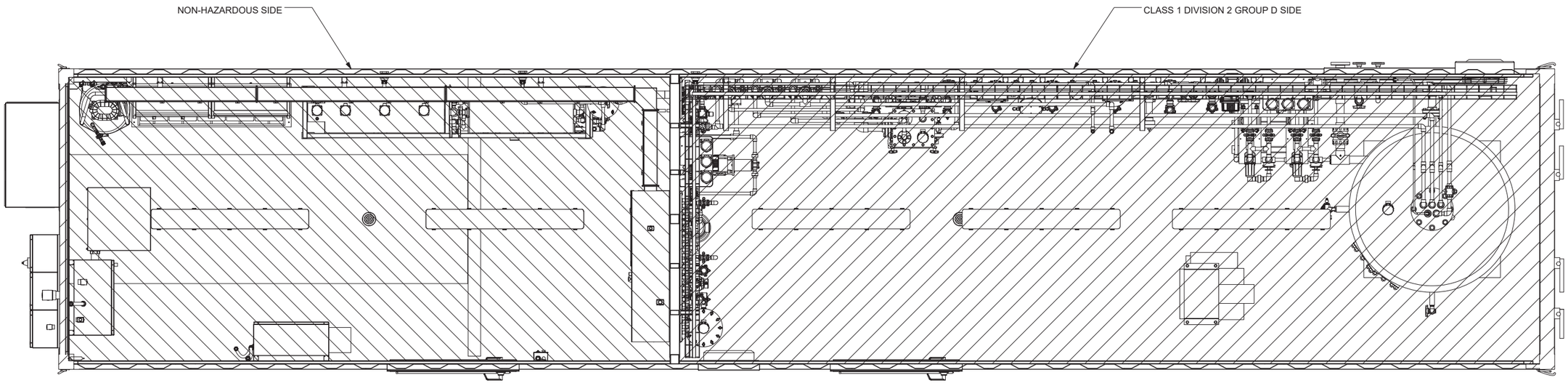
TITLE: ANAEROBIC MBR PILOT PLANT
END VIEWS - GENERAL ARRANGEMENT

CLIENT: CDM SMITH | PROJECT: 1539

DRAWN BY: CLR | DRAWN DATE: 04-07-16

DRAWING NAME: 1539-10ML-06 | P.O.:

SCALE: NONE | REVISION: 2



REV	DATE	BY	CHECKED	DESCRIPTION
1				
2				
3				
4				

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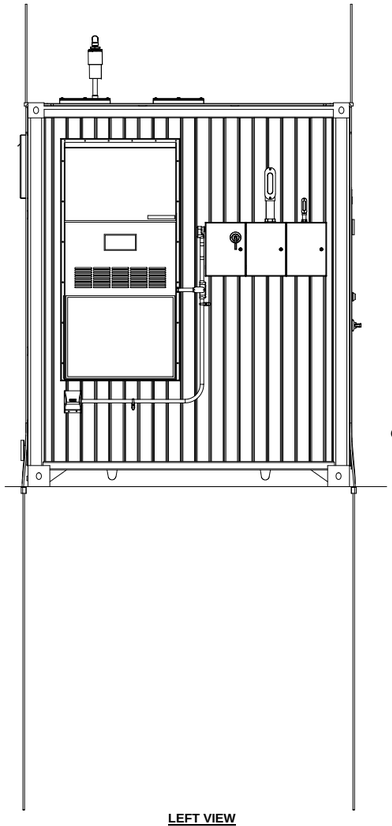
FRAC: ±1/16 0.XX: ±0.01

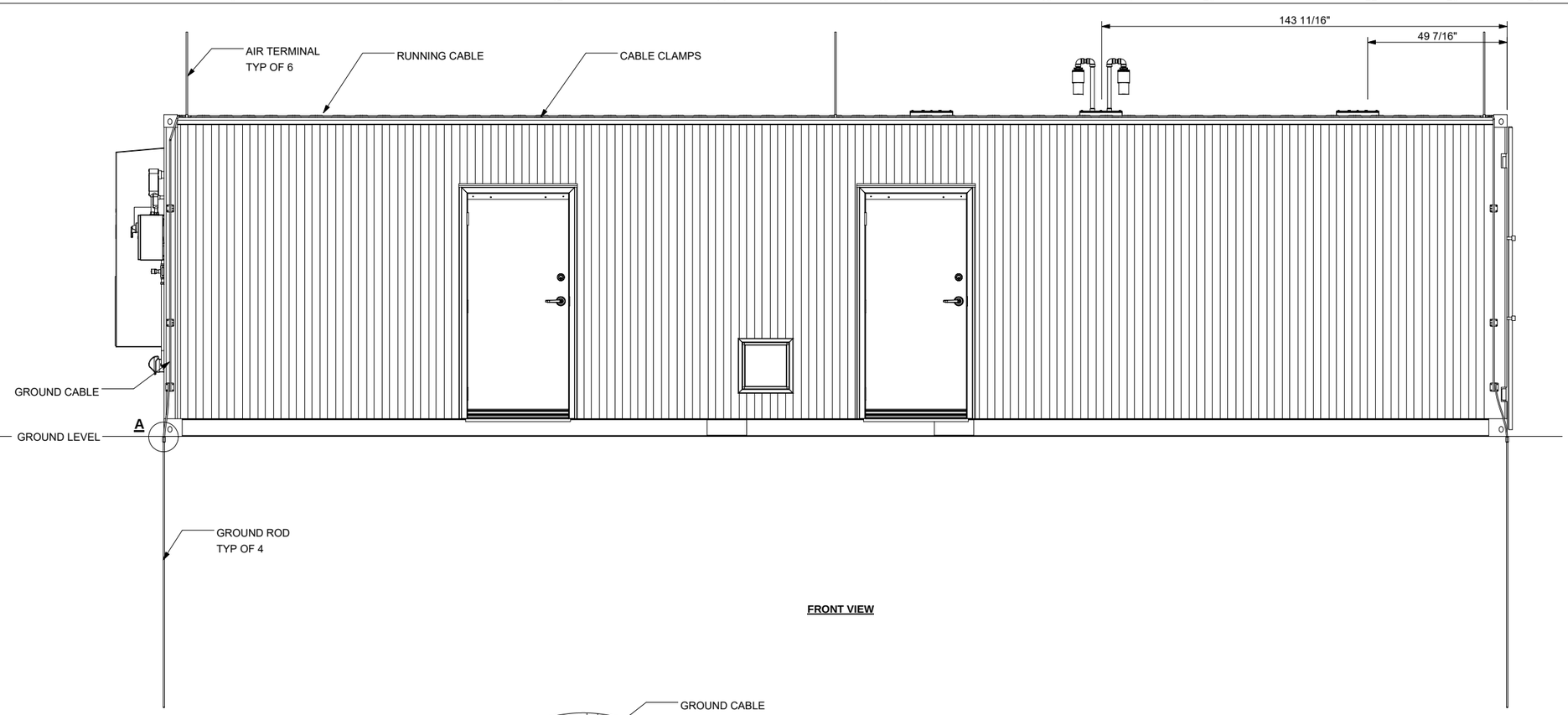
ANGLES: ±1° 0.XXX: ±0.005

TITLE: ANAEROBIC MBR PILOT PLANT
ELECTRICAL CLASSIFICATION SEPARATION - GENERAL ARRANGEMENT

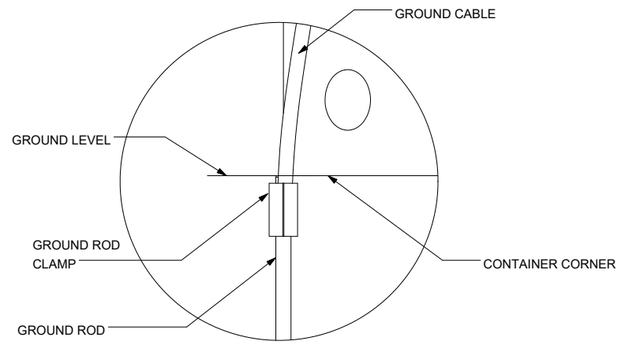
CLIENT: CDM SMITH	PROJECT: 05-03-16
DRAWN BY: AJB	DRAWN DATE: 05-03-16
DRAWING NAME: 1539-10ML-07	P.O.:
SCALE: NONE	REVISION: 0



LEFT VIEW



FRONT VIEW



DETAIL A

NOTES:

1. QUANTITY: 1
2. UNITS: INCHES
3. INSTALL AIR TERMINALS AND GROUND RODS IN THE FIELD

REV	DATE	BY	CHECKED	DESCRIPTION
1	05-03-16	CLR		REROUTE LIGHTNING CABLE, REPOSITION AIR TERMINALS
2				
3				
4				

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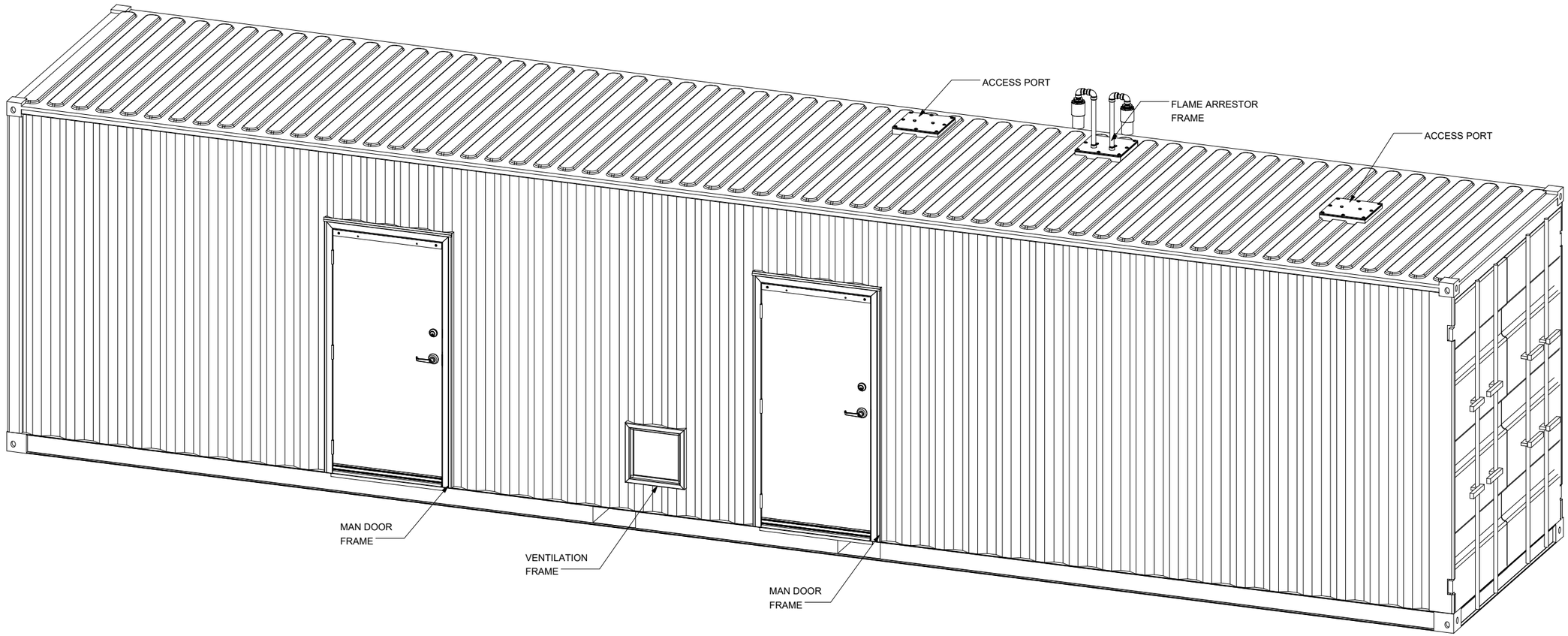
DIMENSIONAL TOLERANCES ARE AS FOLLOWS UNLESS OTHERWISE SPECIFIED

FRAC: ±1/16 0.XX: ±0.01
ANGLES: ±1° 0.XXX: ±0.005

TITLE: ANAEROBIC MBR PILOT PLANT
LIGHTNING PROTECTION - FABRICATION

CLIENT: CDM SMITH	PROJECT: 1539
DRAWN BY: CLR	DRAWN DATE: 04-12-16
DRAWING NAME: 1539-10MF-01	P.O.:
SCALE: NONE	REVISION: 1



NOTES:

1. QUANTITY: 1
2. UNITS: INCHES

REV	DATE	BY	CHECKED	DESCRIPTION
1	03-29-16	AJB		ADDED ACCESS PORTS TO ROOF
2	05-03-16	CLR		UPDATE DRAWING TO SHOW MECHANICAL MODIFICATION, ADD ODOR CONTROL VESSELS TO FLAME ARRESTOR
3				
4				

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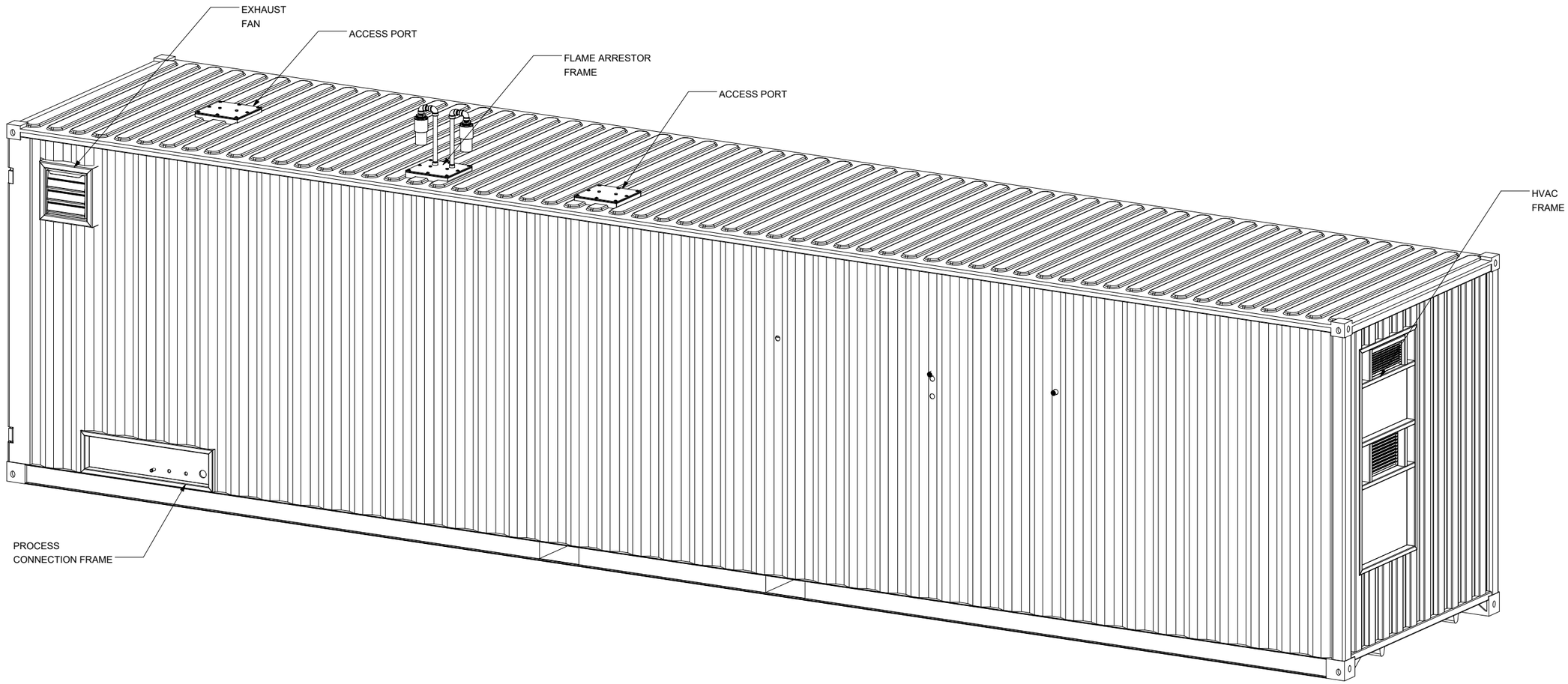
FRAC: ±1/16 0.XX: ±0.01
ANGLES: ±1˚ 0.XXX: ±0.005

TITLE: ANAEROBIC MBR PILOT PLANT
CONTAINER FRONT - GENERAL ARRANGEMENT

CLIENT: CDM SMITH	PROJECT: 1539
DRAWN BY: AJB	DRAWN DATE: 03-23-16
DRAWING NAME: 1539-11ML-01	P.O.:
SCALE: NONE	REVISION: 2



NOTES:

1. QUANTITY: 1
2. UNITS: INCHES

REV	DATE	BY	CHECKED	DESCRIPTION
1	03-29-16	AJB		ADDED ACCESS PORTS TO ROOF
2	05-03-16	CLR		UPDATE DRAWING TO SHOW MECHANICAL MODIFICATIONS, ADD ODOR CONTROL VESSELS TO FLAME ARRESTOR
3				
4				

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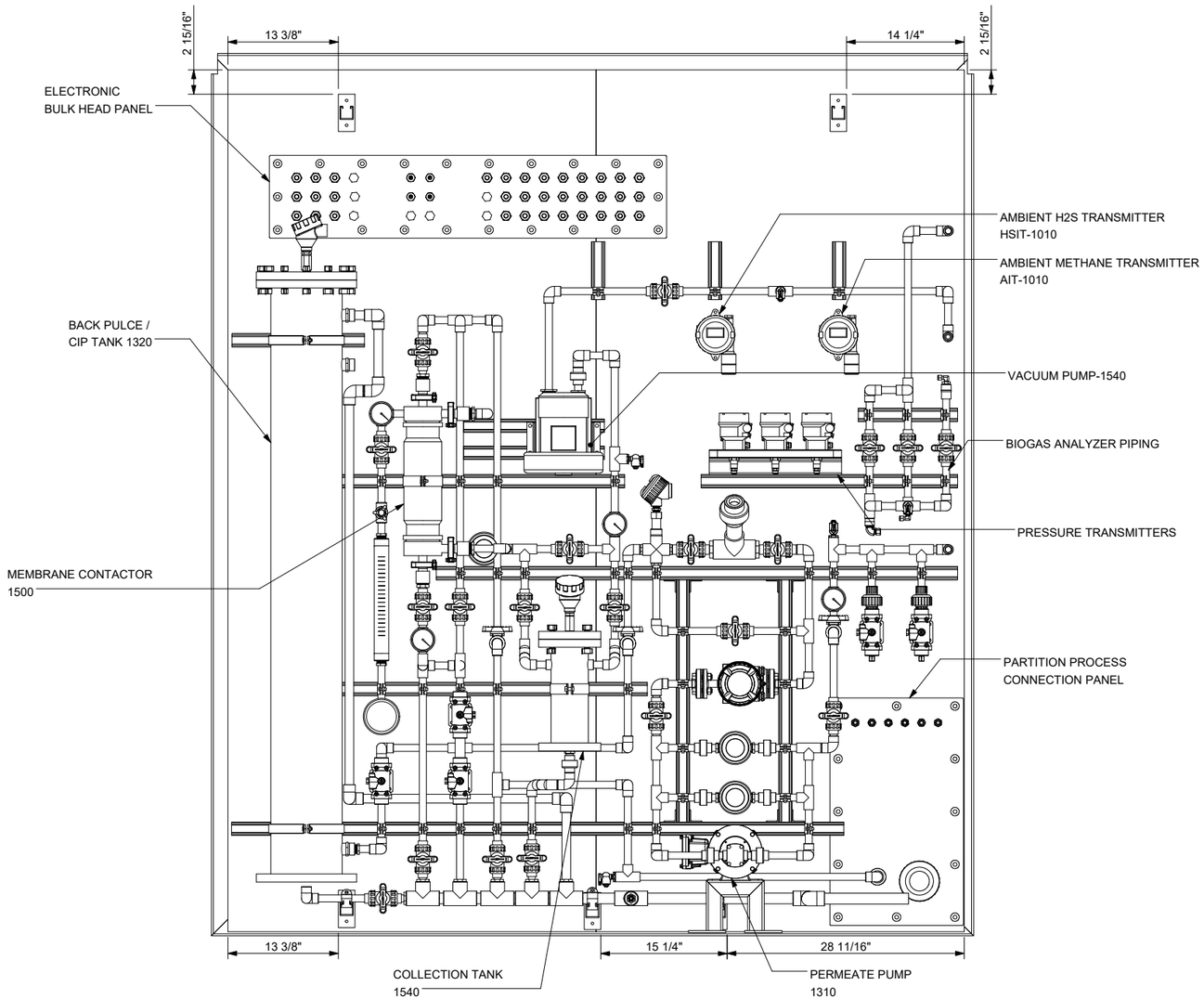
DIMENSIONAL TOLERANCES ARE AS FOLLOWS UNLESS OTHERWISE SPECIFIED

FRAC: ±1/16 0.XX: ±0.01
ANGLES: ±1° 0.XXX: ±0.005

TITLE: ANAEROBIC MBR PILOT PLANT
CONTAINER BACK - GENERAL ARRANGEMENT

CLIENT: CDM SMITH	PROJECT: 1539
DRAWN BY: AJB	DRAWN DATE: 03-23-16
DRAWING NAME: 1539-11ML-02	P.O.:
SCALE: NONE	REVISION: 2



FRONT VIEW

REV	DATE	BY	CHECKED	DESCRIPTION
1	05-16-16	CLR		UPDATE DRAWING TO SHOW MECHANICAL MODIFICATIONS
2	06-06-16	CLR		UPDATE DRAWING TO SHOW MECHANICAL MODIFICATIONS, ADD BACKPULSE / CIP TANK OVER FLOW PIPE
3				
4				

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FRAC: ±1/16 0.XX: ±0.01

ANGLES: ±1° 0.XXX: ±0.005

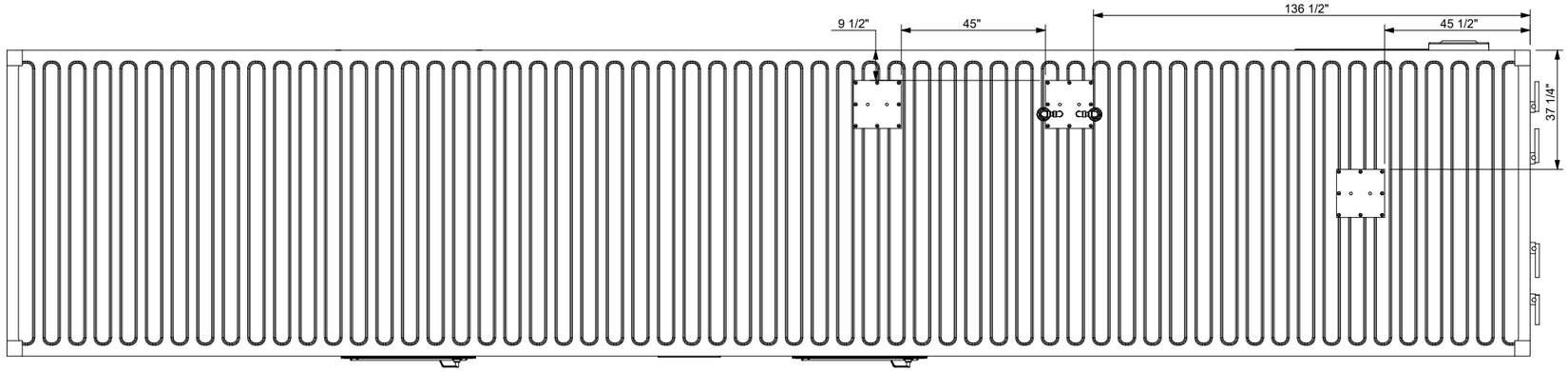
TITLE: ANAEROBIC MBR PILOT PLANT
CENTER PARTITION - GENERAL ARRANGMENT

CLIENT: CDM SMITH | **PROJECT:** 1539

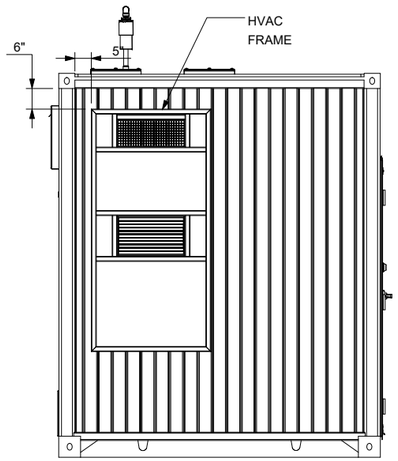
DRAWN BY: CLR | **DRAWN DATE:** 04-08-16

DRAWING NAME: 1539-11ML-04 | **P.O.:**

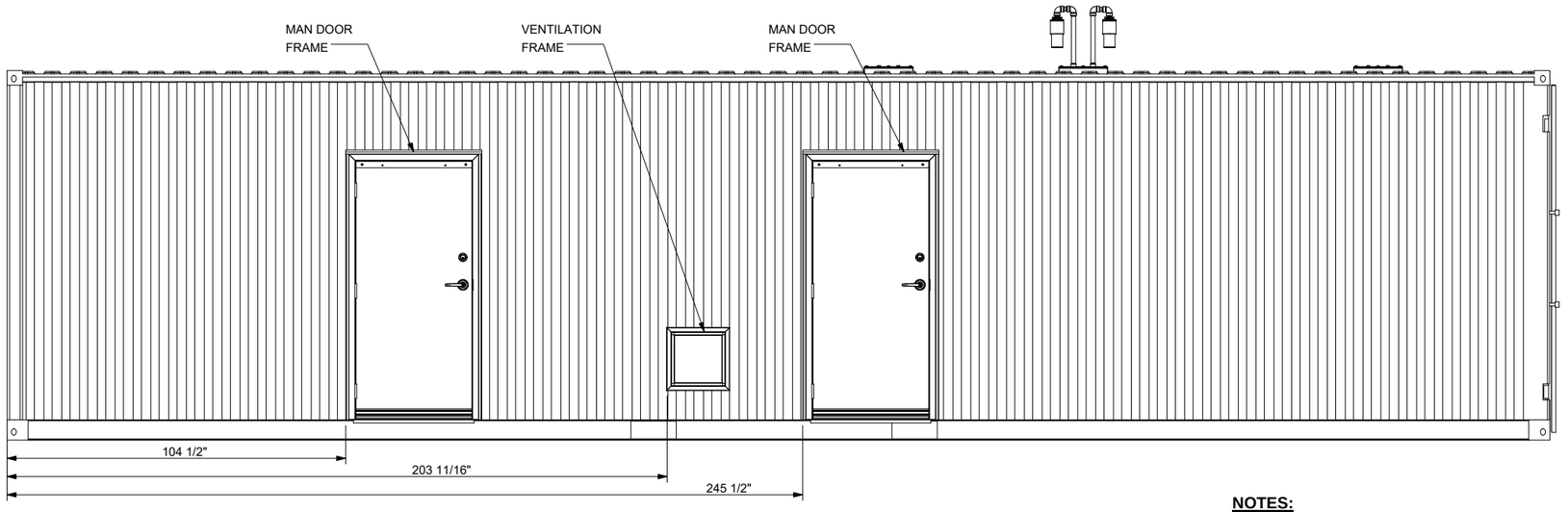
SCALE: NONE | **REVISION:** 2



TOP VIEW



LEFT VIEW



FRONT VIEW

NOTES:

1. QUANTITY: 1
2. UNITS: INCHES

REV	DATE	BY	CHECKED	DESCRIPTION
1	03-29-16	AJB		ADDED ACCESS PORTS TO ROOF
2	05-03-16	CLR		UPDATE DRAWING TO SHOW MECHANICAL MODIFICATIONS, ADD ODOR CONTROL VESSEL TO FLAME ARRESTOR.
3				
4				

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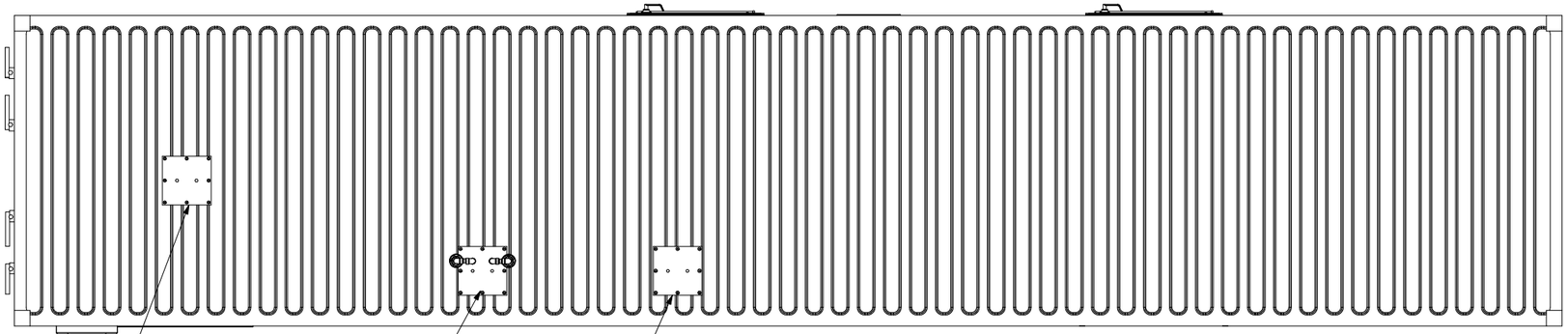
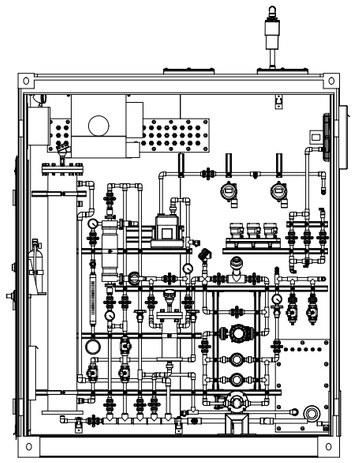
FRAC: ±1/16 0.XX: ±0.01
ANGLES: ±1° 0.XXX: ±0.005

TITLE: ANAEROBIC MBR PILOT PLANT
CONTAINER FRONT - FABRICATION

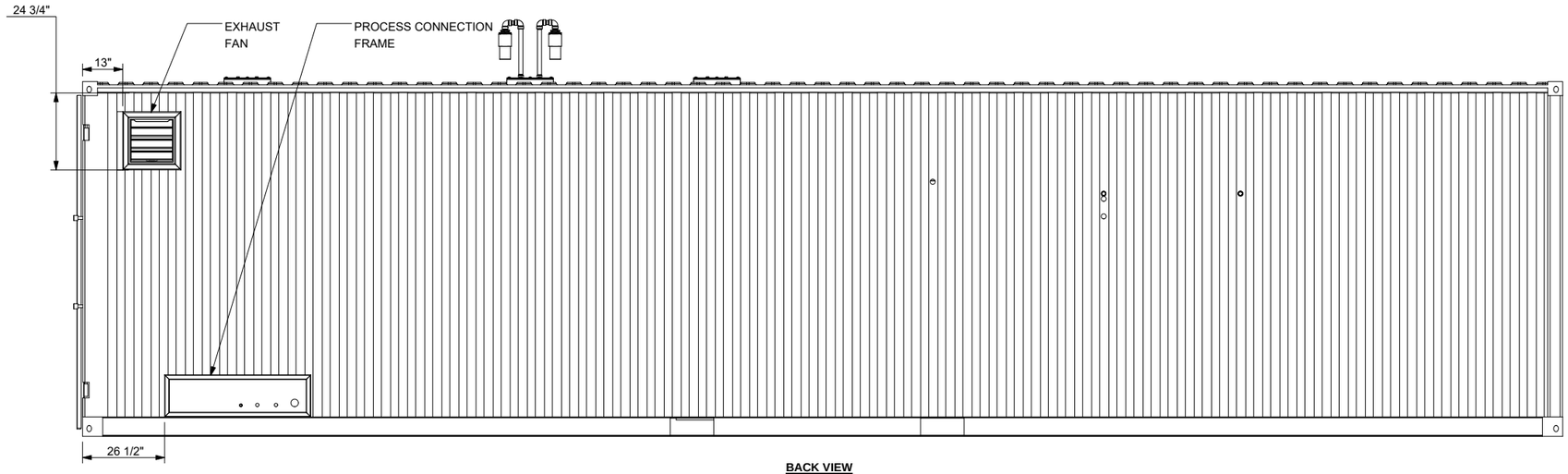
CLIENT: CDM SMITH	PROJECT: 1539
DRAWN BY: AJB	DRAWN DATE: 03-23-16
DRAWING NAME: 1539-11MF-01	P.O.:
SCALE: NONE	REVISION: 2



TOP VIEW



LEFT VIEW



BACK VIEW

NOTES:

1. QUANTITY: 1
2. UNITS: INCHES

REV	DATE	BY	CHECKED	DESCRIPTION
1	03-29-16	AJB		ADDED ACCESS PORTS TO ROOF
2	05-03-16	CLR		UPDATE DRAWING TO SHOW MECHANICAL MODIFICATION, ADD ODOR CONTROL VESSEL TO FLAME ARRESTOR.
3	06-06-16	CLR		UPDATE DRAWING TO SHOW ALL MECHANICAL MODIFICATIONS
4				

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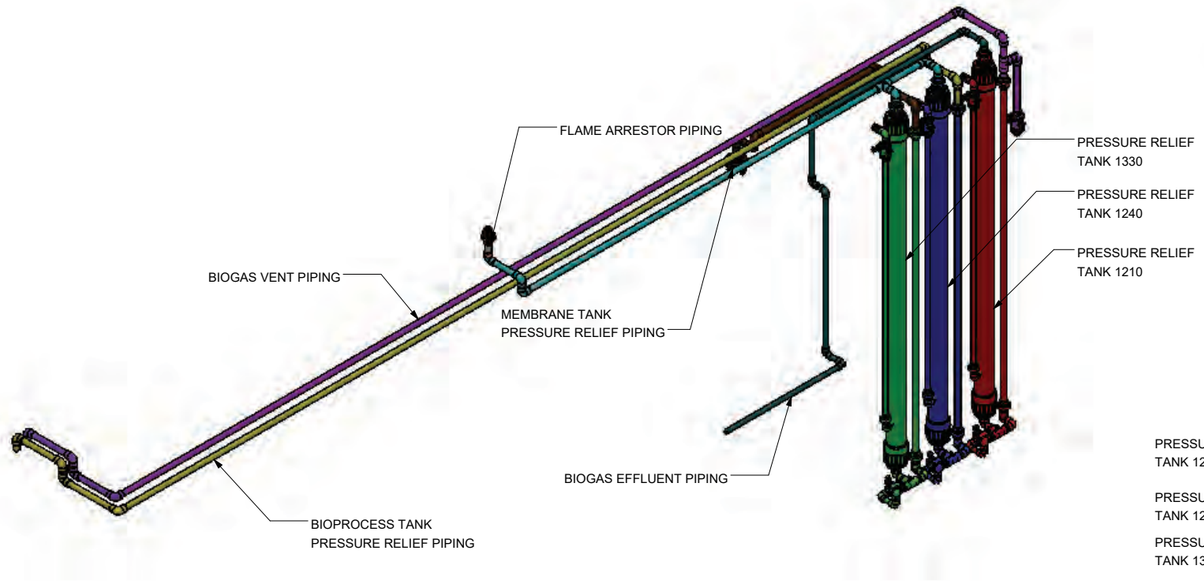
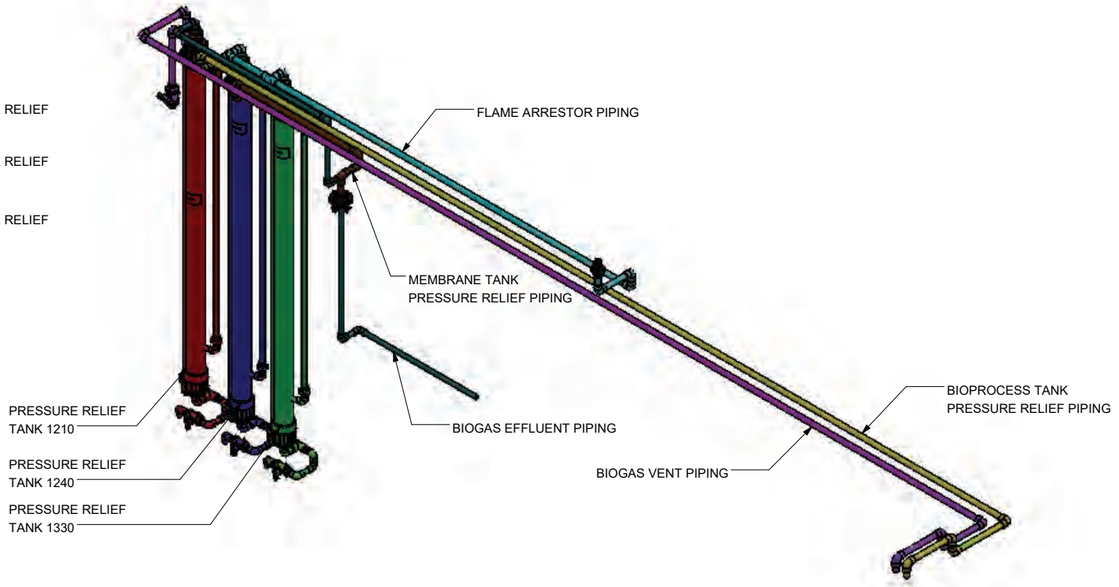
FRAC: ±1/16 0.XX: ±0.01
ANGLES: ±1° 0.XXX: ±0.005

TITLE: ANAEROBIC MBR PILOT PLANT
CONTAINER BACK - FABRICATION

CLIENT: CDM SMITH
PROJECT: 1539
DRAWN BY: AJB
DRAWN DATE: 03-23-16
DRAWING NAME: 1539-11MF-02
P.O.:
SCALE: NONE
REVISION: 3





REV	DATE	BY	CHECKED	DESCRIPTION
1	05-04-16	CLR		UPDATE DRAWING TO SHOW MECHANICAL MODIFICATION, CENTER TANKS BETWEEN UNISTRUT
2	06-06-16	CLR		UPDATE DRAWING TO SHOW MECHANICAL MODIFICATIONS, ADD HOSE BIBS TO PRESSURE VESSELS
3				
4				

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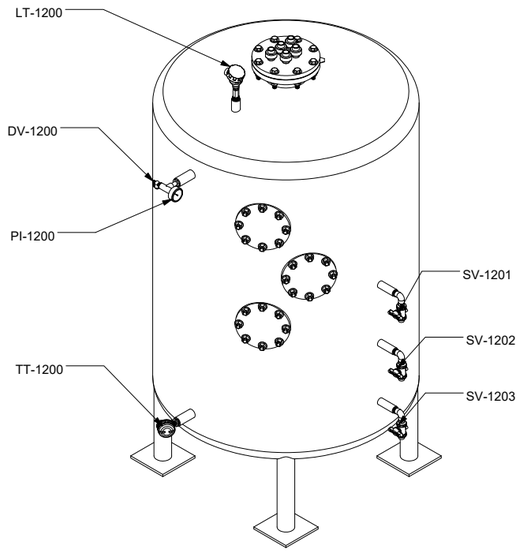
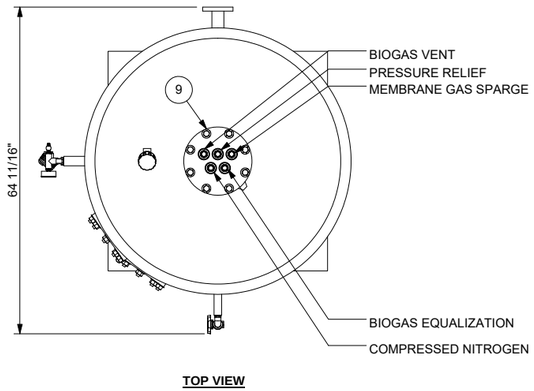
FRAC: ±1/16 0.XX: ±0.01
ANGLES: ±1° 0.XXX: ±0.005

TITLE: ANAEROBIC MBR PILOT PLANT
PRESSURE VESSEL PIPING - GENERAL ARRANGMENT

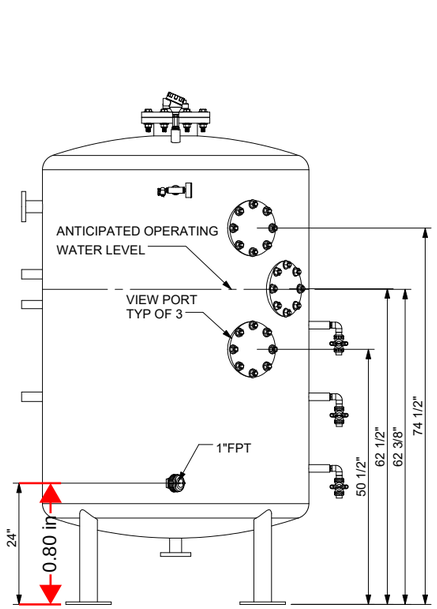
CLIENT: CDM SMITH	PROJECT: 1539
DRAWN BY: CLR	DRAWN DATE: 04-08-16
DRAWING NAME: 1539-12ML-02	P.O.:
SCALE: NONE	REVISION: 2



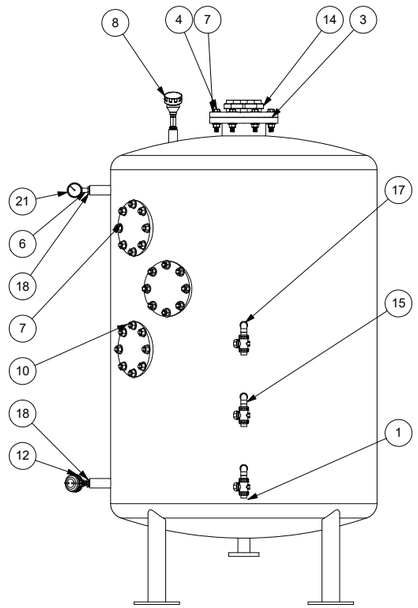


TOP VIEW

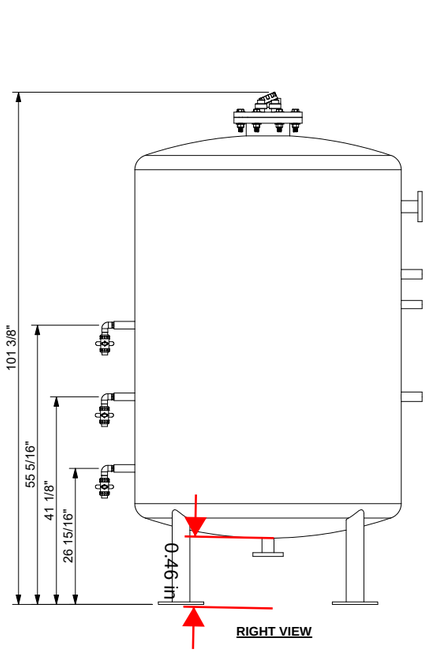
ITEM	TAG NAME	DESCRIPTION	MANUFACTURER	PART NUMBER	QTY.
1		BALL VALVE, TRUE UNION, 1/2"SOC/FPT, PVC/EPDM, T-HANDLE ACTUATOR	ASAHI	1601-005	3
2		GASKET, RIBBED, 6", EPDM	ASAHI	3113-060	3
3		GASKET, RIBBED, 8", EPDM	ASAHI	3113-080	1
4		HEX BOLT, 3/4"-10 X 4", 304SS	GENERIC BOLT	N/A	8
5		HEX NUT, 3/4-10, 304SS	GENERIC NUT	N/A	8
6		PIPE, SCH80, 1/2", GRAY PVC	GENERIC PIPE	PVCPG-SCH80-005	1
7		WASHER, 3/4" X 1-3/4", 304SS	GENERIC WASHER	N/A	40
8		LEVEL TRANSMITTER, CONTINUOUS CAPACITANCE, 3/4"MPT CONN, 0...71", PFA COATED, REMOTE TRANSMITTER, LOOP POWERED, (1)4...20MA, C1D2ABCD	INTEMPCO	LTX20-A-A2-U-P3-S-D1-71	1
9		BIOPROCESS TANK 8" BLIND FLANGE, 1" THICK, PVC	INTUITECH	1539-1200-01	1
10		BIOPROCESS TANK WINDOW, 1" THICK, CLEAR ACRYLIC	INTUITECH	1539-1200-02	3
11		VALVE, BALL, 1/4" TUBE X 1/4" MPT, 90DEG, PP/PPS/EPDM	PARKER	LFPP4VME4	1
12		TEMPERATURE TRANSMITTER, 0...150°F, ±0.08%ACC, 3WIRE PT100, THERMOWELL, C276, 2WIRE, 10...30VDC, 4...20MA, FM NI C1D2 A...D, R1T185L483-H4C08-SL-6HN31, T-440-385U-S(0-150)F	PYROMATION	R1T185L483-H4C1208-SL-6HN31, T-440-385U-S(0-150)F	1
13		TEE, SCH80, 1/2"SOC, PVC	SPEARS	801-005	1
14		UNION, SERIES 2000, SCH80, 3/4"SOC, PVC/FKM	SPEARS	8057-007	5
15		ELBOW, SCH80, 1/2" SOC, PVC	SPEARS	806-005	3
16		REDUCER BUSHING, SCH80, 1/2"SPG X 1/4"FPT, PVC	SPEARS	838-072	2
17		REDUCER BUSHING, SCH80, 3/4"MPT X 1/2"FPT, PVC	SPEARS	839-101	3
18		REDUCER BUSHING, SCH80, 1"MPT X 1/2"FPT, PVC	SPEARS	839-130	2
19		REDUCER BUSHING, SCH80, 1"MPT X 3/4"FPT, PVC	SPEARS	839-131	1
20		HEX NUT, 3/4-10	UINTAH	NA	24
21		PRESSURE GAUGE, CENTER BACK MOUNT, LIQUID FILLABLE, 0...15PSI/0...100KPA, ±2.5%ACC, 2.5"DIA, 1/4"MPT, 316LSS, TYPE 232.54	WIKA	9745130-0013	1



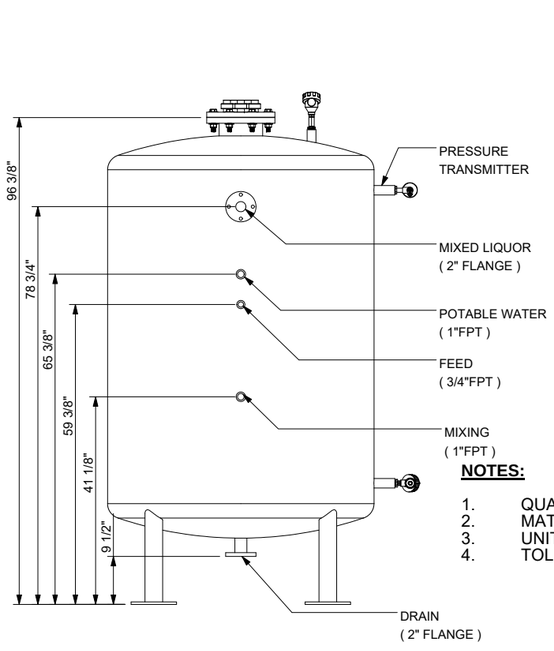
LEFT VIEW



FRONT VIEW



RIGHT VIEW



BACK VIEW

NOTES:

1. QUANTITY: 1
2. MATERIAL: FRP COLOR: WHITE
3. UNITS: INCHES
4. TOLERANCES: ±1/4"

REV	DATE	BY	CHECKED	DESCRIPTION
1				
2				
3				
4				

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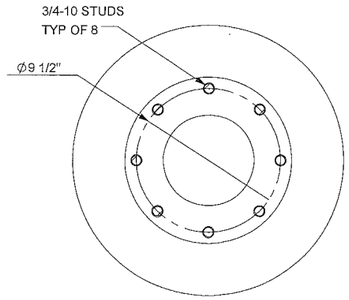
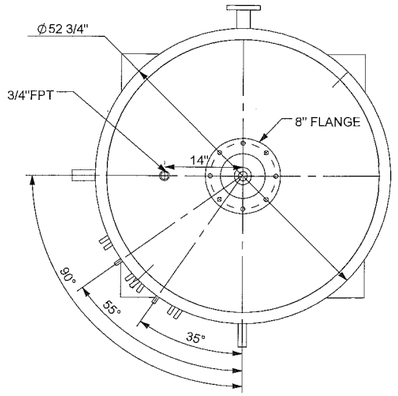
FRAC: ±1/16 0.XX: ±0.01
ANGLES: ±1° 0.XXX: ±0.005

TITLE: ANAEROBIC MBR PILOT PLANT
BIOPROCESS TANK 1200 - FABRICATION

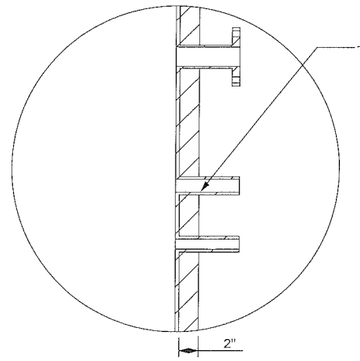
CLIENT: CDM SMITH	PROJECT: 1539
DRAWN BY: CLR	DRAWN DATE: 04-07-16
DRAWING NAME: 1539-12MF-01	P.O.:
SCALE: NONE	REVISION: 0



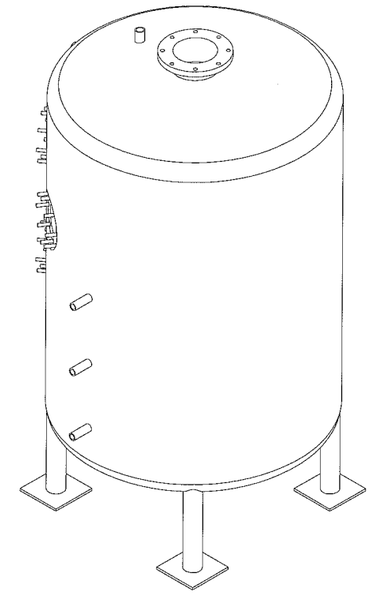
DETAIL A

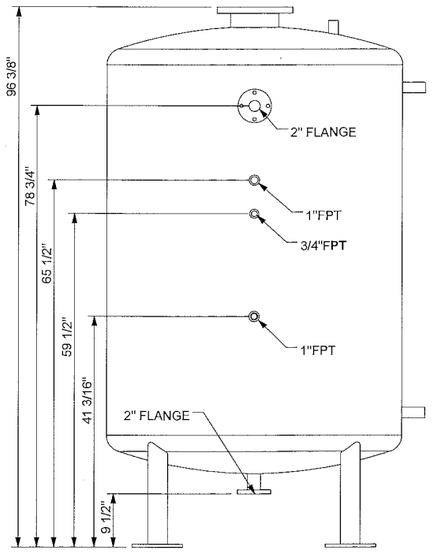


TOP VIEW

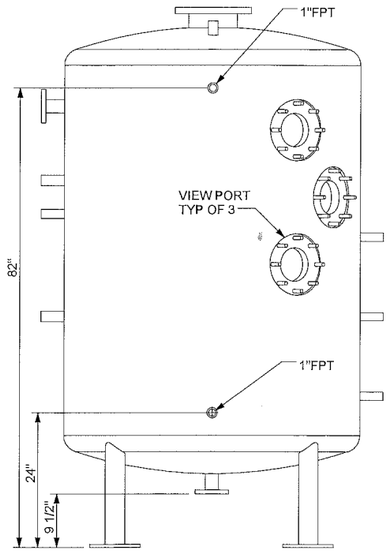


DETAIL A

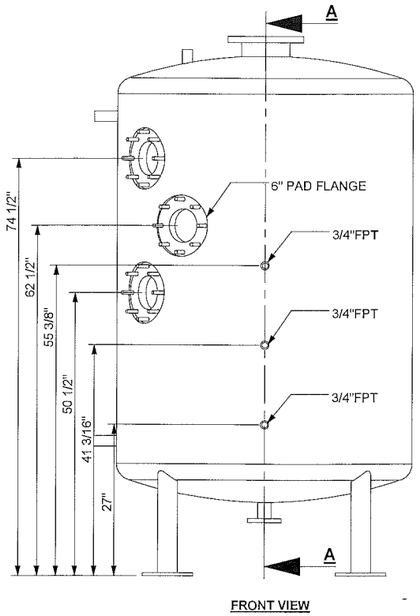




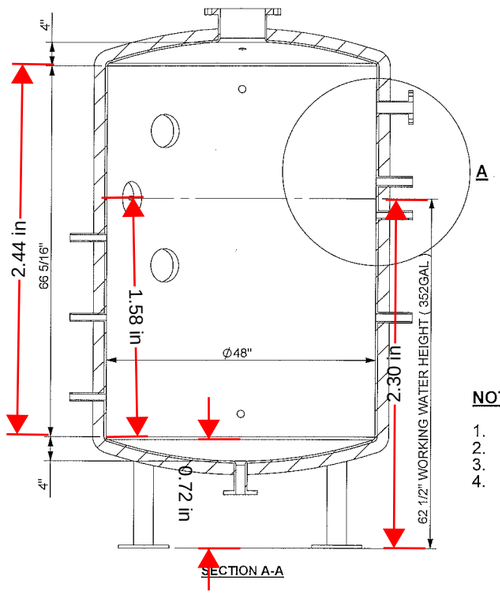
BACK VIEW



LEFT VIEW



FRONT VIEW



SECTION A-A

NOTES:

1. QUANTITY: 1
2. MATERIAL: FRP COLOR: WHITE
3. UNITS: INCHES
4. TOLERANCES: ±1/4"

REV	DATE	BY	CHECKED	DESCRIPTION
1	03-24-16	AJB		ADDED NOTE FOR 2" FLANGE ON BOTTOM OF TANK. ADDED DETAIL WITH PAD FLANGE BOLT CIRCLE.
2	04-13-16	AJB		ADDED 1"FPT NOZZLE, MODIFIED HEIGHTS OF WINDOWS AND OTHER NOZZLES. ADDED DISH HEIGHT DIMENSIONS.
3				
4				

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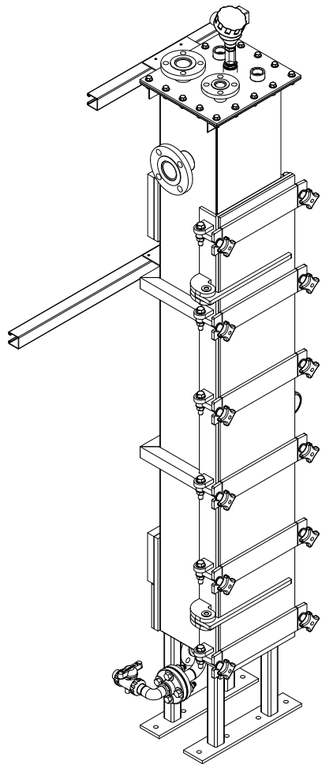
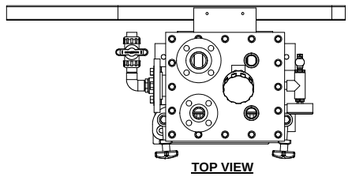
FRAC: ±1/16 0.XX: ±0.01

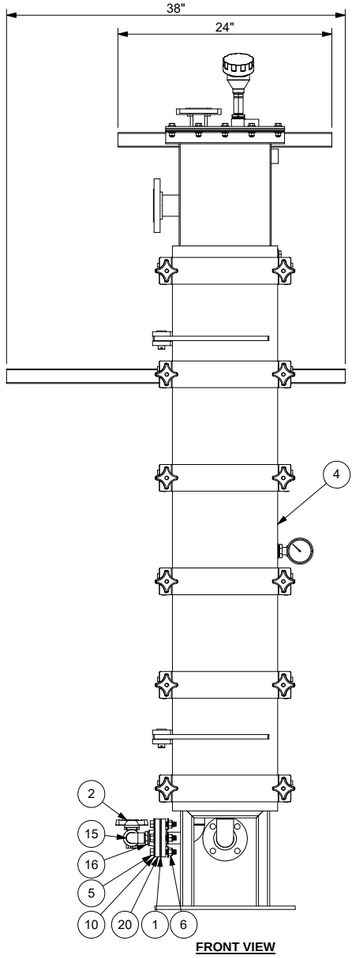
ANGLES: ±1° 0.XXX: ±0.005

TITLE: ANAEROBIC MBR PILOT PLANT BIOPROCESS TANK 1200 - FABRICATION	
CLIENT: DDM SMITH	PROJECT: 1539
DRAWN BY: AJB	DRAWN DATE: 03-21-16
DRAWING NAME: 1539-12MF-06	P.O.:
SCALE: NONE	REVISION: 2

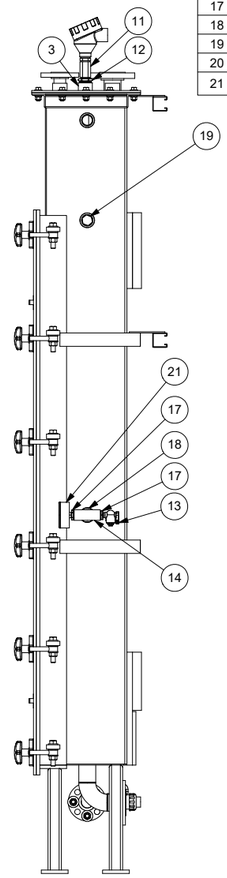




TOP VIEW



FRONT VIEW



RIGHT VIEW

ITEM	TAG NAME	DESCRIPTION	MANUFACTURER	PART NUMBER	QTY.	LENGTH
1		GASKET, 1" 150# FLANGE, EPDM			1	
2	SV-1300	BALL VALVE, TRUE UNION, 1/2"SOC/FPT, PVC/EPDM, T-HANDLE ACTUATOR	ASAHI	1601-005	1	
3		COUPLING, 1"FPT, 316SS	FERGUSON	N/A	1	
4	MEMBRANE TANK-1300	STAINLESS STEEL MEMBRANE TANK, 16"WIDTH, 14.16"LENGTH, 89.81"HEIGHT, 316SS	GE W&PT	DWG. NO. ZW500DAWP-A-210 REV. R0P0	1	
5		HEX BOLT, 1/2"-13 X 2-1/2", 304SS	GENERIC BOLT	N/A	4	
6		HEX NUT, 1/2-13, 304SS	GENERIC NUT	N/A	4	
7		PIPE, SCH80, 1/2", PVC	GENERIC PIPE	PVCPG-SCH80-005	1	1 15/16"
8		PIPE, SCH80, 1/2", PVC	GENERIC PIPE	PVCPG-SCH80-005	1	1 7/16"
9		PIPE, SCH80, 1/2", PVC	GENERIC PIPE	PVCPG-SCH80-005	1	2 1/4"
10		WASHER, 1/2", 304SS	GENERIC WASHER	N/A	8	
11	LT-1300	LEVEL TRANSMITTER, CONTINUOUS CAPACITANCE, 3/4"MPT CONN, 0...71", PFA COATED, REMOTE TRANSMITTER, LOOP POWERED, (1)4...20MA, C1D2ABCD	INTEMPCO	LTX20-A-A2-U-P3-S-D1-71	1	
12		REDUCER BUSHING, 1"MPT X 3/4"FPT, 316SS	MCMASTER CARR	4452K176	1	
13	DV-1300	VALVE, BALL, 1/4" TUBE X 1/4" MPT, 90DEG, PP/PPS/EPDM	PARKER	LFPP4VME4	1	
14		TEE, SCH80, 1/2"SOC, PVC	SPEARS	801-005	1	
15		ELBOW, SCH80, 1/2"SOC X 1/2"FPT, PVC	SPEARS	807-005	1	
16		REDUCER BUSHING, SCH80, 1"SPIG X 1/2"SOC, PVC	SPEARS	837-130	1	
17		REDUCER BUSHING, SCH80, 1/2"SPG X 1/4"FPT, PVC	SPEARS	838-072	2	
18		REDUCER BUSHING, SCH80, 1"MPT X 1/2"FPT, PVC	SPEARS	839-130	1	
19		PLUG, SCH80, 3/4MPT, PVC	SPEARS	850-007	1	
20		FLANGE, VANSTONE, SCH80, 1"SOC, PVC	SPEARS	854-010	1	
21	PI-1300	PRESSURE GAUGE, CENTER BACK MOUNT, LIQUID FILLABLE, 0...15PSI/0...100KPA, ±2.5%ACC, 2.5"DIA, 1/4"MPT, 316LSS, TYPE 232.54	WIKA	9745130-0013	1	

NOTES:

1. QUANTITY: 1
2. UNITS: INCHES

REV	DATE	BY	CHECKED	DESCRIPTION
1	05-25-16	CLR		ADD SV-1300
2	06-06-16	CLR		MOVED LOCATION OF SV-1300, REPOSITION LT-1300 TO CLEAR INTERNAL MEMBRANE
3				
4				

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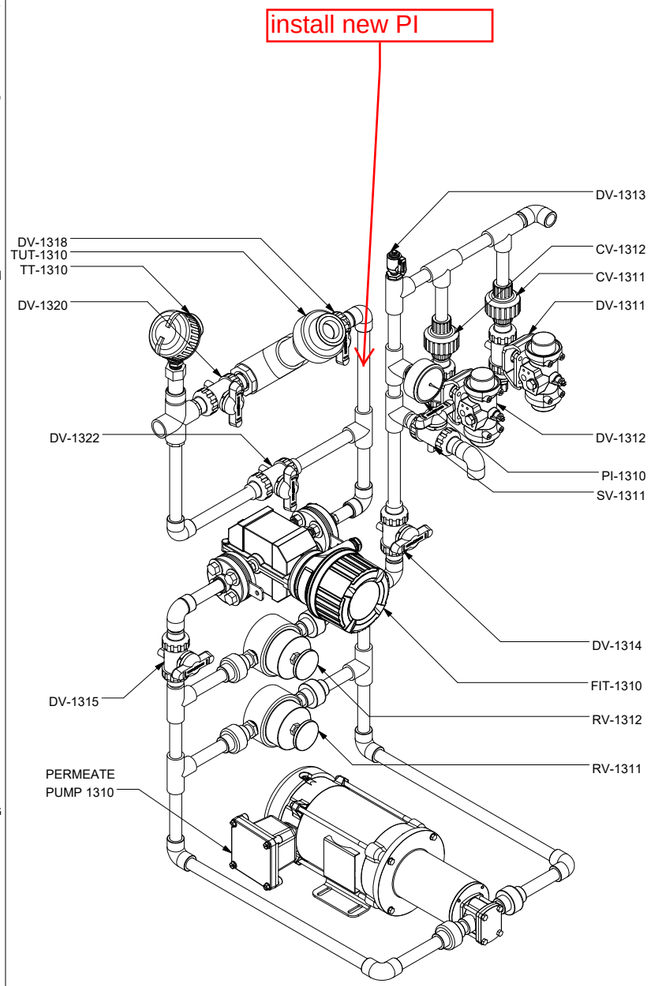
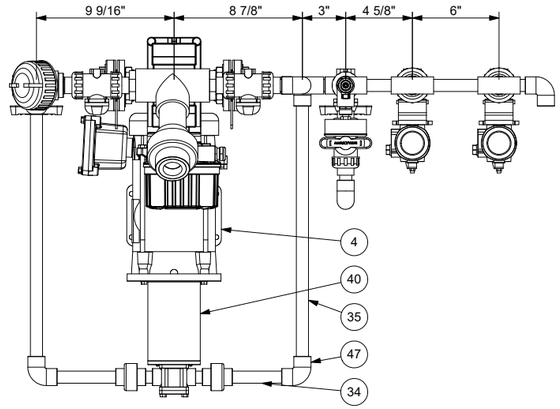
FRAC: ±1/16 0.XX: ±0.01
ANGLES: ±1° 0.XXX: ±0.005

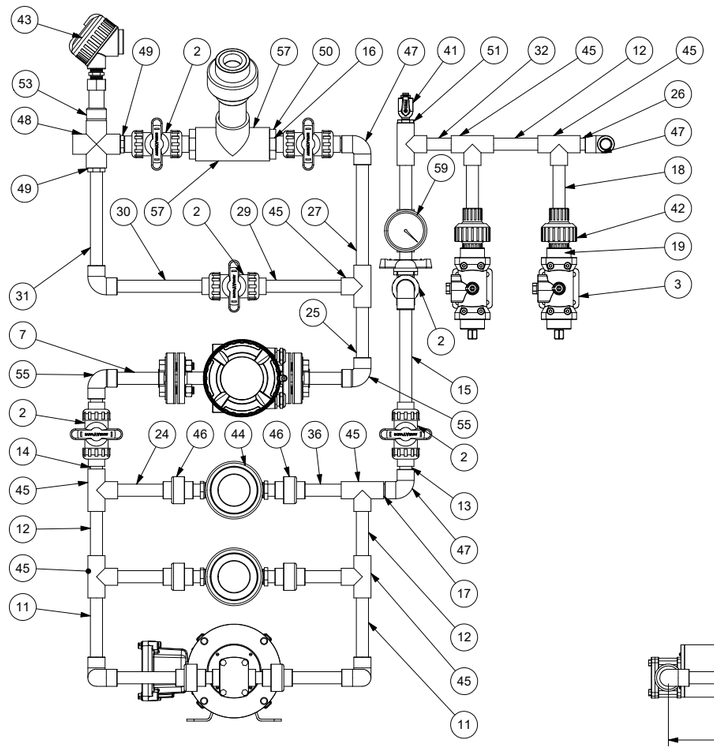
TITLE: ANAEROBIC MBR PILOT PLANT
MEMBRANE TANK 1300 - FABRICATION

CLIENT: CDM SMITH	PROJECT: 1539
DRAWN BY: CLR	DRAWN DATE: 04-07-16
DRAWING NAME: 1539-13MF-01	P.O.:
SCALE: NONE	REVISION: 2

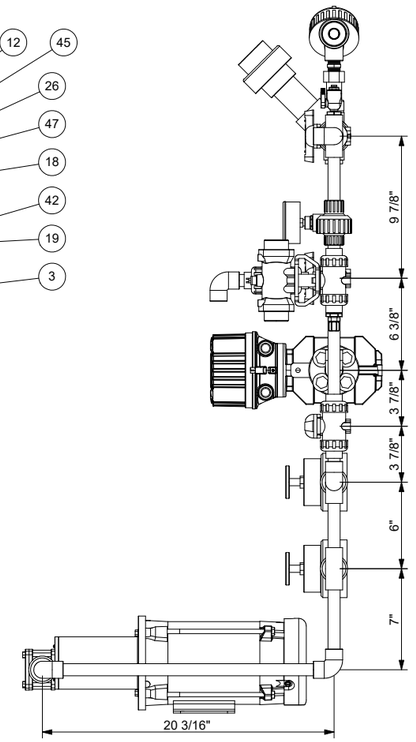




TOP VIEW



FRONT VIEW



RIGHT VIEW

NOTES:

1. QUANTITY: 1
2. UNITS: INCHES
3. TOLERANCES: ±1/8"
4. USE ℄ DIMENSIONS TO VERIFY CUT LENGTHS

REV	DATE	BY	CHECKED	DESCRIPTION
1	05-10-16	CLR		CHANGE CROSS TO 3/4"
2	05-27-16	CLR		ADD 3/4" THERMOWELL TO TEMPERTURE TRANSMITTER
3				
4				

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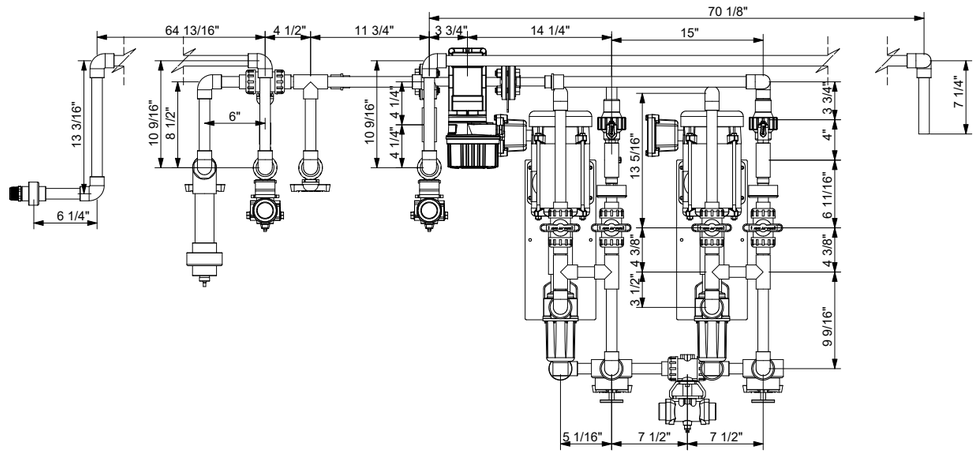
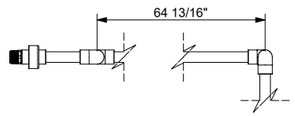
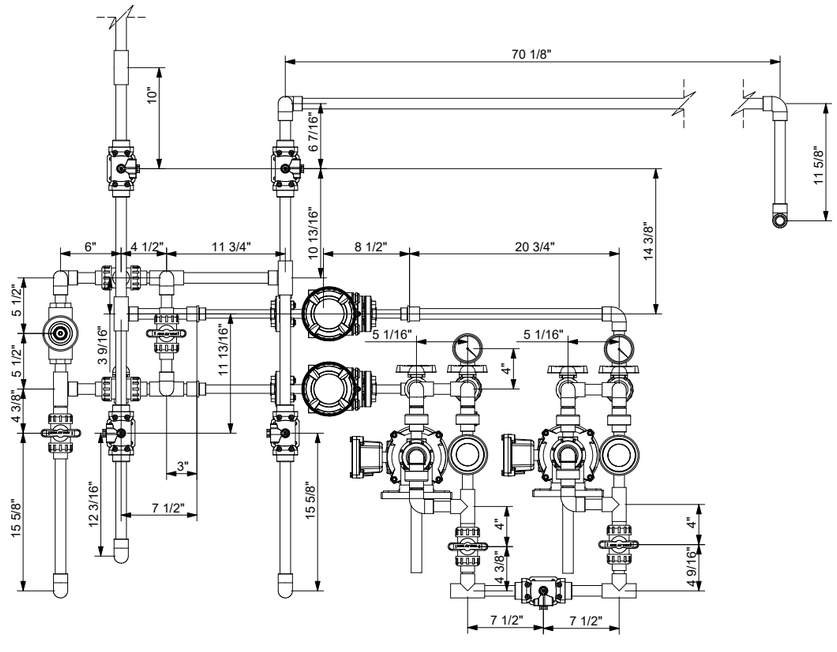
FRAC: ±1/16 0.XX: ±0.01
ANGLES: ±1° 0.XXX: ±0.005

TITLE: ANAEROBIC MBR PILOT PLANT PERMEATE PUMP PIPING 1 OF 2 - FABRICATION	
CLIENT: CDM SMITH	PROJECT: 1539
DRAWN BY: CLR	DRAWN DATE: 04-07-16
DRAWING NAME: 1539-13MF-05	P.O.:
SCALE: NONE	REVISION: 2

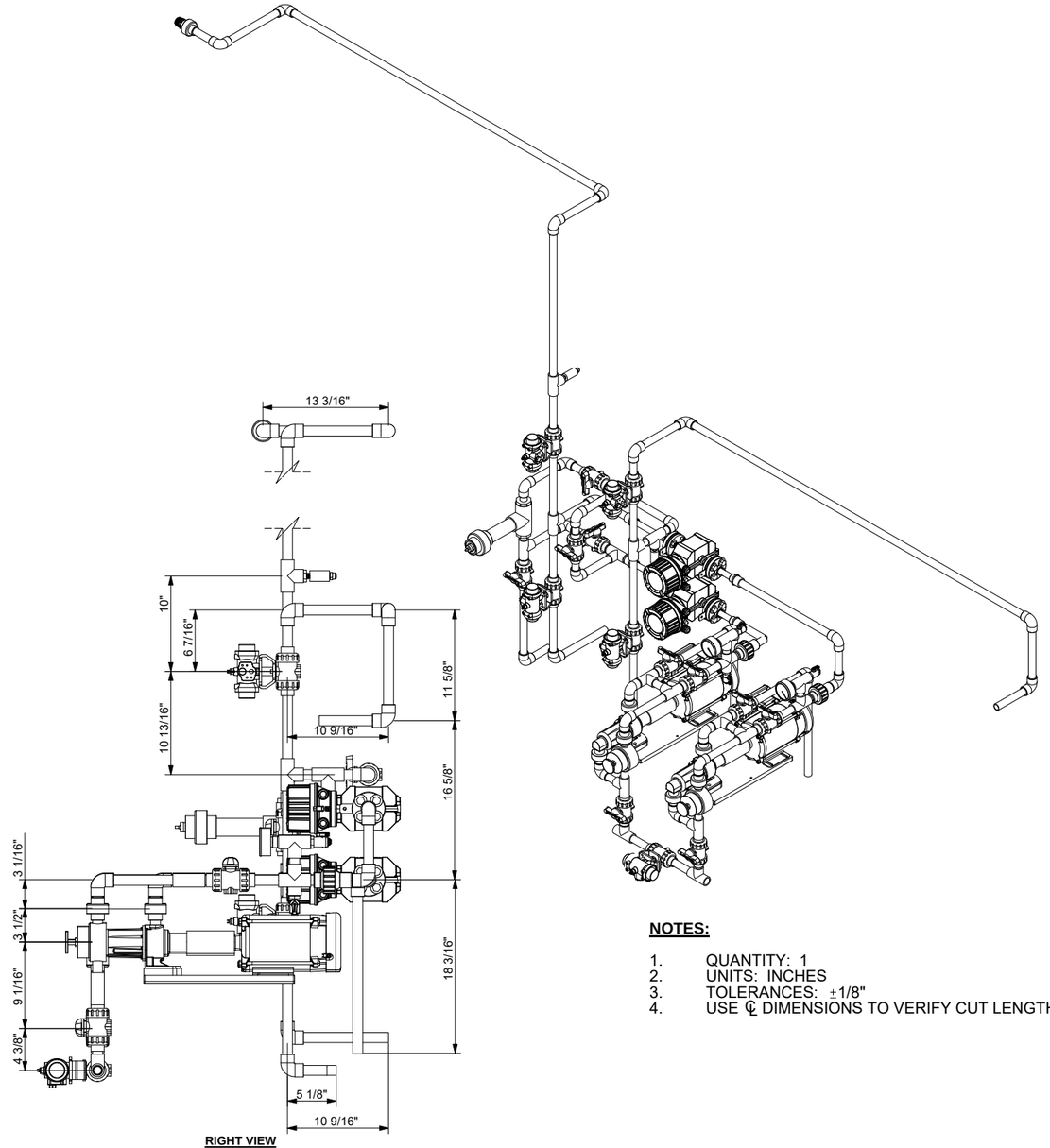


TOP VIEW





FRONT VIEW



RIGHT VIEW

NOTES:

1. QUANTITY: 1
2. UNITS: INCHES
3. TOLERANCES: ±1/8"
4. USE ℄ DIMENSIONS TO VERIFY CUT LENGTHS

REV	DATE	BY	CHECKED	DESCRIPTION
5	06-06-16	CLR		MOVE LOCATION OF SV-1544, DV-1441 PNEUMATIC ACTUATED
6				
7				
8				

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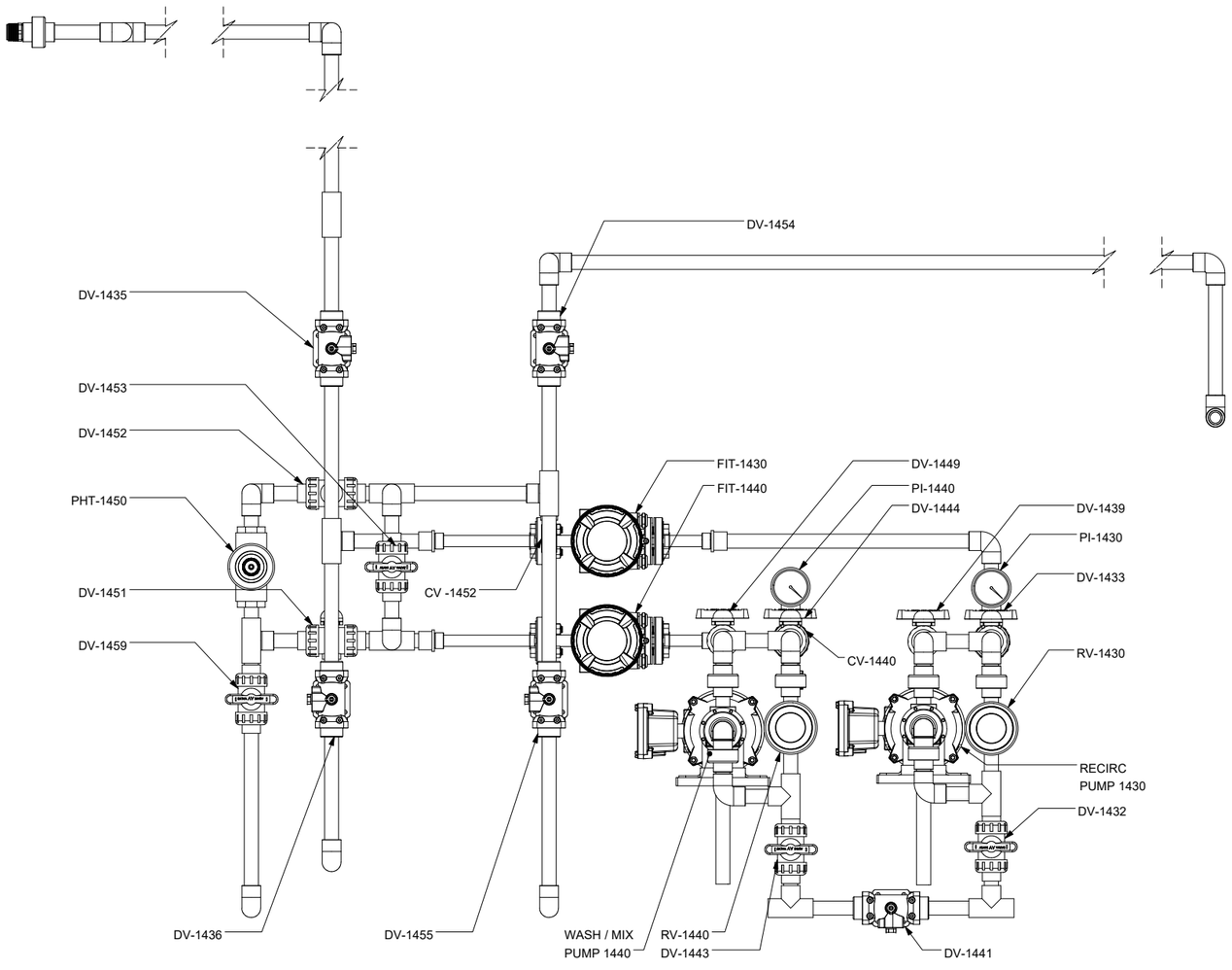
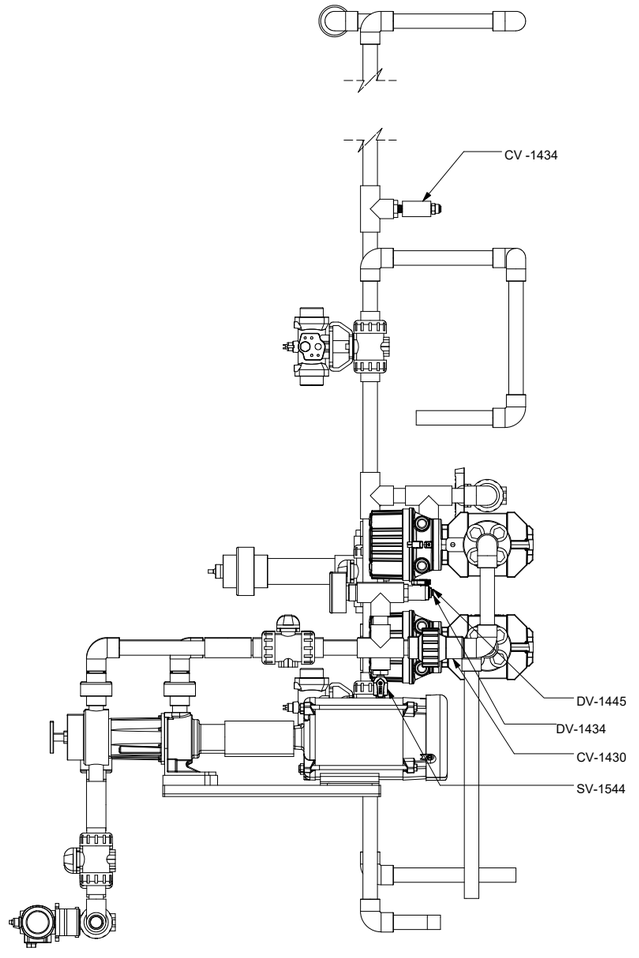
FRAC: ±1/16 0.XX: ±0.01
ANGLES: ±1° 0.XXX: ±0.005

TITLE: ANAEROBIC MBR PILOT PLANT
PUMP RACK PIPING 1 0F 4 - FABRICATION

CLIENT: CDM SMITH	PROJECT: 1539
DRAWN BY: CLR	DRAWN DATE: 04-07-16
DRAWING NAME: 1539-14MF-03	P.O.:
SCALE: NONE	REVISION: 5



FRONT VIEW



RIGHT VIEW

NOTES:

1. QUANTITY: 1
2. UNITS: INCHES
3. TOLERANCES: ±1/8"
4. USE ℄ DIMENSIONS TO VERIFY CUT LENGTHS

REV	DATE	BY	CHECKED	DESCRIPTION
1	05-06-16	CLR		UPDATE DRAWING TO SHOW MECHANICAL MODIFICATION
2	05-25-16	CLR		ADD CV-1434 AND CV-1452
3	06-06-16	CLR		MOVE SV-1544 LOCATION, DV-1441 PNEUMATIC ACTUATED
4				

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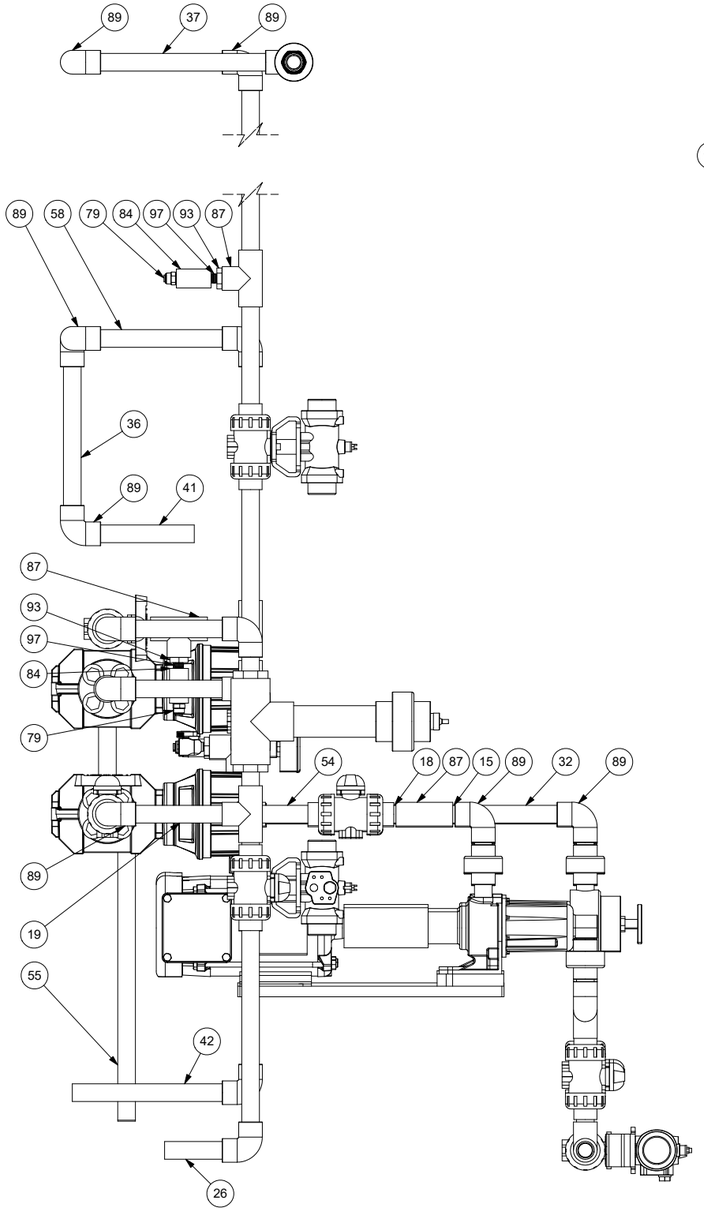
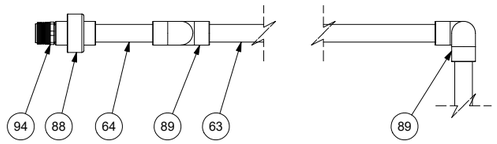
FRAC: ±1/16 0.XX: ±0.01
ANGLES: ±1° 0.XXX: ±0.005

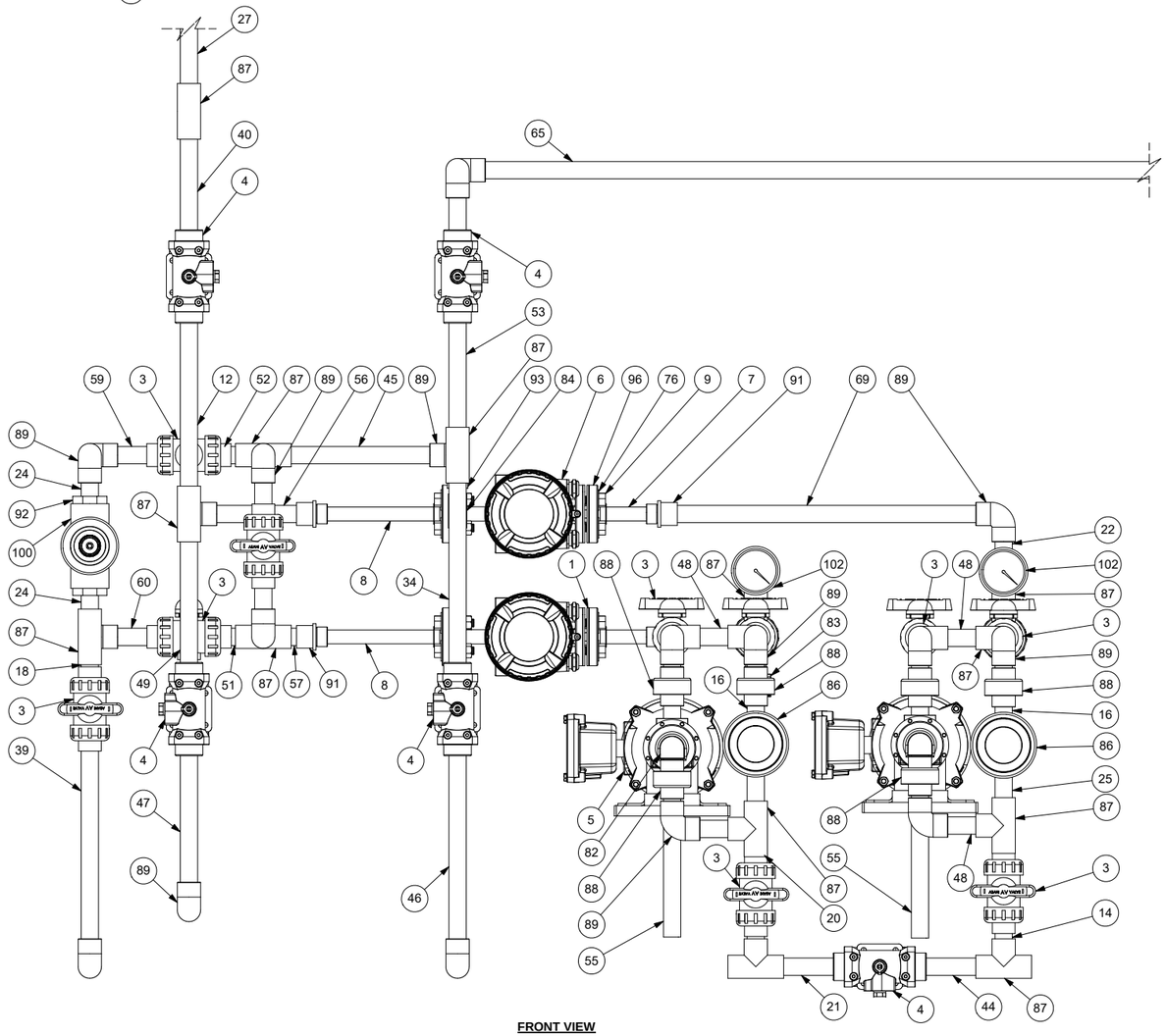
TITLE: ANAEROBIC MBR PILOT PLANT
PUMP RACK PIPING 2 0F 4 - FABRICATION

CLIENT: CDM SMITH	PROJECT: 1539
DRAWN BY: CLR	DRAWN DATE: 04-07-16
DRAWING NAME: 1539-14MF-04	P.O.:
SCALE: NONE	REVISION: 3



LEFT VIEW





FRONT VIEW

REV	DATE	BY	CHECKED	DESCRIPTION
1	05-06-16	CLR		UPDATE DRAWING TO SHOW MECHANICAL MODIFICATIONS
2	05-20-16	CLR		UPDATE MODEL TO REFLECT ACTUAL COMPONENTS
3	05-26-16	CLR		ADD CHECK VALVES FOR CHEMICAL INJECTION
4	06-06-16	CLR		MOVED LOCATION OF SV-1544, DV-1442 PNEUMATIC ACTUATED

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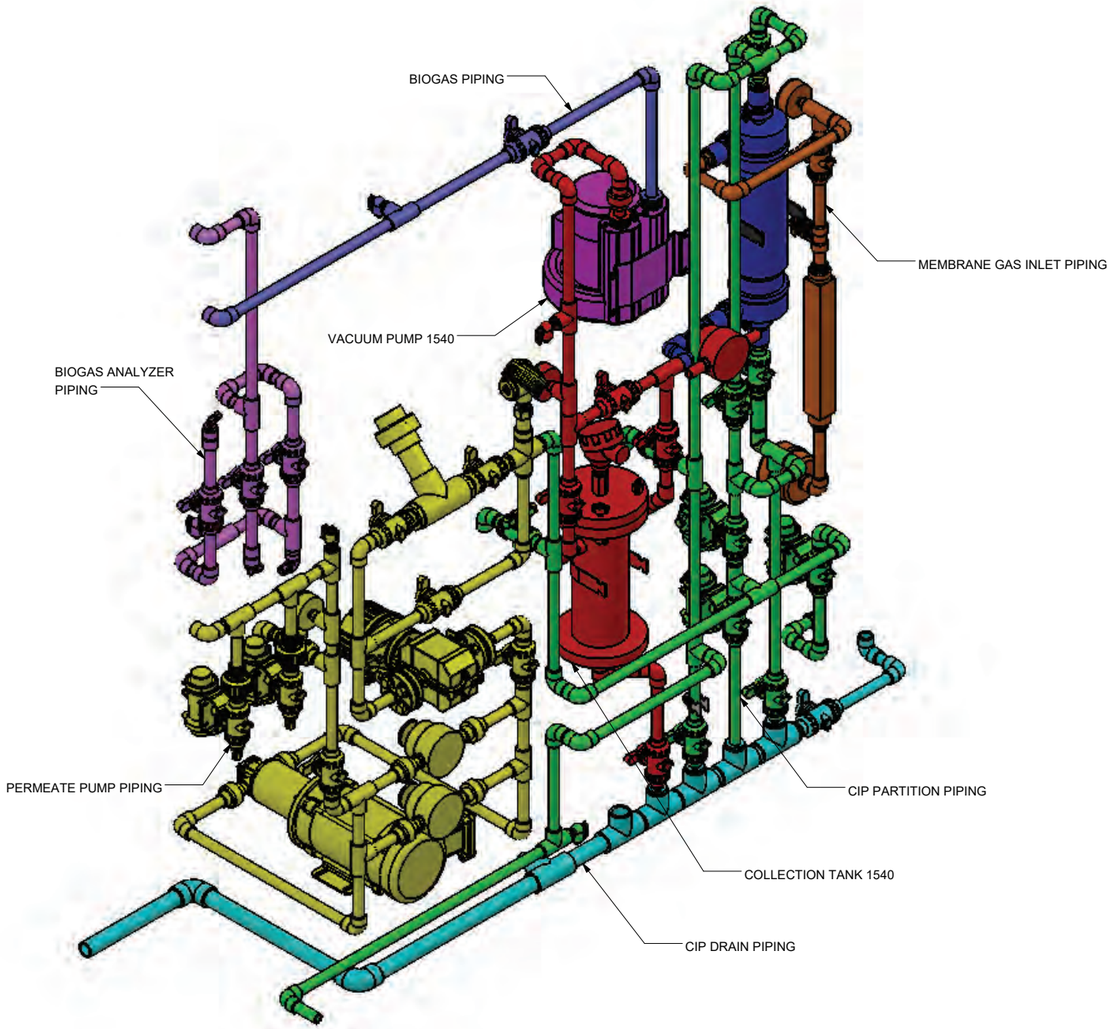
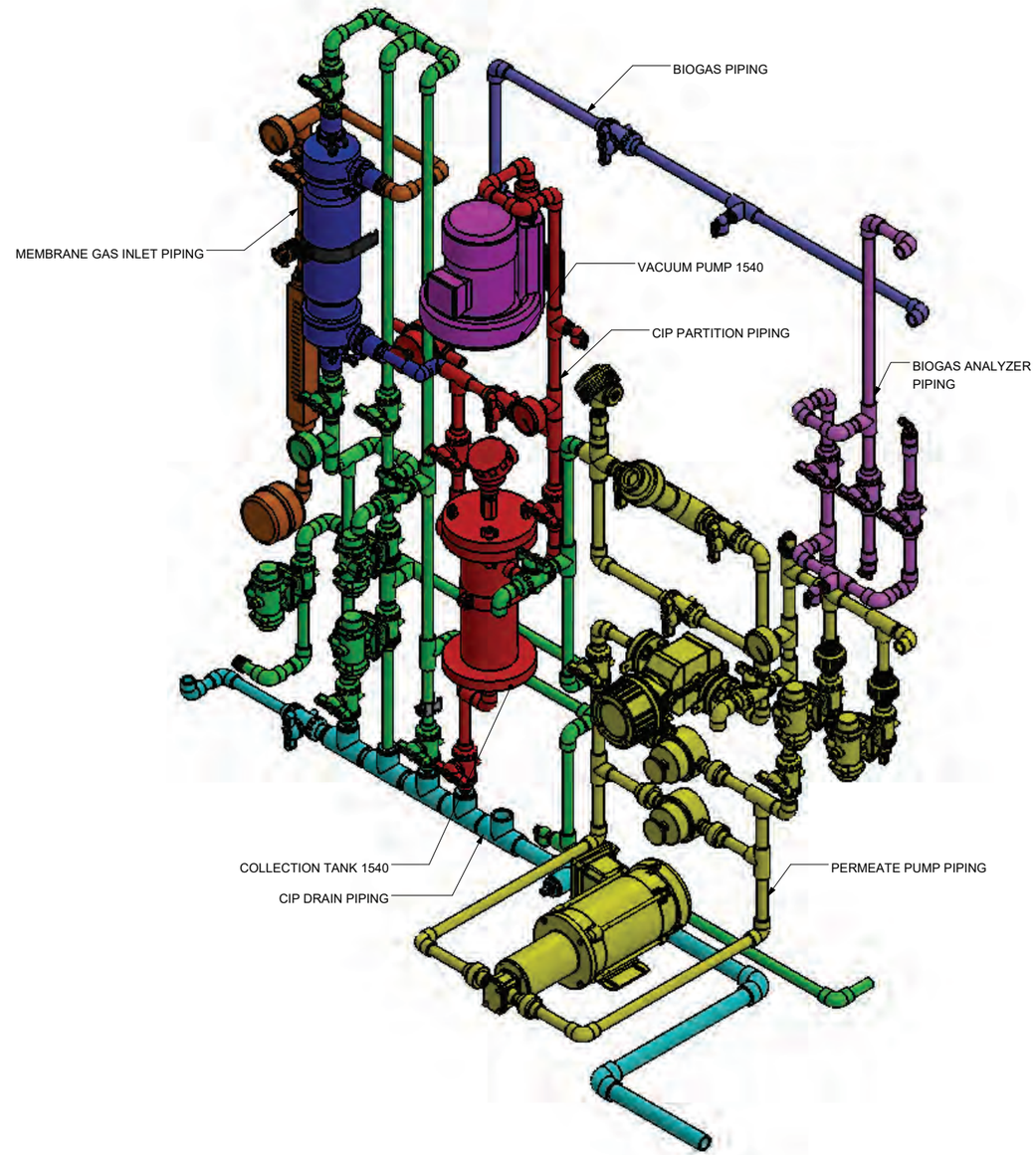
FRAC: ±1/16 0.XX: ±0.01

ANGLES: ±1° 0.XXX: ±0.005

TITLE: ANAEROBIC MBR PILOT PLANT
PUMP RACK PIPING 3 0F 4 - FABRICATION

CLIENT: CDM SMITH	PROJECT: 1539
DRAWN BY: CLR	DRAWN DATE: 04-07-16
DRAWING NAME: 1539-14MF-05	P.O.:
SCALE: NONE	REVISION: 4





REV	DATE	BY	CHECKED	DESCRIPTION
1	05-03-16	CLR		UPDATE DRAWING TO SHOW MECHANICAL MODIFICATION
2	06-06-16	CLR		UPDATE DRAWING TO SHOW MECHANICAL MODIFICATION
3				
4				

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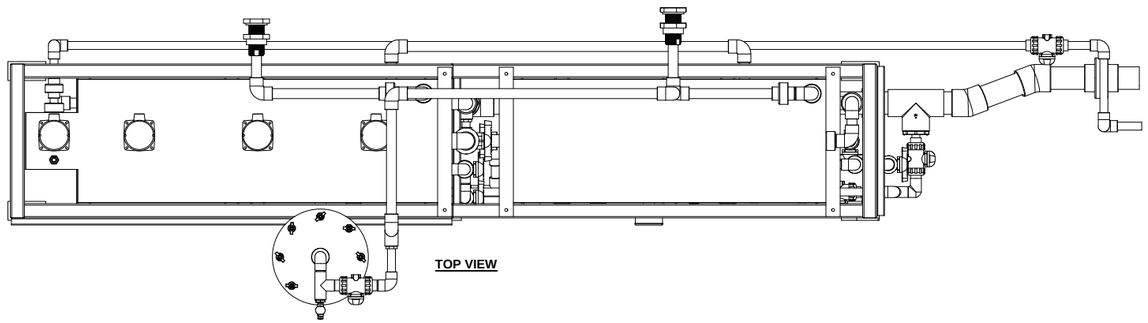
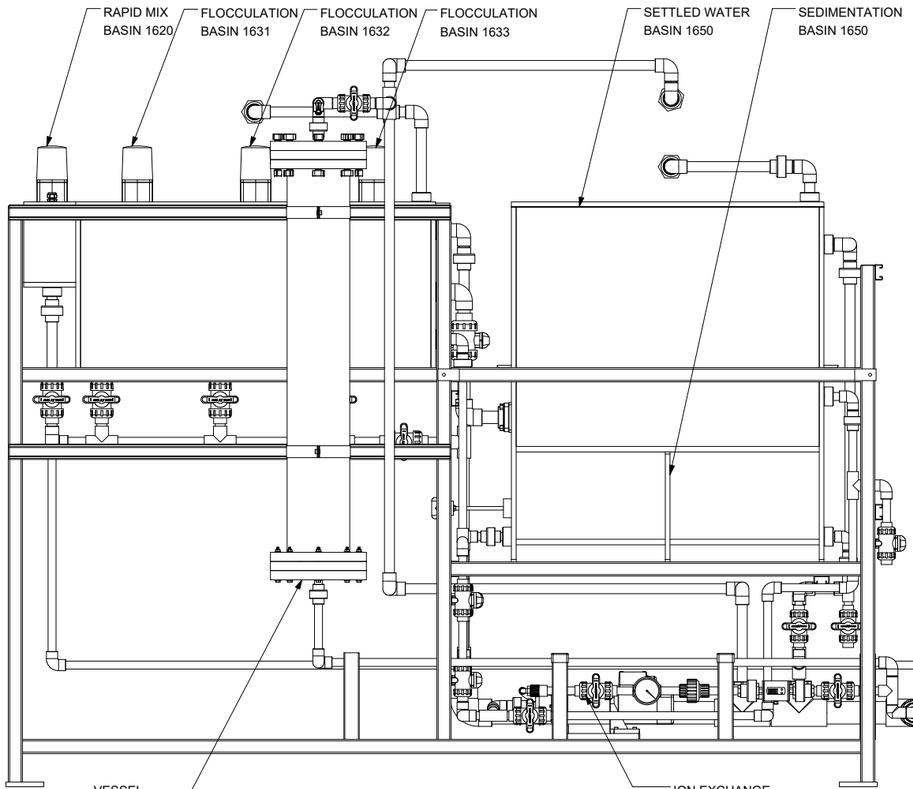
FRAC: ±1/16 0.XX: ±0.01
ANGLES: ±1˚ 0.XXX: ±0.005

TITLE: ANAEROBIC MBR PILOT PLANT
CONTAINER PARTITION PIPING - GENERAL ARRANGMENT

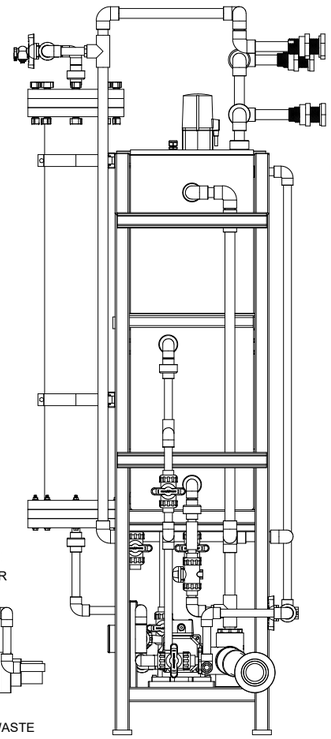
CLIENT: CDM SMITH	PROJECT: 1539
DRAWN BY: CLR	DRAWN DATE: 04-08-16
DRAWING NAME: 1539-15ML-01	P.O.:
SCALE: NONE	REVISION: 2



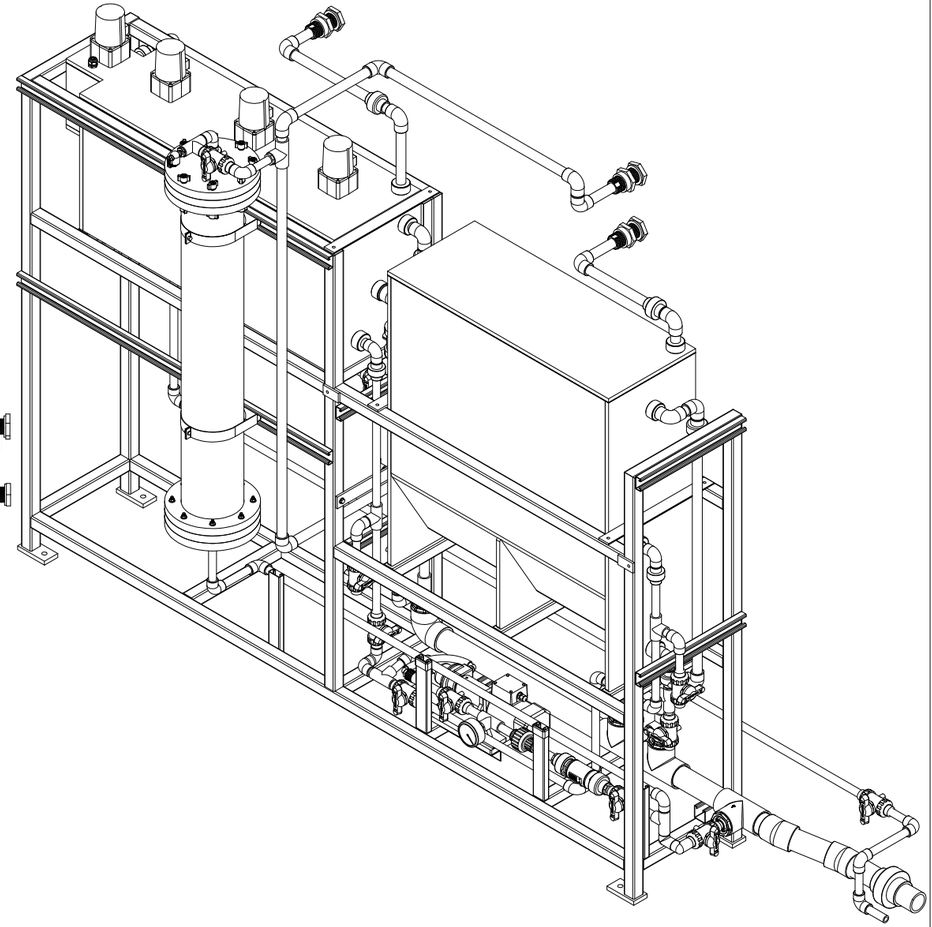
TOP VIEW



FRONT VIEW



RIGHT VIEW



NOTES:

1. QUANTITY: 1
2. UNITS: INCHES

REV	DATE	BY	CHECKED	DESCRIPTION
1	05-04-15	CLR		INCREASED TANK SEDIMENTATION TANK HEIGHT
2	06-03-16	CLR		MOVE VESSEL 1720 TO FRONT SIDE OF SKID FRAME
3				
4				

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FRAC: ±1/16 0.XX: ±0.01

ANGLES: ±1˚ 0.XXX: ±0.005

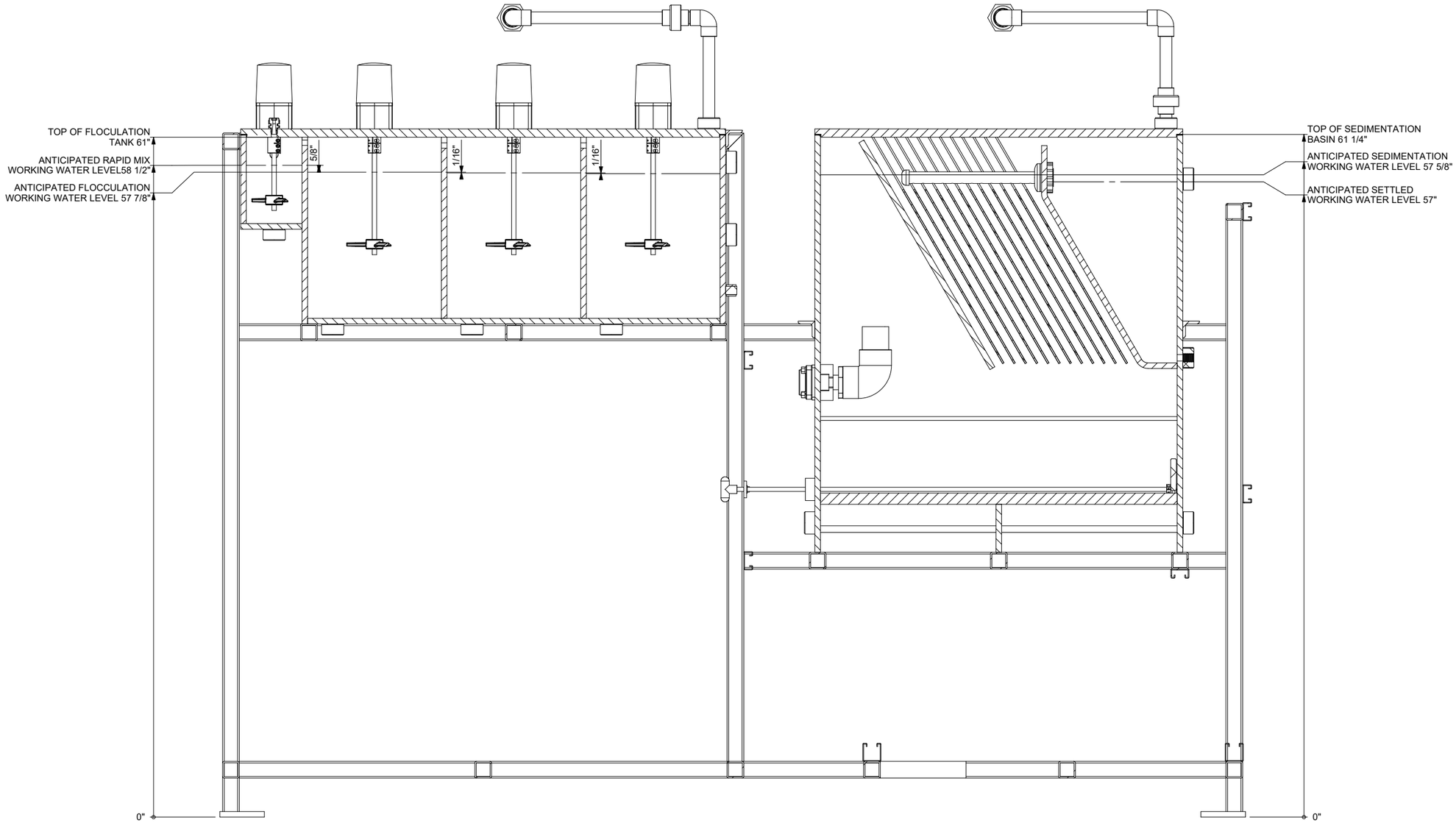
TITLE: ANAEROBIC MBR PILOT PLANT
FLOCCULATION & SEDIMENTATION MODULE - GENERAL ARRANGMENT

CLIENT: CDM SMITH | PROJECT: 1539

DRAWN BY: CLR | DRAWN DATE: 04-06-16

DRAWING NAME: 1539-16ML-01 | P.O.:

SCALE: NONE | REVISION: 2



REV	DATE	BY	CHECKED	DESCRIPTION
1	05-04-16	CLR		INCREASED HIEGHT OF SEDIMENTATION TANK, UPDATED WATER LEVELS IN TANKS.
2				
3				
4				

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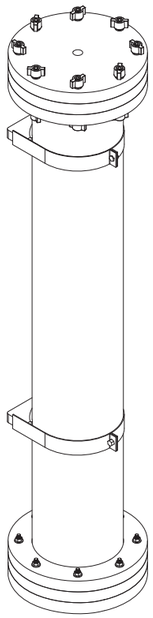
FRAC: ±1/16 0.XX: ±0.01

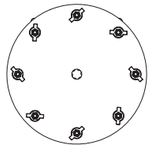
ANGLES: ±1° 0.XXX: ±0.005

TITLE: ANAEROBIC MBR PILOT PLANT
FLOCCULATION & SEDIMENTATION MODULE ELEVATION - GENERAL ARRANGMENT

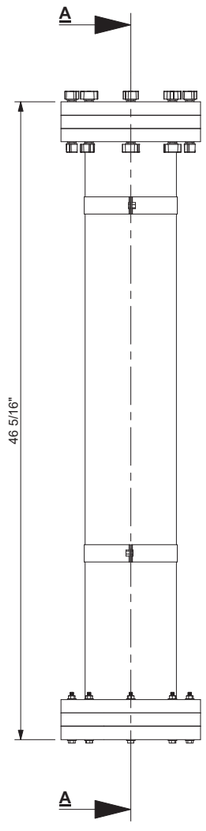
CLIENT: CDM SMITH	PROJECT: 1539
DRAWN BY: CLR	DRAWN DATE: 04-06-16
DRAWING NAME: 1539-16ML-02	P.O.:
SCALE: NONE	REVISION: 1

ITEM	TAG NAME	DESCRIPTION	MANUFACTURER	PART NUMBER	QTY.
1		SCREEN, PLAIN WEAVE, 100X100 MESH, 149MICRON, 48"WIDTH, 316SS, PRICE/SF	CUSTOM FILTRATION	WS10096	2
2		HEX BOLT, 1/4-20 X 3-1/2", 316SS	GENERIC BOLT	N/A	8
3		HEX BOLT, 1/4-20 X 4", 304SS	GENERIC BOLT	N/A	8
4		FLAT WASHER, 1/4" X 5/8", 304SS	GENERIC WASHER	N/A	32
5		PIPE, SCH40, 6", CLEAR PVC	HARVEL	4000H-060	1
6		O-RING, 7-7/8"OD, 7-1/2"ID, 0.210"WIDTH, 70 DUROMETER, EPDM	HYDRAPAK	2-367-E70	4
7		ION EXCHANGE COLUMN BRACKET, 3/4" PVC	INTUITECH	1539-1600-03	2
8		6" COLUMN MEDIA SUPPORT, 1" THICK, PVC	INTUITECH	202-F1-060	2
9		COLUMN FLANGE, 1", PVC	INTUITECH	203-F1-060	2
10		FLANGE 1" PVC	INTUITECH	205-F1-060	2
11		THUMB SCREW KNOB, WING TYPE, FOR 1/4" BOLT WITH 7/16" HEX HEAD, NYLON BLACK	MICRO PLASTICS	29WN014B	16
12		HEX NUT, 1/4-20, 304SS	UINTAH	N/A	16
13		PIPE CLAMP, RIGID, 6", TWO PIECE, 304SS	UNISTRUT	P1124SS	2

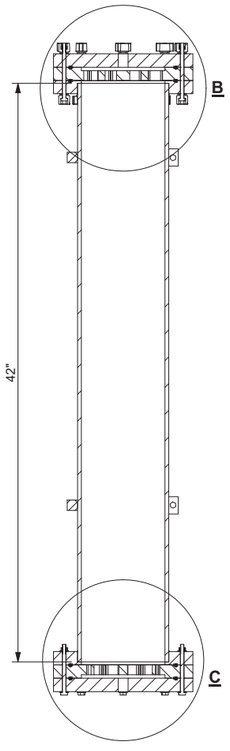




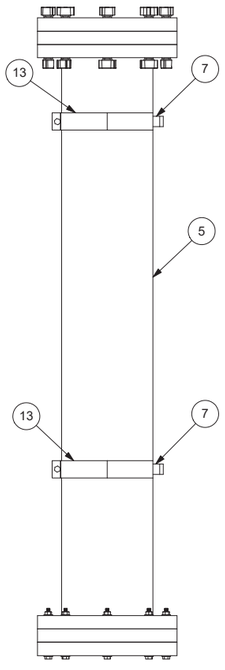
TOP VIEW



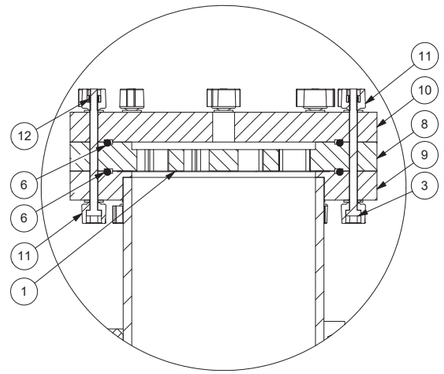
FRONT VIEW



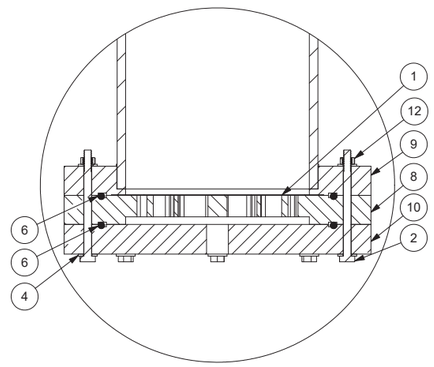
SECTION A-A



RIGHT VIEW



DETAIL B



DETAIL C

NOTES:

1. QUANTITY: 1
2. UNITS: INCHES

REV	DATE	BY	CHECKED	DESCRIPTION
1	05-04-16	CLR		UPDATE COMPONENT LAYOUT AND DISCRIPTION
2				
3				
4				

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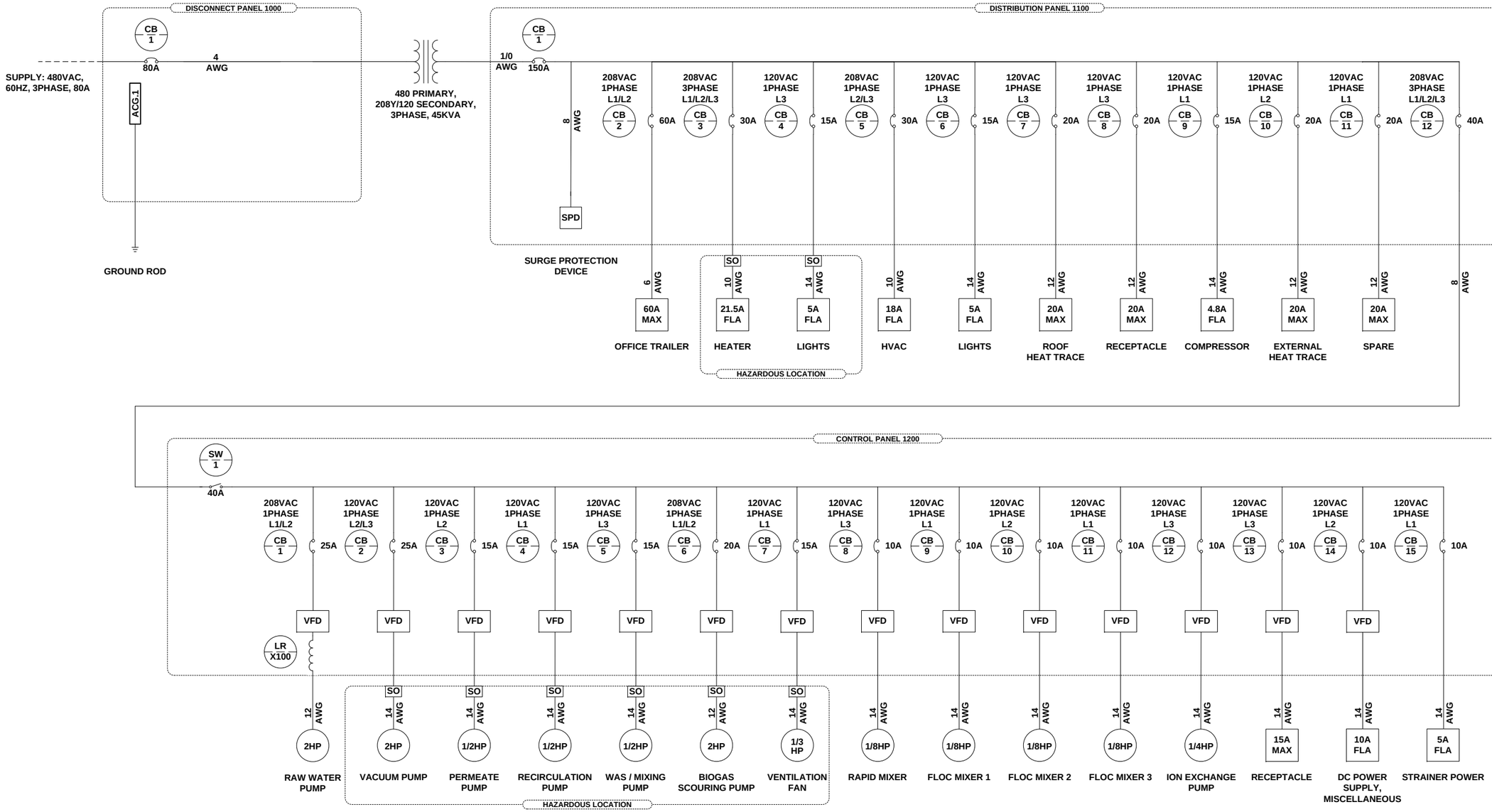
DIMENSIONAL TOLERANCES ARE AS FOLLOWS UNLESS OTHERWISE SPECIFIED

FRAC: ±1/16 0.XX: ±0.01
ANGLES: ±1° 0.XXX: ±0.005

TITLE: ANAEROBIC MBR PILOT PLANT VESSEL 1710 - FABRICATION	
CLIENT: CDM SMITH	PROJECT: 1539
DRAWN BY: CLR	DRAWN DATE: 04-06-16
DRAWING NAME: 1539-16MF-12	P.O.:
SCALE: NONE	REVISION: 1



REV	DATE	BY	DESCRIPTION
1	11-10-16	RSR	MADE VARIOUS CHANGES TO THE LOAD BALANCING.
2	03-31-16	REM	FIXED FLA CURRENT ON THE HVAC, MOVED THE VENTILATION FAN TO THE CONTROL PANEL AND ADDED A VFD. FIXED WIRE GAUGE SIZES.
3	05-06-16	RSR	CHANGED BREAKER SIZES FOR VACUUM PUMP AND BIOGAS SCOURING PUMP, REMOVED 2 RECEPTACLES FROM POWER DISTRIBUTION PANEL
4	06-06-16	RSR	CHANGED OFFICE TRAILER BREAKER TO 60A. MADE VARIOUS WIRE SIZE CHANGES, CHANGED DESCRIPTIONS FOR HEAT TRACE CIRCUITS

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DIMENSIONAL TOLERANCES ARE AS FOLLOWS, UNLESS OTHERWISE SPECIFIED

FRAC: ± 1/16 0.XX: ± 0.01

ANGLES: ± 1° 0.XXX: ± 0.005

TITLE: ANAEROBIC MBR PILOT PLANT ONE LINE DIAGRAM

CLIENT: CDM SMITH | PROJECT: 1539

DRAWN BY: RSR | DRAWN DATE: 12-28-15

DRAWING NAME: 1539-B0LD-10.VSD | P.O.:

SCALE: NONE | REVISION: 4

CDM SMITH

ANAEROBIC MBR PILOT PLANT

CONTROL PHILOSOPHY

RELEASE 3

SEPTEMBER 7, 2016

CONTROL PHILOSOPHY

Feed Pump 1100 and Strainer) Pump is flow controlled with a PID (Proportional-Integral-Derivative) loop using the level transmitter LT-1200 for feedback. The strainer cycle can be initiated manually by an operator using a pushbutton, or automatically based on pump runtime. During the strain cycle the feed pump will control to separate user defined set-point.

WAS/Mixing Pump 1440) Pump is flow controlled through a PID loop using the associated flow meter FIT-1440 for feedback. Normal mode of operation is mixing, with shorter periods of waste. Waste cycle can be initiated manually by an operator or automatically based on system runtime. The waste step continues until a predetermined volume is pumped to waste. This totalized volume will be reset to zero once the next waste cycle starts. There is also a cumulative totalized waste volume that can only be reset by a pushbutton on the HMI. Any bioprocess tank volume lost through pumping to waste, is compensated for by the feed pump's level control.

Recirculation Pump 1430) Pump is flow controlled through a PID loop using the associated flow meter FIT-1430 for feedback. Normal mode of operation is flow into the bottom of the membrane tank, with shorter de-foam periods during which the flow enters the top of the membrane tank. During de-foam, the associated anti-foam chemical pump will pace itself to the same flowmeter and maintain a predefined chemical dose. The de-foam cycle can be initiated manually by an operator, or automatically based on system runtime. All de-foam variables (frequency, duration and flow rate) are user-defined by an operator.

Biogas Pump 1410) The biogas sparge pump is flow controlled through a PID loop using the associated flow meter FIT-1410. Sparging can enter the membrane tank through both sparge valves at the same time or cycle between the two valves at a user-defined interval. Condensation collection tanks are located on the suction and discharge lines of the pump. Level transmitters in the collection tank and an automated valve are used to monitor and drain any accumulated condensate. The valve open and valve close setpoints associated with LT-1410 and LT-1420 are adjustable by an operator.

Permeate Pump 1310) This gear pump is bi-directional and used for both permeate and CIP/back-pulsing. The pump is flow controlled using a PID loop and the associated flow meter FIT-1310. The CIP/Backpulse tank can be configured by an operator to automatically fill using either permeate or potable water. Any bioprocess tank volume lost through permeate, is compensated for by the feed pump's level control.

Vacuum Pump 1540) The vacuum pump is pressure controlled through a PID loop using the associated pressure transmitter PT-1540 for feedback. A condensate collection tank on the suction side of the pump will collect any liquid in the case of a damaged membrane. If this occurs, the vacuum pump will shut down and all permeate will be diverted from the non-hazardous area to the waste line until the proper repairs can be made. The high condensate level setpoint for the collection tank is user-defined..

Rapid Mixer 1620 and Flocculation Mixers 1631, 1632 and 1633) All mixers are variable speed with direct entry of the mixing speed. Using the permeate temperature and impellor geometry, the correct motor speed is calculated to maintain a required speed.

Ion Exchange Pump 1710) Pump is flow controlled through a PID loop using the associated flow meter FIT-1710 for feedback. It is operated at a slightly lower flow rate (about 5%) than the permeate pump. The sed tank is always full and overflowing slightly through the stand pipe to ensure a constant head on pump 1710. Because of the resultant lak of flow, the Ion Exchange pump will not run while Permeate is being used to fill the CIP Tank.

pH Adjustment Feed Pump 1810) The pH pump uses a simple PID control loop (forward or reverse based on acid or caustic) with pH as the feedback. pH feedback is provided by pH sensor PHT-1450.

Coagulant Feed Pump 1830) The Coagulant Feed Pump uses a simple pace loop which uses the permeate flow rate, the chemical concentration, and the user entered dose (in mg/L) to calculate the required chemical flow rate.

Pressure Relief Tank 1210) Pressure relief tank 1210 is designed to maintain 41.5 inH2O of pressure within the bioreactor tank. This pressure is controlled by the height of the water in the relief tank. When the pressure in the bioprocess tank reaches this value, biogas will begin to bubble through the relief tank and vent out the flame arrestor after the oxygen and methane concentrations are measured.

Pressure Relief Tanks 1240 and 1330) Pressure relief tanks 1240 and 1330 are designed as emergency pressure reliefs. Using the same operating principal as tank 1210, if the pressure within the bioprocess tank or the membrane reaches 69.2 inH2O, excess biogas will bubble through the relief tank and vent out of the flame arrestor.

CDM SMITH

ANAEROBIC MBR PILOT PLANT

COMPONENT LIST

SEPTEMBER 7, 2016

Table of Contents

Container Components - Hazardous Location 3
Container Components - Non-Hazardous Location..... 4
Process Components - Hazardous Location 5
Process Components - Non-Hazardous Location 11

Container Components - Hazardous Location

TAG NAME	DESCRIPTION	MANUFACTURER	PART NUMBER
AIT-1231	HYDROGEN SULPHIDE GAS TRANSMITTER, DIFFUSION, DISPLAY, 0…100PPM, ±5%ACC, -40...104°F, 24VDC, (1)4-20MA (2)NO/NC, CSA, XP C1D1BCD	RKI INSTRUMENTS	65-2615RK-05
AIT-1232	METHANE GAS TRANSMITTER, DIFFUSION, DISPLAY, 0...100%VOL, ±5%ACC, -4...122°F, 24VDC, (1)4-20MA, (2)NO/NC, CULUS, XP C1D1BCD	RKI INSTRUMENTS	65-2619RK-CH4
	LIGHT FIXTURE, LINEAR FLUORESCENT, WET/HAZARDOUS LOCATION, 48", (2)T8 32W LAMPS, PC/SS/SI, 120/277VAC, NI C1D2ABCD	BEGHELLI	HZ100T84HT232W120/277V
	EXHAUST FAN, DIRECT DRIVE, 18", 3200CFM@0"SP, 2920CFM@0.25"SP, 1/3HP115/208...230VAC, XP C1D12FG	DELHI	SD18-XPF
	UNIT HEATER, WALL/CEILING MOUNT, 12"FAN, 5KW, INTEGRAL DISCONNECT & THERMOSTAT, 24VDC CONTROL, 208VAC, 3PHASE, 60HZ, CSAUS, XP C1D1/2CD C2D1/2FG	HAZLOC	XEU1-12-050-208360-B-C
	EMERGENCY LIGHT, 2 LAMP, HAZARDOUS LOCATION, 32...104°F, 6VDC 8W HALOGEN LAMP, LEAD-ACID BATT, 2HOUR, 120/220/240/277VAC, UL, NI C1D2ABCD	HUBBELL LIGHTING	C1D2-6V36

Container Components - Non-Hazardous Location

TAG NAME	DESCRIPTION	MANUFACTURER	PART NUMBER
	HVAC UNIT, WALL-MOUNT, 16,400BTU/HR COOL, 5KW HEAT, 150CFM@0.5" VENT, WASHABLE FILTER, BUCKEYE GRAY, 197-253VAC, 60HZ, 1PHASE	BARD	W18A1-A08XW4XXX
	LIGHT FIXTURE, LINEAR FLUORESCENT, WET LOCATION, 48", (2)T8 232W LAMPS, PC/SS/SI, 120/277VAC	BEGHELLI	BS100T84HT232W120/277V
	EMERGENCY LIGHT, 2 LAMP, LEAD-ACID BATTERY, 1 1/2HOUR, 120/277VAC, GRAINGER: 2XLG1	LITHONIA	ELT618NY
	TRANSFORMER, GENERAL PURPOSE DRY, 3PHASE, 480V PRIMARY, 208Y/120V SECONDARY, 60HZ, 45KVA	SQUARE D	EE45T3H

Process Components - Hazardous Location

TAG NAME	DESCRIPTION	MANUFACTURER	PART NUMBER
AIR FILTER 1530	INTAKE AIR FILTER, DISPOSABLE, 99% @ 2 MICRONS, 12 CFM, 1/2"MPT, STEEL	SOLBERG	FS-10-050
BIOGAS PUMP 1410	DIAPHRAGM PUMP, MOTOR-DRIVEN, 4.5CFM@5PSIG, 316SS/PTFE/FFKM, TEFC, 1½HP, 230/460VAC, XP C1D12D/C2D12FG	KNF	PU3160-N0150.1.2
BIOPROCESS TANK 1200	PRESSURE VESSEL, 48"DIA X 60"SS, 93"OAH, 5PSIG WP, 470GAL, FRP	MIDWESTERN FABRICATORS	N/A

TAG NAME	DESCRIPTION	MANUFACTURER	PART NUMBER
FIT-1100	FLOW TRANSMITTER, ELECTROMAGNETIC, DISPLAY, 1/2"FLG, 0.15...27GPM, ±0.5%ACC, PTFE/C22, 20…30VDC, 1/2"COND, (1)4...20MA/HART, NI C1D2ABCD/NSF61	ENDRESS & HAUSER	5P1B15-C6DBBADEA1KHAL5
FIT-1230	MASS FLOW TRANSMITTER, THERMAL, DISPLAY, 0.05...5SLPM, ±0.8%ACC, 1/8"FPT, 316SS/FFKM, 3WIRE, 15...30VDC, (1)4…20MA/0...5VDC/1...5VDC/0...10VDC, NI C1D2ABCD	ALICAT SCIENTIFIC	MS-5SLPM-X
FIT-1310	FLOW TRANSMITTER, ELECTROMAGNETIC, DISPLAY, 1/2"FLG, 0.15...27GPM, ±0.5%ACC, PTFE/C22, 20…30VDC, 1/2"COND, (1)4...20MA/HART, NI C1D2ABCD, NSF61	ENDRESS & HAUSER	5P1B15-C6DBBADEA1KHAL5
FIT-1410	MASS FLOW TRANSMITTER, THERMAL, DISPLAY, 0.25...250SLPM, ±0.8%ACC, 1/2"FPT, 316SS/FFKM, 3WIRE, 15...30VDC, (1)4…20MA/0...5VDC/1...5VDC/0...10VDC, NI C1D2ABCD	ALICAT SCIENTIFIC	MS-250SLPM-X
FIT-1430	FLOW TRANSMITTER, ELECTROMAGNETIC, DISPLAY, 1/2"FLG, 0.15...27GPM, ±0.5%ACC, PTFE/C22, 20…30VDC, 1/2"COND, (1)4...20MA/HART, NI C1D2ABCD/NSF61	ENDRESS & HAUSER	5P1B15-C6DBBADEA1KHAL5
FIT-1440	FLOW TRANSMITTER, ELECTROMAGNETIC, DISPLAY, 1/2"FLG, 0.15...27GPM, ±0.5%ACC, PTFE/C22, 20…30VDC, 1/2"COND, (1)4...20MA/HART, NI C1D2ABCD/NSF61	ENDRESS & HAUSER	5P1B15-C6DBBADEA1KHAL5

TAG NAME	DESCRIPTION	MANUFACTURER	PART NUMBER
FLAME ARRESTOR 1230	FLAME ARRESTOR, 1"FPT, 316SS	GROTH	7622-10-55-N0
FLAME ARRESTOR 1240	FLAME ARRESTOR, 1"FPT, 316SS	GROTH	7622-10-55-N0
LT-1200	LEVEL TRANSMITTER, CONTINUOUS CAPACITANCE, 3/4"MPT CONN, 0...84", PFA COATED, REMOTE TRANSMITTER, LOOP POWERED, (1)4...20MA, NI C1D2ABCD	INTEMPCO	LTX20-A-A2-U-P3-S-D1-84
LT-1220	LEVEL TRANSMITTER, CONTINUOUS CAPACITANCE, 3/4"MPT CONN, 0...12", PFA COATED, REMOTE TRANSMITTER, LOOP POWERED, (1)4...20MA, NI C1D2ABCD	INTEMPCO	LTX20-A-A2-U-P3-S-D1-12
LT-1300	LEVEL TRANSMITTER, CONTINUOUS CAPACITANCE, 3/4"MPT CONN, 0...84", PFA COATED, REMOTE TRANSMITTER, LOOP POWERED, (1)4...20MA, NI C1D2ABCD	INTEMPCO	LTX20-A-A2-U-P3-S-D1-84
LT-1410	LEVEL TRANSMITTER, CONTINUOUS CAPACITANCE, 3/4"MPT CONN, 0...12", PFA COATED, REMOTE TRANSMITTER, LOOP POWERED, (1)4...20MA, NI C1D2ABCD	INTEMPCO	LTX20-A-A2-U-P3-S-D1-12
LT-1420	LEVEL TRANSMITTER, CONTINUOUS CAPACITANCE, 3/4"MPT CONN, 0...12", PFA COATED, REMOTE TRANSMITTER, LOOP POWERED, (1)4...20MA, NI C1D2ABCD	INTEMPCO	LTX20-A-A2-U-P3-S-D1-12
LT-1540	LEVEL TRANSMITTER, CONTINUOUS CAPACITANCE, 3/4"MPT CONN, 0...12", PFA COATED, REMOTE TRANSMITTER, LOOP POWERED, (1)4...20MA, NI C1D2ABCD	INTEMPCO	LTX20-A-A2-U-P3-S-D1-12
LT-1320	LEVEL TRANSMITTER, CONTINUOUS CAPACITANCE, 3/4"MPT CONN, 0...72", PFA COATED, REMOTE TRANSMITTER, LOOP POWERED, (1)4...20MA, NI C1D2ABCD	INTEMPCO	LTX20-A-A2-U-P3-S-D1-72
MEMBRANE CONTACTOR 1500	MEMBRANE CONTACTOR, EXTRA FLOW X50, 4” X 13” HOUSING, 1” SANITARY CONNECTIONS, 2…15GPM, 104°F@75PSIG MAX, PE/PP/FKM	LIQUI-CEL	G492
PERMEATE PUMP 1310	GEAR PUMP, 56C MOUNT, 1.4GPM@110PSIG, 2.1GPM@0PSIG, 1/2"FPT X 1/2"FPT, 316/PTFE	OBERDORFER	RM1041EPC-M1
	MOTOR, TEFC, 56C FRAME, 1/2HP, 1725RPM@60HZ, 3PHASE, 2.1...2/1A, 208...230/480VAC, UL/UR/CSA, XP C1D12D/C2D12FG	BALDOR	CM7006A
PHT-1450	PH SENSOR, DIFFERENTIAL, 0…14PH, TEMP COMP, -5…95°C, 0.1%ACC, CPVC/TITANIUM	THERMO SCIENTIFIC	PH21A1A2
	UNIVERSAL BODY, 1"MPT PC, CPVC/FKM, NI C1D2ABCD	THERMO SCIENTIFIC	DS21-WA
	COMMUNICATION ADAPTER, MODBUS TCPIP/ETHERNET IP, 48V POE, CPVC/FKM, 10'CABLE, RJ45 EC, NI C1D2ABCD	THERMO SCIENTIFIC	CA27R1A
	IN-LINE TEE MOUNT, 1 1/2"UNION, FOR DATA STICK INSTRUMENTS, CPVC	THERMO SCIENTIFIC	MH1042-RT

TAG NAME	DESCRIPTION	MANUFACTURER	PART NUMBER
PT-1200	PRESSURE TRANSMITTER, CAPACITIVE, 0...6PSIG, ±0.15%ACC, ½"MPT/¼"FPT CONN, C276/AL2O3/FKM, 2WIRE, 12...45VDC, 4...20MA/HART, ½"FPT COND, NI/IS C123D1 ABCDEFG/C1D2ABCD	ENDRESS & HAUSER	PMC51-FA22ID1FGFRLCA
PT-1300	PRESSURE TRANSMITTER, CAPACITIVE, 0...6PSIG, ±0.15%ACC, ½"MPT/¼"FPT CONN, C276/AL2O3/FKM, 2WIRE, 12...45VDC, 4...20MA/HART, ½"FPT COND, NI/IS C123D1 ABCDEFG/C1D2ABCD	ENDRESS & HAUSER	PMC51-FA22ID1FGFRLCA
PT-1310	PRESSURE TRANSMITTER, CAPACITIVE, 0...30PSIG, ±0.15%ACC, ½"MPT/¼"FPT CONN, C276/AL2O3/FKM, 2WIRE, 12...45VDC, 4...20MA/HART, ½"FPT COND, NI/IS C123D1 ABCDEFG/C1D2ABCD	ENDRESS & HAUSER	PMC51-FA22ID1KGFRLCA
PT-1430	PRESSURE TRANSMITTER, CAPACITIVE, 0...30PSIG, ±0.15%ACC, ½"MPT/¼"FPT CONN, C276/AL2O3/FKM, 2WIRE, 12...45VDC, 4...20MA/HART, ½"FPT COND, NI/IS C123D1 ABCDEFG/C1D2ABCD	ENDRESS & HAUSER	PMC51-FA22ID1KGFRLCA

TAG NAME	DESCRIPTION	MANUFACTURER	PART NUMBER
PT-1440	PRESSURE TRANSMITTER, CAPACITIVE, 0...30PSIG, ±0.15%ACC, ½"MPT/¼"FPT CONN, C276/AL2O3/FKM, 2WIRE, 12...45VDC, 4...20MA/HART, ½"FPT COND, NI/IS C123D1 ABCDEFG/C1D2ABCD	ENDRESS & HAUSER	PMC51-FA22ID1KGFRLCA
PT-1540	PRESSURE TRANSMITTER, CAPACITIVE, 0...30PSIG, ±0.15%ACC, ½"MPT/¼"FPT CONN, C276/AL2O3/FKM, 2WIRE, 12...45VDC, 4...20MA/HART, ½"FPT COND, NI/IS C123D1 ABCDEFG/C1D2ABCD	ENDRESS & HAUSER	PMC51-FA22ID1KGFRLCA
PV-1530	VALVE, GLOBE NEEDLE, 1/2"FPT X 1/2"FPT, CPVC	MARQUEST	NG-500-PVC
RECIRC PUMP 1430	PUMP, PROGRESSIVE CAVITY, CLOSE-COUPLED, 14.2GPM@0PSIG, 11.6GPM@30PSIG, 3/4"FPT SUCTION, 3/4"FPT DISCHARGE, 1/2HP, 230/440VAC, 3PHASE, 316SS/NBR W/ABRASION RESISTANT SEAL KIT	MOYNO	34450
	MOTOR, TEFC, 56C FRAME, 1/2HP, 1725RPM@60HZ, 3PHASE, 2.1...2/1A, 208...230/480VAC, UL/UR/CSA, XP C1D12D/C2D12FG	BALDOR	CM7006A
RV-1311	PRESSURE RELIEF VALVE, INLINE ADJUSTABLE, CV=3.31, 10...80PSIG, 150PSIG MAX, +-5PSIG, 3/4"FPT, 0...140F, PVC/VITON, SET TO 25PSIG	RK INDUSTRIES	MRB-751-V
RV-1312	PRESSURE RELIEF VALVE, INLINE ADJUSTABLE, CV=3.31, 10...80PSIG, 150PSIG MAX, +-5PSIG, 3/4"FPT, 0...140F, PVC/VITON, SET TO 25PSIG	RK INDUSTRIES	MRB-751-V
RV-1410	PRESSURE RELIEF VALVE, INLINE ADJUSTABLE, CV=3.31, 10...80PSIG, 150PSIG MAX, +-5PSIG, 3/4"FPT, 0...140F, PVC/VITON, SET TO 25PSIG	RK INDUSTRIES	MRB-751-V
RV-1430	PRESSURE RELIEF VALVE, INLINE ADJUSTABLE, CV=3.31, 10...80PSIG, 150PSIG MAX, +-5PSIG, 3/4"FPT, 0...140F, PVC/VITON, SET TO 25PSIG	RK INDUSTRIES	MRB-751-V
RV-1440	PRESSURE RELIEF VALVE, INLINE ADJUSTABLE, CV=3.31, 10...80PSIG, 150PSIG MAX, +-5PSIG, 3/4"FPT, 0...140F, PVC/VITON, SET TO 25PSIG	RK INDUSTRIES	MRB-751-V

TAG NAME	DESCRIPTION	MANUFACTURER	PART NUMBER
TT-1200	TEMPERATURE TRANSMITTER, RTD, 0...150°F, ±0.08%ACC, 1/2"MTP CONN, HEAVY THERMOWELL, 12"LENGTH, C276, 1/2"COND, 3WIRE, 10…30VDC, (1)4…20MA, NI C1D2ABCD	PYROMATION	R1T185L483-H4C1229-SL-6HN31,T-440-385U-S(0-150)F
TT-1310	TEMPERATURE TRANSMITTER, RTD, 0...150°F, ±0.08%ACC, 1/2"MTP CONN, HEAVY THERMOWELL, 2.5"LENGTH, C276, 1/2"COND, 3WIRE, 10…30VDC, (1)4…20MA, NI C1D2ABCD	PYROMATION	R1T185L483-H4C02529-SL-6HN31,T-440-385U-S(0-150)F
TUT-1310	TURBIDITY TRANSMITTER, IR LED TYPE, 0.1...4000NTU, ±1%ACC, 1"MPT PC, PC/GLASS/FKM, 48V POE, RJ45 EC, 30'CABLE, MODBUS TCP/IP, NI C1D2ABCD	THERMO SCIENTIFIC	RT1173
VACUUM PUMP 1540	REGENERATIVE BLOWER, 1STAGE VACUUM, OIL-LESS, 58SCFM@0"WC, 13SCFM@60"WC, 1¼"FPT INLET, 1¼"FPT OUTLET, TEFC, 1HP, 208-230/480VAC, 3PHASE, XP C1D12D/C2D12FG	AIRTECH VACUUM	3BA1300-EXP(1HP)
WAS/MIX PUMP 1440	PUMP, PROGRESSIVE CAVITY, CLOSE-COUPLED, 14.2GPM@0PSIG, 11.6GPM@30PSIG, 3/4"FPT SUCTION, 3/4"FPT DISCHARGE, 1/2HP, 230/440VAC, 3PHASE, 316SS/NBR W/ABRASION RESISTANT SEAL KIT	MOYNO	34450
	MOTOR, TEFC, 56C FRAME, 1/2HP, 1725RPM@60HZ, 3PHASE, 2.1...2/1A, 208...230/480VAC, UL/UR/CSA, XP C1D12D/C2D12FG	BALDOR	CM7006A

Process Components - Non-Hazardous Location

TAG NAME	DESCRIPTION	MANUFACTURER	PART NUMBER
AIR PREPARATION MODULE 1910	OIL MIST/PARTICLE SEPARATOR, 99.9% > 0.3 MICRON, 145PSIG MAX, 41…140°F, ¼"FPT/MODULAR, AUTO DRAIN, MTG BRACKET, SERVICE INDICATOR	SMC	AM150C-N02BC-T
	WATER DROPLET SEPARATOR, 99% REMOVAL, 145PSIG MAX, 41…140°F, ¼"FPT/MODULAR, AUTO, DRAIN, MTG BRACKET	SMC	AMG150C-N02BC
	PRESSURE REGULATOR, RELIEVING, 7…123PSIG RANGE, 145PSIG MAX, 23…140°F, ¼"FPT/MODULAR, SQUARE GAUGE	SMC	AR20K-N02E-Z
	ISOLATION VALVE, 3WAY, 145PSIG MAX, 23…140°F, ¼"FPT/MODULAR	SMC	VHS20-N02-Z
	MODULAR CONNECTOR, FOR ¼" BODY	SMC	Y200
CHEMICAL FEED PUMP 1810	PUMP DRIVE, 200:1 RATIO, EASY LOAD 3	INTUITECH	5110-200
CHEMICAL FEED PUMP 1820	PUMP DRIVE, 200:1 RATIO, EASY LOAD 3	INTUITECH	5110-200
CHEMICAL FEED PUMP 1830	PUMP DRIVE, 200:1 RATIO, EASY LOAD 3	INTUITECH	5110-200
CHEMICAL FEED PUMP 1840	PUMP DRIVE, 200:1 RATIO, EASY LOAD 3	INTUITECH	5110-200
CHEMICAL FEED PUMP 1850	PUMP DRIVE, 200:1 RATIO, EASY LOAD 3	INTUITECH	5110-200
CHEMICAL TANK 1810	TANK, RECTANGULAR, 4GAL, 8-1/4" X 7-7/8" X 17-5/8", HDLPE	RONCO	B269
	MOTOR, WATERTIGHT, 1/30HP, 115VAC, 1PHASE, 0.46FLA, 483RPM	ORIENTAL MOTOR	FPW425A2-3U
	MIXER PADDLE, 4-BLADE, 2-3/8"DIA, 3/8" X 22-1/8" SHAFT, PTFE COATED	COLE PARMER	T-06367-80
CHEMICAL TANK 1820	TANK, RECTANGULAR, 4GAL, 8-1/4" X 7-7/8" X 17-5/8", HDLPE	RONCO	B269
	MOTOR, WATERTIGHT, 1/30HP, 115VAC, 1PHASE, 0.46FLA, 483RPM	ORIENTAL MOTOR	FPW425A2-3U
	MIXER PADDLE, 4-BLADE, 2-3/8"DIA, 3/8" X 22-1/8" SHAFT, PTFE COATED	COLE PARMER	T-06367-80
COMPRESSOR 1910	COMPRESSOR, LUBRICATED PISTON, 1.45SCFM@115PSIG , 6.3GAL TANK, AUTO DRAIN, 50% DUTY, TENV, ½HP, 1PHASE, 60HZ, 115VAC, 4.8A, CSA/CE, P50/24AL	WERTHER INTERNATIONAL	M06090US-C1246

TAG NAME	DESCRIPTION	MANUFACTURER	PART NUMBER
FIT-1710	FLOW TRANSMITTER, MAGNETIC, DISPLAY, 0.030...6.604GPM, -4...176°F, ±2.5%ACC, G1/2, 316SS/PEEK/VITON, M12 CONN, (1)4-20MA/0...10V/NO/NC, (1)NO/NC, CULUS/CE	IFM EFECTOR	SM6001
	MOTOR, WATERTIGHT, 1/30HP, 230VAC, 3PHASE, 0.22FLA, 533RPM	ORIENTAL MOTOR	FPW425S2-3

ALARM LIST

Message	Condition	Shutdown
Ambient Hydrogen Sulphide Concentration High	Instrument value greater than specified limit for 30	X
Feed Pump Flow Transmitter Failed Alarm	No transmitter signal for 30 seconds	X
Biogas Flow Transmitter Failed Alarm	No transmitter signal for 30 seconds	X
Permeate Pump Flow Transmitter Failed Alarm	No transmitter signal for 30 seconds	X
Biogas Sparge Flow Transmitter Failed Alarm	No transmitter signal for 30 seconds	X
Ambient Methane Gas Concentration High Alarm	Instrument value greater than specified limit for 30	X
Backpulse CIP Tank Level Low Alarm	Tank level less than specified limit for 30 seconds	X
Bioprocess Tank Temperature Transmitter Failed Alarm	No transmitter signal for 30 seconds	
Bioprocess Tank 1200 Pressure Transmitter Failed Alarm	No transmitter signal for 30 seconds	
Membrane Tank 1300 Pressure Transmitter Failed Alarm	No transmitter signal for 30 seconds	
Permeate Pressure Transmitter Failed Alarm	No transmitter signal for 30 seconds	
Recirculation Pressure Transmitter Failed Alarm	No transmitter signal for 30 seconds	
WAS Mixing Pressure Transmitter Failed Alarm	No transmitter signal for 30 seconds	
Vacuum Pump 1540 Pressure Transmitter Failed Alarm	No transmitter signal for 30 seconds	X
Recirculation Flow Transmitter Failed Alarm	No transmitter signal for 30 seconds	X
WAS Mixing Flow Transmitter Failed Alarm	No transmitter signal for 30 seconds	X
Ion Exchange Flow Transmitter Failed Alarm	No transmitter signal for 30 seconds	
Bioprocess Tank Temperature Transmitter Failed Alarm	No transmitter signal for 30 seconds	
Permeate Turbidity Transmitter Failed Alarm	No transmitter signal for 30 seconds	
Ambient Hydrogen Sulphide Transmitter Failed	No transmitter signal for 30 seconds	X
Biogas Pump 1410 Failed Alarm	Device commanded to run but not running after 30	X
Condensation Tank 1220 Level Transmitter Failed Alarm	No transmitter signal for 30 seconds	X
Bioreactor Tank Level Transmitter Failed Alarm	No transmitter signal for 30 seconds	
Membrane Tank Level Transmitter Failed Alarm	No transmitter signal for 30 seconds	
Backpulse CIP Tank Level Transmitter Failed	No transmitter signal for 30 seconds	
Ambient Methane Gas Transmitter Failed Alarm	No transmitter signal for 30 seconds	X
Permeate Pump 1310 Failed Alarm	Device commanded to run but not running after 30	
Chemical Pump 1810 Fault Alarm	Chemical pump motor has experienced a fault **NOTE:** Cycle power to the chemical pump (by disconnecting wiring) to allow alarm reset.	
Chemical Pump 1820 Fault Alarm	Chemical pump motor has experienced a fault **NOTE:** Cycle power to the chemical pump (by disconnecting wiring) to allow alarm reset.	
Chemical Pump 1830 Fault Alarm	Chemical pump motor has experienced a fault **NOTE:** Cycle power to the chemical pump (by disconnecting wiring) to allow alarm reset.	
Chemical Pump 1840 Fault Alarm	Chemical pump motor has experienced a fault **NOTE:** Cycle power to the chemical pump (by disconnecting wiring) to allow alarm reset.	
Chemical Pump 1850 Fault Alarm	Chemical pump motor has experienced a fault **NOTE:** Cycle power to the chemical pump (by disconnecting wiring) to allow alarm reset.	
Feed Pump 1100 Flow Low Alarm	Value outside of defined deadband for the specified delay time	X
Feed Pump 1100 Flow High Alarm	Value outside of defined deadband for the specified delay time	
Feed Pump Pressure Switch High Alarm	Feed pump pressure greater than switching limit	X
Vacuum Pump 1540 Failed Alarm	Device commanded to run but not running after 30	X
Vacuum Pump 1540 Not in Auto Alarm	Control not in auto mode	
Vacuum Pump 1540 Pressure Low Alarm	Value outside of defined deadband for the specified delay time	X
Vacuum Pump 1540 Pressure High Alarm	Value outside of defined deadband for the specified delay time	X

Feed Pump 1100 Not in Auto Alarm	Control not in auto mode	
Permeate Pump 1310 Not in Auto Alarm	Control not in auto mode	
Permeate Pump 1310 Flow Low Alarm	Value outside of defined deadband for the specified delay time	X
Permeate Pump 1310 Flow High Alarm	Value outside of defined deadband for the specified delay time	
Condensate Collection Tank 1410 Drain Valve DV-1419 Open Too Long Alarm	Valve open for greater than specified time limit	X
Flocculation Mixer 3 Calculation Low Alarm	Mixer cannot attain entered auto setpoint	
Bioprocess Tank Temperature High Alarm	Value greater than specified limit for 30 seconds	
Bioprocess Tank Temperature Low Alarm	Value less than specified limit for 30 seconds	
Permeate Temperature Transmitter Failed Alarm	No transmitter signal for 30 seconds	
Permeate Temperature Low Alarm	Value less than specified limit for 30 seconds	
Permeate Turbidity High Alarm	Value greater than specified limit for 300 seconds	
Ion Exchange Pump 1710 Failed Alarm	Device commanded to run but not running after 30 seconds	X
Ion Exchange Pump 1710 Not in Auto Alarm	Control not in auto mode	
Ion Exchange Pump 1710 Flow Low Alarm	Value outside of defined deadband for the specified delay time	X
Ion Exchange Pump 1710 Flow High Alarm	Value outside of defined deadband for the specified delay time	
PLC Program Downloaded Alarm	New PLC program downloaded	X
Compressor Air Pressure Low Alarm	Air Compressor pressure less than 50 PSIG for 2 seconds	X
Rapid Mixer Calculation High Alarm	Mixer cannot attain entered auto setpoint	
Rapid Mixer Calculation Low Alarm	Mixer cannot attain entered auto setpoint	
Flocculation Mixer 1 Calculation High Alarm	Mixer cannot attain entered auto setpoint	
Flocculation Mixer 1 Calculation Low Alarm	Mixer cannot attain entered auto setpoint	
Flocculation Mixer 2 Calculation High Alarm	Mixer cannot attain entered auto setpoint	
Flocculation Mixer 2 Calculation Low Alarm	Mixer cannot attain entered auto setpoint	
Flocculation Mixer 3 Calculation High Alarm	Mixer cannot attain entered auto setpoint	
Flocculation Mixer 2 Failed Alarm	Device commanded to run but not running after 30	
Flocculation Mixer 3 Failed Alarm	Device commanded to run but not running after 30	
Biogas Pump 1410 Not in Auto Alarm	Control not in auto mode	
Biogas Pump 1410 Flow Low Alarm	Value outside of defined deadband for the specified delay time	X
Biogas Pump 1410 Flow High Alarm	Value outside of defined deadband for the specified delay time	
Feed Pump 1100 Failed Alarm	Device commanded to run but not running after 30	X
Recirculation Pump 1430 Failed Alarm	Device commanded to run but not running after 30	X
Recirculation Pump 1430 Flow Low Alarm	Value outside of defined deadband for the specified delay time	X
Recirculation Pump 1430 Flow High Alarm	Value outside of defined deadband for the specified delay time	
Chemical Cabinet 1 Leak Alarm	Leak detected inside chemical cabinet	X
Chemical Cabinet 2 Leak Alarm	Leak detected inside chemical cabinet	X
Biogas Methane Transmitter Failed Alarm	No transmitter signal for 30 seconds	
Condensation Collection Tank 1420 Level Transmitter Failed Alarm	No transmitter signal for 30 seconds	X
Condensation Collection Tank 1540 Level Transmitter Failed Alarm	No transmitter signal for 30 seconds	X
Biogas Oxygen Transmitter Failed Alarm	No transmitter signal for 30 seconds	
WAS Mixing pH Transmitter Failed Alarm	No transmitter signal for 30 seconds	
Condensate Collection Tank 1420 Drain Valve DV-1429 Open Too Long Alarm	Valve open for greater than specified time limit	X
Condensate Collection Tank 1220 Drain Valve DV-1229 Open Too Long Alarm	Valve open for greater than specified time limit	X
Condensation Collection Tank 1540 Level High	Value greater than specified limit for 30 seconds	X
Chemical Pump 1810 Calculation High Alarm	Pump cannot attain currently configured chemical dose	

Chemical Pump 1810 Calculation Low Alarm	Pump cannot attain currently configured chemical dose	
Chemical Pump 1820 Calculation High Alarm	Pump cannot attain currently configured chemical dose	
Chemical Pump 1820 Calculation Low Alarm	Pump cannot attain currently configured chemical dose	
Chemical Pump 1830 Calculation High Alarm	Pump cannot attain currently configured chemical dose	
Chemical Pump 1830 Calculation Low Alarm	Pump cannot attain currently configured chemical dose	
Chemical Pump 1840 Calculation High Alarm	Pump cannot attain currently configured chemical dose	
WAS/MIX Pump 1440 Flow Low Alarm	Value outside of defined deadband for the specified delay time	X
WAS/MIX Pump 1440 Flow High Alarm	Value outside of defined deadband for the specified delay time	
Permeate Pressure High Alarm	Value greater than specified limit for 30 seconds	X
Permeate Pressure Low Alarm	Value less than specified limit for 30 seconds	X
Bioprocess Tank 1200 Pressure High Alarm	Value greater than specified limit for 30 seconds	
Bioprocess Tank 1200 Pressure Low Alarm	Value less than specified limit for 30 seconds	
Membrane Tank 1300 Pressure High Alarm	Value greater than specified limit for 30 seconds	
Membrane Tank 1300 Pressure Low Alarm	Value less than specified limit for 30 seconds	
Recirculation Pressure High Alarm	Value greater than specified limit for 30 seconds	X
Recirculation Pressure Low Alarm	Value less than specified limit for 30 seconds	
WAS Mixing Pressure High Alarm	Value greater than specified limit for 30 seconds	X
WAS Mixing Pressure Low Alarm	Value less than specified limit for 30 seconds	
Bioreactor Tank Level High Alarm	Value greater than specified limit for 30 seconds	
Bioreactor Tank Level Low Alarm	Value less than specified limit for 30 seconds	
Membrane Tank Level High Alarm	Value greater than specified limit for 30 seconds	
Membrane Tank Level Low Alarm	Value less than specified limit for 30 seconds	
Biogas Oxygen Concentration High Alarm	Value greater than specified limit for 30 seconds	
Biogas Oxygen Concentration Low Alarm	Value less than specified limit for 30 seconds	
Biogas Methane Concentration High Alarm	Value greater than specified limit for 30 seconds	
Biogas Methane Concentration Low Alarm	Value less than specified limit for 30 seconds	
Hazardous Area Ventilation Fan Set to Off Alarm	Fan control set to off	
Biogas Transmitter Flow High Alarm	Value outside of defined deadband for the specified delay time	
Biogas Transmitter Flow Low Alarm	Value outside of defined deadband for the specified delay time	
Hazardous Area Ventilation Fan Failed Alarm	Device commanded to run but not running after 30 seconds	
PLC Power Failed Alarm	UPS Power Failed	
Rapid Mixer Failed Alarm	Device commanded to run but not running after 30	
Flocculation Mixer 1 Failed Alarm	Device commanded to run but not running after 30	
Emergency Stop Alarm	Emergency stop button depressed **NOTE:** Rotate button clockwise to release before resetting alarm.	X
Chemical Pump 1840 Calculation Low Alarm	Pump cannot attain currently configured chemical dose	
Chemical Pump 1850 Calculation High Alarm	Pump cannot attain currently configured chemical dose	
Chemical Pump 1850 Calculation Low Alarm	Pump cannot attain currently configured chemical dose	
Chemical Pump 1810 pH High Alarm	Value outside of defined deadband for the specified delay time	
Chemical Pump 1810 pH Low Alarm	Value outside of defined deadband for the specified delay time	
Power Supply Currently Operating in Battery Backup Mode Alarm	Main Power Failed	X
WAS/MIX Pump 1440 Failed Alarm	Device commanded to run but not running after 30	X

Power Supply Backup Capacitor Requires Replacement Alarm	UPS capacitor needs replacement in 2 months	
WAS Mixing pH High Alarm	Value outside of defined deadband for the specified delay time	
WAS Mixing pH Low Alarm	Value outside of defined deadband for the specified delay time	
WAS/Mixing Pump 1440 Not In Auto Alarm	Control not in auto mode	
Recirculation Pump 1430 Not in Auto Alarm	Control not in auto mode	
Strainer Not In Auto Alarm	Control not in auto mode	
Ventilation Fan Not In Auto Alarm	Control not in auto mode	

I/O ADDRESSING

PLC ADDRESS	TAG NUMBER	DESCRIPTION
%IW1	FIT-1100	FEED FLOW TRANSMITTER
%IW2	FIT-1230	BIOGAS VENT FLOW TRANSMITTER
%IW3	FIT-1310	PERMEATE PUMP FLOW TRANSMITTER
%IW4	FIT-1410	MEMBRANE GAS SPARGE FLOW TRANSMITTER
%IW5	FIT-1430	RECIRCULATION PUMP FLOW TRANSMITTER
%IW6	FIT-1440	WAS / MIXING PUMP FLOW TRANSMITTER
%IW7	FIT-1710	ION EXCHANGE FLOW TRANSMITTER
%IW8	TT-1200	BIOPROCESS TANK TEMPERATURE TRANSMITTER
%IW9	TT-1310	PERMEATE TEMPERATURE TRANSMITTER
%IW10	PT-1200	BIOPROCESS TANK PRESSURE TRANSMITTER
%IW11	PT-1300	MEMBRANE TANK PRESSURE TRANSMITTER
%IW12	PT-1310	PERMEATE PUMP PRESSURE TRANSMITTER
%IW13	PT-1430	RECIRCULATION PUMP PRESSURE TRANSMITTER
%IW14	PT-1440	WAS PUMP PRESSURE TRANSMITTER
%IW15	PT-1540	VACUUM PUMP PRESSURE TRANSMITTER
%IW16	LT-1200	BIOPROCESS TANK LEVEL TRANSMITTER
%IW17	LT-1220	COLLECTION TANK 1220 LEVEL TRANSMITTER
%IW18	LIT-1300	MEMBRANE TANK LEVEL TRANSMITTER
%IW19	LT-1320	BACKPULSE / CIP TANK LEVEL TRANSMITTER
%IW20	LT-1410	COLLECTION TANK 1410 LEVEL TRANSMITTER
%IW21	LT-1420	COLLECTION TANK 1420 LEVEL TRANSMITTER
%IW22	LT-1540	COLLECTION TANK 1540 LEVEL TRANSMITTER
%IW23	AIT-1231	BIOGAS O2 TRANSMITTER
%IW24	AIT-1232	BIOGAS METHANE TRANSMITTER
%IW25	HSIT-1010	AMBIENT HYDROGEN SULFIDE GAS TRANSMITTER
%IW26	AIT-1010	AMBIENT METHANE GAS TRANSMITTER
%MW10	SIC-1100	FEED PUMP SPEED COMMAND
%MW11	SIC-1310	PERMEATE PUMP SPEED COMMAND
%MW12	SIC-1410	BIOGAS PUMP SPEED COMMAND
%MW13	SIC-1430	RECIRCULATION PUMP SPEED COMMAND
%MW15	SIC-1440	WAS / MIXING PUMP SPEED COMMAND
%MW16	SIC-1540	VACUUM PUMP SPEED COMMAND
%MW17	SIC-1620	RAPID MIXER SPEED COMMAND
%MW18	SIC-1631	FLOCCULATION MIXER 1 SPEED COMMAND
%MW20	SIC-1632	FLOCCULATION MIXER 2 SPEED COMMAND
%MW21	SIC-1633	FLOCCULATION MIXER 3 SPEED COMMAND
%MW22	SIC-1710	ION EXCHANGE PUMP SPEED COMMAND
%MW23	SC-1810	PH ADJUSTMENT FEED PUMP SPEED COMMAND
%MW25	SC-1820	ANTI-FOAM PUMP SPEED COMMAND
%MW26	SC-1830	COAGULANT FEED PUMP SPEED COMMAND
%MW27	SC-1840	SODIUM HYPOCHLORITE FEED PUMP SPEED COMMAND
%MW28	SC-1850	CITRIC ACID FEED PUMP SPEED COMMAND
%IW34.0	PB1	EMERGENCY STOP PUSHBUTTON
%IW34.1	R3	REMOTE START COMMAND

%IW34.2	SIC-1100	FEED PUMP ON/OFF STATUS
%IW34.3	SIC-1310	PERMEATE PUMP ON/OFF STATUS
%IW34.4	SIC-1410	BIOGAS PUMP ON/OFF STATUS
%IW34.5	SIC-1430	RECIRCULATION PUMP ON/OFF STATUS
%IW34.6	SIC-1440	WAS/MIXING PUMP ON/OFF STATUS
%IW34.7	SIC-1540	VACUUM PUMP ON/OFF STATUS
%IW34.8	SIC-1620	RAPID MIXER ON/OFF STATUS
%IW34.9	SIC-1631	FLOCCULATION MIXER 1 ON/OFF STATUS
%IW34.10	SIC-1632	FLOCCULATION MIXER 2 ON/OFF STATUS
%IW34.11	SIC-1633	FLOCCULATION MIXER 3 ON/OFF STATUS
%IW34.12	SIC-1710	ION EXCHANGE PUMP ON/OFF STATUS
%IW34.13	PSH	FEED PUMP DISCHARGE PRESSURE HIGH SWITCH
%IW34.14	FIT-1310	PERMEATE FLOW DIRECTION
%MW35.0	L1	ON LIGHT
%MW35.1	L2	ALARM LIGHT
%MW35.2	SIC-1100	FEED PUMP ON/OFF COMMAND
%MW35.3	SIC-1310	PERMEATE PUMP FORWARD ON/OFF COMMAND
%MW35.4	SIC-1410	BIOGAS PUMP ON/OFF COMMAND
%MW35.5	SIC-1430	RECIRCULATION PUMP ON/OFF COMMAND
%MW35.6	SIC-1440	WAS / MIXING PUMP ON/OFF COMMAND
%MW35.7	SIC-1540	VACUUM PUMP ON/OFF COMMAND
%MW35.8	SIC-1620	RAPID MIXER ON/OFF COMMAND
%MW35.9	SIC-1631	FLOCCULATION MIXER 1 ON/OFF COMMAND
%MW35.10	SIC-1632	FLOCCULATION MIXER 2 ON/OFF COMMAND
%MW35.11	SIC-1633	FLOCCULATION MIXER 3 ON/OFF COMMAND
%MW35.12	SIC-1700	ION EXCHANGE PUMP ON/OFF COMMAND
%MW35.13	R4	DCF STRAINER PURGE VALVE ON/OFF COMMAND
%MW35.14	R5	DCF STRAINER CLEANING DISC COMMAND
%MW35.15	L	HIGH AMBIENT GAS ALARM BEACON
%IW36.0	PIT-1910	SUPPLY AIR PRESSURE LOW STATUS
%IW36.1	LSH-1801	CHEMICAL LEAK DETECTION
%IW36.2	LSH-1802	CHEMICAL LEAK DETECTION
%IW36.3	SC-1810	PH ADJUSTMENT FEED PUMP MOTOR FAULT
%IW36.4	SC-1820	ANTI-FOAM FEED PUMP MOTOR FAULT
%IW36.5	SC-1830	COAGULANT FEED PUMP MOTOR FAULT
%IW36.6	SC-1840	SODIUM HYPOCHLORITE FEED PUMP MOTOR FAULT
%IW36.7	SC-1850	CITRIC ACID FEED PUMP MOTOR FAULT
%MW37.0	SIC-1310	PERMEATE PUMP REVERSE ON/OFF COMMAND
%MW1026	PHT-1450	WAS/MIXING PH TRANSMITTER
%MW1040	TUT-1310	PERMEATE TURBIDITY TRANSMITTER
%MW1500.0	DV-1229	COLLECTION TANK 1220 DRAIN VALVE
%MW1500.1	DV-1409	MEMBRANE TANK 1300 DRAIN VALVE
%MW1500.2	DV-1311	SODIUM HYPOCHLORITE INJECTION VALVE
%MW1500.3	DV-1312	CITRIC ACID INJECTION VALVE
%MW1500.4	DV-1316	BACKPULSE/CIP TANK INLET VALVE
%MW1500.5	DV-1317	MEMBRANE CONTACTOR INLET VALVE
%MW1500.6	DV-1319	PERMEATE TO WASTE VALVE

%MW1500.7	DV-1321	BACKPULSE/CIP TANK POTABLE WATER INLET VALVE
%MW1501.0	DV-1419	COLLECTION TANK 1410 DRAIN VALVE
%MW1501.1	DV-1425	MEMBRANE GAS-SPARGE INLET VALVE
%MW1501.2	DV-1426	MEMBRANE GAS-SPARGE INLET VALVE
%MW1501.3	DV-1429	COLLECTION TANK 1420 DRAIN VALVE
%MW1501.4	DV-1435	RECIRCULATION VALVE
%MW1501.5	DV-1436	DEFOAM RECIRCULATION VALVE
%MW1501.6	DV-1454	BIOPROCESS MIXING VALVE
%MW1501.7	DV-1455	BIOPROCESS TO WASTE VALVE
%MW1502.0	DV-1308	RECIRCULATION VALVE
%MW1502.1	DV-1441	WAS/MIXING PUMP INLET VALVE
%MW1502.2	DV-1442	MEMBRANE TO WASTE VALVE

MEMBRANE SEQUENCE MATRIX

STEP NUMBER	STEP DESCRIPTION	AUTO STEP ADVANCE		MANUAL STEP ADVANCE		FLOW							DEVICES																														
		CONDITION	GO TO STEP	CONDITION	GO TO STEP	FEED	PERMEATE / BACKPULSE	BIOGAS	RECIRCULATION	WAS / MIXING	MEMBRANE VACUUM	ION EXCHANGE	1 FEED PUMP 1100	2 1310 (FORWARD COMMAND) PERMEATE/BACKPULSE PUMP	3 1310 (REVERSE COMMAND) PERMEATE/BACKPULSE PUMP	4 BIOGAS SPARGE PUMP 1410	5 RECIRCULATION PUMP 1430	6 WAS/MIXING PUMP 1440	7 MEMBRANE VACUUM PUMP 1540	8 ION EXCHANGE PUMP 1710	9 PH ADJUSTMENT PUMP 1810	10 ANTI-FOAM PUMP 1820	11 COAGULANT FEED PUMP 1830	12 SODIUM HYPOCHLORITE PUMP 1840	13 CITRIC ACID PUMP 1850	14	15 COLLECTION TANK 1220 DRAIN VALVE DV-1228	16 INJECTION VALVE DV-1311 SODIUM HYPOCHLORITE	17 DV-1312 CITRIC ACID INJECTION VALVE	18 VALVE DV-1316 BACKPULSE/CIP TANK INLET	19 VALVE DV-1317 MEMBRANE CONTACTOR INLET	20 WATER INLET VALVE DV-1321 BACKPULSE/CIP TANK POTABLE	21 VALVE DV-1409 MEMBRANE TANK 1300 DRAIN	22 VALVE DV-1419 COLLECTION TANK 1410 DRAIN	23 UPPER IN-FT VALVE DV-1425 MEMBRANE GAS-SPARGE	24 LOWER IN-FT VALVE DV-1426 MEMBRANE GAS-SPARGE	25 VALVE DV-1429 COLLECTION TANK 1420 DRAIN	26 RECIRCULATION VALVE DV-1436	27 DV-1435 DEFOAM RECIRCULATION VALVE	28 1454 BIOPROCESS MIXING VALVE DV-	29 DV-1455 BIOPROCESS TO WASTE VALVE	30 DV-1441 WAS/MIXING PUMP INLET VALVE	31 DV-1442 MEMBRANE TO WASTE VALVE	32 MIXED LIQUOR VALVE DV-1308
0	OFFLINE	EVENT 1	1	EVENT 2	4,5,6,7,9,16																																						
1	PRE PRODUCTION - SPARGE	TIME	2	TIME	2	FLOW 1		FLOW 1	FLOW 1	FLOW 1	PRESSURE	FLOW 1	X			X	X	X	X		E		E				E				X	E		E	E	E	E	X		X		X		X
2	PRE PRODUCTION	TIME	3	TIME	3	FLOW 1	FLOW 1	FLOW 1	FLOW 1	FLOW 1	PRESSURE	FLOW 1	X	X		X	X	X	X		E		E				E			E	X	E		E	E	E	E	X		X		X		X
3	PRODUCTION	EVENT 3	4,5,6,7,9	EVENT 2	0,4,5,6,7,9	FLOW 1	FLOW 2	FLOW 1	FLOW 1	FLOW 1	PRESSURE	FLOW 1	X	X		X	X	X	X	X	E		E				E			E	X	E		E	E	E	E	X		X		X		X
4	RELAX	TIME	3	TIME	3	FLOW 1		FLOW 1	FLOW 1	FLOW1			X			X	X	X	X								E							E	E	E	E	X		X		X		X
5	DEFOAM	TIME	3	TIME	3	FLOW 1	FLOW 2	FLOW 1	FLOW 2	FLOW 1	PRESSURE	FLOW 1	X	X		X	X	X	X	X	E	X	E				E			E	X	E		E	E	E	E		X	X		X		X
6	W.A.S. TO WASTE	EVENT 4	3	EVENT 4	3	FLOW 1	FLOW 2	FLOW 1	FLOW 1	FLOW 2	PRESSURE	FLOW 1	X	X		X	X	X	X	X	E		E				E			E	X	E		E	E	E	E	X			X	X		X
7	BACKPULSE	TIME	8	TIME	8	FLOW 1	FLOW 3	FLOW 1	FLOW 1				X		X	X	X	X	X		E		E				E			X		E		E	E	E	E	X		X		X		X
8	BACKPULSE - RELAX	TIME	3	TIME	3	FLOW 1		FLOW 1	FLOW 1	FLOW 1			X			X	X	X	X		E		E				E							E	E	E	E	X		X		X		X
9	MAINTENANCE CLEAN - PERMEATE OFF 1	TIME	10	TIME	10			FLOW 1	FLOW 1	FLOW 1	PRESSURE					X	X	X	X		E						E							E	E	E	E	X		X		X		X
10	MAINTENANCE CLEAN - CHEM BACKPULSE 1	TIME*	11	TIME	11		FLOW 4			FLOW 1	PRESSURE					X			X	X		E				E	E							E				E		X		X		X
11	MAINTENANCE CLEAN - RELAX 1	TIME	12	TIME	12					FLOW 1	PRESSURE								X	X		E													E				E		X		X		X
12	MAINTENANCE CLEAN - CHEM BACKPULSE 2	TIME*	13	TIME	13		FLOW 5			FLOW 1	PRESSURE					X			X	X		E				E	E							E				E		X		X		X
13	MAINTENANCE CLEAN - RELAX 2	TIME	12,14	TIME	12,14					FLOW 1	PRESSURE								X	X		E													E				E		X		X		X
14	MAINTENANCE CLEAN - CLEAN BACKPULSE	TIME*	15	TIME	15		FLOW 6			FLOW 1	PRESSURE					X			X	X		E									X			E				E		X		X		X
15	MAINTENANCE CLEAN - PERMEATE OFF 2	TIME	3,9	TIME	0,9			FLOW 1		FLOW 1	PRESSURE						X		X	X		E													E	E	E	E			X		X		X
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LEGEND	
X	OPEN OR RUNNING
E	ENABLED
TIME	TIME SETPOINT
FLOW	FLOW SETPOINT
EVENT 1	SYSTEM MODE IS AUTO
EVENT 2	SYSTEM MODE IS SEMI, AND OPERATOR PRESSES THE PRODUCTION, DEFOAM, WAS TO WASTE, RELAX/BACKPULSE, MAINTENANCE CLEAN OR RECOVERY CLEAN BUTTON.
EVENT 3	SYSTEM MODE IN AUTO AND THE RELAX, BACKPULSE, DEFOAM, WAS TO WASTE OR MAINTENANCE CLEAN IS CONFIGURED AND RUNTIME HAS EXCEEDED THE DEFINED LIMIT.
EVENT 4	PRE-DEFINED VOLUME HAS BEEN PUMPED TO WASTE.
EVENT 5	MEMBRANE TANK LEVEL IS LESS THAN CONFIGURED STEP LIMIT
EVENT 6	CONTINUE BACKPULSE-FILL / RELAX CYCLE BASED ON CONFIGURED TIME LIMIT UNTIL MEMBRANE TANK LEVEL IS GREATER THAN CONFIGURED STEP LIMIT
EVENT 7	MEMBRANE TANK LEVEL IS GREATER THAN CONFIGURED STEP LIMIT

* HIGH TANK LEVEL WILL ALSO ADVANCE STEP

STEP NUMBER	STEP DESCRIPTION	AUTO STEP ADVANCE		MANUAL STEP ADVANCE		FLOW							FIELD DEVICES																																			
		CONDITION	GO TO STEP	CONDITION	GO TO STEP	FEED	PERMEATE / BACKPULSE	BIOGAS	RECIRCULATION	WAS / MIXING	MEMBRANE VACUUM	ION EXCHANGE	1 FEED PUMP 1100	2 PERMEATE/BACKPULSE PUMP 1310 (FORWARD COMMAND)	3 PERMEATE/BACKPULSE PUMP 1310 (REVERSE COMMAND)	4 BIOGAS SPARGE PUMP 1410	5 RECIRCULATION PUMP 1430	6 WAS/MIXING PUMP 1440	7 MEMBRANE VACUUM PUMP 1540	8 ION EXCHANGE PUMP 1710	9 PH ADJUSTMENT PUMP 1810	10 ANTI-FOAM PUMP 1820	11 COAGULANT FEED PUMP 1830	12 SODIUM HYPOCHLORITE PUMP 1840	13 CITRIC ACID PUMP 1850	14	15 VALVE DV-1229	16 INJECTION VALVE DV-1311	17 CITRIC ACID INJECTION VALVE DV-1312	18 BACKPULSE/CIP TANK INLET VALVE DV-1316	19 VALVE DV-1317	20 BACKPULSE/CIP TANK POTABLE WATER INLET VALVE DV-1321	21 MEMBRANE TANK 1300 DRAIN VALVE DV-1409	22 COLLECTION TANK 1410 DRAIN VALVE DV-1419	23 INLET VALVE DV-1425	24 MEMBRANE GAS-SPARGE UPPER INLET VALVE DV-1426	25 COLLECTION TANK 1420 DRAIN VALVE DV-1429	26 RECIRCULATION VALVE DV-1436	27 DEFOAM RECIRCULATION VALVE DV-1435	28 BIOPROCESS MIXING VALVE DV-1454	29 BIOPROCESS TO WASTE VALVE DV-1455	30 WAS/MIXING PUMP INLET VALVE DV-1441	31 MEMBRANE TO WASTE VALVE DV-1442	32 MIXED LIQUOR VALVE DV-1308
0	OFFLINE	EVENT 1	1	EVENT 1	1																																												
1	R.C. - PERMEATE OFF	TIME	2	TIME	2			FLOW 1	FLOW 1	FLOW 1						X	X	X			E						E					E		E	E	E	E	X		X			X	
2	R.C.- MEMBRANE DRAIN 1	EVENT 2	3	EVENT 2	3													X									E					E					E			X			X	
3	R.C.- MEMBRANE FILL	EVENT 3	4	EVENT 3	4		FLOW 7			FLOW 1					X			X			E						E			X		E		E			E			X		X		
4	R.C.- BIOGAS SPARGE	TIME	5	TIME	5			FLOW 2		FLOW 1						X		X			E						E					E		E	E	E	E			X		X		
5	R.C.- MEMBRANE DRAIN TO WASTE 1	EVENT 2	6	EVENT 2	6					FLOW 1								X			E						E					E	X	E			E			X		X		
6	R.C.- CHEM BACKPULSE FILL 1	EVENT 4	7	EVENT 4	7		FLOW 7			FLOW 1					X			X			E			E	E		E	E	E	X		E		E			E			X		X		
7	R.C.- CLEAN BACKPULSE FILL 1	EVENT 5	8	EVENT 5	8		FLOW 7			FLOW 1					X			X			E						E			X		E		E			E			X		X		
8	R.C.- SOAK 1	TIME	9	TIME	9					FLOW 1								X			E						E					E		E			E			X		X		
9	R.C.- MEMBRANE DRAIN TO WASTE 2	EVENT 6	10	EVENT 6	10					FLOW 1								X			E						E					E	X	E			E			X		X		
10	R.C.- CHEM BACKPULSE FILL 2	EVENT 4	11	EVENT 4	11		FLOW 7			FLOW 1					X			X			E			E	E		E	E	E	X		E		E			E			X		X		
11	R.C.- CLEAN BACKPULSE FILL 2	EVENT 5	12	EVENT 5	12		FLOW 7			FLOW 1					X			X			E						E			X		E		E			E			X		X		
12	R.C.- SOAK 2	TIME	13	TIME	13					FLOW 1								X			E						E					E		E			E			X		X		
13	R.C.- MEMBRANE DRAIN TO WASTE 3	EVENT 6	14	EVENT 6	14					FLOW 1								X			E						E					E	X	E			E			X		X		
14	R.C.- PERMEATE FILL	EVENT 3	15	EVENT 7	15		FLOW 7			FLOW 1					X			X			E						E			X		E		E			E			X		X		
15	R.C.- SOAK	TIME	16	TIME	16					FLOW 1								X			E						E					E		E			E			X		X		
16	R.C.- MEMBRANE DRAIN TO WASTE 4	EVENT 2	0	EVENT 2	0					FLOW 1								X			E						E					E	X	E			E			X		X		
17																																																
18																																																
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LEGEND	
X	OPEN OR RUNNING
E	ENABLED
TIME	TIME SETPOINT
FLOW	FLOW SETPOINT
EVENT 1	SYSTEM MODE IS SEMI, AND OPERATOR PRESSES THE RECOVERY CLEAN BUTTON.
EVENT 2	MEMBRANE TANK LEVEL IS LESS THAN CONFIGURED STEP LIMIT
EVENT 3	MEMBRANE TANK LEVEL IS GREATER THAN CONFIGURED STEP LIMIT
EVENT 4	MEMBRANE TANK LEVEL IS REACHES 90%
EVENT 5	MEMBRANE TANK LEVEL IS REACHES 100%
EVENT 6	MEMBRANE TANK LEVEL IS LESS THAN CONFIGURED STEP LIMIT

STRAINER SEQUENCE MATRIX

STEP NUMBER	STEP DESCRIPTION	AUTO STEP ADVANCE		MANUAL STEP ADVANCE		FLOW	FIELD DEVICES									
							1	2	3	4	5	6	7	8	9	10
		CONDITION	GO TO STEP	CONDITION	GO TO STEP	FEED	FEED PUMP 1100		DCF STRAINER DISC EXTEND	DCF STRAINED PURGE VALVE						
0	NORMAL OPERATION	EVENT 1	1	EVENT 2	1	FLOW 1	X									
1	STRAINER - PRE FLOW	TIME	2	TIME	2	FLOW 2	X									
2	STRAINER - PLUNGER EXTEND	TIME	3	TIME	3	FLOW 2	X		X							
3	STRAINER - VALVE OPEN	TIME	4	TIME	4	FLOW 2	X		X	X						
4	STRAINER - PLUNGER RETRACT	TIME	0	TIME	0	FLOW 2	X									
5																
6																
7																
8																
9																
10																
11																
12																
13																

LEGEND	
X	OPEN OR RUNNING
TIME	TIME SETPOINT
FLOW	FLOW SETPOINT
EVENT 1	FEED PUMP RUNTIME HAS EXCEEDED THE DEFINED LIMIT
EVENT 2	SYSTEM IS IN OPERATION AND AN OPERATOR PRESSES THE FILTER STRAIN BUTTON

DECLARATION OF CONFORMITY

IN ACCORDANCE TO ISO/IEC GUIDE 22

FOR A

Liquid Pump

CE Ex II 2 G D c TX

MANUFACTURER: **Gardner Denver Oberdorfer Pumps**
5900 Firestone Drive
Syracuse, NY 13206 USA
Phone: 315 437-0361
Fax: 315 463-9561

MODEL NUMBERS: Chemsteel™ Sealed Metal Pump Heads of type R102, R103, R104, R106, S103, S104, S106, S207, S210, S214, S417, S923, S930, S935, or S946 (exclusively configured with mechanical shaft seals)

Chemsteel™ Seal-less Mag Drive Metallic Pump Heads of type RM102, RM103, RM104, RM106, SM103, SM104, SM106, SM207, SM210, SM214, SM417, SM923, SM930, SM935 or SM946 (exclusively configured with metallic containment cans)

REPORT#: SF-OBERDOR-051404-01S

TECHNICAL FILE#: CSAX 07-04

DIRECTIVES: ATEX Directive 94/9/EC EN13463-1:2009, EN 13463-5:2011

STANDARDS:

- Non-electrical equipment for potentially explosive atmospheres Part 1: Basic method and requirements, EN 13463-1:2009
- Non-electrical equipment for use in potentially explosive atmospheres Part 5: Protection by constructional safety, EN 13463- 5:2011

TEST FACILITY: **Gardner Denver Oberdorfer Pumps**
5900 Firestone Drive
Syracuse, NY 13206 USA

The Oberdorfer Pumps, Model Chemsteel™ Liquid Pumps are in effective conformance to the Directives and Standards referenced above. The technical file and documentation (has been submitted to the designated Notified Body:

Intertek Testing & Certification Ltd (0359)
Chester, UK
CH1 6DD
Ref 04014624 (G101763708)

Authorized by: *David Asermily*
Date: 27 June 2014

Name: David Asermily
Title: Engineering Manager

Gas Detection For Life

CALIBRATION CERTIFICATION FOR RKI INSTRUMENTS PRODUCT

Instrument Model: M2A IR Transmitter **Part Number:** 65-2649RK-CH4

Serial Number: M2A643852

RKI Instruments, Inc. certifies that this instrument has been tested, inspected and calibrated by a qualified technician and was found to meet or exceed the manufacturer's specifications per ISO 9001 Quality System. The primary error source for this calibration is the accuracy of the gas. Gases are certified by the manufacturer at ±1% to ±15% by volume using a gravimetric method of analysis against NIST traceable weights. All test and calibration records are maintained at RKI Instruments Inc. This certificate shall not be reproduced except in full, without the written approval of RKI Instruments, Inc.

Test Conditions: 74 °F 50 RH

Channel Number	Calibration gas & concentration	Fresh air reading	Span Set to	Gas Mfg. Co. Lot No.	Cyl Exp Month
1	50 %LEL CH4	0 %LEL	50 %LEL	Air Liquide SBO0104896	Jan-18
2					
3					
4					
5					
6					
7					
8					

Instrument reading is within +/- 5% of Calibration Gas.

Calibrated by: Anthony Iglesias Date: April 1, 2016

Calibration Certified by: Date: 04-01-16

RKI Instruments, Inc. • 33248 Central Avenue, Union City, CA 94587 • Phone (510) 441-5656 • (800) 754-5165 • Fax (510) 441-5650

Gas Detection For Life

CALIBRATION CERTIFICATION FOR RKI INSTRUMENTS PRODUCT

Instrument Model: M2A H2S Transmitter **Part Number:** 65-2645RK-05

Serial Number: M2A644042

RKI Instruments, Inc. certifies that this instrument has been tested, inspected and calibrated by a qualified technician and was found to meet or exceed the manufacturer's specifications per ISO 9001 Quality System. The primary error source for this calibration is the accuracy of the gas. Gases are certified by the manufacturer at ±1% to ±15% by volume using a gravimetric method of analysis against NIST traceable weights. All test and calibration records are maintained at RKI Instruments Inc. This certificate shall not be reproduced except in full, without the written approval of RKI Instruments, Inc.

Test Conditions: 74 °F 50 RH

Channel Number	Calibration gas & concentration	Fresh air reading	Span Set to	Gas Mfg. Co. Lot No.	Cyl Exp Month
1	24 PPM H2S	0 PPM	24 PPM	Air Liquide 401-150200	Nov-18
2					
3					
4					
5					
6					
7					
8					

Instrument reading is within +/- 5% of Calibration Gas.

Note:

Calibrated by: Anthony Iglesias Date: April 1, 2016

Calibration Certified by: A. Iglesias Date: 04-01-16

RKI Instruments, Inc. • 33248 Central Avenue, Union City, CA 94587 • Phone (510) 441-5656 • (800) 754-5165 • Fax (510) 441-5650

RT Test Certificate

Sensor Model Number		**RT1173**
Sensor Serial Number		**B46472**
Characteristic	**Requirement**	**Result**
Calibration	Calibration per RT Test	Pass
	Programming of Serial Number	Pass
	Read back of code version	2.17
	Read back of serial number	Pass
	Read back of sensor value (NTU) in test sample	Pass
	Read back of sensor information when configured as a system per customer order if applicable	Pass

Certified by:

Thermo Fisher Scientific
Water and Lab Products
Quality Assurance

Date: 02/26/2016

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Water and Lab Products

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Tel: (613) 9757-4300
In Australia: (1300) 735-295
InfoWaterAU@thermofisher.com

Thermo SCIENTIFIC
A Thermo Fisher Scientific Brand

CERTIFICATE OF COMPLIANCE (COC)

Liqui-Cel® Extra-Flow Contactor Product(s):

GROUP TYPE	CARTRIDGE NUMBER	PRODUCT SERIAL NUMBER	INTEGRITY TESTS ---------- PASS/FAIL	DIMESIONAL TESTS ---------- PASS/FAIL	PERFORMANCE TESTS ---------- PASS/FAIL	PRESSURE DROP ---------- PASS/FAIL	FINAL INSPECTION ---------- PASS/FAIL
G492	S09558913	S09773163	PASS	PASS	PASS	PASS	PASS

Fully assembled products are manufactured with Sound Engineering Practice (SEP) according to European PED Regulations.

THIS CERTIFIES THAT THE PRODUCT DESCRIBED ABOVE MEETS THE APPLICABLE PRODUCT SPECIFICATION.

Kind regards,

Mark Norton
Plant Manager
3M Industrial Business Group
Membranes Business Unit USA

Industrial Business Group
Membranes Business Unit
13840 South Lakes Drive
Charlotte, North Carolina 28273
USA

Phone: +1 704 587 8888
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3M Deutschland GmbH
Membranes Business Unit
Öhder Straße 28
42289 Wuppertal
Germany

Phone: +49 202 6099 - 658
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3M Japan Ltd.
Membranes Business Unit
6-7-29, Kita-Shinagawa,
Shinagawa-ku, Tokyo 141-8684
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Endress+Hauser GmbH+Co.
2340 Endress Place
Greenwood, In. 46143-9772

Final Inspection Report / Endprüfprotokoll

The manufacturer confirms that all measuring equipment used to assure the quality of the products has been calibrated and is traceable to national (e.g. DKD/DAkkS, NIST, NABL...) or international standards.

Der Hersteller bestätigt, dass die zu Qualitätsprüfungen des Erzeugnisses eingesetzten Messmittel gültig kalibriert waren und auf nationale (z.B. DKD/DAkkS, NIST, NABL...) bzw. internationale Normale rückführbar sind.

Cerabar M

TAG number	Messstellen-Nummer	
Order code	Bestellcode	PMC51-2CWV9/0
Serial number	Seriennummer	L200DE15128
Extended order code	Erweiterter Bestellcode	PMC51-FA22ID1KGFRLCA
Sensor range	Sensor-Messbereich	-15..30 psi
Adjusted measuring range	Eingestellter Messbereich	0...30 psi
Maximum permissible error	Max. zulässige Messabweichung	± 0.15 %
Output type	Ausgang	4...20 mA HART
Software version	Softwareversion	01.00.03
Output mode	Ausgangsmodus	linear

INTUITECH INC

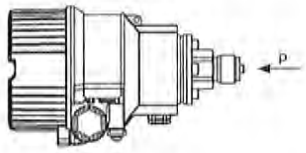
Customer order number	Auftragsnummer des Kunden	2016-19348
E+H sales order number	E+H Auftragsnummer	3018431628000030
Internal order number	Interne Auftragsnummer	3800205959/0030

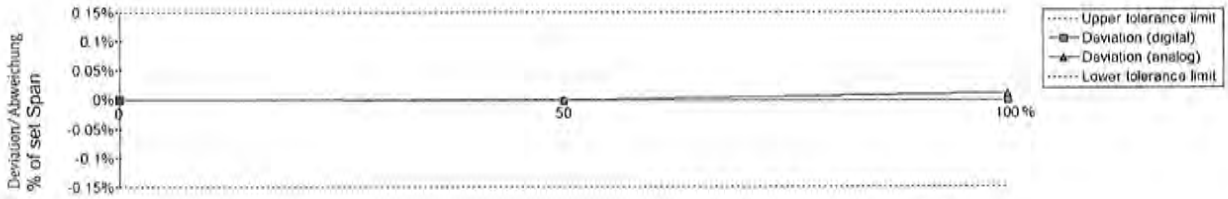
Ambient temperature	Umgebungs-Temperatur	22.4 °C (± 1 °C)
Ambient humidity	Umgebungs-Luftfeuchte	26.3 %rel.F (± 10 %rel.F)
Ambient pressure	Umgebungs-Luftdruck	962.1 mbar (± 0.2 mbar)
Calibrated according to fix point method IEC 60770.	Prüfung nach Grenzpunktmethode gemäß IEC 60770.	

Measuring results / Messergebnisse

Calibration point / Kalibrierpunkt	Nominal value ($p_{Ref.}$) / Sollwert ($p_{Ref.}$)	Measured value (digital readout) / Istwert (Digitaler Wert)	Deviation (digital) / Abweichung (digital)	Nominal value (I_{Out} calculated) / Sollwert (I_{Out} berechnet)	Current output (analog) / Istwert Stromausgang (analog)	Rel. deviation (analog) / Rel. Abweichung (analog)
%	psi	psi	% of Span	mA	mA	%
0	0.00090	0.00132	0.00146	4.00048	4.00042	-0.00037
50	15.0894	15.0887	-0.00254	12.04768	12.04762	-0.00041
100	29.4160	29.4159	-0.00061	19.68856	19.69031	0.01132

Calibration orientation
Kalibrierlage





Calibration carried out in output mode linear/
Kalibration erfolgte im Ausgangsmodus linear.

Measuring point in % of adjusted measuring range/
Messpunkt in % vom eingestellten Messbereich

We confirm that all tests, according to the Inspection and Test Plan (ITP), have been performed successfully. At the time of verification, the measuring points of the device indicated above were in compliance to the published valid technical specification (TI).

Wir bestätigen, dass alle Tests aus den Inspektions- und Testplänen (ITP) erfolgreich durchgeführt wurden. Das Gerät entsprach zum Zeitpunkt der Prüfung an den aufgeführten Messpunkten den gültigen technischen Spezifikationen (TI).

TI 436P

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Operator / geprüft durch 155448
Date of inspection / Prüfdatum 24. Feb 2016

Endress+Hauser
People for Process Automation

Endress+Hauser GmbH+Co.
2340 Endress Place
Greenwood, In. 46143-9772

Final Inspection Report / Endprüfprotokoll

The manufacturer confirms that all measuring equipment used to assure the quality of the products has been calibrated and is traceable to national (e.g. DKD/DAkkS, NIST, NABL...) or international standards

Der Hersteller bestätigt, dass die zu Qualitätsprüfungen des Erzeugnisses eingesetzten Messmittel gültig kalibriert waren und auf nationale (z.B. DKD/DAkkS, NIST, NABL...) bzw. internationale Normale rückführbar sind.

Cerabar M

TAG number	Messstellen-Nummer	
Order code	Bestellcode	PMC51-2CWV9/0
Serial number	Seriennummer	L200DD15128
Extended order code	Erweiterter Bestellcode	PMC51-FA22ID1KGFRLCA
Sensor range	Sensor-Messbereich	-15...30 psi
Adjusted measuring range	Eingestellter Messbereich	0...30 psi
Maximum permissible error	Max. zulässige Messabweichung	± 0.15 %
Output type	Ausgang	4...20 mA HART
Software version	Softwareversion	01.00.03
Output mode	Ausgangsmodus	linear

INTUITECH INC

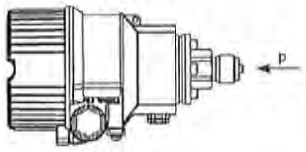
Customer order number	Auftragsnummer des Kunden	2016-19348
E+H sales order number	E+H Auftragsnummer	3018431628000030
Internal order number	Interne Auftragsnummer	3800205959/0030

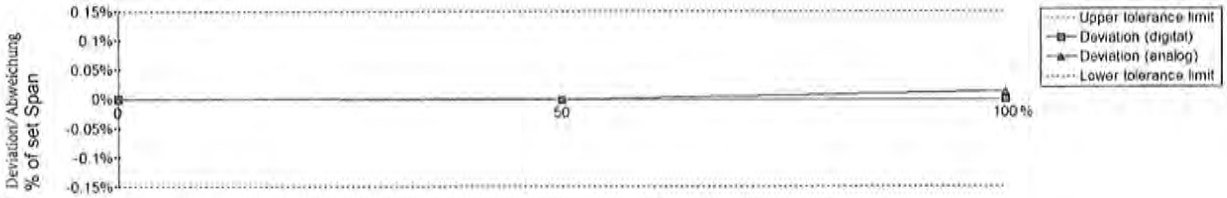
Ambient temperature	Umgebungs-Temperatur	22.4 °C (± 1 °C)
Ambient humidity	Umgebungs-Luftfeuchte	26.3 %rel.F (± 10 %rel.F)
Ambient pressure	Umgebungs-Luftdruck	962.1 mbar (± 0.2 mbar)
Calibrated according to fix point method IEC 60770.	Prüfung nach Grenzpunktmethode gemäß IEC 60770.	

Measuring results / Messergebnisse

Calibration point	Nominal value ($p_{Ref.}$)	Measured value (digital readout)	Deviation (digital)	Nominal value (I_{Out} calculated)	Current output (analog)	Rel. deviation (analog)
Kalibrierpunkt	Sollwert ($p_{Ref.}$)	Istwert (Digitaler Wert)	Abweichung (digital)	Sollwert (I_{Out} berechnet)	Istwert Stromausgang (analog)	Rel. Abweichung (analog)
%	psi	psi	% of Span	mA	mA	%
0	0.00090	0.00122	0.00111	4.00048	4.00046	-0.00013
50	15.0891	15.0884	-0.00224	12.04752	12.04746	-0.00041
100	29.4151	29.4148	-0.00121	19.68808	19.69006	0.01283

Calibration orientation
Kalibrierlage





Calibration carried out in output mode linear/
Kalibration erfolgte im Ausgangsmodus linear.

Measuring point in % of adjusted measuring range/
Messpunkt in % vom eingestellten Messbereich

We confirm that all tests, according to the Inspection and Test Plan (ITP), have been performed successfully. At the time of verification, the measuring points of the device indicated above were in compliance to the published valid technical specification (TI).

Wir bestätigen, dass alle Tests aus den Inspektions- und Testplänen (ITP) erfolgreich durchgeführt wurden. Das Gerät entsprach zum Zeitpunkt der Prüfung an den aufgeführten Messpunkten den gültigen technischen Spezifikationen (TI).

TI 436P

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Dieses Dokument wurde elektronisch erzeugt und ist ohne Unterschrift gültig.

Operator / geprüft durch 155448
Date of inspection / Prüfdatum 24. Feb 2016

Endress+Hauser
People for Process Automation

Endress+Hauser GmbH+Co.
2340 Endress Place
Greenwood, In. 46143-9772

Final Inspection Report / Endprüfprotokoll

The manufacturer confirms that all measuring equipment used to assure the quality of the products has been calibrated and is traceable to national (e.g. DKD/DAkkS, NIST, NABL...) or international standards.

Der Hersteller bestätigt, dass die zu Qualitätsprüfungen des Erzeugnisses eingesetzten Messmittel gültig kalibriert waren und auf nationale (z.B. DKD/DAkkS, NIST, NABL...) bzw. internationale Normale rückführbar sind.

Cerabar M

TAG number	Messstellen-Nummer	
Order code	Bestellcode	PMC51-2CWV9/0
Serial number	Seriennummer	L200DC15128
Extended order code	Erweiterter Bestellcode	PMC51-FA22ID1KGFRLCA
Sensor range	Sensor-Messbereich	-15...30 psi
Adjusted measuring range	Eingestellter Messbereich	0...30 psi
Maximum permissible error	Max. zulässige Messabweichung	± 0.15 %
Output type	Ausgang	4...20 mA HART
Software version	Softwareversion	01.00.03
Output mode	Ausgangsmodus	linear

INTUITECH INC

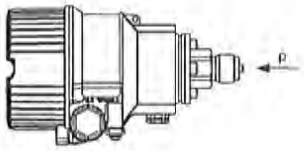
Customer order number	Auftragsnummer des Kunden	2016-19348
E+H sales order number	E+H Auftragsnummer	3018431628000030
Internal order number	Interne Auftragsnummer	3800205959/0030

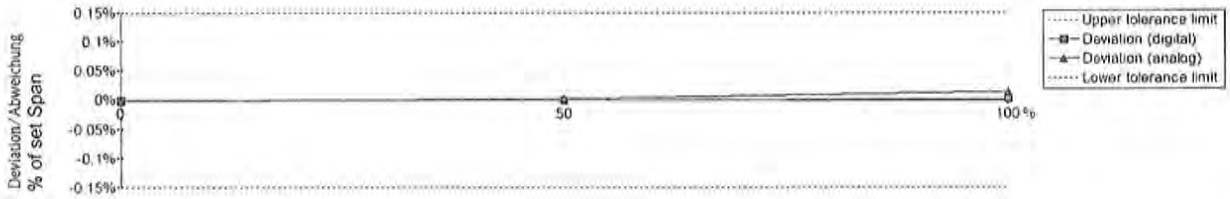
Ambient temperature	Umgebungs-Temperatur	22.4°C (± 1 °C)
Ambient humidity	Umgebungs-Luftfeuchte	25.9 %rel.F (± 10 %rel.F)
Ambient pressure	Umgebungs-Luftdruck	961.9 mbar (± 0.2 mbar)
Calibrated according to fix point method IEC 60770.	Prüfung nach Grenzpunktmethode gemäß IEC 60770.	

Measuring results / Messergebnisse

Calibration point / Kalibrierpunkt	Nominal value ($p_{Ref.}$) Sollwert ($p_{Ref.}$)	Measured value (digital readout) Istwert (Digitaler Wert)	Deviation (digital) Abweichung (digital)	Nominal value (I_{Out} calculated) Sollwert (I_{Out} berechnet)	Current output (analog) Istwert Stromausgang (analog)	Rel. deviation (analog) Rel. Abweichung (analog)
%	psi	psi	% of Span	mA	mA	%
0	0.00090	0.00087	-0.00010	4.00048	4.00013	-0.00226
50	15.1680	15.1680	-0.00011	12.08980	12.08993	0.00210
100	29.9619	29.9623	0.00151	19.97968	19.98192	0.01445

Calibration orientation
Kalibrierlage





Calibration carried out in output mode linear/
Kalibration erfolgte im Ausgangsmodus linear.

Measuring point in % of adjusted measuring range/
Messpunkt in % vom eingestellten Messbereich

We confirm that all tests, according to the Inspection and Test Plan (ITP), have been performed successfully. At the time of verification, the measuring points of the device indicated above were in compliance to the published valid technical specification (TI).

Wir bestätigen, dass alle Tests aus den Inspektions- und Testplänen (ITP) erfolgreich durchgeführt wurden. Das Gerät entsprach zum Zeitpunkt der Prüfung an den aufgeführten Messpunkten den gültigen technischen Spezifikationen (TI).

TI 436P

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Operator / geprüft durch 155448
Date of inspection / Prüfdatum 24. Feb 2016

Endress+Hauser
People for Process Automation

End of document
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Endress+Hauser GmbH+Co.
2340 Endress Place
Greenwood, In. 46143-9772

Final Inspection Report / Endprüfprotokoll

The manufacturer confirms that all measuring equipment used to assure the quality of the products has been calibrated and is traceable to national (e.g. DKD/DAkkS, NIST, NABL...) or international standards.

Der Hersteller bestätigt, dass die zu Qualitätsprüfungen des Erzeugnisses eingesetzten Messmittel gültig kalibriert waren und auf nationale (z.B. DKD/DAkkS, NIST, NABL...) bzw. internationale Normale rückführbar sind.

Cerabar M

TAG number	Messstellen-Nummer	
Order code	Bestellcode	PMC51-40JU2/0
Serial number	Seriennummer	L200DA15128
Extended order code	Erweiterter Bestellcode	PMC51-FA22ID1FGFRLCA
Sensor range	Sensor-Messbereich	-6...6 psi
Adjusted measuring range	Eingestellter Messbereich	0...6 psi
Maximum permissible error	Max. zulässige Messabweichung	± 0.15 %
Output type	Ausgang	4...20 mA HART
Software version	Softwareversion	01.00.03
Output mode	Ausgangsmodus	linear

INTUITECH INC

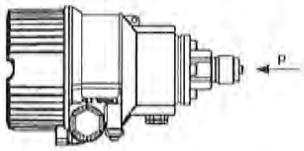
Customer order number	Auftragsnummer des Kunden	2016-19348
E+H sales order number	E+H Auftragsnummer	3018431628000020
Internal order number	Interne Auftragsnummer	3800205959/0020

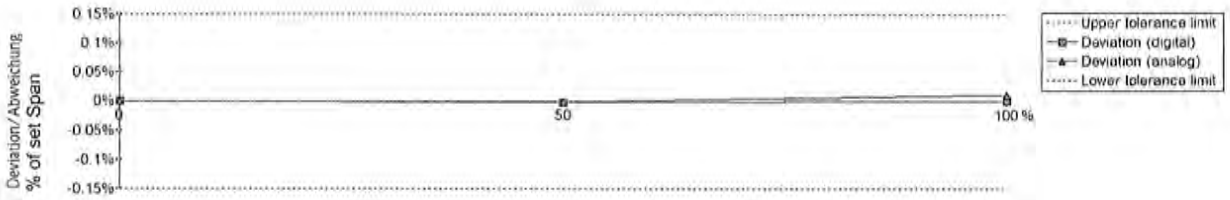
Ambient temperature	Umgebungs-Temperatur	22.4 °C (± 1 °C)
Ambient humidity	Umgebungs-Luftfeuchte	25.9 %rel.F (± 10 %rel.F)
Ambient pressure	Umgebungs-Luftdruck	962.7 mbar (± 0.2 mbar)
Calibrated according to fix point method IEC 60770.	Prüfung nach Grenzpunktmethode gemäß IEC 60770.	

Measuring results / Messergebnisse

Calibration point / Kalibrierpunkt	Nominal value ($p_{Ref.}$) / Sollwert ($p_{Ref.}$)	Measured value (digital readout) / Istwert (Digitaler Wert)	Deviation (digital) / Abweichung (digital)	Nominal value (I_{Out} calculated) / Sollwert (I_{Out} berechnet)	Current output (analog) / Istwert Stromausgang (analog)	Rel. deviation (analog) / Rel. Abweichung (analog)
%	psi	psi	% of Span	mA	mA	%
0	0.00006	0.00010	0.00072	4.00016	4.00021	0.00030
50	3.02793	3.02784	-0.00160	12.07448	12.07445	-0.00022
100	6.01824	6.01825	0.00016	20.04864	20.05038	0.01127

Calibration orientation
Kalibrierlage





Calibration carried out in output mode linear/
Kalibration erfolgte im Ausgangsmodus linear.

Measuring point in % of adjusted measuring range/
Messpunkt in % vom eingestellten Messbereich

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People for Process Automation

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Endress+Hauser GmbH+Co.
2340 Endress Place
Greenwood, In. 46143-9772

Final Inspection Report / Endprüfprotokoll

The manufacturer confirms that all measuring equipment used to assure the quality of the products has been calibrated and is traceable to national (e.g. DKD/DAkkS, NIST, NABL...) or international standards.

Der Hersteller bestätigt, dass die zu Qualitätsprüfungen des Erzeugnisses eingesetzten Messmittel gültig kalibriert waren und auf nationale (z.B. DKD/DAkkS, NIST, NABL...) bzw. internationale Normale rückführbar sind.

Cerabar M

TAG number	Messstellen-Nummer	
Order code	Bestellcode	PMC51-40JU2/0
Serial number	Seriennummer	L200DB15128
Extended order code	Erweiterter Bestellcode	PMC51-FA22ID1FGFRLCA
Sensor range	Sensor-Messbereich	-6...6 psi
Adjusted measuring range	Eingestellter Messbereich	0...6 psi
Maximum permissible error	Max. zulässige Messabweichung	± 0.15 %
Output type	Ausgang	4...20 mA HART
Software version	Softwareversion	01.00.03
Output mode	Ausgangsmodus	linear

INTUITECH INC

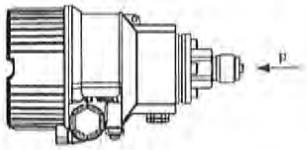
Customer order number	Auftragsnummer des Kunden	2016-19348
E+H sales order number	E+H Auftragsnummer	3018431628000020
Internal order number	Interne Auftragsnummer	3800205959/0020

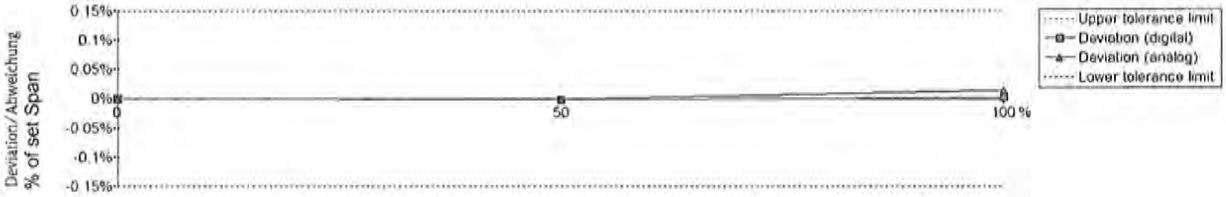
Ambient temperature	Umgebungs-Temperatur	22.4 °C (± 1 °C)
Ambient humidity	Umgebungs-Luftfeuchte	25.9 %rel.F (± 10 %rel.F)
Ambient pressure	Umgebungs-Luftdruck	962.7 mbar (± 0.2 mbar)
Calibrated according to fix point method IEC 60770.	Prüfung nach Grenzpunktmethode gemäß IEC 60770.	

Measuring results / Messergebnisse

Calibration point / Kalibrierpunkt	Nominal value ($p_{Ref.}$) / Sollwert ($p_{Ref.}$)	Measured value (digital readout) / Istwert (Digitaler Wert)	Deviation (digital) / Abweichung (digital)	Nominal value (I_{Out} calculated) / Sollwert (I_{Out} berechnet)	Current output (analog) / Istwert Stromausgang (analog)	Rel. deviation (analog) / Rel. Abweichung (analog)
%	psi	psi	% of Span	mA	mA	%
0	0.00006	0.00012	0.00103	4.00016	4.00010	-0.00036
50	3.02769	3.02754	-0.00255	12.07384	12.07370	-0.00088
100	6.01758	6.01769	0.00183	20.04688	20.04914	0.01461

Calibration orientation
Kalibrierlage





Calibration carried out in output mode linear /
Kalibration erfolgte im Ausgangsmodus linear.

Measuring point in % of adjusted measuring range /
Messpunkt in % vom eingestellten Messbereich

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Cerabar M

TAG number	Messstellen-Nummer	
Order code	Bestellcode	PMC51-2CWV9/0
Serial number	Seriennummer	L200DF15128
Extended order code	Erweiterter Bestellcode	PMC51-FA22ID1KGFRLCA
Sensor range	Sensor-Messbereich	-15...30 psi
Adjusted measuring range	Eingestellter Messbereich	0...30 psi
Maximum permissible error	Max. zulässige Messabweichung	± 0.15 %
Output type	Ausgang	4...20 mA HART
Software version	Softwareversion	01.00.03
Output mode	Ausgangsmodus	linear

INTUITECH INC

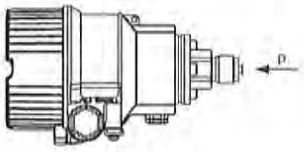
Customer order number	Auftragsnummer des Kunden	2016-19348
E+H sales order number	E+H Auftragsnummer	3018431628000030
Internal order number	Interne Auftragsnummer	3800205959/0030

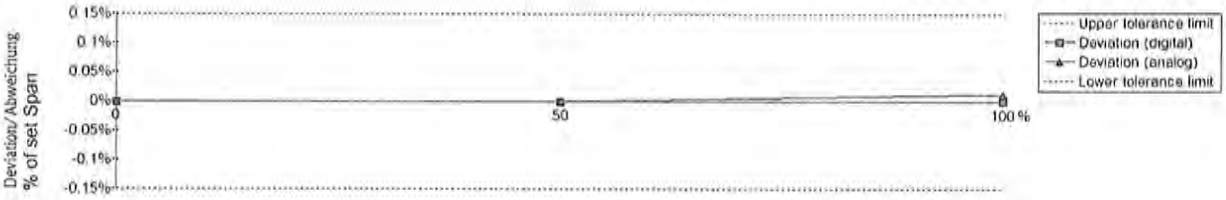
Ambient temperature	Umgebungs-Temperatur	22.4°C (± 1 °C)
Ambient humidity	Umgebungs-Luftfeuchte	25.9 %rel.F (± 10 %rel.F)
Ambient pressure	Umgebungs-Luftdruck	961.9 mbar (± 0.2 mbar)
Calibrated according to fix point method IEC 60770.	Prüfung nach Grenzpunktmethode gemäß IEC 60770.	

Measuring results / Messergebnisse

Calibration point	Nominal value ($p_{Ref.}$)	Measured value (digital readout)	Deviation (digital)	Nominal value (I_{Out} calculated)	Current output (analog)	Rel. deviation (analog)
Kalibrierpunkt	Sollwert ($p_{Ref.}$)	Istwert (Digitaler Wert)	Abweichung (digital)	Sollwert (I_{Out} berechnet)	Istwert Stromausgang (analog)	Rel. Abweichung (analog)
%	psi	psi	% of Span	mA	mA	%
0	0.00090	0.00083	-0.00024	4.00048	4.00024	-0.00153
50	15.1675	15.1673	-0.00103	12.08936	12.08958	0.00141
100	29.9605	29.9607	0.00062	19.97896	19.98086	0.01231

Calibration orientation
Kalibrierlage





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People for Process Automation

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GROTH CORPORATION
a Continental Disc Company

CERTIFIED TEST REPORT

Flame Check, Detonation Arrester, Flame Arrester, Flame Trap

Designed and Manufactured under an ISO 9001:2008 Certified Quality System.
TUV America Inc. Certificate Registration No: 951 06 3823 ANAB Accredited

Model: 7622B-01-55-N0
Groth Flame Check
Connection: 1" FPT
Body: 316 SS
Element: 316 SS
Equipment MAWP: 25 psig

Customer: WESTERN ENGINEERING
Serial No.: 1604125-01-1
Tag No.:

MATERIAL TRACEABILITY

Part Type	Traceability Number
Body	HT0102
Inlet Base	NA
Element Housing	NA
Outlet Base	NA
Element	NA

OTHER TEST PERFORMED

Leak Test Pressure psig

Quality Assurance

May 03, 2016
Date Tested

13650 N. Promenade Blvd. Stafford, TX 77477
Office: (281) 295-6800 (800) 354-7684 Fax: (281) 295-6999 www.grothcorp.com

GROTH CORPORATION
a Continental Disc Company

CERTIFIED TEST REPORT

Flame Check, Detonation Arrester, Flame Arrester, Flame Trap

Designed and Manufactured under an ISO 9001:2008 Certified Quality System.
TUV America Inc. Certificate Registration No: 951 06 3823 ANAB Accredited

Model: 7622B-01-55-N0
Groth Flame Check
Connection: 1" FPT
Body: 316 SS
Element: 316 SS
Equipment MAWP: 25 psig

Customer: WESTERN ENGINEERING
Serial No.: 1604125-01-2
Tag No.:

MATERIAL TRACEABILITY

Part Type	Traceability Number
Body	HT0102
Inlet Base	NA
Element Housing	NA
Outlet Base	NA
Element	NA

OTHER TEST PERFORMED

Leak Test Pressure psig

Quality Assurance

May 03, 2016
Date Tested

13650 N. Promenade Blvd. Stafford, TX 77477
Office: (281) 295-6800 (800) 354-7684 Fax: (281) 295-6999 www.grothcorp.com

Alicat Scientific, Inc.

7641 N. Business Park Dr., Tucson, AZ 85743 U.S.A., 1.888.290.6060

Calibration Data Sheet

Certification Number: 139052

Customer:	Intuitech, Inc.
Sales Order Number:	SO328794
Serial Number:	131198
Model Number:	MS-5SLPM-D-X
Software Version:	6v09.0-R22
Adder Codes:	CM, GAS; 60% CH4 + 40% CO2
Process Gas:	60% CH4 + 40% CO2 (Selectable)
Calibration Gas:	Air
Range:	5.000 SLPM
Gas Temperature:	21.2°C
Ambient Humidity:	48%
Calibration Procedure/Rev. #:	DOC-AUTOCAL-GASFLOW/Rev. 88
Calibrated By:	Rick Patton
Calibration Date:	4/11/2016
Full Scale Pressure:	160.00 PSIA
Full Scale Pressure Accuracy:	+/-0.5% of Full Scale
Temperature Accuracy:	+/-1.5°C
Standard Temp. & Pressure:	25.00°C, 14.69595 PSIA
Normal Temp. & Pressure:	0.00°C, 14.69595 PSIA
Calibration due 1 yr. after receipt:	

Equipment Used

Temperature:	TOOL-TEMP18	**Pressure:**	TOOL-PRESSURE8
Tool Due Date:	6/11/2016	Tool Due Date:	3/9/2017
Manufacturer/Model:	SELCO	Manufacturer/Model:	Alicat / P-100PSIG-D
Device Uncertainty:	+/- 0.75°C	Device Uncertainty:	+/- 0.2% of full scale

All test equipment used for calibration is NIST traceable.

Calibration

Uncertainty: +/- (0.8% of Reading + 0.2% of Full Scale)
Units of measure: SLPM

Calibration Pressure: N/A

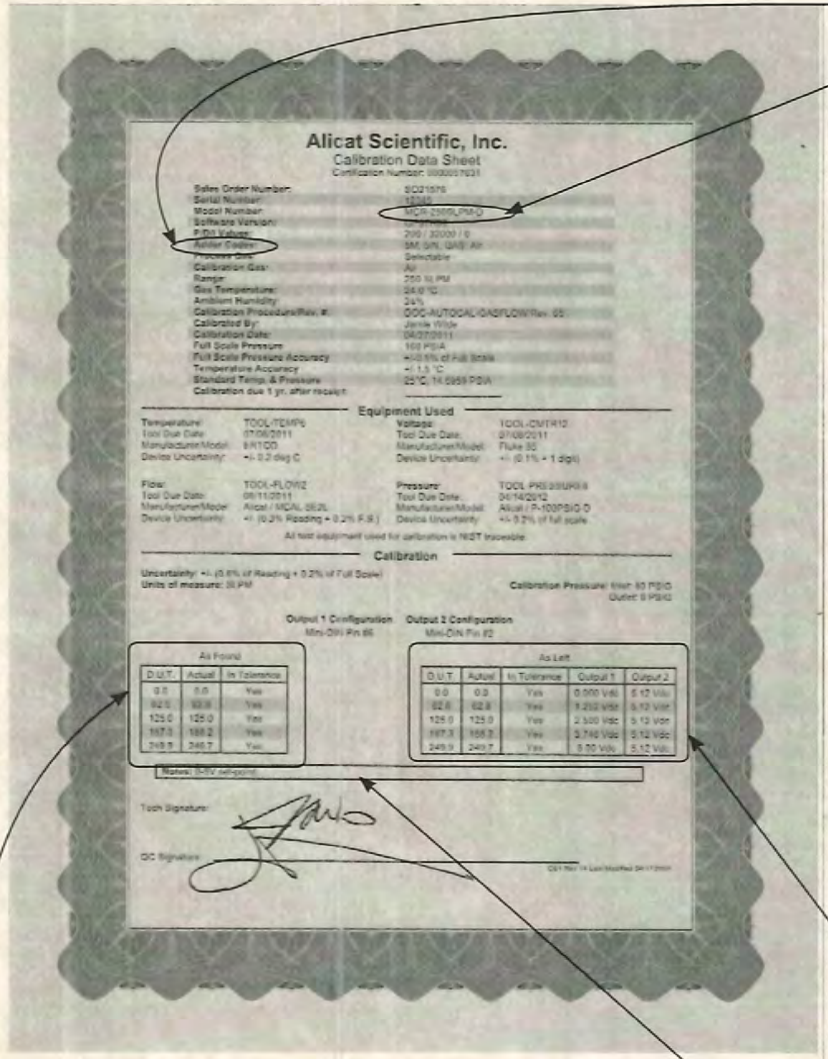
Output 1 Configuration
Indust. Con. Pin #6

D.U.T.	Actual	In Tolerance	Output 1
0.000	0.000	Yes	4.00 mA
1.240	1.249	Yes	7.97 mA
2.487	2.501	Yes	11.96 mA
3.735	3.754	Yes	15.95 mA
4.990	5.001	Yes	19.97 mA

Notes: Factory Custom:
G37 Mix1 = 60% CH4 + 40% CO2

Tech Signature:

QC Signature:



Alicat Scientific, Inc.
Calibration Data Sheet

Sales Order Number:	SO21575
Serial Number:	123456
Model Number:	MCR-2SLPM-D
Software Version:	10v100
P-Chi Values:	200 / 32000 / 0
Adder Codes:	5M, S/N, GAS: Air
Pressure Type:	Selectable
Calibration Gas:	Air
Range:	200 SLPM
Gas Temperature:	24.0 °C
Ambient Humidity:	24%
Calibration Procedure/Rev. #:	DOC-AUTOCAL/GASFLOW Rev. 05
Calibrated By:	Jamie Wilde
Calibration Date:	04/27/2011
Full Scale Pressure	100 PSIA
Full Scale Pressure Accuracy	+/-0.5% of Full Scale
Temperature Accuracy	+/- 1.5 °C
Standard Temp. & Pressure	25°C, 14.6959 PSIA
Calibration due 1 yr. after receipt	

Equipment Used

Temperature:	TOOL-TEMP6	Voltage:	TOOL-CMTR12
Tool Due Date:	07/06/2011	Tool Due Date:	07/06/2011
Manufacturer/Model:	ERTCO	Manufacturer/Model:	Fluke 80
Device Uncertainty:	+/- 0.2 deg C	Device Uncertainty:	+/- (0.1% + 1 dgt)
Flow:	TOOL-FLOW2	Pressure:	TOOL-PRESSURE6
Tool Due Date:	06/11/2011	Tool Due Date:	04/14/2012
Manufacturer/Model:	Alicat / MCAL-2SLPM	Manufacturer/Model:	Alicat / P-100PSIG-D
Device Uncertainty:	+/- (0.2% Reading + 0.2% F.S.)	Device Uncertainty:	+/- 0.2% of full scale

All test equipment used for calibration is NIST traceable.

Calibration

Uncertainty: +/- (0.6% of Reading + 0.2% of Full Scale)
Units of measure: SLPM

Calibration Pressure: Inlet: 80 PSIG, Outlet: 0 PSIG

Output 1 Configuration: Mini-DIN Pin #6 — Output 2 Configuration: Mini-DIN Pin #2

As Found

D.U.T.	Actual	In Tolerance
0.0	0.0	Yes
62.5	62.6	Yes
125.0	125.0	Yes
187.5	188.2	Yes
249.9	249.7	Yes

As Left

D.U.T.	Actual	In Tolerance	Output 1	Output 2
0.0	0.2	Yes	0.000 Vdc	5.12 Vdc
62.5	62.6	Yes	1.252 Vdc	5.12 Vdc
125.0	125.0	Yes	2.500 Vdc	5.12 Vdc
187.5	188.3	Yes	3.748 Vdc	5.12 Vdc
249.9	249.7	Yes	5.00 Vdc	5.12 Vdc

Notes: 5-5V set-point

Tech Signature:

QC Signature:

Model Type
M = mass flow meter
V = volumetric flow meter
P = pressure gauge
MC = mass flow controller
MCV = mass flow controller integrated shutoff valve
MCP = mass flow controller moderate flow valve
MCR = mass flow controller, high flow
VC = volumetric controller
VCR = volumetric controller, high flow
PC = pressure controller
PCR = pressure controller, high flow
PCD = dual valve pressure controller
L = liquid meter
LC = liquid controller
LCR = liquid controller, high flow
MS = mass flow meter*
MCS = mass flow controller*
MCRS = mass flow controller, high flow*
PS = pressure gauge*
PCS = pressure controller*
PCRS = pressure controller, high flow*
* "S" adder indicates aggressive gas configuration

Key to Common Adder Codes:	
Parameters	
M = Mass	P = Pressure
T = Temperature	V = Volumetric
Analog Output Signals	
1M, 1P, 1T or 1V = *1-5V primary output*	
12M, 12P, 12T, or 12V = *1-5V secondary output*	
5M, 5P, 5T or 5V = *0-5V primary output*	
52M, 52P, 52T or 52V = *0-5V secondary output*	
10M, 10P, 10T or 10V = *0-10V primary output*	
102M, 102P, 102T or 102V = *0-10V secondary output*	
CM, CP, CT or CV = *4-20mA primary output*	
C2M, C2P, C2T or C2V = *4-20mA secondary output*	
Set Points (controllers only)	
1IN = *1-5V set-point*	10IN = *0-10V set-point*
5IN = *0-5V set-point*	CIN = *4-20mA set-point*
Others	
GAS = *primary calibration gas*	TOT = *totalizer*
DS = *downstream valve*	
For explanation of additional adder codes please contact Alicat.	

D.U.T. (Device Under Test) = What this device reads/shows at corresponding **"Actual"** value.

Actual = Readings of the Calibrator while this unit was showing the number seen under **"D.U.T."** - after calibration adjustments.

In Tolerance = Yes/No as to whether or not this unit was in spec after calibration.

Output Columns = The output value on stated pin when **"D.U.T."** reads corresponding value.

Any special configuration information will appear here.

These three columns appear only on Recalibration Certificates.

D.U.T. = What this device reads/shows at corresponding **"Actual"** value.

Actual = Readings of the Calibrator while this unit was showing the number under **"D.U.T."** as received from the customer.

In Tolerance = Yes/No as to whether or not this unit was in spec as received from the customer.

Alicat Scientific, Inc.

7641 N. Business Park Dr., Tucson, AZ 85743 U.S.A., 1.888.290.6060

Calibration Data Sheet

Certification Number: 139021

Customer:	Intuitech, Inc.
Sales Order Number:	SO328794
Serial Number:	131197
Model Number:	MS-250SLPM-D-X
Software Version:	6v07.0-R22
Adder Codes:	CM, GAS: 60% CH4 + 40% CO2
Process Gas:	60% CH4 + 40% CO2 (Selectable)
Calibration Gas:	Air
Range:	250.0 SLPM
Gas Temperature:	21.8°C
Ambient Humidity:	46%
Calibration Procedure/Rev. #:	DOC-AUTOCAL-GASFLOW/Rev. 88
Calibrated By:	Kenyon Ellefson
Calibration Date:	4/8/2016
Full Scale Pressure:	160.00 PSIA
Full Scale Pressure Accuracy:	+/-0.5% of Full Scale
Temperature Accuracy:	+/-1.5°C
Standard Temp. & Pressure:	25.00°C, 14.69595 PSIA
Normal Temp. & Pressure:	0.00°C, 14.69595 PSIA
Calibration due 1 yr. after receipt:	

Equipment Used

Temperature:	TOOL-TEMP18	**Pressure:**	TOOL-PRESSURE8
Tool Due Date:	6/11/2016	Tool Due Date:	3/9/2017
Manufacturer/Model:	SELCO	Manufacturer/Model:	Alicat / P-100PSIG-D
Device Uncertainty:	+/- 0.75°C	Device Uncertainty:	+/- 0.2% of full scale
Flow:	TOOL-FLOW2	**Voltage:**	TOOL-CMTR20
Tool Due Date:	4/10/2016	Tool Due Date:	7/17/2016
Manufacturer/Model:	Alicat / MCRM-500SLPM-D	Manufacturer/Model:	Fluke / 87V
Device Uncertainty:	+/- (0.3% Reading + 0.2% F.S.)	Device Uncertainty:	+/- (0.1% + 1 digit)

All test equipment used for calibration is NIST traceable.

Calibration

Uncertainty: +/- (0.8% of Reading + 0.2% of Full Scale)
Units of measure: SLPM

Calibration Pressure: N/A

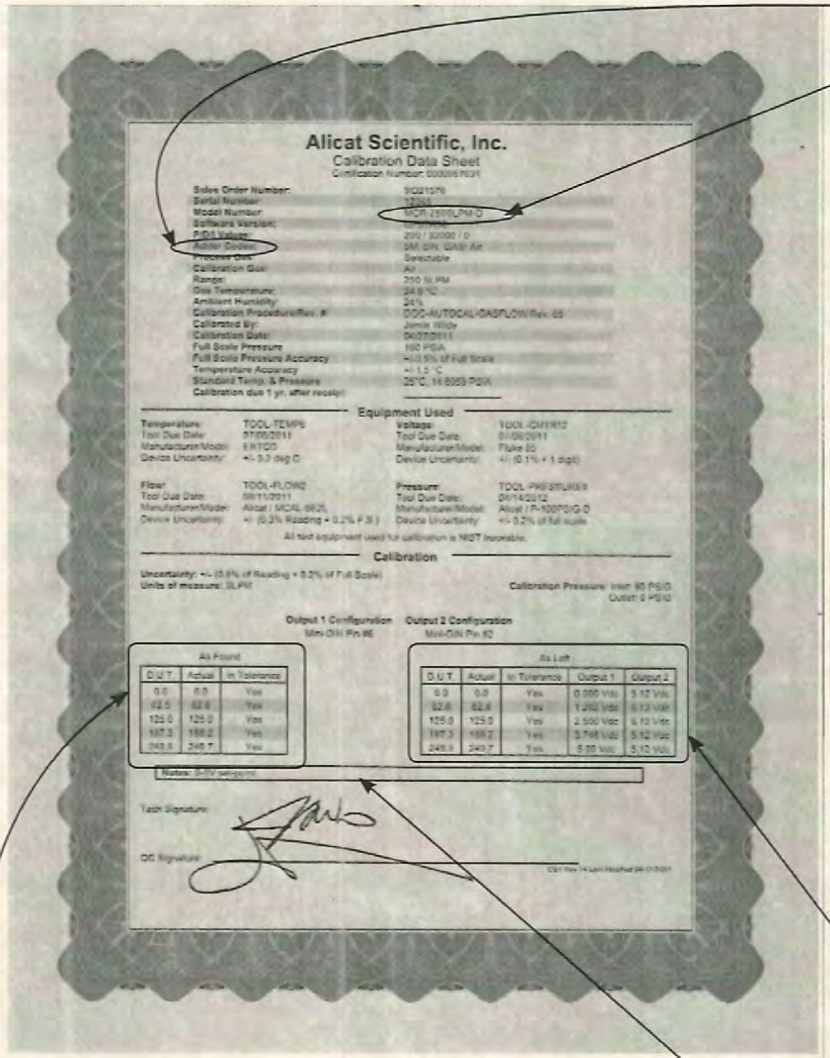
Output 1 Configuration
Indust. Con. Pin #6

D.U.T.	Actual	In Tolerance	Output 1
0.0	0.0	Yes	4.00 mA
62.6	62.6	Yes	8.01 mA
125.5	125.2	Yes	12.03 mA
188.0	187.7	Yes	16.03 mA
250.5	250.5	Yes	20.03 mA

Notes: Factory Custom:
G37 Mix1 = 60% CH4 + 40% CO2

Tech Signature:

QC Signature:



Alicat Scientific, Inc.
Calibration Data Sheet

Model Type
M = mass flow meter
V = volumetric flow meter
P = pressure gauge
MC = mass flow controller
MCV = mass flow controller integrated shutoff valve
MCP = mass flow controller moderate flow valve
MCR = mass flow controller, high flow
VC = volumetric controller
VCR = volumetric controller, high flow
PC = pressure controller
PCR = pressure controller, high flow
PCD = dual valve pressure controller
L = liquid meter
LC = liquid controller
LCR = liquid controller, high flow
MS = mass flow meter*
MCS = mass flow controller*
MCRS = mass flow controller, high flow*
PS = pressure gauge*
PCS = pressure controller*
PCRS = pressure controller, high flow*
* "S" adder indicates aggressive gas configuration

Key to Common Adder Codes:	
Parameters	
M = Mass	P = Pressure
T = Temperature	V = Volumetric
Analog Output Signals	
1M, 1P, 1T or 1V = *1-5V primary output*	
12M, 12P, 12T, or 12V = *1-5V secondary output*	
5M, 5P, 5T or 5V = *0-5V primary output*	
52M, 52P, 52T or 52V = *0-5V secondary output*	
10M, 10P, 10T or 10V = *0-10V primary output*	
102M, 102P, 102T or 102V = *0-10V secondary output*	
CM, CP, CT or CV = *4-20mA primary output*	
C2M, C2P, C2T or C2V = *4-20mA secondary output*	
Set Points (controllers only)	
1IN = *1-5V set-point*	10IN = *0-10V set-point*
5IN = *0-5V set-point*	CIN = *4-20mA set-point*
Others	
GAS = *primary calibration gas*	TOT = *totalizer*
DS = *downstream valve*	
For explanation of additional adder codes please contact Alicat.	

D.U.T. (Device Under Test) = What this device reads/shows at corresponding **"Actual"** value.

Actual = Readings of the Calibrator while <u>this</u> unit was showing the number seen under **"D.U.T."** - after calibration adjustments.

In Tolerance = Yes/No as to whether or not this unit was in spec after calibration.

Output Columns = The output value on stated pin when **"D.U.T."** reads corresponding value.

These three columns appear only on Recalibration Certificates.

D.U.T. = What this device reads/shows at corresponding **"Actual"** value.

Actual = Readings of the Calibrator while this unit was showing the number under **"D.U.T."** as received from the customer.

In Tolerance = Yes/No as to whether or not this unit was in spec as received from the customer.

Any special configuration information will appear here.

Alicat Scientific, Inc.

7641 N. Business Park Dr., Tucson, AZ 85743 U.S.A., 1.888.290.6060

Calibration Data Sheet

Certification Number: 158728

Customer:	Kansas State University
Sales Order Number:	SO334330
Serial Number:	146215
Model Number:	MS-5SLPM-D-X
Software Version:	6v22.4-R22
Adder Codes:	CM, GAS: 60% CH4 + 40% CO2, TOT
Process Gas:	60% CH4 + 40% CO2 (Selectable)
Calibration Gas:	Air
Range:	5.000 SLPM
Gas Temperature:	25.16°C
Ambient Humidity:	37.81%
Calibration Procedure/Rev. #:	DOC-AUTOCAL-GASFLOW/Rev. 92
Calibrated By:	George Greenler
Calibration Date:	2/22/2017
Full Scale Pressure:	160.00 PSIA
Pressure Accuracy:	+/-0.5% of Full Scale
Temperature Accuracy:	+/-1.5°C
Standard Temp. & Pressure:	25.00°C, 14.69595 PSIA
Normal Temp. & Pressure:	0.00°C, 14.69595 PSIA
Calibration due 1 yr. after receipt:	

Equipment Used

Voltage:	TOOL-CMTR24	**Temperature:**	TOOL-TEMP18
Tool Due Date:	4/21/2017	Tool Due Date:	6/8/2017
Manufacturer/Model:	FLUKE 87V	Manufacturer/Model:	SELCO
Device Uncertainty:	+/- (0.1% + 1 digit)	Device Uncertainty:	+/- 0.75ºC
Flow:	TOOL-FLOW18	**Pressure:**	TOOL-PRESSURE8
Tool Due Date:	3/27/2017	Tool Due Date:	3/9/2017
Manufacturer/Model:	Alicat / MCM-5SLPM-D	Manufacturer/Model:	Alicat / P-100PSIG-D
Device Uncertainty:	+/- (0.3% Reading + 0.2% F.S.)	Device Uncertainty:	+/- 0.2% of full scale

All test equipment used for calibration is NIST traceable.

Calibration

Uncertainty: +/- (0.8% of Reading + 0.2% of Full Scale) **Calibration Pressure:** N/A
Units of measure: SLPM

Output 1 Configuration
Indust. Con. Pin #6

D.U.T.	Actual	In Tolerance	Output 1
0.000	0.000	Yes	4.00 mA
1.250	1.250	Yes	8.00 mA
2.496	2.500	Yes	11.99 mA
3.743	3.750	Yes	15.98 mA
4.995	5.000	Yes	19.98 mA

Notes: Max range of totalizer is 9999.999. Total will rollover and display error message when it reaches max.

Tech Signature:

QC Signature:

Certificate of Factory Acceptance Testing Compliance

We certify to the best of our knowledge and understanding that the following statements are true.

- The AnMBR Pilot module has successfully passed factory acceptance testing, and has performed within specified operating parameters. The factory acceptance testing was performed in adherence to published manufacturer recommendations and client specifications
with the following exceptions:

Intuitech, Inc.

By

Elliot Moellmer
Name

Testing Engineer
Title

06/10/16
Date

Pump / Blower / Mixer Information & Testing Checkout Form

Intuitech

Motor Info:

Tag Name	1633
Device Description	Floc Mixer 3
Manufacturer	Oriental Motor
Model Number	FPW425S2-9
Serial Number	N/A

Motor Electrical:

Wired for High Voltage		Motor Voltage:	230 VAC	Motor Amps:	0.4 A
Wired for Low Voltage	X				
Phase:	3	Service Factor:		Full Load Amps:	0.2
*Amperage L1:		*Amperage L2:		*Amperage L3:	
Wired According to Drawings?		*Measured Maximum Amperage			

Date: 5-27-16
Initial: RSTC

VFD Info: (if applicable)

Tag Name	SIC-1631
Manufacturer	Schneider Electric
Model Number	ATV12H018F1
Serial Number	8B1549954013

Configurations: (for VFD settings changed from factory default) See Reverse for Configuration Examples

Menu Path / Configuration Option	Setting
ConF > bFr	60
ConF > LSP	5
ConF > nCr	0.4
ConF > nPr	0.2
ConF > AI1t	0A
ConF > FULL > I_O > tCt	LEL
ConF > FULL > I_O > r1	FtA
ConF > FULL > I_O > Ftd	5
ConF > FULL > FLt > Atr_ > Atr	YES
ConF > FULL > FLt > tht > Ith	0.25
ConF > FULL > drC > nSP	1600
ConF > SCS	Str1
Electronic Configuration Saved to Project Directory	File Name:

Date: 5-27-16
Initial: RSTC

Across-the-Line Starters: (if applicable)

Set Overload:	(amps)	Verify Breaker Size:	(amps)
Overload Tested/Tripped:			

Date: _____
Initial: _____

Rotation & Operation Verification:

Rotation Direction[1]:	Clockwise		Is Direction Correct?	Yes
Mixers	Paddle:	Turbine: X	Down Flow: X	Up Flow:
	Max RPM:	200	Hertz:	60
	Min RPM:	19	Hertz:	5
Compressors	Low Flow:		@ High Pressure:	
	High Flow:		@ Low Pressure:	
Pumps	Low Flow:		Discharge Pressure:	
	High Flow:		Discharge Pressure:	
Does Pump Performance Match Curves?[2]				

[1] Direction defined as viewed from the cooling fan (or from above for mixers)
[2] Attach pump curves

Date: 5-27-16
Initial: BSR

Configuration Examples:

Menu Path / Configuration Option	Setting
FUN > tCC > Act >	2C
FUN > dO > Ftd >	5
Dip- Switch Group SW1	↑↓↑↓↓↓
Jumper J-2	L2 – L4
Electronic Configuration Saved to Project Directory	File Name:

Pump / Blower / Mixer Information & Testing Checkout Form

Intuitech

Motor Info:

Tag Name	1632
Device Description	Floc Mixer 2
Manufacturer	Oriental Motor
Model Number	FPW425S2-9
Serial Number	N/A

Motor Electrical:

Wired for High Voltage		Motor Voltage:	230 VAC	Motor Amps:	0.4 A
Wired for Low Voltage	X				
Phase:	3	Service Factor:		Full Load Amps:	0.22
*Amperage L1:		*Amperage L2:		*Amperage L3:	
Wired According to Drawings?		*Measured Maximum Amperage			

Date: 5-27-16
Initial: RSR

VFD Info: (if applicable)

Tag Name	SIC-1631
Manufacturer	Schneider Electric
Model Number	ATV12H018F1
Serial Number	8B1533454011

Configurations: (for VFD settings changed from factory default) See Reverse for Configuration Examples

Menu Path / Configuration Option	Setting
ConF > bFr	60
ConF > LSP	5
ConF > nCr	0.4
ConF > nPr	0.2
ConF > AI1t	0A
ConF > FULL > I_O > tCt	LEL
ConF > FULL > I_O > r1	FtA
ConF > FULL > I_O > Ftd	5
ConF > FULL > FLt > Atr_ > Atr	YES
ConF > FULL > FLt > tht > Ith	0.25
ConF > FULL > drC > nSP	1600
ConF > SCS	Str1
Electronic Configuration Saved to Project Directory	File Name:

Date: 5-27-16
Initial: RSR

Across-the-Line Starters: (if applicable)

Set Overload:	(amps)	Verify Breaker Size:	(amps)
Overload Tested/Tripped:			

Date: _____
Initial: _____

Rotation & Operation Verification:

Rotation Direction[1]:	Clockwise		Is Direction Correct?	Yes
Mixers	Paddle:	Turbine: X	Down Flow: X	Up Flow:
	Max RPM:	200	Hertz:	60
	Min RPM:	19	Hertz:	5
Compressors	Low Flow:		@ High Pressure:	
	High Flow:		@ Low Pressure:	
Pumps	Low Flow:		Discharge Pressure:	
	High Flow:		Discharge Pressure:	
Does Pump Performance Match Curves?[2]				

[1] Direction defined as viewed from the cooling fan (or from above for mixers)
[2] Attach pump curves

Date: 5-27-16
Initial: BSB

Configuration Examples:

Menu Path / Configuration Option	Setting
FUN > tCC > Act >	2C
FUN > dO > Ftd >	5
Dip- Switch Group SW1	↑↓↑↓↓↓
Jumper J-2	L2 – L4
Electronic Configuration Saved to Project Directory	File Name:

Pump / Blower / Mixer Information & Testing Checkout Form

Intuitech

Motor Info:

Tag Name	1631
Device Description	Floc Mixer 1
Manufacturer	Oriental Motor
Model Number	FPW425S2-9
Serial Number	N/A

Motor Electrical:

Wired for High Voltage		Motor Voltage:	230 VAC	Motor Amps:	0.4 A
Wired for Low Voltage	X				
Phase:	3	Service Factor:		Full Load Amps:	0.2 A
*Amperage L1:		*Amperage L2:		*Amperage L3:	
Wired According to Drawings?		*Measured Maximum Amperage			

Date: 5-27-16
Initial: BSD

VFD Info: (if applicable)

Tag Name	SIC-1631
Manufacturer	Schneider Electric
Model Number	ATV12H018F1
Serial Number	8B1550954034

Configurations: (for VFD settings changed from factory default) See Reverse for Configuration Examples

Menu Path / Configuration Option	Setting
ConF > bFr	60
ConF > LSP	5
ConF > nCr	0.4
ConF > nPr	0.2
ConF > AI1t	0A
ConF > FULL > I_O > tCt	LEL
ConF > FULL > I_O > r1	FtA
ConF > FULL > I_O > Ftd	5
ConF > FULL > FLt > Atr_ > Atr	YES
ConF > FULL > FLt > tht > Ith	0.25
ConF > FULL > drC > nSP	1600
ConF > SCS	Str1
Electronic Configuration Saved to Project Directory	File Name:

Date: 5-27-16
Initial: BSD

Across-the-Line Starters: (if applicable)

Set Overload:	(amps)	Verify Breaker Size:	(amps)
Overload Tested/Tripped:			

Date: _____
Initial: _____

Rotation & Operation Verification:

Rotation Direction[1]:	Clockwise		Is Direction Correct?	Yes
Mixers	Paddle:	Turbine: X	Down Flow: X	Up Flow:
	Max RPM:	200	Hertz:	60
	Min RPM:	19	Hertz:	5
Compressors	Low Flow:		@ High Pressure:	
	High Flow:		@ Low Pressure:	
Pumps	Low Flow:		Discharge Pressure:	
	High Flow:		Discharge Pressure:	
Does Pump Performance Match Curves?[2]				

[1] Direction defined as viewed from the cooling fan (or from above for mixers)
[2] Attach pump curves

Date: 5-27-16
Initial: RSR

Configuration Examples:

Menu Path / Configuration Option	Setting
FUN > tCC > Act >	2C
FUN > dO > Ftd >	5
Dip- Switch Group SW1	↑↓↑↓↓↓
Jumper J-2	L2 – L4
Electronic Configuration Saved to Project Directory	File Name:

Instrumentation Configuration & Testing Checkout Form

Intuitech

General:

Tag Name	LT-1320
Device Description	Backpulse/CIP Tank Level Transmitter
Manufacturer	INTEMPCO
Model Number	LTX20
Sensor Serial #	04160006

Supply Power:

Supply Voltage:	24 VDC			Measured Value:	24.03 VDC
Signal	4-20mA	X	Other		

Date: 06/09/16
Initial: EJS

Configuration: (settings changed from factory default) See Reverse for Configuration Examples

Menu Path / Configuration Option	Setting
Electronic Configuration Saved to Project Directo	Folder Name:

Date: _____
Initial: _____

I/O Testing:

	PLC Count	Engineering Units	mA Value
Range Test	16072	8.1 GAL	12.05 mA
	29054	14.5 GAL	18.52 mA
Discrete Test	0 / OFF	1 / ON	

Date: 06/09/16
Initial: EJS

Flow/Sample Rate Testing:

Required Flow Rate:*		
Measured Flow Rate:		

*As published by the manufacturer

Date: _____
Initial: _____

Calibration:

Calibration Method:			
1 Point Calibration		1 Point Calibration Standard Value:	
		1 Point Instrument Value:	
2 Point Calibration		2 Point Calibration Standard Value:	
		2 Point Instrument Value:	
Comments:			

Date: _____
Initial: _____

Configuration Examples

Menu Path / Configuration Option	Setting
FUN > tCC > ACt >	2C
FUN > dO > Ftd >	5
Dip - Switch Group SW1	↑↓↑↓↓↓
Jumper J-2	L2 – L4
Electronic Configuration Saved to Project Directory	Folder Name:

Instrumentation Configuration & Testing Checkout Form

Intuitech

General:

Tag Name	LT-1300
Device Description	Membrane Tank Level Transmitter
Manufacturer	INTEMPCO
Model Number	LTX20
Sensor Serial #	04160008

Supply Power:

Supply Voltage:	24 VDC			Measured Value:	24.02 VDC
Signal	4-20mA	X	Other		

Date: 06/10/16
Initial:

Configuration: (settings changed from factory default) See Reverse for Configuration Examples

Menu Path / Configuration Option	Setting

Electronic Configuration Saved to Project Directo	Folder Name:

Date:
Initial:

I/O Testing:

	PLC Count		Engineering Units		mA Value
Range Test	120		0.1 GAL		4.2 mA
	24961		22.5 GAL		16.54 mA
Discrete Test	0 / OFF		1 / ON		

Date: 06/10/16
Initial:

Flow/Sample Rate Testing:

Required Flow Rate:*		
Measured Flow Rate:		

*As published by the manufacturer

Date:
Initial:

Calibration:

Calibration Method:			
1 Point Calibration		1 Point Calibration Standard Value:	
		1 Point Instrument Value:	
2 Point Calibration		2 Point Calibration Standard Value:	
		2 Point Instrument Value:	
Comments:			

Date: _____
Initial: _____

Configuration Examples

Menu Path / Configuration Option	Setting
FUN > tCC > ACt >	2C
FUN > dO > Ftd >	5
Dip - Switch Group SW1	↑↓↑↓↓↓
Jumper J-2	L2 – L4
Electronic Configuration Saved to Project Directory	Folder Name:

Instrumentation Configuration & Testing Checkout Form

Intuitech

General:

Tag Name	LT-1410
Device Description	Collection Tank 1410 Tank Level Transmitter
Manufacturer	INTEMPCO
Model Number	LTX20
Sensor Serial #	04160002

Supply Power:

Supply Voltage:	24 VDC			Measured Value:	24.03 VDC
Signal	4-20mA	X	Other		

Date: 6-9-16
Initial: DSR

Configuration: (settings changed from factory default) See Reverse for Configuration Examples

Menu Path / Configuration Option	Setting
Electronic Configuration Saved to Project Directo	Folder Name:

Date: _____
Initial: _____

I/O Testing:

	PLC Count	Engineering Units	mA Value
Range Test	218	0.1 inches	4.13 mA
	1925	7.25 inches	13.71 mA

Discrete Test	0 / OFF		1 / ON	

Date: 6-9-16
Initial: DSR

Flow/Sample Rate Testing:

Required Flow Rate:*		
Measured Flow Rate:		

*As published by the manufacturer

Date: _____
Initial: _____

Calibration:

Calibration Method:			
1 Point Calibration		1 Point Calibration Standard Value:	
		1 Point Instrument Value:	
2 Point Calibration		2 Point Calibration Standard Value:	
		2 Point Instrument Value:	
Comments:			

Date: _____
Initial: _____

Configuration Examples

Menu Path / Configuration Option	Setting
FUN > tCC > ACt >	2C
FUN > dO > Ftd >	5
Dip - Switch Group SW1	↑↓↑↓↓↓
Jumper J-2	L2 – L4
Electronic Configuration Saved to Project Directory	Folder Name:

Instrumentation Configuration & Testing Checkout Form

Intuitech

General:

Tag Name	LT-1540
Device Description	Collection Tank 1540 Tank Level Transmitter
Manufacturer	INTEMPCO
Model Number	LTX20
Sensor Serial #	04160004

Supply Power:

Supply Voltage:	24 VDC			Measured Value:	24.03 VDC
Signal	4-20mA	X	Other		

Date: 6-9-16
Initial: BSR

Configuration: (settings changed from factory default) See Reverse for Configuration Examples

Menu Path / Configuration Option	Setting
Electronic Configuration Saved to Project Directo	Folder Name:

Date: _____
Initial: _____

I/O Testing:

	PLC Count		Engineering Units	mA Value
Range Test	221		0.1 inches	4.17 mA
	19247		7.25 inches	13.69 mA
Discrete Test	0 / OFF		1 / ON	

Date: 6-9-16
Initial: BSR

Flow/Sample Rate Testing:

Required Flow Rate:*		
Measured Flow Rate:		

*As published by the manufacturer

Date: _____
Initial: _____

Calibration:

Calibration Method:			
1 Point Calibration		1 Point Calibration Standard Value:	
		1 Point Instrument Value:	
2 Point Calibration		2 Point Calibration Standard Value:	
		2 Point Instrument Value:	
Comments:			

Date: _____
Initial: _____

Configuration Examples

Menu Path / Configuration Option	Setting
FUN > tCC > ACt >	2C
FUN > dO > Ftd >	5
Dip - Switch Group SW1	↑↓↑↓↓↓
Jumper J-2	L2 – L4
Electronic Configuration Saved to Project Directory	Folder Name:

Instrumentation Configuration & Testing Checkout Form

Intuitech

General:

Tag Name	LT-1420
Device Description	Collection Tank 1420 Tank Level Transmitter
Manufacturer	INTEMPCO
Model Number	LTX20
Sensor Serial #	04160005

Supply Power:

Supply Voltage:	24 VDC			Measured Value:	24.02 VDC
Signal	4-20mA	X	Other		

Date: 6-9-16
Initial: BSR

Configuration: (settings changed from factory default) See Reverse for Configuration Examples

Menu Path / Configuration Option	Setting
Electronic Configuration Saved to Project Directo	Folder Name:

Date: _____
Initial: _____

I/O Testing:

	PLC Count			Engineering Units	mA Value
Range Test	237			0.1 inches	4.2 mA
	19243			7.25 inches	13.68 mA
Discrete Test	0 / OFF		1 / ON		

Date: 6-9-16
Initial: _____

Flow/Sample Rate Testing:

Required Flow Rate:*		
Measured Flow Rate:		

*As published by the manufacturer

Date: _____
Initial: _____

Calibration:

Calibration Method:			
1 Point Calibration		1 Point Calibration Standard Value:	
		1 Point Instrument Value:	
2 Point Calibration		2 Point Calibration Standard Value:	
		2 Point Instrument Value:	
Comments:			

Date: _____
Initial: _____

Configuration Examples

Menu Path / Configuration Option	Setting
FUN > tCC > ACt >	2C
FUN > dO > Ftd >	5
Dip - Switch Group SW1	↑↓↑↓↓↓
Jumper J-2	L2 – L4
Electronic Configuration Saved to Project Directory	Folder Name:

Instrumentation Configuration & Testing Checkout Form

General:

Tag Name	LT-1220
Device Description	Collection Tank 1220 Level Transmitter
Manufacturer	INTEMPCO
Model Number	LTX20
Sensor Serial #	04160003

Supply Power:

Supply Voltage:	24 VDC			Measured Value:	24.03 VDC
Signal	4-20mA	X	Other		

Date: 6-9-16
Initial: BSZ

Configuration: (settings changed from factory default) See Reverse for Configuration Examples

Menu Path / Configuration Option	Setting
Electronic Configuration Saved to Project Directo	Folder Name:

Date: _____
Initial: _____

I/O Testing:

	PLC Count	Engineering Units	mA Value
Range Test	241	.1 inches	4.2 mA
	19244	7.25 inches	13.7 mA
Discrete Test	0 / OFF	1 / ON	

Date: 6-9-16
Initial: BSZ

Flow/Sample Rate Testing:

Required Flow Rate:*		
Measured Flow Rate:		

*As published by the manufacturer

Date: _____
Initial: _____

Calibration:

Calibration Method:			
1 Point Calibration		1 Point Calibration Standard Value:	
		1 Point Instrument Value:	
2 Point Calibration		2 Point Calibration Standard Value:	
		2 Point Instrument Value:	
Comments:			

Date: _____
Initial: _____

Configuration Examples

Menu Path / Configuration Option	Setting
FUN > tCC > ACt >	2C
FUN > dO > Ftd >	5
Dip - Switch Group SW1	↑↓↑↓↓↓
Jumper J-2	L2 – L4
Electronic Configuration Saved to Project Directory	Folder Name:

Pump / Blower / Mixer Information & Testing Checkout Form

Intuitech
Intuitive Technology
Process Automation, Metering, Monitoring and Control System Integration

Motor Info:

Tag Name	1620
Device Description	Rapid Mixer 1620
Manufacturer	Oriental Motor
Model Number	FPW425S2-3
Serial Number	N/A

Motor Electrical:

Wired for High Voltage		Motor Voltage:	230 VAC	Motor Amps:	0.4 A
Wired for Low Voltage	X				
Phase:	3	Service Factor:		Full Load Amps:	0.2
*Amperage L1:		*Amperage L2:		*Amperage L3:	
Wired According to Drawings?		Yes			

*Measured Maximum Amperage

Date: 5-27-16
Initial: RSD

VFD Info: (if applicable)

Tag Name	SIC-1620
Manufacturer	Schneider Electric
Model Number	ATV12H018F1
Serial Number	8B1550954036

Configurations: (for VFD settings changed from factory default) See Reverse for Configuration Examples

Menu Path / Configuration Option	Setting
ConF > bFr	60
ConF > LSP	5
ConF > nCr	0.4
Conf > nPr	0.2
ConF > AI1t	0A
ConF > FULL > I_O > tCt	LEL
ConF > FULL > I_O > r1	FtA
ConF > FULL > I_O > Ftd	5
ConF > FULL > FLt > Atr_ > Atr	YES
ConF > FULL > FLt > tht > Ith	0.25
ConF > FULL > drC > nSP	1600
ConF > SCS	Str1
Electronic Configuration Saved to Project Directory	File Name:

Date: 5-27-16
Initial: RSD

Across-the-Line Starters: (if applicable)

Set Overload:	(amps)	Verify Breaker Size:	(amps)
Overload Tested/Tripped:			

Date: _____
Initial: _____

Rotation & Operation Verification:

Rotation Direction[1]:	Clockwise		Is Direction Correct?	Yes
Mixers	Paddle:	Turbine: X	Down Flow: X	Up Flow:
	Max RPM:	597	Hertz:	60
	Min RPM:	57	Hertz:	5
Compressors	Low Flow:		@ High Pressure:	
	High Flow:		@ Low Pressure:	
Pumps	Low Flow:		Discharge Pressure:	
	High Flow:		Discharge Pressure:	
Does Pump Performance Match Curves?[2]				

[1] Direction defined as viewed from the cooling fan (or from above for mixers)
[2] Attach pump curves

Date: 6-2-16
Initial: _____

Configuration Examples:

Menu Path / Configuration Option	Setting
FUN > tCC > Act >	2C
FUN > dO > Ftd >	5
Dip- Switch Group SW1	↑↓↑↓↓↓
Jumper J-2	L2 – L4
Electronic Configuration Saved to Project Directory	File Name:

Pump / Blower / Mixer Information & Testing Checkout Form

Intuitech

Motor Info:

Tag Name	1440
Device Description	WAS/Mixing Pump
Manufacturer	Baldor
Model Number	M7006A
Serial Number	W1602242885

Motor Electrical:

Wired for High Voltage		Motor Voltage:	230 VAC	Motor Amps:	2.1 A
Wired for Low Voltage	X				
Phase:	3	Service Factor:	1.0	Full Load Amps:	2.1 A
*Amperage L1:		*Amperage L2:		*Amperage L3:	
Wired According to Drawings?		Yes	*Measured Maximum Amperage		

Date: 6-2-16
Initial: RSR

VFD Info: (if applicable)

Tag Name	SIC-1440
Manufacturer	Schneider Electric
Model Number	ATV12H037F1
Serial Number	8B1542422025

Configurations: (for VFD settings changed from factory default) See Reverse for Configuration Examples

Menu Path / Configuration Option	Setting
ConF > bFr	60
ConF > LSP	10
ConF >nCr	2.1
ConF >AI1t	0A
ConF > FULL > I_O > tCt	LEL
ConF > FULL > I_O > r1	FtA
ConF > FULL > I_O > Ftd	10
ConF > FULL > FLt > Atr_ > Atr	YES
ConF > FULL > FLt > tht > Ith	2.625
ConF > FULL > drC > nSP	1725
ConF > SCS	Str1
Electronic Configuration Saved to Project Directory	File Name:

Date: 5-27-16
Initial: RSR

Across-the-Line Starters: (if applicable)

Set Overload:	(amps)	Verify Breaker Size:	(amps)
Overload Tested/Tripped:			

Date: _____
Initial: _____

Rotation & Operation Verification:

Rotation Direction[1]: CW			Is Direction Correct?	Yes
Mixers	Paddle:	Turbine:	Down Flow:	Up Flow:
	Max RPM:		Hertz:	
	Min RPM:		Hertz:	
Compressors	Low Flow:		@ High Pressure:	
	High Flow:		@ Low Pressure:	
Pumps	Low Flow:	1.58 GPM	Discharge Pressure:	1 psi
	High Flow:	8.16 GPM	Discharge Pressure:	9 psi
Does Pump Performance Match Curves?[2]				

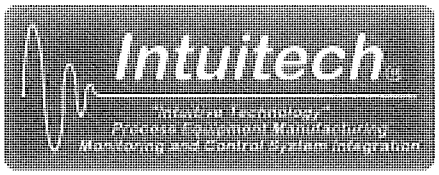
[1] Direction defined as viewed from the cooling fan (or from above for mixers)
[2] Attach pump curves

Date: 6-2-16
Initial: PSR

Configuration Examples:

Menu Path / Configuration Option	Setting
FUN > tCC > Act >	2C
FUN > dO > Ftd >	5
Dip- Switch Group SW1	↑↓↑↓↓↓
Jumper J-2	L2 – L4
Electronic Configuration Saved to Project Directory	File Name:

Pump / Blower / Mixer Information & Testing Checkout Form



Motor Info:

Tag Name	1310
Device Description	Permeate Pump
Manufacturer	Baldor
Model Number	CM7006A
Serial Number	W1603162975

Motor Electrical:

Wired for High Voltage		Motor Voltage:	230 VAC	Motor Amps:	2.1 A
Wired for Low Voltage	X				
Phase:	3	Service Factor:		Full Load Amps:	2.1
*Amperage L1:		*Amperage L2:		*Amperage L3:	
Wired According to Drawings?		*Measured Maximum Amperage			

Date: 5-27-16
Initial: BSR

VFD Info: (if applicable)

Tag Name	SIC-1310
Manufacturer	Schneider Electric
Model Number	ATV12H037F1
Serial Number	8B1601166213

Configurations: (for VFD settings changed from factory default) See Reverse for Configuration Examples

Menu Path / Configuration Option	Setting
ConF > bFr	60
ConF > LSP	3
ConF >nCr	2.1
ConF >AI1t	0A
ConF > FULL > I_O > tCt	LEL
ConF > FULL > I_O > r1	FtA
ConF > FULL > I_O > Ftd	3
ConF > FULL > FLt > Atr_ > Atr	YES
ConF > FULL > FLt > tht > Ith	2.6
ConF > FULL > drC > nSP	1725
ConF > FULL > Fun > rrs	L2H
ConF > SCS	Str1
Electronic Configuration Saved to Project Directory	File Name:

Date: 5-27-16
Initial: BSR

Across-the-Line Starters: (if applicable)

Set Overload:	(amps)	Verify Breaker Size:	(amps)
Overload Tested/Tripped:			

Date: _____
Initial: _____

Rotation & Operation Verification:

Rotation Direction[1]:	Bidirectional			Is Direction Correct?	Yes
Mixers	Paddle:		Turbine:	Down Flow:	Up Flow:
	Max RPM:			Hertz:	
	Min RPM:			Hertz:	
Compressors	Low Flow:			@ High Pressure:	
	High Flow:			@ Low Pressure:	
Pumps	Low Flow:	.16 GPM		Discharge Pressure:	1.16 psi
	High Flow:	2.82 GPM		Discharge Pressure:	.5 psi
Does Pump Performance Match Curves?[2]					

[1] Direction defined as viewed from the cooling fan (or from above for mixers)
[2] Attach pump curves

Date: 5-27-16
Initial: RSR

Configuration Examples:

Menu Path / Configuration Option	Setting
FUN > tCC > Act >	2C
FUN > dO > Ftd >	5
Dip- Switch Group SW1	↑↓↑↓↓↓
Jumper J-2	L2 – L4
Electronic Configuration Saved to Project Directory	File Name:

Instrumentation Configuration & Testing Checkout Form

Intuitech

General:

Tag Name	FIT-1310
Device Description	Permeate Pump Flow Transmitter
Manufacturer	Endress Hauser
Model Number	5P1B15-C6DBBADEA1KHAL5
Sensor Serial #	L3625E16000

Supply Power:

Supply Voltage:	24 VDC			Measured Value:	23.64 VDC
Signal	4-20mA	X	Other		

Date: 5-27-16
Initial: RSR

Configuration: (settings changed from factory default) See Reverse for Configuration Examples

Menu Path / Configuration Option	Setting
ProMag100 > Setup > Current Output 1 > 20mA Value	3.0
ProMag100 > Setup > Current Output 1 > Failure Mode	MIN
ProMag100 > Setup > Device Tag	FIT-1310
Setup > Pulse Frequency – Switch Output 1 > Operating Mode	SWITCH
Setup > Pulse Frequency – Switch Output Function > Operating Mode	Flow Dir. Check
Setup > Output Conditioning > Measuring Mode > Output 1	For. Rev. Flow
Electronic Configuration Saved to Project Directo	Folder Name:

Date: 5-27-16
Initial: RSR

I/O Testing:

	PLC Count	Engineering Units	mA Value
Range Test	16016	-1.5 GPM	12.00 mA
	21336	2.0 GPM	14.7 mA
Discrete Test	0 / OFF REV	1 / ON FOR	

Date: 5-27-16
Initial: RSR

Flow/Sample Rate Testing:

Required Flow Rate:*		
Measured Flow Rate:		

*As published by the manufacturer

Date: _____
Initial: _____

Calibration:

Calibration Method:			
1 Point Calibration		1 Point Calibration Standard Value:	
		1 Point Instrument Value:	
2 Point Calibration		2 Point Calibration Standard Value:	
		2 Point Instrument Value:	
Comments:			

Date: _____
Initial: _____

Configuration Examples

Menu Path / Configuration Option	Setting
FUN > tCC > ACt >	2C
FUN > dO > Ftd >	5
Dip - Switch Group SW1	↑↓↑↓↓↓
Jumper J-2	L2 – L4
Electronic Configuration Saved to Project Directory	Folder Name:

Instrumentation Configuration & Testing Checkout Form

Intuitech

General:

Tag Name	FIT-1430
Device Description	Recirculation Pump Flow Transmitter
Manufacturer	Endress Hauser
Model Number	5P1B15-C6DBBADEA1KHAL5
Sensor Serial #	L3025C16000

Supply Power:

Supply Voltage:	24 VDC			Measured Value:	23.6 VDC
Signal	4-20mA	X	Other		

Date: 5-27-16
Initial: RSR

Configuration: (settings changed from factory default) See Reverse for Configuration Examples

Menu Path / Configuration Option	Setting
ProMag100 > Setup > Current Output 1 > 20mA Value	12.0
ProMag100 > Setup > Current Output 1 > Failure Mode	MIN
ProMag100 > Setup > Device Tag	FIT-1430
Electronic Configuration Saved to Project Directo	Folder Name:

Date: 5-27-16
Initial: RSR

I/O Testing:

Range Test	PLC Count		Engineering Units	mA Value
	7992		3.0 GPM	7.94 mA
	24002		9.0 GPM	15.9 mA
Discrete Test	0 / OFF		1 / ON	

Date: 5-27-16
Initial: RSR

Flow/Sample Rate Testing:

Required Flow Rate:*		
Measured Flow Rate:		

*As published by the manufacturer

Date: _____
Initial: _____

Calibration:

Calibration Method:			
1 Point Calibration		1 Point Calibration Standard Value:	
		1 Point Instrument Value:	
2 Point Calibration		2 Point Calibration Standard Value:	
		2 Point Instrument Value:	
Comments:			

Date: _____
Initial: _____

Configuration Examples

Menu Path / Configuration Option	Setting
FUN > tCC > ACt >	2C
FUN > dO > Ftd >	5
Dip - Switch Group SW1	↑↓↑↓↓↓
Jumper J-2	L2 – L4
Electronic Configuration Saved to Project Directory	Folder Name:

Instrumentation Configuration & Testing Checkout Form

Intuitech

General:

Tag Name	FIT-1440
Device Description	WAS / Mixing Pump Flow Transmitter
Manufacturer	Endress Hauser
Model Number	5P1B15-C6DBBADEA1KHAL5
Sensor Serial #	L3025F16000

Supply Power:

Supply Voltage:	24 VDC			Measured Value:	23.6 VDC
Signal	4-20mA	X	Other		

Date: 5-27-16
Initial: RSR

Configuration: (settings changed from factory default) See Reverse for Configuration Examples

Menu Path / Configuration Option	Setting
ProMag100 > Setup > Current Output 1 > 20mA Value	12.0
ProMag100 > Setup > Current Output 1 > Failure Mode	MIN
ProMag100 > Setup > Device Tag	FIT-1440
Electronic Configuration Saved to Project Directo	Folder Name:

Date: 5/27/16
Initial:

I/O Testing:

	PLC Count		Engineering Units	mA Value
Range Test	7992		3.0 GPM	8.00 mA
	15998		6.0 GPM	11.97 mA
Discrete Test	0 / OFF		1 / ON	

Date: 5-27-16
Initial:

Flow/Sample Rate Testing:

Required Flow Rate:*		
Measured Flow Rate:		

*As published by the manufacturer

Date:
Initial:

Calibration:

Calibration Method:		
1 Point Calibration	1 Point Calibration Standard Value:	
	1 Point Instrument Value:	
2 Point Calibration	2 Point Calibration Standard Value:	
	2 Point Instrument Value:	
Comments:		

Date: _____
Initial: _____

Configuration Examples

Menu Path / Configuration Option	Setting
FUN > tCC > ACt >	2C
FUN > dO > Ftd >	5
Dip - Switch Group SW1	↑↓↑↓↓↓
Jumper J-2	L2 – L4
Electronic Configuration Saved to Project Directory	Folder Name:

Instrumentation Configuration & Testing Checkout Form

Intuitech

General:

Tag Name	FIT-1710
Device Description	Ion Exchange Pump Flow Transmitter
Manufacturer	IFM Efector
Model Number	SM6001
Sensor Serial #	N/A

Supply Power:

Supply Voltage:	24VDC			Measured Value:	24.08 VDC
Signal	4-20mA	X	Other		

Date: 5-27-16
Initial: BSR

Configuration: (settings changed from factory default) See Reverse for Configuration Examples

Menu Path / Configuration Option	Setting
eF > uni	GPM
OU2	I
ASP2	0.0
AEP2	3.00
LFC (Low Flow Cut-off)	
Fdir (Flow Direction)	
Electronic Configuration Saved to Project Directo	Folder Name:

Date: 5/27/16
Initial:

I/O Testing:

	PLC Count		Engineering Units	mA Value
Range Test				
Discrete Test	0 / OFF		1 / ON	

Date: _____
Initial: _____

Flow/Sample Rate Testing:

Required Flow Rate:*		
Measured Flow Rate:		

*As published by the manufacturer

Date: _____
Initial: _____

Calibration:

Calibration Method:			
1 Point Calibration		1 Point Pre-Calibration Reading:	
		1 Point Post-Calibration Reading:	
2 Point Calibration		2 Point Pre-Calibration Reading:	
		2 Point Post-Calibration Reading:	
Comments:			

Date: _____
Initial: _____

Configuration Examples

Menu Path / Configuration Option	Setting
FUN > tCC > ACt >	2C
FUN > dO > Ftd >	5
Dip - Switch Group SW1	↑↓↑↓↓↓
Jumper J-2	L2 – L4
Electronic Configuration Saved to Project Directory	Folder Name:

Instrumentation Configuration & Testing Checkout Form

Intuitech

General:

Tag Name	PIT-1910
Device Description	Compressor Air Pressure Transmitter
Manufacturer	IFM Efector
Model Number	PQ3834
Sensor Serial #	N/A

Supply Power:

Supply Voltage:	24 VDC				Measured Value:	24.08 VDC
Signal	4-20mA	X	Other	P.N.P. NO		

Date: 5-27-16
Initial: DSR

Configuration: (settings changed from factory default) See Reverse for Configuration Examples

Menu Path / Configuration Option	Setting
eF > Uni	PSi
eF > Clor	G-on
SP1	51
rP1	50
Electronic Configuration Saved to Project Directory	Folder Name:

Date: 5/27/16
Initial:

I/O Testing:

Range Test	PLC Count		Engineering Units	mA Value
Discrete Test	0 / OFF		1 / ON	

Date: _____
Initial: _____

Flow/Sample Rate Testing:

Required Flow Rate:*		
Measured Flow Rate:		

*As published by the manufacturer

Date: _____
Initial: _____

Calibration:

Calibration Method:			
1 Point Calibration		1 Point Calibration Standard Value:	
		1 Point Instrument Value:	
2 Point Calibration		2 Point Calibration Standard Value:	
		2 Point Instrument Value:	
Comments:			

Date: _____
Initial: _____

Configuration Examples

Menu Path / Configuration Option	Setting
FUN > tCC > ACt >	2C
FUN > dO > Ftd >	5
Dip - Switch Group SW1	↑↓↑↓↓↓
Jumper J-2	L2 – L4

Electronic Configuration Saved to Project Directory	Folder Name:

Instrumentation Configuration & Testing Checkout Form

General:

Tag Name	PT-1200
Device Description	Bioprocess Tank Pressure Transmitter
Manufacturer	Endress Hauser
Model Number	PMC51-FA22ID1FGFRLCA
Sensor Serial #	L200DA5128

Supply Power:

Supply Voltage:	24 VDC			Measured Value:	23.65 VDC
Signal	4-20mA	X	Other		

Date: 5-27-16
Initial: RSR

Configuration: (settings changed from factory default) See Reverse for Configuration Examples

Menu Path / Configuration Option	Setting
Setup > Press Eng Unit	PSI
Setup > Set URV	5
Setup > Extended Setup > Device Tag	PT-1200
Electronic Configuration Saved to Project Directo	Folder Name:

Date: 5/27/16
Initial:

I/O Testing:

	PLC Count			Engineering Units	mA Value
Range Test	16000			2.5 psi	12.05 mA
	32007			5.0 psi	20.04 mA
Discrete Test	0 / OFF		1 / ON		

Date: 5-27-16
Initial:

Flow/Sample Rate Testing:

Required Flow Rate:*		
Measured Flow Rate:		

*As published by the manufacturer

Date:
Initial:

Calibration:

Calibration Method:		
1 Point Calibration	1 Point Calibration Standard Value:	
	1 Point Instrument Value:	
2 Point Calibration	2 Point Calibration Standard Value:	
	2 Point Instrument Value:	
Comments:		

Date: _____
Initial: _____

Configuration Examples

Menu Path / Configuration Option	Setting
FUN > tCC > ACt >	2C
FUN > dO > Ftd >	5
Dip - Switch Group SW1	↑↓↑↓↓↓
Jumper J-2	L2 – L4
Electronic Configuration Saved to Project Directory	Folder Name:

Instrumentation Configuration & Testing Checkout Form

Intuitech

General:

Tag Name	PT-1300
Device Description	Membrane Tank Pressure Transmitter
Manufacturer	Endress Hauser
Model Number	PMC51-FA22ID1FGFRLCA
Sensor Serial #	L206DB15128

Supply Power:

Supply Voltage:	24 VDC				Measured Value:	22.68 VDC
Signal	4-20mA	X	Other			

Date: 5-27-16
Initial: RSR

Configuration: (settings changed from factory default) See Reverse for Configuration Examples

Menu Path / Configuration Option	Setting
Setup > Press Eng Unit	PSI
Setup > Set URV	5
Setup > Extended Setup > Device Tag	PT-1300
Electronic Configuration Saved to Project Directo	Folder Name:

Date: 5/27/16
Initial: [signature]

I/O Testing:

	PLC Count		Engineering Units	mA Value
Range Test	7968		1.25 psi	8.03 mA
	23998		3.75 psi	16.02 mA
Discrete Test	0 / OFF	1 / ON		

Date: 5-27-16
Initial: _____

Flow/Sample Rate Testing:

Required Flow Rate:*		
Measured Flow Rate:		

*As published by the manufacturer

Date: _____
Initial: _____

Calibration:

Calibration Method:			
1 Point Calibration		1 Point Calibration Standard Value:	
		1 Point Instrument Value:	
2 Point Calibration		2 Point Calibration Standard Value:	
		2 Point Instrument Value:	
Comments:			

Date: _____
Initial: _____

Configuration Examples

Menu Path / Configuration Option	Setting
FUN > tCC > ACt >	2C
FUN > dO > Ftd >	5
Dip - Switch Group SW1	↑↓↑↓↓↓
Jumper J-2	L2 – L4
Electronic Configuration Saved to Project Directory	Folder Name:

Instrumentation Configuration & Testing Checkout Form

Intuitech

General:

Tag Name	PT-1310
Device Description	Permeate Pump Pressure Transmitter
Manufacturer	Endress Hauser
Model Number	PMC51-FA22ID1KGFRLCA
Sensor Serial #	L200DC15128

Supply Power:

Supply Voltage:	24 VDC			Measured Value:	21.36 VDC
Signal	4-20mA	X	Other		

Date: 5-27-16
Initial: PSR

Configuration: (settings changed from factory default) See Reverse for Configuration Examples

Menu Path / Configuration Option	Setting
Setup > Press Eng Unit	PSI
Setup > Set LRV	-14.7
Setup > Set URV	30.0
Setup > Extended Setup > Device Tag	PT-1310
Electronic Configuration Saved to Project Directo	Folder Name:

Date: 5/27/16
Initial: BH

I/O Testing:

	PLC Count		Engineering Units	mA Value
Range Test	6960		-5.0 psi	7.53 mA
	17698		10.0 psi	12.92 mA
Discrete Test	0 / OFF	1 / ON		

Date: 5-27-16
Initial: PSR

Flow/Sample Rate Testing:

Required Flow Rate:*		
Measured Flow Rate:		

*As published by the manufacturer

Date: _____
Initial: _____

Calibration:

Calibration Method:			
1 Point Calibration		1 Point Calibration Standard Value:	
		1 Point Instrument Value:	
2 Point Calibration		2 Point Calibration Standard Value:	
		2 Point Instrument Value:	
Comments:			

Date: _____
Initial: _____

Configuration Examples

Menu Path / Configuration Option	Setting
FUN > tCC > ACt >	2C
FUN > dO > Ftd >	5
Dip - Switch Group SW1	↑↓↑↓↓↓
Jumper J-2	L2 – L4
Electronic Configuration Saved to Project Directory	Folder Name:

Instrumentation Configuration & Testing Checkout Form

Intuitech
Intuitive Technology
Process Equipment Maintenance
Monitoring and Control System Integration

General:

Tag Name	PT-1430
Device Description	Recirculation Pump Pressure Transmitter
Manufacturer	Endress Hauser
Model Number	PMC51-FA22ID1KGFRLCA
Sensor Serial #	L200DD15128

Supply Power:

Supply Voltage:	24 VDC			Measured Value:	22.68 VDC
Signal	4-20mA	X	Other		

Date: 5-27-16
Initial: RSD

Configuration: (settings changed from factory default) See Reverse for Configuration Examples

Menu Path / Configuration Option	Setting
Setup > Press Eng Unit	PSI
Setup > Set URV	30.0
Setup > Extended Setup > Device Tag	PT-1430
Electronic Configuration Saved to Project Directo	Folder Name:

Date: 5/27/16
Initial: EM

I/O Testing:

Range Test	PLC Count			Engineering Units	mA Value	
	7992			7.5 psi	8.0 mA	
	15992			15 psi	12.01 mA	
Discrete Test	0 / OFF		1 / ON			

Date: 5-27-16
Initial: RSR

Flow/Sample Rate Testing:

Required Flow Rate:*		
Measured Flow Rate:		

*As published by the manufacturer

Date: _____
Initial: _____

Calibration:

Calibration Method:			
1 Point Calibration		1 Point Calibration Standard Value:	
		1 Point Instrument Value:	
2 Point Calibration		2 Point Calibration Standard Value:	
		2 Point Instrument Value:	
Comments:			

Date: _____
Initial: _____

Configuration Examples

Menu Path / Configuration Option	Setting
FUN > tCC > ACt >	2C
FUN > dO > Ftd >	5
Dip - Switch Group SW1	↑↓↑↓↓↓
Jumper J-2	L2 – L4
Electronic Configuration Saved to Project Directory	Folder Name:

Instrumentation Configuration & Testing Checkout Form

General:

Tag Name	PT-1440
Device Description	WAS Pump Pressure Transmitter
Manufacturer	Endress Hauser
Model Number	PMC51-FA22ID1KGFRLCA
Sensor Serial #	L200DE15128

Supply Power:

Supply Voltage:	24 VDC			Measured Value:	22.68 VDC
Signal	4-20mA	X	Other		

Date: 5-27-16
Initial: PSR

Configuration: (settings changed from factory default) See Reverse for Configuration Examples

Menu Path / Configuration Option	Setting
Setup > Press Eng Unit	PSI
Setup > Set URV	30.0
Setup > Extended Setup > Device Tag	PT-1440
Electronic Configuration Saved to Project Directo	Folder Name:

Date: 5/27/16
Initial: [signature]

I/O Testing:

	PLC Count		Engineering Units	mA Value
Range Test	15992		15 psi	11.97 mA
	23992		22.5 psi	15.99 mA
Discrete Test	0 / OFF	1 / ON		

Date: 5-27-16
Initial: PSR

Flow/Sample Rate Testing:

Required Flow Rate:*		
Measured Flow Rate:		

*As published by the manufacturer

Date: _____
Initial: _____

Calibration:

Calibration Method:			
1 Point Calibration		1 Point Calibration Standard Value:	
		1 Point Instrument Value:	
2 Point Calibration		2 Point Calibration Standard Value:	
		2 Point Instrument Value:	
Comments:			

Date: _____
Initial: _____

Configuration Examples

Menu Path / Configuration Option	Setting
FUN > tCC > ACt >	2C
FUN > dO > Ftd >	5
Dip - Switch Group SW1	↑↓↑↓↓↓
Jumper J-2	L2 – L4
Electronic Configuration Saved to Project Directory	Folder Name:

Instrumentation Configuration & Testing Checkout Form

General:

Tag Name	PT-1540
Device Description	Vacuum Pump Pressure Transmitter
Manufacturer	Endress Hauser
Model Number	PMC51-FA22ID1KGFRLCA
Sensor Serial #	L200DF15128

Supply Power:

Supply Voltage:	24 VDC			Measured Value:	20.68 VDC
Signal	4-20mA	X	Other		

Date: 5-27-16
Initial: BSR

Configuration: (settings changed from factory default) See Reverse for Configuration Examples

Menu Path / Configuration Option	Setting
Setup > Press Eng Unit	inHG
Setup > Set LRV	-30.0
Setup > Set URV	0
Setup > Extended Setup > Device Tag	PT-1540
Electronic Configuration Saved to Project Directo	Folder Name:

Date: 5/27/16
Initial: BSR

I/O Testing:

	PLC Count			Engineering Units	mA Value
Range Test	16008			-15 in Hg	11.89 mA
	26664			-5 in Hg	17.23 mA
Discrete Test	0 / OFF		1 / ON		

Date: 5-27-16
Initial: BSR

Flow/Sample Rate Testing:

Required Flow Rate:*		
Measured Flow Rate:		

*As published by the manufacturer

Date: _____
Initial: _____

Calibration:

Calibration Method:			
1 Point Calibration		1 Point Calibration Standard Value:	
		1 Point Instrument Value:	
2 Point Calibration		2 Point Calibration Standard Value:	
		2 Point Instrument Value:	
Comments:			

Date: _____
Initial: _____

Configuration Examples

Menu Path / Configuration Option	Setting
FUN > tCC > ACt >	2C
FUN > dO > Ftd >	5
Dip - Switch Group SW1	↑↓↑↓↓↓
Jumper J-2	L2 – L4
Electronic Configuration Saved to Project Directory	Folder Name:

Instrumentation Configuration & Testing Checkout Form

Intuitech

General:

Tag Name	FIT-1100
Device Description	Feed Flow Transmitter
Manufacturer	Endress Hauser
Model Number	5P1B15-C6DBBADEA1KHAL5
Sensor Serial #	L302-5D16000

Supply Power:

Supply Voltage:	24 VDC			Measured Value:	23.62 VDC
Signal	4-20mA	X	Other		

Date: 5-27-16
Initial: RSR

Configuration: (settings changed from factory default) See Reverse for Configuration Examples

Menu Path / Configuration Option	Setting
ProMag100 > Setup > Current Output 1 > 20mA Value	3.0
ProMag100 > Setup > Current Output 1 > Failure Mode	MIN
ProMag100 > Setup > Device Tag	FIT-1100
Electronic Configuration Saved to Project Directo	Folder Name:

Date: 5/27/16
Initial: [signature]

I/O Testing:

Range Test	PLC Count		Engineering Units	mA Value
	15992		1.5 GPM	12.07 mA
	31978		3.0 GPM	20.1 mA
Discrete Test	0 / OFF	1 / ON		

Date: 5-17-16
Initial: RSR

Flow/Sample Rate Testing:

Required Flow Rate:*		
Measured Flow Rate:		

*As published by the manufacturer

Date: _____
Initial: _____

Calibration:

Calibration Method:			
1 Point Calibration		1 Point Calibration Standard Value:	
		1 Point Instrument Value:	
2 Point Calibration		2 Point Calibration Standard Value:	
		2 Point Instrument Value:	
Comments:			

Date: _____
Initial: _____

Configuration Examples

Menu Path / Configuration Option	Setting
FUN > tCC > ACt >	2C
FUN > dO > Ftd >	5
Dip - Switch Group SW1	↑↓↑↓↓↓
Jumper J-2	L2 – L4
Electronic Configuration Saved to Project Directory	Folder Name:

Pump / Blower / Mixer Information & Testing Checkout Form

Intuitech

Motor Info:

Tag Name	FAN
Device Description	Ventilation Fan
Manufacturer	CANARM
Model Number	AX12-4M
Serial Number	J15P

Motor Electrical:

Wired for High Voltage		Motor Voltage:	230 VAC	Motor Amps:	1.2A
Wired for Low Voltage	X				
Phase:	3	Service Factor:	1.0	Full Load Amps:	1.2A
*Amperage L1:		*Amperage L2:		*Amperage L3:	
Wired According to Drawings?		Yes	*Measured Maximum Amperage		

Date: 5-28-16
Initial: BSR

VFD Info: (if applicable)

Tag Name	SIC-1010
Manufacturer	Schneider Electric
Model Number	ATV12H037F1
Serial Number	8B1552837083

Configurations: (for VFD settings changed from factory default) See Reverse for Configuration Examples

Menu Path / Configuration Option	Setting
ConF > bFr	60
ConF > LSP	10
ConF >nCr	1.2
ConF >AI1t	0A
ConF > FULL > I_O > tCt	LEL
ConF > FULL > I_O > r1	FtA
ConF > FULL > I_O > Ftd	10
ConF > FULL > FLt > Atr_ > Atr	YES
ConF > FULL > FLt > tht > Ith	1.4
ConF > FULL > drC > nSP	1725
ConF > SCS	Str1
Electronic Configuration Saved to Project Directory	File Name:

Date: 5-28-16
Initial: BSR

Across-the-Line Starters: (if applicable)

Set Overload:	(amps)	Verify Breaker Size:	(amps)
Overload Tested/Tripped:			

Date: _____
Initial: _____

Rotation & Operation Verification:

Rotation Direction[1]: CCW			Is Direction Correct? Yes	
Mixers	Paddle:	Turbine:	Down Flow:	Up Flow:
	Max RPM:		Hertz:	
	Min RPM:		Hertz:	
Compressors	Low Flow:		@ High Pressure:	
	High Flow:		@ Low Pressure:	
Pumps	Low Flow:		Discharge Pressure:	
	High Flow:		Discharge Pressure:	
Does Pump Performance Match Curves?[2]				

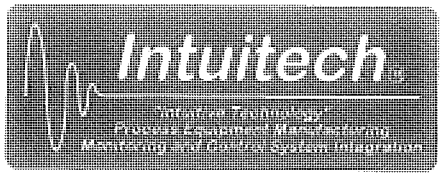
[1] Direction defined as viewed from the cooling fan (or from above for mixers)
[2] Attach pump curves

Date: 5-26-16
Initial: RSR

Configuration Examples:

Menu Path / Configuration Option	Setting
FUN > tCC > Act >	2C
FUN > dO > Ftd >	5
Dip- Switch Group SW1	↑↓↑↓↓↓
Jumper J-2	L2 – L4
Electronic Configuration Saved to Project Directory	File Name:

Pump / Blower / Mixer Information & Testing Checkout Form



Motor Info:

Tag Name	1410
Device Description	Biogas Scouring Pump
Manufacturer	KNF
Model Number	C145T17XK6A
Serial Number	B39931831

Motor Electrical:

Wired for High Voltage		Motor Voltage:	208 VAC	Motor Amps:	4.7 A
Wired for Low Voltage	X				
Phase:	3	Service Factor:	1.15	Full Load Amps:	4.7
*Amperage L1:		*Amperage L2:		*Amperage L3:	
Wired According to Drawings?		Yes	*Measured Maximum Amperage		

Date: 5-27-16
Initial: RSR

VFD Info: (if applicable)

Tag Name	SIC-1410
Manufacturer	Schneider Electric
Model Number	ATV12HU15M2
Serial Number	8B1608210086

Configurations: (for VFD settings changed from factory default) See Reverse for Configuration Examples

Menu Path / Configuration Option	Setting
ConF > bFr	60
ConF > LSP	10
ConF >nCr	4.7
ConF >AI1t	0A
ConF > FULL > I_O > tCt	LEL
ConF > FULL > I_O > r1	FtA
ConF > FULL > I_O > Ftd	10
ConF > FULL > FLt > Atr_ > Atr	YES
ConF > FULL > FLt > tht > Ith	5.9
ConF > FULL > drC > nSP	1755
ConF > SCS	Str1
Electronic Configuration Saved to Project Directory	File Name:

Date: 5-27-16
Initial: RSR

Across-the-Line Starters: (if applicable)

Set Overload:	(amps)	Verify Breaker Size:	(amps)
Overload Tested/Tripped:			

Date: _____
Initial: _____

Rotation & Operation Verification:

Rotation Direction[1]: CW			Is Direction Correct?	Yes
Mixers	Paddle:	Turbine:	Down Flow:	Up Flow:
	Max RPM:		Hertz:	
	Min RPM:		Hertz:	
Compressors	Low Flow:		@ High Pressure:	
	High Flow:		@ Low Pressure:	
Pumps	Low Flow:	39 SLPM	Discharge Pressure:	.5 psi
	High Flow:	180 SLPM	Discharge Pressure:	2 psi
Does Pump Performance Match Curves?[2]				

[1] Direction defined as viewed from the cooling fan (or from above for mixers)
[2] Attach pump curves

Date: 5-27-16
Initial: PSD

Configuration Examples:

Menu Path / Configuration Option	Setting
FUN > tCC > Act >	2C
FUN > dO > Ftd >	5
Dip- Switch Group SW1	↑↓↑↓↓↓
Jumper J-2	L2 – L4
Electronic Configuration Saved to Project Directory	File Name:

Pump / Blower / Mixer Information & Testing Checkout Form

Motor Info:

Tag Name	1430
Device Description	Recirculation Pump
Manufacturer	Baldor
Model Number	M7006A
Serial Number	W16022192670

Motor Electrical:

Wired for High Voltage		Motor Voltage:	208…230 VAC	Motor Amps:	2.1 A
Wired for Low Voltage	X				
Phase:	3	Service Factor:	1.0	Full Load Amps:	2.1 A
*Amperage L1:		*Amperage L2:		*Amperage L3:	
Wired According to Drawings?		Yes	*Measured Maximum Amperage		

Date: 5-27-16
Initial: BSR

VFD Info: (if applicable)

Tag Name	SIC-1430
Manufacturer	Schneider Electric
Model Number	ATV12H037F1
Serial Number	8B1601166210

Configurations: (for VFD settings changed from factory default) See Reverse for Configuration Examples

Menu Path / Configuration Option	Setting
ConF > bFr	60
ConF > LSP	10
ConF >nCr	2.1
ConF >AI1t	0A
ConF > FULL > I_O > tCt	LEL
ConF > FULL > I_O > r1	FtA
ConF > FULL > I_O > Ftd	10
ConF > FULL > FLt > Atr_ > Atr	YES
ConF > FULL > FLt > tht > Ith	2.625
ConF > FULL > drC > nSP	1725
ConF > SCS	Str1
Electronic Configuration Saved to Project Directory	File Name:

Date: 5-27-16
Initial: BSR

Across-the-Line Starters: (if applicable)

Set Overload:		(amps)	Verify Breaker Size:		(amps)
Overload Tested/Tripped:					

Date: _____
Initial: _____

Rotation & Operation Verification:

Rotation Direction[1]: CW			Is Direction Correct?	YES
Mixers	Paddle:	Turbine:	Down Flow:	Up Flow:
	Max RPM:		Hertz:	
	Min RPM:		Hertz:	
Compressors	Low Flow:		@ High Pressure:	
	High Flow:		@ Low Pressure:	
Pumps	Low Flow:	1.52	Discharge Pressure:	2 psi
	High Flow:	8.22	Discharge Pressure:	8 psi
Does Pump Performance Match Curves?[2]				

[1] Direction defined as viewed from the cooling fan (or from above for mixers)
[2] Attach pump curves

Date: 6-2-16
Initial: ESP

Configuration Examples:

Menu Path / Configuration Option	Setting
FUN > tCC > Act >	2C
FUN > dO > Ftd >	5
Dip- Switch Group SW1	↑↓↑↓↓↓
Jumper J-2	L2 – L4
Electronic Configuration Saved to Project Directory	File Name:

Pump / Blower / Mixer Information & Testing Checkout Form

Intuitech

Motor Info:

Tag Name	1710
Device Description	Ion Exchange Pump
Manufacturer	Oriental Motor
Model Number	BHI62ST-A
Serial Number	N/A

Motor Electrical:

Wired for High Voltage		Motor Voltage:	230 VAC	Motor Amps:	1.0 A
Wired for Low Voltage	X				
Phase:	3	Service Factor:		Full Load Amps:	
*Amperage L1:		*Amperage L2:		*Amperage L3:	
Wired According to Drawings?		Yes	*Measured Maximum Amperage		

Date: 5-27-16
Initial: RSR

VFD Info: (if applicable)

Tag Name	SIC-1710
Manufacturer	Schneider Electric
Model Number	ATV12H018F1
Serial Number	8B1550954043

Configurations: (for VFD settings changed from factory default) See Reverse for Configuration Examples

Menu Path / Configuration Option	Setting
ConF > bFr	60
ConF > LSP	5
ConF >nCr	1.0
ConF >AI1t	0A
ConF > FULL > I_O > tCt	LEL
ConF > FULL > I_O > r1	FtA
ConF > FULL > I_O > Ftd	5
ConF > FULL > FLt > Atr_ > Atr	YES
ConF > FULL > FLt > tht > Ith	1.2
ConF > FULL > drC > nSP	1500
ConF > SCS	Str1
Electronic Configuration Saved to Project Directory	File Name:

Date: 5-27-16
Initial: RSR

Across-the-Line Starters: (if applicable)

Set Overload:	(amps)	Verify Breaker Size:	(amps)
Overload Tested/Tripped:			

Date: _____
Initial: _____

Rotation & Operation Verification:

Rotation Direction[1]: CW			Is Direction Correct? YES	
Mixers	Paddle:	Turbine:	Down Flow:	Up Flow:
	Max RPM:		Hertz:	
	Min RPM:		Hertz:	
Compressors	Low Flow:		@ High Pressure:	
	High Flow:		@ Low Pressure:	
Pumps	Low Flow:	0.13	Discharge Pressure:	2 psi
	High Flow:	~~1.6~~ 1.56	Discharge Pressure:	4 psi
Does Pump Performance Match Curves?[2]				

[1] Direction defined as viewed from the cooling fan (or from above for mixers)
[2] Attach pump curves

Date: 5-27-16
Initial: PSR

Configuration Examples:

Menu Path / Configuration Option	Setting
FUN > tCC > Act >	2C
FUN > dO > Ftd >	5
Dip- Switch Group SW1	↑↓↑↓↓↓
Jumper J-2	L2 – L4
Electronic Configuration Saved to Project Directory	File Name:

Certificate of On-Site Installation Compliance

Intuitech®
"Intuitive Technology"
Process Equipment Manufacturing
Monitoring and Control System Integration

We certify to the best of our knowledge and understanding that the following statements are true.

- The An MBR Pilot module installation has been completed, inspected, and found to be installed correctly. The installation was performed in adherence to published manufacturer recommendations,
  with the following exceptions:
  Trailer Wiring conduit needs rerouting

Intuitech, Inc.

By

Eliot MacIlmer
Name

Start-Up Engineer
Title

06/10/16
Date

CLIENT: CDM Smith
DATE: 06/07/16 3:16 PM
PROJECT: 1539
FILENAME: Certificate of On-Site Installation Compliance.doc
AUTHOR: REM

Certificate of On-Site Training Compliance

Intuitech®
"Intuitive Technology"
Process Equipment Manufacturing
Monitoring and Control System Integration

We certify to the best of our knowledge and understanding that the following statements are true.

Training provided by the authorized Intuitech representative for the ABMET Filter Pilot Plant has been completed satisfactorily. Trainees were given ample opportunity to ask questions and have them answered. At this time we feel all contractual requirements for phase 1 training have been met. phase 2 training is pending

CDM Smith

Signature

Principal

Title

6/10/16

Date

Certificate of Start-Up Testing Compliance

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Process Equipment Manufacturing
Monitoring and Control System Integration

We certify to the best of our knowledge and understanding that the following statements are true.

- The AnMBR Pilot module has successfully completed start-up and compliance testing*, and was found to perform within specified operating parameters. The testing was performed in adherence to published manufacturer recommendations and client specifications
with the following exceptions:
Ambient alarm beacon needs installation
Recovery Clean sequencing needs additional programming
Feed Pump & Strainer programming needs testing
Biogas scour piping needs rebuilding to balance
Vacuum blower design needs to be addressed.
Investigate HMI security group problem

Intuitech, Inc.

* Phase 1 of 2 phases

Patrick J. Evans

By

Patrick J. Evans

Name

Principal

Title

6/10/16

Date

Certificate of On-Site Installation & Operation Compliance

Intuitech®
"Intuitive Technology"
Process Equipment Manufacturing
Monitoring and Control System Integration

We certify to the best of our knowledge and understanding that the following statements are true.

- The installation of module(s) AnMBR Pilot has been completed, inspected, found to be undamaged and installed correctly. The installation was performed in adherence to published manufacturer requirements. Proper environemtal protection has been provided. For Phase 2 Startup

Intuitech, Inc.

By

Eliot Maellmer
Name

Field Engineer
Title

07/13/16
Date

Comms Adapter for TUT-131Ø is broken. Needs replacing. to arrive Ø7/14/16
Pipe support to be shipped & installed on Ø7/14/16
5 PSI gauge to be shipped & installed on Ø7/14/16
One biogas sparge valve still needs to be installed.
Vacuum pump still outstanding, VFD & wiring is installed.
O-ring for mixed liquor valve to be shipped & installed Ø7/14/16

- The module(s) AnMBR Pilot, as received, operates as intended and adheres to the equipment specifications in the Operations and Maintenance manual.
- All instrumentation has been calibrated or verified and shown to operate properly.
- Training was provided with sufficient oppourtunity to ask questions.
- All on site start-up obligations to be provided by Intuitech Inc. have been met.

For Phase 2 Startup
Signee

By

Patrick J. Evans
Name

Principal
Title

7/13/16
Date

Certificate of On-Site Training Compliance

Intuitech®
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Process Equipment Manufacturing
Monitoring and Control System Integration

We certify to the best of our knowledge and understanding that the following statements are true.

Training provided by Eliot Moellmer, (authorized Intuitech Inc. representative) for CDM Smith, has been completed satisfactorily. Trainees were given oppourtunities to ask questions and have those questions answered. At this time we feel all contractual requirememnts for training have been met. For Phase 2 startup.

Intuitech Inc.:

Authorized Intuitech Representative

07/13/16
Date

Authorized signee:

Signature

Principal
Title

7/13/16
Date

Field Testing Completion & Checklist Form

Intuitech

Client: CDM Smith
Project: 1539

Date:

Items	Intuitech	CDM	Comments
Verify Proper Electrical Connections	EM		Office trailer to be connected at a later date
Verify Proper Hydraulic Connections	EM		
Vacuum Pump Testing Sheet			Suitability of vacuum pump to be discussed later
Instrument Calibration (pH)	EM		
Pressure Testing	EM		
Vacuum Testing	EM		
Install Alarm Beacon Light			To be installed on 2nd trip
Install Remaining Tags			Tags not shipped - installed by CDM
Test Remaining Alarms	EM		
Loop Tuning / Record Tuning Parameters	EM		
Calibrate Membrane and Bioprocess Tank Level Transmitters	EM		
Ensure Indusoft License Key is Recognized on Start-up	EM		Changed to soft key
Verify Data Logging	EM		
Verify Remote Access	EM		ULTRA-VNC
Relocate Pneumatic Valve to Proper Location	EM		

Deficiencies complete with noted exceptions:

Signature — Date: 06/10/16

Signature — Date

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USA
Email: info@indusoft.com
Phone: 512.349.0334
Fax: 512.349.0375

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NS: 557748

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Appendix C

Frontier O&M Manual

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INSTALLATION SUBCONTRACTOR OPERATIONS AND MAINTENANCE MANAUAL ANAEROBIC MEMBRANE BIOREACTOR (AnMBR) FOR SUSTAINABLE WASTEWATER TREATMENT FORT RILEY, KANSAS

SUBCONTRACT NO: 6444-001-006-CS

Submitted to:

CDM Federal Programs
3201 Jermantown Road, Suite 400
Fairfax, VA 22030

Submitted by :

Frontier Services, Inc.
13406 Holmes Road
Kansas City, MO 64145

August 2016

Revision 0

Issued to: _____ Date: _____

Copy #: _____ ☐ Controlled ☐ Uncontrolled

Table of Contents

List of Appendices ii
List of Acronyms iii
1.0 Introduction 1-1
1.1 Project Description 1-1
1.2 Scope of Work 1-1
1.3 Equipment Listing 1-2
1.4 Points of Contact 1-2
1.5 As-Built Drawings 1-3
2.0 Installation Instructions 2-1
3.0 Operating Procedures 3-1
3.1 Preliminary Checks Prior to System Start-Up 3-1
3.2 Start Up and Operation 3-1
3.2 Emergency Shutdown 3-3
3.3 Power Failure 3-3
4.0 Inspection & Maintenance 4-1
4.1 General Inspection and Maintenance Activities 4-1
4.2 Equipment-Specific Inspection and Maintenance Activities 4-1
4.2 Maintenance Schedules 4-2
4.3 Spare Parts 4-2
4.5 Warranty 4-3
5.0 Health & Safety 5-1

List of Appendices

Appendix	Title
A	Moyno Model C23AC1E Single Stage Progressive Cavity Pump, 2 HP
B	Eaton Model DCF400 Disc Cleaning Filter and Electric Semi-Automatic Control Panel
C	Miscellaneous Pipe, Valves, and Instrumentation
D	As-Built Drawings
E	Warranty Documentation

List of Acronyms

AnMBR	anaerobic membrane bioreactor
CDM	CDM Federal Programs / CDM Smith
DoD	Department of Defense
ESTCP	Environmental Security Technology Certification Program
Frontier	Frontier Services, Inc.
gpm	gallons per minute
HOA	Hand-Off-Auto
MCP	Main Control Panel
SOW	Scope of Work

1.0 Introdu ction

This document constitutes the Operations and Maintenance (O&M) Manual prepared by Frontier Services, Inc. (Frontier) for CDM Federal Programs / CDM Smith (CDM) under Subcontract No. 6444-001-006-CS. In accordance with this subcontract agreement, Frontier served as the Installation Subcontractor for the Anaerobic Membrane Bioreactor (AnMBR) for Sustainable Wastewater Treatment in Fort Riley, Kansas. *As such, this O&M Manual covers the process equipment, instrumentation, and appurtenances furnished by Frontier, namely the influent pump and strainer, in support of the AnMBR Pilot System*. O&M documentation for the Pilot System Trailer, as furnished by the Pilot System Subcontractor (under a separate agreement with CDM), are not covered herein.

This O&M Manual addresses Section 1.4(5) of the Installation Subcontractor Scope of Work (SOW), inclusive of manufacturer's installation instructions (refer to Section 2.0); procedures for startup, shutdown, normal operations, and emergency operations (refer to Section 3.0); inspection and maintenance, including spare parts (refer to Section 4.0); health and safety considerations (refer to Section 5.0); and copies of approved shop drawings (**Appendices A – C**). Additionally, **Appendix D** and **Appendix E** present final as-built drawings and manufacturer warranty information, respectively.

1.1 Projec t Descri ption

CDM, serving as the Engineer for the Department of Defense (DoD), is in the process of executing Environmental Security Technology Certification Program (ESTCP) Project No. ER-201434, entitled Anaerobic Membrane Bioreactor for Sustainable Wastewater Treatment Project. The primary purpose of this Project is to demonstrate and validate the use of AnMBR technology for domestic wastewater treatment. The Project Site is an existing sewage pump station located in Camp Forsyth, Fort Riley in Kansas. As part of the Project, a gas-sparged AnMBR pilot plant (Pilot System) was designed by CDM and fabricated by the Pilot System Subcontractor . The Pilot System will be operated for a period of 15 months by CDM. After the 15-month period, Frontier will remove the Pilot System and restore the Project Site to its original condition.

1.2 Scope of Work

Under the subcontract agreement with CDM, Frontier's Scope of Work (SOW) included the following tasks:

- Furnish and install influent pump and strainer
- Unload and set Pilot System Trailer and Office Trailer upon delivery
- Install all interconnecting mechanical, electrical, and instrumentation and controls between the Pilot System Trailer and influent pump and strainer.
- Conduct field testing of the pump and strainer
- Assist in startup of the Pilot System
- After the 15-month Pilot System study period (performed by CDM), disconnect Pilot System Trailer and Office Trailers and demolish, remove, and/or disconnect all utilities, equipment, pipe, conduit, and appurtenances
- Restore Project Site to its original condition

1.3 Equipment Listing

In the context of this O&M Manual, the primary new equipment provided by Frontier included:

1. Moyno Model C23AC1E Single Stage Progressive Cavity Pump, 2 HP (refer to **Appendix A**)
2. Eaton Model DCF400 Disc Cleaning Filter and Electric Semi-Automatic Control Panel (refer to **Appendix B**)
3. Miscellaneous Pipe, Valves, and Instrumentation (refer to **Appendix C**)

1.4 Points of Contact

Contact information for the primary vendors and suppliers are presented in the following table.

Company	Project Role	Contact Information
Frontier Services, Inc.	Installation Subcontractor	Frontier Services, Inc. (Attn: Scott Siegwald) 13406 Holmes Kansas City, MO 64145 816-9102-2243
Lee Matthews	Supplier / Pump and Strainer	Lee Matthews (Attn: Daniel Bailey) 318 Broadway Kansas City, MO 64105 816-221-0650
Missouri Electric	Electrician	Missouri Electric, Inc. (Attn: Tom Nelson) 1109 Fredrick Ave St Joseph, MO 64501 816-279-1056

1.5 As-Built Drawings

As-built drawings associated with Frontier's (Installation Subcontractor) SOW are provided in **Appendix D**.

2.0 Installation Instruction s

This section addresses installation instructions for the influent pump and strainer.

Moyno Model C23AC1E Single Stage Progressive Cavity Pump, 2 HP

- Check to ensure that the alignment of the pump with the drive unit.
- Ensure all guards are securely fixed in position.
- Check all joints in the system for leakage.
- Check operation of pressure switch on the discharge side of the pump to prevent over-pressurizing the system.
- Ensure placement of a check valve on the discharge side of the pump to prevent reverse flow through the system.
- Check the pressure gauge fitted to the outlet port.
- Bump 3-phase electric motor to verify power and direction of rotation. To do so, place motor in manual mode and bump by quickly by selecting START then STOP from main control panel. Rotation arrows are located on the nameplate. If rotation is backwards, have certified electrician swap two incoming power leads. NOTE: When the motor is being wired and checked for rotation, the start/stop sequence must be instantaneous to prevent dry running or pressurizing upstream equipment.
- *ENSURE THAT THE PUMP IS FILLED WITH FLUID BEFORE STARTING*. The initial filling is not for priming purposes, but to provide the necessary lubrication of the stator until the pump primes itself. When the pump is stopped, sufficient liquid will normally be trapped in the rotor/stator assembly to provide lubrication upon restarting.
- Check packing gland adjustment. The packing gland will require adjustment during the initial running in period. Newly packed glands must be allowed to run-in with only finger tight compression on the gland follower nuts. This should continue for about 3 days. The gland follower should be gradually tightened over the next week to achieve a leakage rate as shown in Section 2.3.1 of the O&M Manual. Gland followers should be adjusted at regular intervals to maintain the recommended leakage flow rate. Under normal working conditions a slight drip from the gland under pressure assists in cooling and lubricating the packing. A correctly adjusted gland will always have small leakage of fluid.

Eaton Model DCF400 Disc Cleaning Filter and Electric Semi-Automatic Control Panel

General

- Check the condition of the filter element. It should be clean and free of damage.
- Confirm that the top and bottom seals are installed properly.
- Verify that the gasket sealing the filter lid to the housing is in good condition and properly installed.
- Verify that all lid bolts are tight.
- Verify that the purge valve is closed.
- Check connection of the drain line to the filter unit's purge valve.
- Verify that the incoming instrument air pressure matches the requirements of the filter unit, 60-120 psig.
- Ensure connection of the incoming single-phase electrical supply to the terminal block labeled "DS1" in the automation enclosure.

Lid/Actuator Rod Seal

- Inspect the lid/actuator rod seal to ensure that the seal lips are installed with the lips facing the process fluid.
- Check tightness of packing wheel. If additional seal compression is needed, tighten the packing wheel one sixth of a turn at a time.
- Before circulating liquids through the filter unit, start the system dry and verify that the cylinder stroke is smooth and even.
- When first pressurizing a DCF filter it may be necessary to tighten the lid/actuator rod seal. If the seal begins to leak, compress the seal by rotating the packing wheel in one sixth of a turn increments.
- Note: The Viton packing is not adjustable. If leaking persists, disassemble the unit and replace packing.

Semi-Automatic Control Panel

- Ensure proper installation of air supply block valve, an air filter, and an air supply bleed valve before the filter solenoid valves.

- Ensure connection of the air supply line to the air supply block valve.
- Ensure connection of the air supply to the ¼ inch (6 mm) NPTI Inlet Port (IN) of the solenoid valves.
- If not already assembled, ensure connection of the air lines from the solenoid valves to the filter. On the cleaning disc solenoid valve, connect port "B" to the lower air port on the linear actuator. Connect port "A" to the upper air port of the linear actuator. On-line (solenoid valve de-energized) the linear actuator is retracted. When the linear actuator solenoid valve is energized, the actuator rod and cleaning disc extend and clean the element. Connect the purge valve solenoid valve port "B" to the lower air port of the rotary actuator. Connect port "A" to the upper air port of the rotary actuator. On-line (solenoid valve de-energized) the purge valve is closed. When the rotary actuator solenoid valve is energized, the purge valve opens.

3.0 Operating Procedures

Routine system starting, operation, and stopping may commence following the installation instructions and preliminary inspection described in Section 2.0.

3.1 Preliminary Checks Prior to System Start-Up

A series of routine checks must be performed prior to a normal system start up or following a maintenance/repair event, a valve adjustment, or other change in system conditions. Preliminary visual checks shall include the following items:

- Check power to all control panels and the Main Control Panel (MCP) inside the Pilot System Trailer.
- Check the position of all Hand-Off-Auto (HOA) selector switches. All HOA switches should be in the Auto position.
- Check to be sure that all shut-off valves are open for both the pump and strainer.
- Check the MCP to ensure that all pumps which are required to be "In Service" are indeed in service.
- Check for any alarms in the MCP, acknowledge all alarms, correct any problems, and then click Reset.

Refer to the Pilot System O&M Manual for further details.

3.2 Start Up and Operation

The following is summary of the startup and operating procedures in accordance with manufacturer O&M literature presented in **Appendices A and B**:

Moyno Model C23AC1E Single Stage Progressive Cavity Pump, 2 HP

Pumps must be filled with liquid before starting. The initial filling is not for priming purposes, but to provide the necessary lubrication of the stator until the pump primes itself. When the pump is stopped, sufficient liquid will normally be trapped in the rotor/stator assembly to provide lubrication upon restarting.

If, however, the pump has been left standing for an appreciable time, moved to a new location, or has been dismantled and re-assembled, it must be refilled with liquid and given a few turns before starting. The pump is normally somewhat stiff to turn by hand owing to the close rotor/stator fit. However, this stiffness disappears when the pump is running normally against pressure.

NOTE: NEVER RUN THE PUMP IN A DRY CONDITION EVEN FOR A FEW REVOLUTIONS OR THE STATOR WILL BE DAMAGED IMMEDIATELY. CONTINUAL DRY RUNNING COULD PRODUCE SOME HARMFUL OR DAMAGING EFFECTS.

Eaton Model DCF400 Disc Cleaning Filter and Electric Semi-Automatic Control Panel

Before circulating liquid through the filter, start the system dry and verify the following:

- Turn the selector switch on the front of the automation enclosure to the ON position. All timed intervals (customer determined) will be started from the time the switch was turned to the ON position. Once the customer supplied timer settings are reached, then the linear actuator will extend the cleaning disc to clean the element or the rotary actuator will rotate the ball valve to purge the contaminants from the filter housing.
- Press the cleaning disc solenoid valve's manual override button to verify that the linear actuator actuates and that the cleaning disc travels to the bottom of the filter element.
- Press the purge valve solenoid valve's manual override button to verify the rotary actuator actuates and the purge valve opens.

During operation:

- The DCF-400 cleaning disc should stroke the element clean to keep the differential pressure between the inlet and outlet of the filter below 5-7 PSID (34-48 kPa). Stroking too frequently will shorten the life of all wear components. Note: The burst strength of the filter element is 110 PSID (7.6 bar, 758 kPa) differential pressure if using slotted or perforated elements and 50 PSID (3.4 bar, 345 kPa) if defined pore elements are used.

- The filter unit is supplied with a valve used to purge the contaminants from the housing. This purge valve should be opened before the collected contaminants exceed the purge volume and cause a differential pressure increase.
- If manually cleaning the filter element, avoid high pressure washing from the outside of the element. This may force contaminants into the filter media and cause permanent blockage and/or element damage.

Note: Startup procedures for the system overall are discussed in the Pilot System O&M Manual.

3.2 Emergency Shutdown

An emergency shutdown is initiated by pressing the E-STOP button on the Main Control Panel. This de-energizes all output circuits instantly. This would rarely be used except in emergency situations (e.g., fire, spills, motor bearing failures or any situation where the operator determines it is necessary to prevent a potential problem). The E-STOP is reset by twisting and pulling out on the E-STOP pushbutton, or by clicking the Reset button in the operator interface work station (if this is where the E-STOP was engaged). Refer to the Pilot System O&M Manual for further details.

3.3 Power Failure

When the Pilot System experiences a power failure numerous alarms will likely appear including communications alarms with the various control panels. In such an event, the Plant Operator would need to acknowledge and reset all alarms in the MCP (as described in the Pilot System O&M Manual) and perform the system checks discussed in Section 3.1. Once that is complete, a system re-start may be initiated as described in Section 3.2.

4.0 Inspection & Maintenance

The Pilot System is comprised of commercially available equipment, instrumentation, and appurtenances. **Appendices A – C** of this manual contains manufacturer-specific procedures for preventative maintenance, repair, and replacement.

4.1 General Inspection and Maintenance Activities

The following is summary of general inspection and maintenance activities:

- Verify that all process piping connections are secure and free of leaks
- Ensure that the inlet and outlet connections to the interconnecting piping are secure and free of leaks.
- Ensure that isolation valves have been installed and are in the open position.
- Check orientation and position of all valves.
- Check connection and condition of all pressure gauges.
- Verify that the input wiring is correctly attached to the terminal strips.

4.2 Equipment-Specific Inspection and Maintenance Activities

The following is summary of inspection and maintenance activities specific to the influent pump and strainer:

Moyno Model C23AC1E Single Stage Progressive Cavity Pump, 2 HP

- Check to ensure that the alignment of the pump with the drive unit.
- Ensure all guards are securely fixed in position.
- Check all joints in the system for leakage.
- Check operation of pressure switch on the discharge side of the pump to prevent over-pressurizing the system.
- Pump bearings should be inspected periodically to see if grease replenishment is necessary, and if so, grease should be added until the chambers at the ends of the bearing spacer are approximately one third full. BP LC2 / Mobilgrease XHP 222 or their equivalent must be used for replenishment.
- Periodic bearing inspection is necessary to maintain optimum bearing performance. The

most expedient time to inspect is during periods of regular scheduled equipment downtime - for routine maintenance or for any other reason.

Refer to **Appendix A**, including Section 2.15, for further maintenance instructions.

Eaton Model DCF400 Disc Cleaning Filter and Electric Semi-Automatic Control Panel

- Check the condition of the filter element. It should be clean and free of damage.
- Confirm that the top and bottom seals are installed properly.
- Inspect the cleaning disc for excessive wear
- Inspect for leakage around the actuator shaft seal.
- Verify that all lid bolts are tight.
- Verify that the purge valve is closed.
- Check connection of the drain line to the filter unit's purge valve.
- Verify that the incoming instrument air pressure matches the requirements of the filter unit, 60-120 psig.

Refer to Table 1 of **Appendix B** for further maintenance instructions.

4.2 Maintenance Schedules

The components of the treatment plant require regular maintenance. Each major component has a preventative maintenance program established by the component manufacturer. O&M manuals for the influent pump and strainer are provided in **Appendix A** and **Appendix B**, respectively. Refer to Section 1.4 and **Appendices A – C** for vendor and supplier contact information as needed.

4.3 Spare Parts

The use of replacement parts that are not manufactured by or approved by Mono or Eaton may affect the safe operation of the pump and it may therefore become a safety hazard to both operators and other equipment. Refer to **Appendix A** for further information regarding replacement parts for the influent pump. A list of replacement parts for the Eaton strainer is presented in Table 2 of **Appendix B**.

4.5 Warranty

Warranty documentation with Frontier's (Installation Subcontractor) SOW are provided in **Appendix E**.

5.0 Health & Safety

This section highlights the most significant health and safety issues specific to the equipment furnished under the Installation Subcontractor SOW.

During O&M, Operators are exposed to the following safety hazards:

- **Hazardous Energy** – The unexpected startup of equipment is a serious hazard during maintenance and repair events. Lockout/tagout procedures must be implemented (consistent with the specific piece of equipment) to ensure that power and other sources of energy are de-energized or isolated. Lockout/tagout procedures (referencing 29 CFR 1926.417) are to be implemented during servicing or maintenance of equipment to preclude the unexpected start-up and/or release of stored energy. To prevent the accidental start-up of equipment, the Operator must turn off the power to the machine and apply a lock or otherwise control the power source to ensure that the equipment cannot be inadvertently energized. Once locks have been applied to a piece of equipment being serviced, the Operator must attempt to start the equipment (i.e. by engaging the disconnect switch). In addition, the Operator must test the power feed to the equipment using a multimeter/voltmeter. These steps are intended to ensure that the power has been properly de-energized or isolated.

- **Electrical Equipment** – Operators must be aware of the potential physical hazards associated with use of electrical equipment (electrical panels, electric motors, electrical controls, and energized wires) during the operation and maintenance of each treatment plant.

  NOTE: PROTECT ALL ELECTRICAL EQUIPMENT FROM SPLASHING WHEN HOSING DOWN. WHERE MONO PUMPS LIMITED

- **Slip/Trip/Fall** – Significant slip/trip/fall hazards exist within lift station, including potentially wet floors, piping, and uneven surfaces.

- **Noise** – Noise (decibel) levels inside the filter building and high service pump building may exceed exposure limits during prolonged occupancy.

- **Machine Guards** – Be sure pump shafts and other moving parts and/or pinch points are properly guarded. Never remove or bypass guards during normal operations.

Additional hazard control measures include, but are not limited to the following:

- Wearing safety glasses and steel-toed boots on a normal basis.
- Using hearing protection when noise levels exceed OSHA limits.
- Properly grounding electrical equipment.
- Using lock out/tag out practices when electrically-powered equipment must be taken out of service for maintenance.
- Wearing the proper protective equipment when handling liquid chemical products, including an apron, nitrile gloves, goggles, and face shield.
- Providing adequate ventilation by opening doors, louvers, and operating exhaust fans, as appropriate.
- Having first aid kit(s), eye wash stations, and fire extinguishers available at the facility.
- Marking slip/trip/fall hazards with signs, paint schemes, or physical barriers, as appropriate.
- Using dollies, forklifts, and/or hoists for lifting equipment and other heavy items, as necessary.

APPENDICES

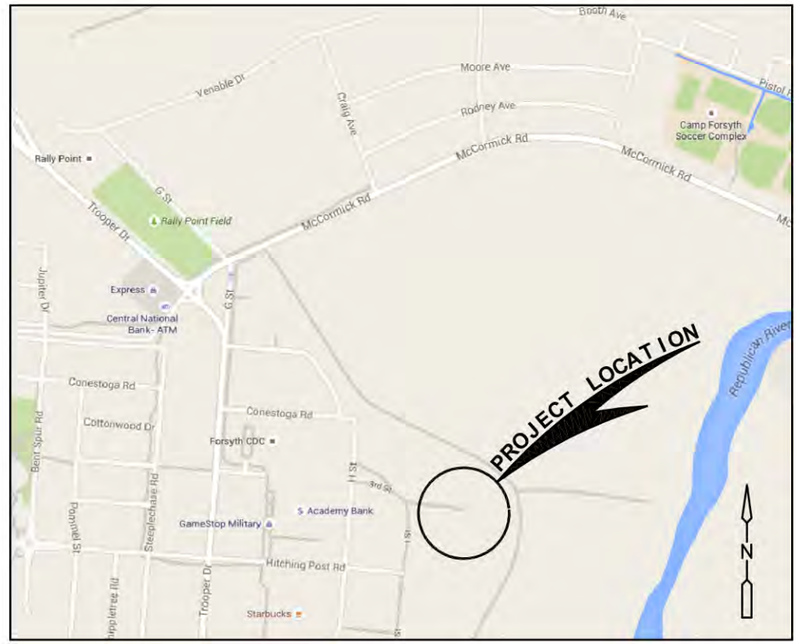
Anaerobic Membrane Bioreactor (AnMBR) for Sustainable Wastewater Treatment Pilot Project Project No. ER-201434

DESIGN DRAWINGS
DECEMBER 2015

PREPARED FOR
United States Department of Defense
Environmental Security Technology Certification Program (ESTCP)

VICINITY MAP
NTS

SHEET	TITLE
G-1	COVER SHEET AND DRAWINGS LIST
G-2	GENERAL NOTES I
G-3	GENERAL NOTES II
G-4	SYMBOLS, ABBREVIATIONS, & LEGENDS
C-1	SITE PLAN
M-1	MECHANICAL PLAN
M-2	MECHANICAL SECTIONS
D-1	CIVIL & MECHANICAL DETAILS.
E-1	ELECTRICAL SITE PLAN
E-2	MCC AND ONE-LINE DIAGRAM
I-1	PROCESS & INSTRUMENTATION DIAGRAM



LOCATION MAP
NTS

As-Built Drawing Package
July 2016

CDM Smith
1755 Creekside Oaks Drive
Suite 200
Sacramento, CA 95833
Tel: (916) 567-9900

GENERAL NOTES:

1. GENERAL NOTES APPLY TO ALL SHEETS, EXCEPT WHERE MORE SPECIFIC REQUIREMENTS ARE PROVIDED
2. THE CONTRACTOR SHALL BE RESPONSIBLE TO VERIFY ALL THE EXISTING ITEMS WITHIN OR ADJACENT TO THE WORK OR THAT MAY BE DISTURBED BY THE WORK (AND THEIR CURRENT CONDITION).
3. UNLESS OTHERWISE NOTED, THE LOCATION, SIZE AND MATERIAL OF EXISTING UNDERGROUND UTILITIES WITHIN THE LIMITS OF THE PROJECT SITE ARE NOT SHOWN ON THESE PLANS.
4. ALL WORK (OTHER THAN SURVEYING AND MONITORING) SHALL BE RESTRICTED TO THE LIMITS OF DISTURBANCE SHOWN ON THE DRAWINGS, UNLESS DEPICTED OTHERWISE. THE LIMITS OF DISTURBANCE ARE THE LIMITS OF THE TEMPORARY CONSTRUCTION EASEMENT.
5. MAINTAIN ACCESS TO ALL PROPERTIES ADJACENT TO THE WORK THROUGHOUT THE PERIOD OF CONSTRUCTION.
6. THE CONTRACTOR SHALL RESTORE ALL DAMAGED OR DISTURBED AREAS TO THEIR ORIGINAL CONDITION AFTER COMPLETION OF THE WORK.
7. ALL EXCESS MATERIALS AND SPOIL SHALL BECOME THE PROPERTY OF THE CONTRACTOR AND SHALL BE DISPOSED OF BY THE CONTRACTOR AT AN OFF-SITE LOCATION, ACCORDING TO ALL APPLICABLE LAWS AND REGULATIONS.
8. MECHANICAL EQUIPMENT USED ON THIS PROJECT SHALL BE SELECTED TO MINIMIZE DAMAGE TO THE ROADS USED AS TRUCK ROUTES TO BRING MATERIAL AND EQUIPMENT TO THE PROJECT. REPLACE DAMAGED ASPHALT CONCRETE (A.C.) PAVEMENT AND CONCRETE PAVEMENT IN KIND.
9. THE CONTRACTOR IS RESPONSIBLE FOR ARRANGING THE REQUIRED INSPECTIONS. THE PRESENCE OR ABSENCE OF A PROJECT REPRESENTATIVE OR OTHER INSPECTOR WILL NOT RELIEVE THE CONTRACTOR OF FULL RESPONSIBILITY FOR THE PROPER PERFORMANCE OF THE WORK.
10. THE TERM "ACCEPTABLE TO THE ENGINEER" SHALL MEAN WRITTEN ACCEPTANCE BY ENGINEER IS TO BE RECEIVED BY THE CONTRACTOR BEFORE WORK IS STARTED.
11. SEE INDIVIDUAL DRAWINGS FOR ADDITIONAL ABBREVIATIONS, SYMBOLS, LEGENDS, NOTES, DETAILS, AND OTHER REQUIREMENTS, IF ANY. NOT ALL OF THESE ITEMS AND/OR "STANDARD" DETAILS SHOWN MAY BE APPLICABLE TO THIS PROJECT. UNLESS OTHERWISE NOTED, IN ALL CASES, THE INFORMATION SHOWN ON INDIVIDUAL DRAWINGS SHALL GOVERN OVER ANY GENERAL INFORMATION.
12. UNLESS NOTED OTHERWISE, ALL WORK SHOWN IN THESE DOCUMENTS IS NEW AND TO BE PERFORMED UNDER THIS CONTRACT. WORK UNDER THIS CONTRACT IS NORMALLY SHOWN IN HEAVY LINES.

HEALTH AND SAFETY NOTES:

1. COMPLY WITH ALL FEDERAL, STATE AND LOCAL LAWS AND ORDINANCES RELATING TO THE SAFETY AND CHARACTER OF WORK, EQUIPMENT AND LABOR PERSONNEL. THIS SHALL INCLUDE BUT IS NOT LIMITED TO, THE SHORING OF TRENCHES, VENTILATION OF CONFINED SPACES, CONFORMANCE TO TRAFFIC CONTROL REQUIREMENTS INCLUDING THE PROVISION AND MAINTENANCE OF BARRICADES AND THE PREPARATION AND IMPLEMENTATION OF TRAFFIC CONTROL PLANS AS REQUIRED.
2. ALL HEALTH AND SAFETY PROTECTION MEASURES SHALL BE INSTALLED AND FUNCTIONAL AT THE SITE PRIOR TO PERFORMING ANY WORK. THE CONTRACTOR SHALL MAINTAIN ALL HEALTH AND SAFETY MEASURES UNTIL FINAL COMPLETION.
3. THE CONTRACTOR IS RESPONSIBLE FOR OBSERVING AND MEETING ALL OSHA REQUIREMENTS.
4. THE CONTRACTOR SHALL PROVIDE TEMPORARY CHAINLINK FENCING AND/OR TRENCH PLATES OVER OPEN TRENCHES AT THE END OF EACH DAY TO PREVENT PEOPLE AND WILDLIFE FORM ENTERING THE TRENCH.

ENVIRONMENTAL PROTECTION AND EROSION, STORM WATER AND SEDIMENTATION CONTROL NOTES:

1. EXCEPT AS NOTED, THE CONTRACTOR IS RESPONSIBLE FOR ALL EROSION, STORM WATER "SWPPP" AND SEDIMENTATION CONTROL AND ENVIRONMENTAL PROTECTION MEASURES. THE CONTRACTOR SHALL BE RESPONSIBLE FOR OBTAINING ALL RELATED PERMITS.
2. ALL ENVIRONMENTAL PROTECTION MEASURES SHALL BE INSTALLED AND FUNCTIONAL AT THE SITE PRIOR TO PERFORMING ANY WORK, UNLESS NOTED. THE CONTRACTOR SHALL MAINTAIN ALL ENVIRONMENTAL PROTECTION MEASURES UNTIL FINAL COMPLETION.
3. SOIL EROSION CONTROL MEASURES SHALL BE IN ACCORDANCE WITH SPECIFICATIONS, ENVIRONMENTAL PROTECTION MEASURES.
4. ALL EXISTING DRAINAGE FEATURES SHALL BE PROPERLY PROTECTED.

MEASUREMENT COORDINATES, & STATIONING NOTES:

1. WRITTEN DISTANCES AND ELEVATIONS SHALL GOVERN OVER SCALED DISTANCES AND ELEVATIONS.
2. DETAILS & DRAWINGS IDENTIFIED AS NTS (NOT-TO-SCALE) SHALL NOT BE SCALED IF DIMENSIONS ARE NOT PROVIDED.
3. PIPE LENGTHS SHOWN IN PROFILE OR PLAN ARE APPROXIMATE AND MAY VARY UP TO 5 PERCENT OF INDICATED LENGTH.
4. DIMENSIONS OF EXISTING STRUCTURES, PIPING, PAVING AND OTHER NON-STRUCTURAL ITEMS ARE APPROXIMATE. FIELD VERIFY ALL DIMENSIONS AND CONDITIONS AND REPORT ALL MAJOR DISCREPANCIES TO THE ENGINEER AT LEAST 7 WORKING DAYS IN ADVANCE OF CONSTRUCTION IN THE AREA.
5. DISCREPANCIES BETWEEN COORDINATES, BEARINGS, LENGTHS, AND STATIONING SHALL BE RESOLVED IN THE FOLLOWING ORDER OF PRECEDENCE:
   A. COORDINATES
   B. BEARINGS AND LENGTHS
   C. STATIONING

SITE PREPARATION NOTES:

1. CONTRACTOR SHALL REMOVE ALL TREES, STUMPS, BRUSH, SHRUBS, ROOTS, GRASS, WEEDS, RUBBISH, AND ROOTS IN EXCESS OF 1-1/2 INCH IN DIAMETER, CONCRETE RUBBLE, OR OTHER DEBRIS WHERE NECESSARY TO PERFORM WORK SHOWN ON DRAWINGS.
2. PROTECT TREES AND OTHER VEGETATION DESIGNATED ON DRAWINGS,
3. DISPOSE OF MATERIAL AND DEBRIS FROM SITE PREPARATIONS OPERATIONS AT AN APPROVED OFF-SITE FACILITY. NO DEBRIS SHALL BE BURIED ON THE SITE OR BURNED.

UTILITY COORDINATION:

A. HE LOCATION OF EXISTING UTILITIES AND UNDERGROUND FACILITIES KNOWN TO THE ENGINEER ARE SHOWN IN THEIR APPROXIMATE LOCATION BASED ON INFORMATION AVAILABLE AT THE TIME OF PREPARING THE DRAWINGS. THE ACTUAL LOCATION, SIZE, TYPE, AND NUMBER OF UTILITIES AND UNDERGROUND FACILITIES MAY DIFFER FROM THAT SHOWN AND UTILITIES OR UNDERGROUND FACILITIES MAY BE PRESENT THAT ARE NOT SHOWN.

B. USE EXTREME CARE WHEN EXCAVATING OR WORKING IN AREAS THAT MAY CONTAIN EXISTING UTILITIES, PROCESS PIPING, CONDUITS OR OTHER UNDERGROUND FACILITIES. USE CAREFUL POTHOLING, HAND DIGGING AND PROBING TO DETERMINE THE EXACT LOCATION OF UNDERGROUND INSTALLATION. SOME LOCATIONS CONTAIN MULTIPLE PIPES OR CONDUITS. PRIOR TO PERFORMING ANY SUBSURFACE WORK, INVESTIGATE, DETERMINE AND PREPARE A PLAN TO TURN OFF OR DISCONNECT EACH UTILITY BELIEVED TO BE WITHIN 100 FEET OF THE SUBSURFACE WORK IN THE EVENT OF AN ACCIDENTAL BREACH OF A UTILITY CONDUIT.

C. WHERE CONNECTIONS TO EXISTING UTILITIES OR OTHER UNDERGROUND FACILITIES IS REQUIRED OR WHERE NEW PIPING OR CONDUITS MAY CROSS OR INTERFERE WITH EXISTING UTILITIES OR UNDERGROUND FACILITIES CAREFULLY EXCAVATE AND UNCOVER EXISTING INSTALLATIONS TO A POINT 1 FOOT BELOW THE PIPE OR CONDUIT TO DETERMINE THE ACTUAL ELEVATION AND ALIGNMENT. CALL THE ENGINEER'S ATTENTION TO DIFFERING EXISTING CONDITIONS THAT MAY REQUIRE A CLARIFICATION OR CHANGE.

EARTHWORK NOTES:

1. BACKFILL MATERIALS SHALL MEET THE FOLLOWING REQUIREMENTS
   a. SHALL CONSIST OF SOIL, LOAM, OR OTHER MATERIAL WITH A LIQUID LIMIT LESS THAN 50 AND A PLASTICITY INDEX LESS THAN 30 WHEN MEASURED IN ACCORDANCE WITH ASTM D4318.
   b. SHALL HAVE AN IN-PLACE WATER CONTENT LESS THAN 30 PERCENT
   c. SHALL HAVE LESS THAN 5 PERCENT (BY WEIGHT) FIBROUS ORGANIC MATERIAL CONTENT
   d. SHALL BE FREE OF ALL ORGANIC MATERIAL, TRASH, OR OTHER OBJECTIONABLE MATERIALS WHICH MAY BE COMPRESSIBLE OR WHICH CANNOT BE PROPERLY COMPACTED.
   e. SOFT, WET, PLASTIC SOILS WHICH MAY BE EXPANSIVE, SHALL NOT BE SUITABLE FOR BACKFILL
   f. SHALL HAVE A MAXIMUM OF 1 PERCENT EXPANSION WHEN TESTING IS PERFORMED ON A SAMPLE REMOLDED TO 95 PERCENT OF MAXIMUM DRY DENSITY (PER ASTM D698) AT 2 PERCENT BELOW OPTIMUM MOISTURE CONTENT UNDER A 100 LBS/SQ FT SURCHARGE.
   g. SHALL NOT CONTAIN GRANITE BLOCKS, BROKEN CONCRETE, MASONRY RUBBLE, ASPHALT PAVEMENT, OR ANY MATERIAL LARGER THAN 3_IN IN ANY DIMENSION.
   h. SHALL BE FREE FROM ROOTS OR ORGANIC MATTER, REFUSE, BOULDER AND MATERIAL LARGER THAN 3-IN IN LARGEST DIMENSION, OR OTHER DELETERIOUS MATERIALS.
   i. IF ONSITE MATERIAL DOES NOT MEET THE SPECIFIED LIQUID LIMIT OR PLASTICITY INDEX, MATERIAL MEETING THE SPECIFICATIONS SHALL BE IMPORTED AT NO ADDITIONAL COST TO THE OWNER.
2. PIPE ZONE AND MATERIALS SHALL BE FREE OF ICE, CLAY, ORGANIC MATTER, OR OTHER OBJECTIONABLE MATERIAL, AND SHALL CONFORM TO THE FOLLOWING GRADATION PER ASTM C136

SIEVE SIZE	PERCENT FINER BY WEIGHT
3/8"	100
#4	90 – 100
#50	10 – 40
#100	3 – 20
#200	0 – 15

3. AGGREGATE BASE COURSE
   a. SHALL BE FREE FROM VEGETABLE MATTER AND OTHER DELETERIOUS SUBSTANCES, AND OF SUCH NATURE THAT AGGREGATE CAN BE COMPACTED READILY UNDER WATERING AND ROLLING TO FORM A FIRM, STABLE BASE.
   b. MATERIALS DERIVED FROM PROCESSING DEMOLISHED OR REMOVED ASPHALT CONCRETE, CONCRETE, OR GLASS ARE NOT ACCEPTABLE.
   c. MINIMUM RESISTIVITY OF THE AGGREGATE BASE SHALL BE 3,000 OHM-CM. THE PH OF THE AGGREGATE BASE SHALL BE BETWEEN 5.5 AND 8.5.
   d. COARSE AGGREGATE MATERIAL RETAINED IN NUMBER 4 SIEVE SHALL CONSIST OF MATERIAL OF WHICH AT LEAST 25 PERCENT BY WEIGHT SHALL BE CRUSHED PARTICLES WHEN TESTED IN ACCORDANCE WITH CALIFORNIA TEST 205.
   e. AGGREGATE SHALL NOT BE TREATED WITH LIME, CEMENT, OR OTHER CHEMICAL MATERIAL BEFORE THE DURABILITY INDEX TEST IS PERFORMED.
   f. AGGREGATE GRADING AND SAND EQUIVALENT TESTS SHALL BE PERFORMED TO REPRESENT NOT MORE THAN 500 CUBIC YARDS OR ONE DAY'S PRODUCTION OF MATERIAL, WHICHEVER IS SMALLER.
   g. SHALL CONFORM TO THE FOLLOWING GRADATION:

SIEVE SIZE	PERCENT FINER BY WEIGHT
1"	100
3/4"	90 – 100
#4	35 – 60
#30	10 – 30
#200	2 – 9

4. 3/4-INCH CRUSHED GRAVEL SHALL BE NON-FROST SUSCEPTIBLE MATERIAL CONFORMING TO THE FOLLOWING GRADATION:

SIEVE SIZE	PERCENT FINER BY WEIGHT
3"	100
#4	20 – 70
#200	0 – 5

5. TESTING:
   a. FOR EACH MATERIAL PROPOSED TO BE USED, CONTRACTOR SHALL SUBMIT DOCUMENTATION SHOWING THE RESULTS OF GRAIN SIZE ANALYSIS AND PROCTOR TESTING TO DETERMINE MAXIMUM DRY DENSITIES REQUIRED FOR COMPACTION TESTING, PER ASTM 1557.
   b. FIELD DENSITY TESTING SHALL BE PERFORMED ON AT LEAST ONE SAMPLE FOR EACH MATERIAL PLACED AND COMPACTED IN THE FIELD.

CONCRETE NOTES:

1. ALL EXCAVATION, TRENCHING, AND RELATED SHORING SHALL COMPLY WITH THE REQUIREMENTS OF OSHA EXCAVATION SAFETY STANDARDS (29 CFR PART 1926.650 SUPPORT.
2. CONTRACTOR SHALL PUT IN PLACE AND MAINTAIN ALL SHORING AS REQUIRED BY FEDERAL, STATE, AND LOCAL SAFETY REQUIREMENTS.
3. CAST-IN-PLACE CONCRETE SHALL HAVE A 28 DAY COMPRESSIVE STRENGTH OF 2500 PSI, PER ACI 318.
4. CEMENT: DOMESTIC PORTLAND CEMENT COMPLYING WITH ASTM C150, TYPE II. AIR ENTRAINING CEMENTS SHALL NOT BE USED.
5. FINE AGGREGATE: WASHED INERT NATURAL SAND CONFORMING TO THE REQUIREMENTS OF ASTM C33
6. COARSE AGGREGATE: WELL_GRADED CRUSHED STONE OR WASHED GRAVEL CONFORMING TO THE REQUIREMENTS OF ASTM C33. GRADING REQUIREMENTS SHALL BE AS LISTED IN ASTM C33 TABLE 2 FOR THE SPECIFIED COARSE AGGREGATE SIZE NUMBER. LIMITS OF DELETERIOUS SUBSTANCES AND PHYSICAL PROPERTY REQUIREMENTS SHALL BE AS LISTED IN ASTM C33, TABLE 3 FOR SEVERE WEATHERING REGIONS. SIZE NUMBERS FOR THE CONCRETE MIXES SHALL BE 57.
7. WATER: POTABLE WATER FREE FROM INJURIOUS AMOUNTS OF OIL, ACID, ALKALI, ORGANIC MATTER, OR OTHER DELETERIOUS SUBSTANCES.
8. ADMIXTURES: ADMIXTURES SHALL BE FREE OF CHLORIDES AND ALKALIS (EXCEPT FOR THOSE ATTRIBUTABLE TO WATER). EACH ADMIXTURE SHALL BE COMPATIBLE WITH ALL THE COMPONENTS IN THE CONCRETE MIX AND SHALL BE SUITABLE WHEN IT IS REQUIRED TO USE MORE THAN ONE ADMIXTURE IN A CONCRETE MIX, THE ADMIXTURES SHALL BE FROM THE SAME MANUFACTURER. ADMIXTURES SHALL BE COMPATIBLE WITH THE CONCRETE MIX INCLUDING OTHER ADMIXTURES.
   a. AIR ENTRAINING ADMIXTURE: THE ADMIXTURE SHALL COMPLY WITH ASTM C260. PROPORTIONING AND MIXING SHALL BE IN ACCORDANCE WITH MANUFACTURER'S RECOMMENDATIONS
   b. WATER REDUCING ADMIXTURE: THE ADMIXTURE SHALL COMPLY WITH ASTM C494, TYPE A. PROPORTIONING AND MIXING SHALL BE IN ACCORDANCE WITH MANUFACTURER'S RECOMMENDATIONS
   c. ADMIXTURES CAUSING RETARDED OR ACCELERATED SETTING OF CONCRETE SHALL NOT BE USED WITHOUT WRITTEN APPROVAL FROM THE ENGINEER. WHEN ALLOWED, THE ADMIXTURES SHALL BE RETARDING OR ACCELERATING WATER REDUCING ADMIXTURES
9. SHEET CURING MATERIALS: WATERPROOF PAPER, POLYETHYLENE FILM OR WHITE BURLAP_POLYETHYLENE SHEETING, ALL COMPLYING WITH ASTM C171.
10. CEMENTIOUS CONTENT SHALL BE 440 POUNDS PER CUBIC YARD MAXIMUM.
11. WATER TO CEMENT RATIO SHALL BE 0.62 MAX.
12. PERCENT AIR ENTRAINMENT, PER ASTM C231, SHALL BE 3.5 TO 5.
13. SLUMP, PER ASTM C143, SHALL BE 1 – 4 INCHES.

REV. NO.	DATE	DRWN	CHKD	REMARKS

DESIGNED BY: WJS
DRAWN BY: WKT
SHEET CHK'D BY: APS
CROSS CHK'D BY: WJS
APPROVED BY: PJE
DATE: DEC 2015

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ESTCP
United States Department of Defense
Environmental Security Technology Certification Program (ESTCP)

Project No. ER-201434: Anaerobic Membrane Bioreactor (AnMBR) for Sustainable Wastewater Treatment

PROJECT NO. 144284-104485
FILE NAME: G-02

GENERAL NOTES I

SHEET NO.
G-2

DESIGN DRAWINGS

XREFs: [CDMS_2234] Images: []
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MECHANICAL AND ELECTRICAL NOTES:

THE INSTALLATION SUBCONTRACTOR'S SUPERINTENDENT SHALL COORDINATE THE EXACT LOCATION, SPACE PRIORITIES AND SEQUENCE OF INSTALLATION OF ALL MECHANICAL AND ELECTRICAL WORK WITH EACH OTHER. THE LOCATION OF MECHANICAL AND ELECTRICAL WORK MAY BE INDICATED DIAGRAMMATICALLY ON THE DRAWINGS. ACTUAL LOCATIONS SHALL FOLLOW LOCATIONS SHOWN ON THE DRAWINGS AS CLOSELY AS PRACTICABLE BUT SHALL BE ALTERED OR ADJUSTED IN THE FIELD BY THE SUPERINTENDENT AS REQUIRED BY THE FOLLOWING:

A. IN FINISHED SPACES INSTALL MECHANICAL AND ELECTRICAL WORK CONCEALED WITHIN THE SPACE AVAILABLE.

B. ORGANIZE MECHANICAL AND ELECTRICAL WORK TO MAKE EFFICIENT USE OF SPACE. COMBINE SIMILAR ITEMS INTO GROUPS; MAKE ALL RUNS PARALLEL TO OR AT RIGHT ANGLES WITH BUILDING LINES.

C. LAYOUT AND INSTALL WORK TO PROVIDE ADEQUATE SPACE AND ACCESS FOR ADJUSTMENT, SERVICING, AND MAINTENANCE AND MAXIMIZE SPACE AVAILABLE FOR FUTURE INSTALLATION OF ADDITIONAL SERVICES OR REPLACEMENT OF EXISTING SERVICES.

D. COORDINATE LOCATION OF FIXTURES, SWITCHES, PANELS, PULLBOXES, AND OTHER EXPOSED MECHANICAL AND ELECTRICAL ITEMS WITH FUNCTIONAL AND VISUAL ELEMENTS. VERIFY LOCATION OF QUESTIONABLE ITEMS WITH ENGINEER BEFORE PROCEEDING.

E. UNLESS OTHERWISE NOTED ON THE DRAWINGS, DO NOT ROUTE PIPING OR CONDUITS THROUGH STRUCTURAL ELEMENTS INCLUDING WALLS, SLABS, BEAMS, AND COLUMNS; DO NOT ROUTE PIPING OR CONDUITS INSIDE STRUCTURAL ELEMENTS ALONG THE PLANE OF A WALL, PLANE OF A SLAB, SPAN OF A BEAM, OR HEIGHT OF A COLUMN.

REFERENCE STANDARDS AND REQUIREMENTS:

THE INSTALLATION SUBCONTRACTOR IS RESPONSIBLE FOR FURNISHING AND INSTALLING MATERIALS AND EQUIPMENT TO MEET THE REQUIREMENTS IN THE FOLLOWING REFERENCE STANDARDS. ANY CHANGES TO THESE REQUIREMENTS MUST BE MADE IN WRITING BY MUTUAL AGREEMENT BETWEEN ENGINEER AND THE INSTALLATION SUBCONTRACTOR.

A. REFERENCE STANDARDS

1. ALL MATERIALS AND METHODS OF INSTALLATION SHALL BE IN ACCORDANCE WITH THE REFERENCE STANDARDS INCLUDED IN TABLE 1.
2. MATERIALS AND METHODS SHALL MEET THE REQUIREMENTS OF THE LATEST VERSION OF THE REFERENCE STANDARDS, WHICH ARE IN EFFECT ON THE DATE OF THE NOTICE TO PROCEED. IF REFERENCE DOCUMENTS HAVE BEEN DISCONTINUED BY THE ISSUING ORGANIZATION, REFERENCES TO THOSE DOCUMENTS SHALL MEAN THE REPLACEMENT DOCUMENTS ISSUED OR OTHERWISE IDENTIFIED BY THAT ORGANIZATION OR, IF THERE ARE NOT REPLACEMENT DOCUMENTS, THE LATEST VERSION OF THE DOCUMENT BEFORE IT WAS DISCONTINUED.
3. WHERE THE REFERENCE STANDARDS CONTAIN REFERENCES TO OTHER STANDARDS, THOSE STANDARD ARE INCLUDED AS REFERENCE UNDER THIS SECTION AS IF REFERENCED DIRECTLY.
4. IN CASE OF CONFLICT BETWEEN THE REQUIREMENTS OF THIS SPECIFICATION AND THOSE OF THE REFERENCE STANDARDS, THE REQUIREMENTS OF THIS SPECIFICATION SHALL PREVAIL.

TABLE 1. REFERENCE STANDARDS

	TITLE
	CIP CONCRETE
	DUCTILE IRON (PLUG VALVES)
	SHEET MATERIALS FOR CURING CONCRETE
	CONCRETE AGGREGATE
	PVC
	PVC FITTINGS
	PVC SOLVENT CEMENT
	NFPA RECOMMENDED PRACTICE FOR THE CLASSIFICATION OF FLAMMABLE LIQUIDS, GASES, OR VAPORS AND OF HAZARDOUS (CLASSIFIED) LOCATIONS FOR ELECTRICAL INSTALLATIONS IN CHEMICAL PROCESS AREAS
	NATIONAL ELECTRIC CODE

B. EACH COMPONENT FURNISHED AS PART OF THE INSTALLATION SHALL MEET THE FOLLOWING REQUIREMENTS:

1. EACH COMPONENT SHALL BE CONSTRUCTED, AND INSTALLED IN ACCORDANCE WITH INDUSTRY STANDARD PRACTICES AND METHODS.
2. EACH COMPONENT SHALL BE NEW AND UNUSED.

CONCRETE NOTES:

1. INTENTIONALLY ROUGHEN THE SURFACES OF WHERE NEW CONCRETE CONTACTS EXISTING CONCRETE TO A CONCRETE SURFACE PROFILE (CSP) 9 PER ICRI GUIDELINE 03732 WITH 1/4" MINIMUM AMPLITUDE. THIS ROUGHENED SURFACE MAY BE ACCOMPLISHED BY RAKING THE PLASTIC CONCRETE OR BY BUSHHAMMERING OR CHISELING HARDENED CONCRETE SURFACES. THOROUGHLY CLEAN JOINT SURFACES OF LOOSE OR WEAKENED MATERIALS BY WATERBLASTING OR SANDBLASTING. SATURATE SURFACE WITH WATER 12 HOURS BEFORE AND AGAIN IMMEDIATELY PRIOR TO CONCRETE PLACEMENT.
2. POST-INSTALLED ANCHORS AND ADHESIVE DOWELS SHALL BE INSTALLED IN ACCORDANCE WITH THE MANUFACTURES'S, RECOMMENDATIONS AND THE CORRESPONDING ICC OR IAPMO EVALUATION SERVICE REPORT. ONLY ANCHORS WITH CURRENT ICC OR IAPMO REPORTS AND ARE QUALIFIED FOR USE IN CRACKED CONCRETE SHALL BE USED.
3. ADHESIVE ANCHORS AND ADHESIVE DOWELS SYSTEM SHALL BE HILTI HIT-HY 200, HILTI HIT RE-500 SD, SIMPSON STRONG TIE SET-XP, SIMPSON STRONG TIE AT-XP, ITW RAMSET RED HEAD EPCON G5, OR EQUAL.
4. EXPANSION ANCHORS SHALL NOT BE USED FOR ANCHORING OF EQUIPMENT SUBJECT TO VIBRATORY LOADS. EXPANSION ANCHORS SHALL BE HILTI KWIK-BOLT TZ, SIMPSON STRONG TIE STRONG BOLT 2, POWERS POWER STUB+SD6, OR EQUAL.
5. WHERE ANCHORS NEED TO BE DRIVEN IN EXISTING CONCRETE FLOORS, WALL, OR CEILINGS, LOCATE EXISTING REBAR PRIOR TO PLACING ANCHORS. AVOID EXISTING REBAR. DETERMINE FINAL LOCATION OF ANCHOR LOCATION BASED ON LOCATION OF EXISTING REBAR. LOCATION OF EQUIPMENT AND PIPING MAY NEED TO BE CHANGED BASED ON LOCATION OF EXISTING REBAR AND POSSIBLE LOCATIONS FOR ANCHORS. COORDINATE ALL CHANGES TO CONTRACT DRAWINGS WITH ENGINEER.

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SHEET CHK'D BY: APS
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DATE: DEC 2015

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Project No. ER-201434: Anaerobic Membrane Bioreactor (AnMBR) for Sustainable Wastewater Treatment

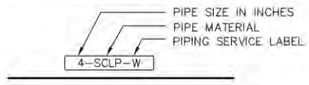
PROJECT NO. 144284-104485
FILE NAME: G-03

GENERAL NOTES II

SHEET NO.
G-3

DESIGN DRAWINGS

PIPE CODE



SECTION IDENTIFICATION

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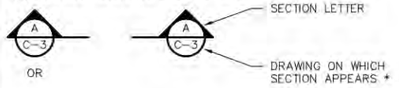
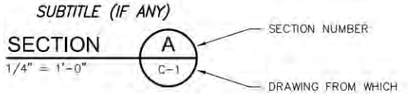


(B) ON DRAWING C-3 THIS SECTION IS IDENTIFIED AS:

SUBTITLE (IF ANY)



DETAIL IDENTIFICATION

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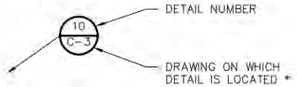

(101) ON DRAWING C-3 THIS DETAIL IS IDENTIFIED AS:

SUBTITLE (IF ANY)

* NOTE: IF SECTION OR DETAIL APPEARS ON THE SAME DRAWING AS THE CALL-OUT, THE DRAWING NUMBER IS REPLACED WITH A DASH.

TYPICAL DETAILS

TYP IN THE BOTTOM OR END OF A CALLOUT INDICATES A TYPICAL DETAIL. REFER TO ALL TYPICAL DETAIL SHEETS IN DIFFERENT DISCIPLINES. TYPICAL DETAILS MAY NOT BE SHOWN IN NUMERICAL ORDER, REVIEW ALL SHEETS.

SYMBOL	FEATURE
	EXISTING FACILITY (LIGHTER LINE WORK)
	NEW OR MODIFIED EXISTING FACILITY (DARKER LINE WORK)
	EXISTING VEGETATION
N	NORTH ARROW
	EXISTING FENCING
	NEW FENCING
	SCARIFY SOIL
	AGGREGATE BASE, CLASS 2 PERMEABLE
	STRUCTURAL FILL
	UNDISTURBED EARTH GRATING
	SPAN DIRECTION WHERE APPLICABLE
4 4 4	CONCRETE
	ASPHALT CONCRETE PAVEMENT (PLAN)

SYMBOL	FEATURE
	AIR FILTER
	PRESSURE REGULATING VALVE
	DIAPHRAGM SEAL
	PLUG VALVE
S	SOLENOID VALVE
	AUTOMATIC STRAINER
P	PNEUMATIC VALVE
	CHECK VALVE
	CONCENTRIC REDUCER/INCREASER
	PROGRESSIVE CAVITY PUMP
	BALL VALVE
	DRAIN
	PLUG VALVE
	CHECK VALVE
	GATE VALVE
	FLOOR DRAIN
	BURIED PIPING
	FLANGED JOINT
S	STRAINER
ASD	ADJUSTABLE SPEED DRIVE
TSH	TEMP SWITCH HIGH
PSH	PRESSURE SWITCH HIGH
PI	PRESSURE INDICATOR
M	MOTOR (VARIABLE SPEED)

ELECTRICAL SYMBOLS

	CONDUIT TURNING DOWN.
	CONDUIT TURNING UP.
	CONDUIT CONCEALED IN OR BELOW FLOOR OR UNDERGROUND.
FRAME/TRIP	LOW VOLTAGE AIR OR MOLDED CASE CIRCUIT BREAKER, 3 POLE UNLESS OTHERWISE NOTED.
M	MOTOR
	PRESSURE OR TEMPERATURE SWITCH
3"C., 3#3/0, #2G	DENOTES ONE 3-INCH CONDUIT CONTAINING THREE NO. 3/0 AWG CONDUCTORS AND 1 NO. 2 AWG GROUND CONDUCTOR.
J OR (J)	JUNCTION BOX

ABBREVATIONS

A	AMPS
AC	ALTERNATING CURRENT
AFD	ADJUSTABLE FREQUENCY DRIVE
AFF	ABOVE FINISHED FLOOR
AIR	SERVICE AIR
AMP	AMPERE
AWG	AMERICAN WIRE GUAGE
BKR	BREAKER
C	CONDUIT
CB	CIRCUIT BREAKER
CKT	CIRCUIT
CP	CONTROL PANEL
CPT	CONTROL POWER TRANSFER
CR	CONTROL RELAY
CT	CURRENT TRANSFORMER
CU	COPPER
DC	DIRECT CURRENT
ELEC	ELECTRICAL
EQUIP	EQUIPMENT
EX	EXISTING
G, GND	GROUND
GFI	GROUND FAULT INTERRUPTER
GRS	GALVANIZED RIGID STEEL
HP	HORSEPOWER
HZ	HERTZ
INSTR	INSTRUMENT
kcmil	1000 CIRCULAR MILS
KVA	KILOVOLOT AMPERES
KW	KILOWATTS
LA	LIGHTNING ARRESTER
LTG	LIGHTING
LP	LIGHTING PANEL
LV	LOW VOLTAGE
MAX	MAXIMUM
MCB	MAIN CIRCUIT BREAKER
MCC	MOTOR CONTROL CENTER
MCP	MOTOR CIRCUIT PROTECTOR
MDP	MAIN DISTRIBUTION PANEL
PVC	POLYVINYL CHLORIDE
SS	SANITARY SEWER
DR	DRAIN
G	GAS
W	WATER
RS	RETURN SLUDGE
EX	EXISTING
BLDG	BUILDING
CONC	CONCRETE
DWG	DRAWING
TYP	TYPICAL
DI	DUCTILE IRON
ELECT	ELECTRICAL
GALV	GALVANIZED
CISP	CAST IRON SOIL PIP
DN	DOWN
MIN	MINIMUM
MAX	MAXIMUM
N	NEUTRAL
NC	NORMALLY CLOSED
NO	NORMALLY OPEN OR NUMBER
NTS	NOT TO SCALE
OL	OVERLOAD
PB	PULL BOX
PH	PHASE
PNL	PANEL OR PANELBOARD
PR	PAIR
PP	POWER PANEL
PT	POTENTIAL TRANSFORMER
PVC	POLYVINYL CHLORIDE
QTY	QUANTITY
SA	SURGE ARRESTER
SV	SOLENOID VALVE
SW	SWITCH
SWBD	SWITCHBOARD
SWGR	SWITCHGEAR
TS	TWISTED SHIELDED OR THERMAL SWITCH
TYP	TYPICAL
UG	UNDERGROUND
V	VOLTS
VA	VOLT AMPS
VFD	VARIABLE
W	WATTS, WIDTH, WITH, WIRE
XFMR	TRANSFORMER

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DATE: DEC 2015

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Environmental Security Technology Certification Program (ESTCP)

Project No. ER-201434: Anaerobic Membrane Bioreactor (AnMBR) for Sustainable Wastewater Treatment

PROJECT NO. 144284-104485
FILE NAME: G-04

SYMBOLS, ABBREVIATIONS, & LEGENDS

SHEET NO. G-4

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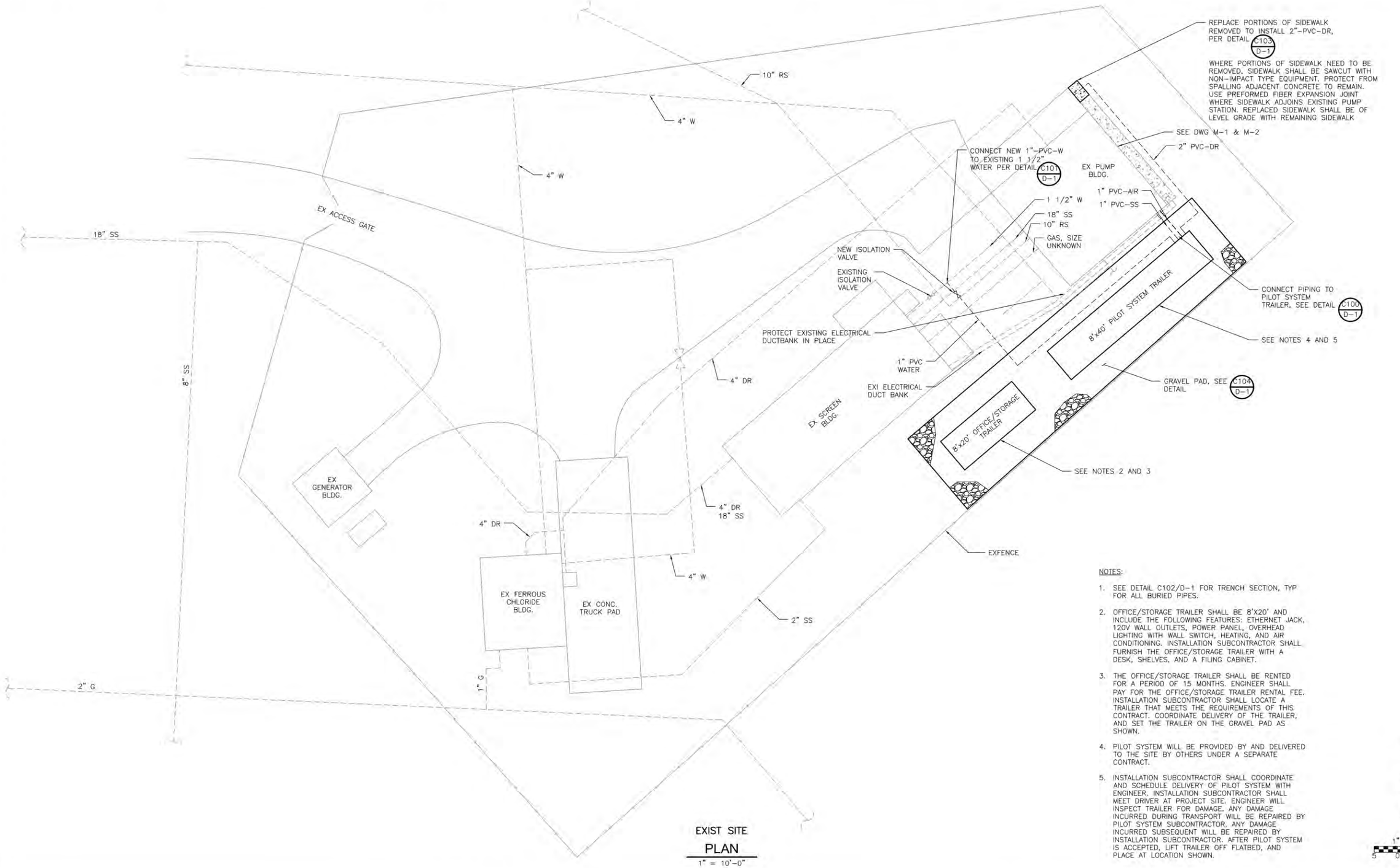

EXIST SITE
PLAN
1" = 10'-0"

NOTES:

1. SEE DETAIL C102/D-1 FOR TRENCH SECTION, TYP FOR ALL BURIED PIPES.
2. OFFICE/STORAGE TRAILER SHALL BE 8'X20' AND INCLUDE THE FOLLOWING FEATURES: ETHERNET JACK, 120V WALL OUTLETS, POWER PANEL, OVERHEAD LIGHTING WITH WALL SWITCH, HEATING, AND AIR CONDITIONING. INSTALLATION SUBCONTRACTOR SHALL FURNISH THE OFFICE/STORAGE TRAILER WITH A DESK, SHELVES, AND A FILING CABINET.
3. THE OFFICE/STORAGE TRAILER SHALL BE RENTED FOR A PERIOD OF 15 MONTHS. ENGINEER SHALL PAY FOR THE OFFICE/STORAGE TRAILER RENTAL FEE. INSTALLATION SUBCONTRACTOR SHALL LOCATE A TRAILER THAT MEETS THE REQUIREMENTS OF THIS CONTRACT. COORDINATE DELIVERY OF THE TRAILER, AND SET THE TRAILER ON THE GRAVEL PAD AS SHOWN.
4. PILOT SYSTEM WILL BE PROVIDED BY AND DELIVERED TO THE SITE BY OTHERS UNDER A SEPARATE CONTRACT.
5. INSTALLATION SUBCONTRACTOR SHALL COORDINATE AND SCHEDULE DELIVERY OF PILOT SYSTEM WITH ENGINEER. INSTALLATION SUBCONTRACTOR SHALL MEET DRIVER AT PROJECT SITE. ENGINEER WILL INSPECT TRAILER FOR DAMAGE. ANY DAMAGE INCURRED DURING TRANSPORT WILL BE REPAIRED BY PILOT SYSTEM SUBCONTRACTOR. ANY DAMAGE INCURRED SUBSEQUENT WILL BE REPAIRED BY INSTALLATION SUBCONTRACTOR. AFTER PILOT SYSTEM IS ACCEPTED, LIFT TRAILER OFF FLATBED, AND PLACE AT LOCATION SHOWN.

N

1" = 10'
5 0 10

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APPROVED BY: PJE
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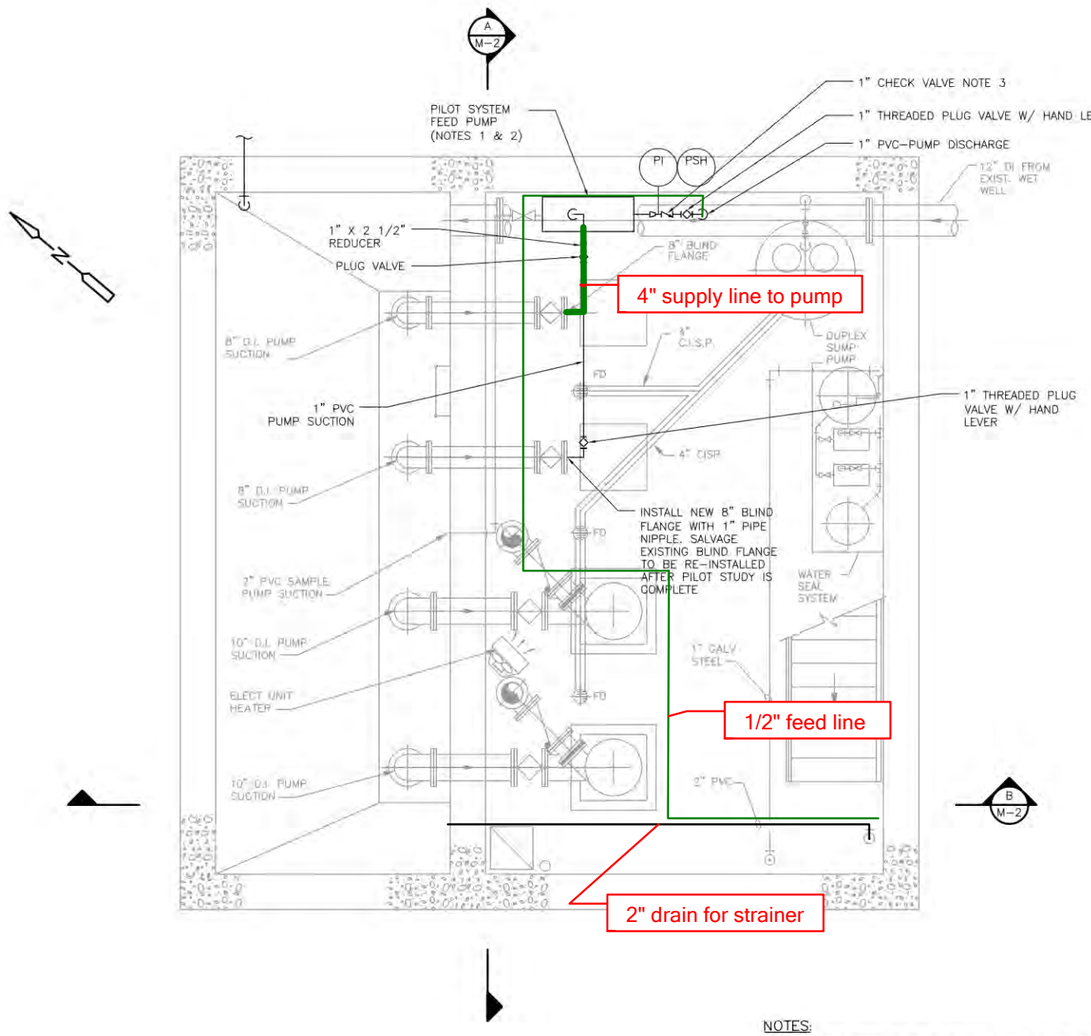
Project No. ER-201434: Anaerobic Membrane Bioreactor (AnMBR) for Sustainable Wastewater Treatment

PROJECT NO. 144284-104465
FILE NAME: C-01

SHEET NO.
C-1

SITE PLAN

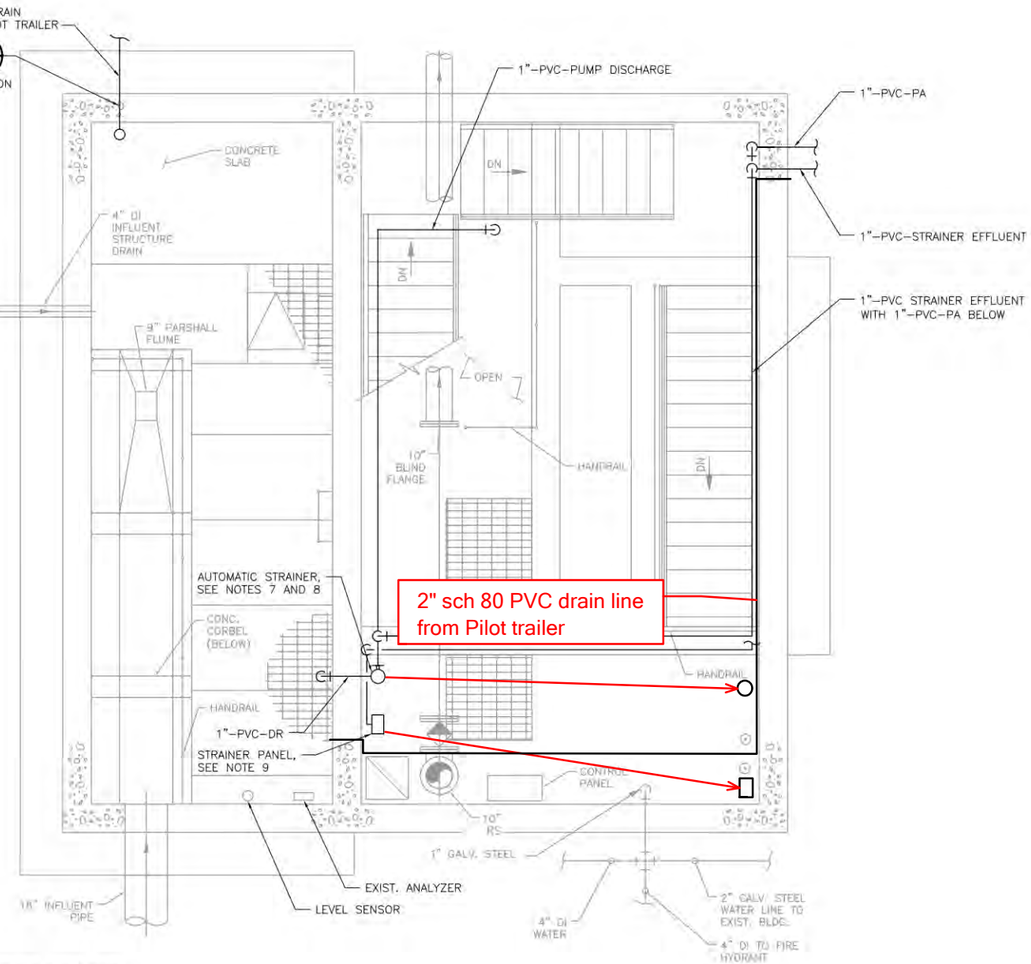
DESIGN DRAWINGS



BASEMENT FLOOR

PLAN

3/8" = 1'-0"



INTERMEDIATE FLOOR

PLAN

3/8" = 1'-0"

NOTES:

1. PILOT FEED PUMP TO BE ALLWEILER AEB1E100-1E/031 GOK Y 113 PP 6FV CAST IRON PROGRESSIVE CAVITY PUMP. CLOSE-COUPLED TO MOTOR. PUMP MOTOR SHALL BE XX.
2. PUMP SHALL BE MOUNTED ON CONCRETE PAD PER C106/D-1.
3. ALL PLUG VALVES TO BE FULL PORT & MADE OF DUCTILE IRON, CONFORMING TO ASTM A536 WITH EPOXY LINING & BUNA-NITRILE ELASTOMER TRIM. VALVES SHALL BE MANUFACTURED BY DEZURIK, HEURY PRATT, OR VALMATIC.
4. ALL CHECK VALVES TO BE PLASTIC BALL. Y-CHECK VALVES. VALVES SHALL BE MANUFACTURED BY HAYWARD, CHEMTROL OR ASAHI/AMERICA.
5. ALL PVC PIPING TO BE SCHEDULE 80 AND MEET ASTM D1784, CLASS 12454-B.
6. ALL PVC FITTINGS TO BE SOLVENT WELDED JOINTS CONFORMING TO ASTM D2467. FITTINGS SHALL MEET ASTM D1784, CLASS 12454-B. SOLVENT SHALL BE AS SPECIFIED IN ASTM D2564.
7. AUTOMATIC STRAINER TO BE EATON DCF400 WITH FLOOR STAND.
8. STRAINER AND STRAINER PANEL SHALL BE ANCHORED TO EXISTING CONCRETE FLOOR PER MANUFACTURER'S RECOMMENDATIONS. SEE STRUCTURE NOTES 2-5 ON SHEET G-3 FOR REQUIREMENTS FOR INSTALLING ANCHORS IN EXISTING CONCRETE.
9. STRAINER PANEL SHALL BE EATON SEMI-AUTO PANEL ASSEMBLY COMPATIBLE WITH THE DCF 400 STRAINER. INSTALL PER P&IDs AND MANUFACTURER'S RECOMMENDATIONS.
10. PROCESS PIPING TO BE ANCHORED TO EXISTING CONCRETE WALLS, CEILINGS, AND FLOORS USING UNISTRUT ANCHORED TO THE CONCRETE AND A PIPE CLAMP TO ANCHOR THE PIPE TO THE UNISTRUT. SEE STRUCTURAL NOTES 2-5 ON SHEET G-3 FOR REQUIREMENTS FOR INSTALLING ANCHORS IN EXISTING CONCRETE.

3/8" = 1'- 0"

2 0 2 4

REV. NO.	DATE	DRWN	CHKD	REMARKS

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Project No. ER-201434: Anaerobic Membrane Bioreactor (AnMBR) for Sustainable Wastewater Treatment

MECHANICAL PLAN

PROJECT NO. 144284-104485
FILE NAME: M-01

SHEET NO.
M-1

DESIGN DRAWINGS

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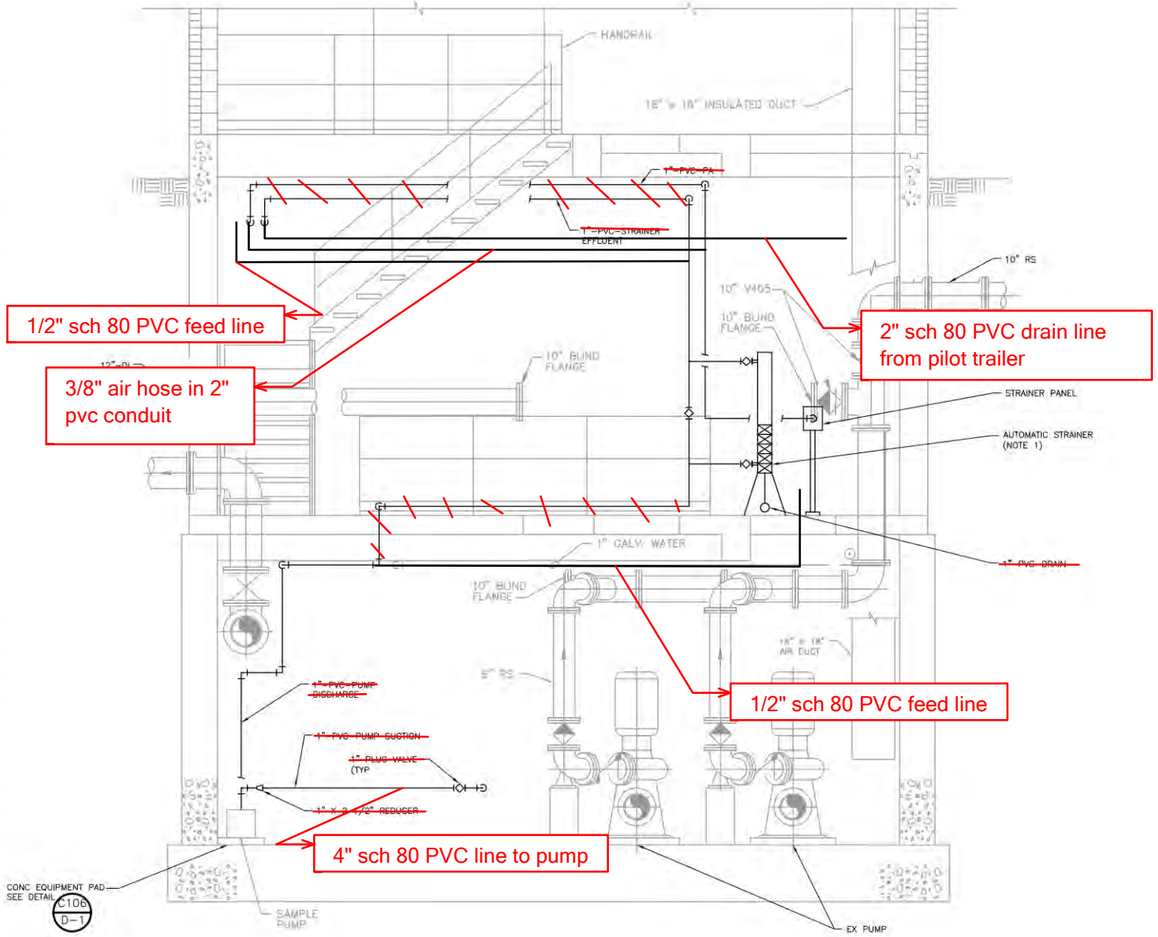
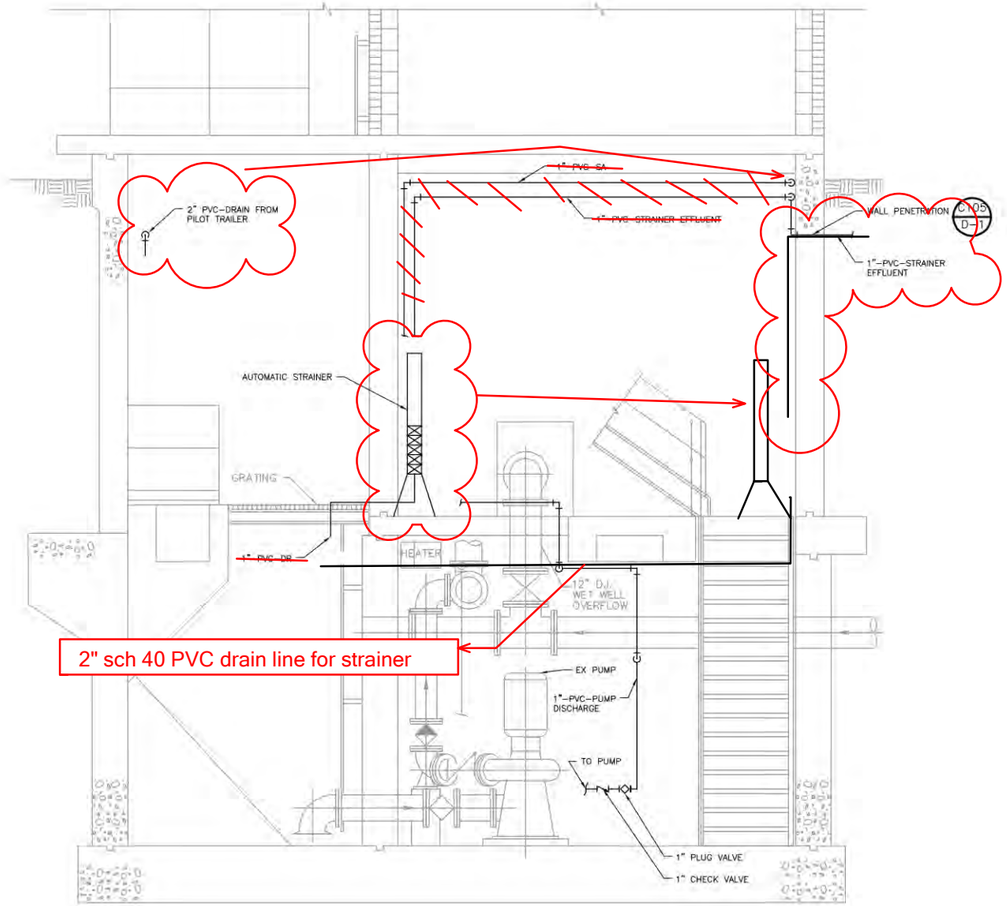


SECTION A
3/8" = 1'-0"
M-1



SECTION B
3/8" = 1'-0"
M-1

NOTES:

1. AUTOMATIC STRAINER TO BE EATON DCF400 WITH FLOOR STAND.

3/8" = 1'- 0"
2 0 2 4

REV. NO.	DATE	DRWN	CHKD	REMARKS

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PROJECT NO. 144284-104485
FILE NAME: M-02

MECHANICAL SECTIONS

SHEET NO. M-2

DESIGN DRAWINGS

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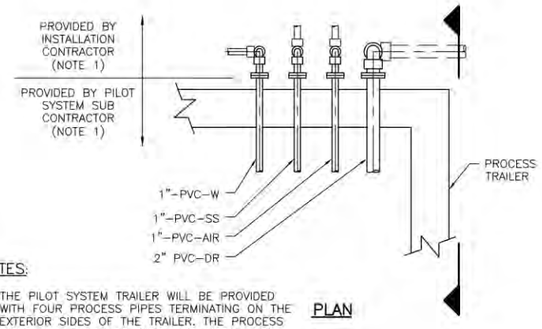
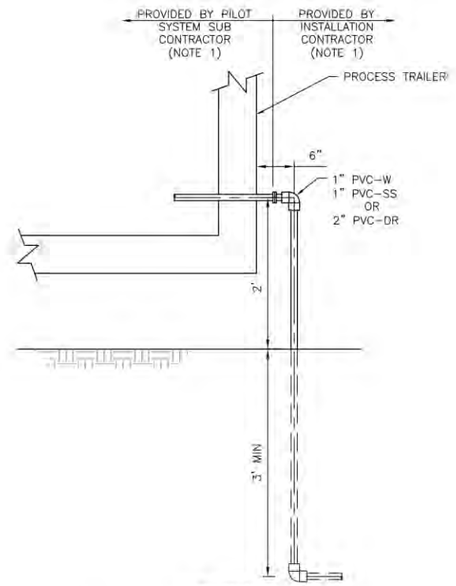


PLAN

NOTES:

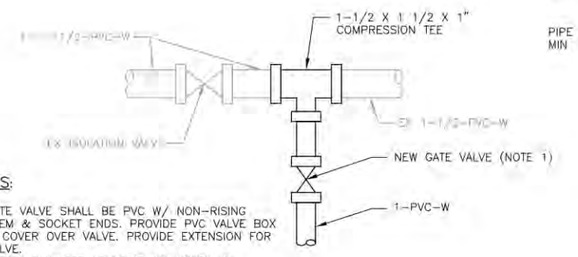
1. THE PILOT SYSTEM TRAILER WILL BE PROVIDED WITH FOUR PROCESS PIPES TERMINATING ON THE EXTERIOR SIDES OF THE TRAILER. THE PROCESS PIPES WILL HAVE NPT ENDS. THE INSTALLATION CONTRACTOR SHALL PROVIDE A THREADED FLANGE COUPLING ADAPTOR TO CONNECT TO THE PROCESS PIPES ON THE PILOT SYSTEM TRAILER.



SECTION

1" = 1'- 0"

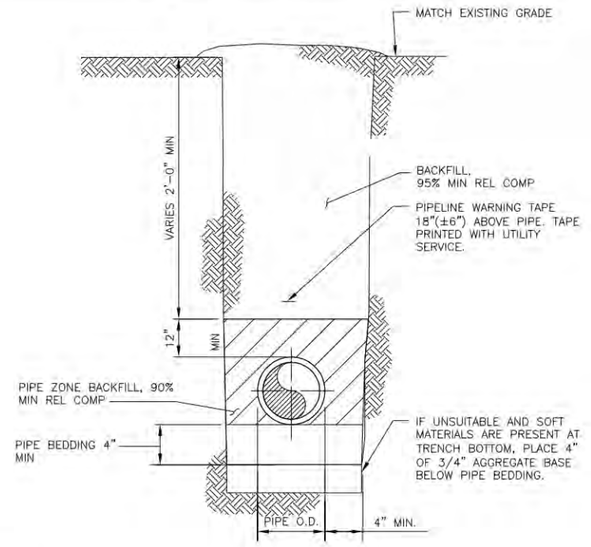
DETAIL C100 (C-1) — 1" = 1'-0"



NOTES:

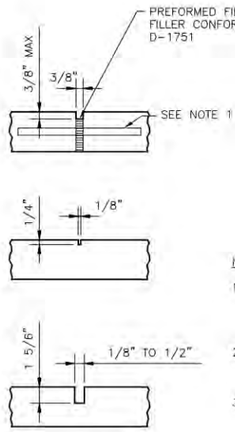
1. GATE VALVE SHALL BE PVC W/ NON-RISING STEM & SOCKET ENDS. PROVIDE PVC VALVE BOX & COVER OVER VALVE. PROVIDE EXTENSION FOR VALVE.
2. NOTIFY ENGINEER AT LEAST 48 HOURS IN ADVANCE OF SHUTTING ISOLATION VALVE AND CONNECTING TO EXISTING WATER LINE.

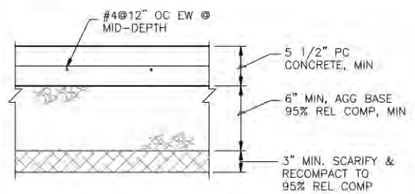
DETAIL C101 (C-1) — NTS



TYPICAL PIPE TRENCH SECTION

DETAIL C102 (C-1) — NTS



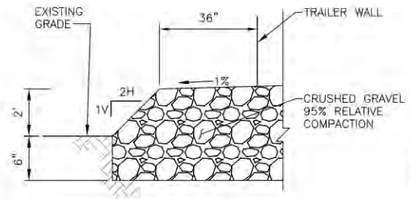


NOTES:

1. WEAKENED PLANE JOINTS SHALL BE CONSTRUCTED AT REGULAR INTERVALS NOT TO EXCEED 10 FEET ON CENTER, EACH WAY. EXPANSION JTS SHALL BE 150'-0" ON CENTER MAXIMUM AND ON BOTH SIDES OF FIXED OBJECTS.
2. SUBGRADE SOILS SHALL BE 3 TO 5 PERCENT ABOVE LABORATORY OPTIMUM MOISTURE PER ASTM D 1557 PRIOR TO CONCRETE PLACEMENT.
3. SIDEWALKS WIDTH AND FINISH SHALL MATCH EXISTING.

SLAB-ON-GRADE

DETAIL C103 (TYP) — NTS

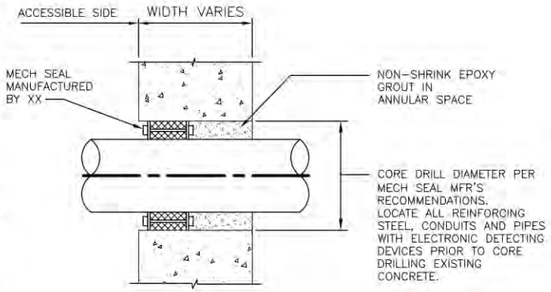


NOTES:

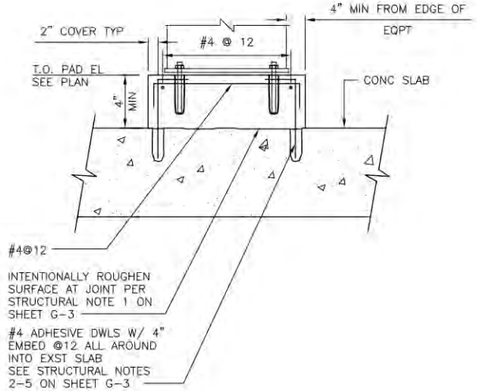
1. REMOVE TOP 6" OF TOPSOIL WITHIN FOOTPRINT OF PAD.
2. AFTER TOPSOIL REMOVAL, REPORT CONDITIONS OF SUBGRADE MATERIALS TO ENGINEER.
3. IF SUBGRADE MATERIALS ARE SUITABLE, THICKNESS OF GRAVEL PAD MAY BE REDUCED.
4. PERFORM PROOF ROLLING OF EXPOSED SUBGRADE. IF LOCALLY SOFT SOILS ARE INDICATED BY PUMPING ACTION OF PROOF ROLLING EQUIPMENT, EXCAVATE SOILS TO A DEPTH OF 1 FOOT AND REPLACE WITH 3/4" CRUSHED GRAVEL.
5. PLACE GRAVEL PAD IN LIFTS NOT EXCEEDING 8-INCHES.

GRAVEL PAD

DETAIL C104 (C-1) — NTS



DETAIL C105 (TYP) — NTS



EQUIPMENT PAD

DETAIL C106 (TYP) — NTS

REV. NO.	DATE	DRWN	CHKD	REMARKS

DESIGNED BY: WJS
DRAWN BY: WKT
SHEET CHK'D BY: APS
CROSS CHK'D BY: WJS
APPROVED BY: PJE
DATE: DEC 2015

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1755 Creekside Oaks Drive
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ESTCP
United States Department of Defense
Environmental Security Technology Certification Program (ESTCP)

Project No. ER-201434: Anaerobic Membrane Bioreactor (AnMBR) for Sustainable Wastewater Treatment

CIVIL & MECHANICAL DETAILS

PROJECT NO. 144284-104485
FILE NAME: D-01
SHEET NO. D-1

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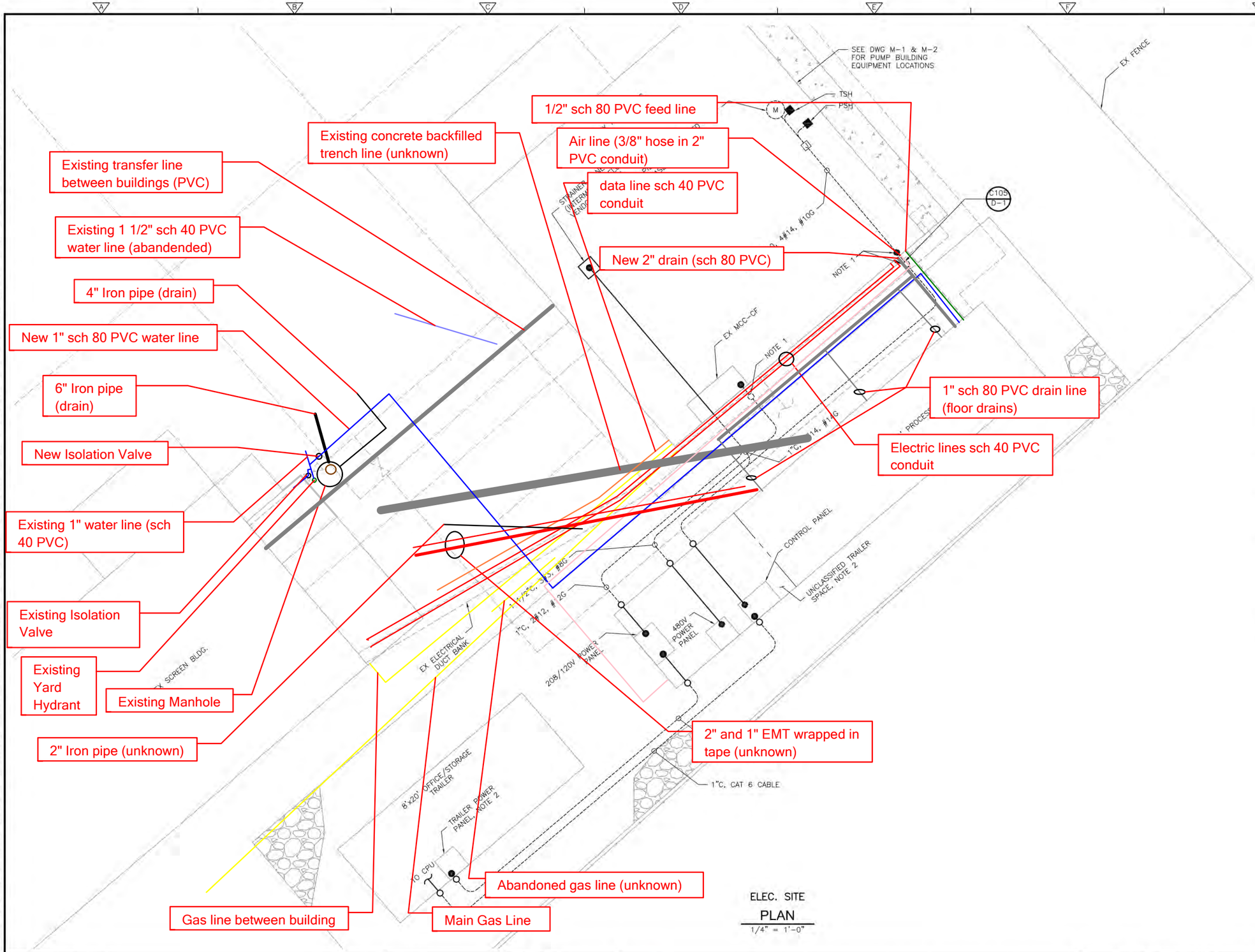

ELEC. SITE PLAN
1/4" = 1'-0"

NOTES:

1. CORE DRILL WALL AND FLOOR AS REQUIRED.
2. VERIFY PANEL LOCATIONS IN THE FIELD BEFORE ROUTING CONDUIT AND CABLE.
3. ALL WIRES AND CABLES SHALL BE OF ANNEALED, 98 PERCENT CONDUCTIVITY, SOFT DRAWN STRANDED COPPER, THHN/THWN, 600V RATED INSULATION, SIZED AS SHOWN. THE CABLES SHALL NOT BE SPLICED.
4. ALL ABOVE GROUND CONDUIT SHALL BE GRS SIZED AS SHOWN. ALL BELOW GROUND CONDUIT SHALL BE PVC SCHEDULE 40 SIZED AS SHOWN 24" MINIMUM COVER. DIRECT BURIED TRANSITIONS FROM BELOW TO ABOVE GROUND SHALL BE MADE WITH PVC COATED GRS CONDUIT.
5. CONDUIT SHALL BE RUN NEAR THE CEILING OR ALONG WALLS AND ROUTED TO AVOID CONFLICTS. PULL BOXES SHALL BE PROVIDED AS REQUIRED BY THE NEC AFTER EVERY 270 DEGREES OF BENDS. CONDUIT SUPPORTS SHALL BE SPACED AT INTERVALS NOT EXCEEDING THE DISTANCE REQUIRED BY THE NEC TO OBTAIN RIGID CONSTRUCTION. EXPOSED CONDUITS SHALL BE RUN AT RIGHT ANGLES AND PARALLEL WITH THE SURROUNDING WALL. NO DIAGONAL RUNS WILL BE ALLOWED.
6. TRAILERS WILL BE PROVIDED WITH PENETRATIONS FOR CONDUIT.
7. NOTIFY ENGINEER AT LEAST 48 HOURS IN ADVANCE OF POWER SHUT DOWN PRIOR TO CONNECTION.

N

1/4" = 1'-0"
2 1 0 2 4

REV. NO.	DATE	DRWN	CHKD	REMARKS

DESIGNED BY: DIS
DRAWN BY: WKT
SHEET CHK'D BY: JLJM
CROSS CHK'D BY: WJS
APPROVED BY: PJE
DATE: DEC 2015

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ESTCP
United States Department of Defense
Environmental Security Technology Certification Program (ESTCP)

Project No. ER-201434: Anaerobic Membrane Bioreactor (AnMBR) for Sustainable Wastewater Treatment

ELECTRICAL SITE PLAN

PROJECT NO. 144284-104485
FILE NAME: E-01
SHEET NO. E-1

DESIGN DRAWINGS

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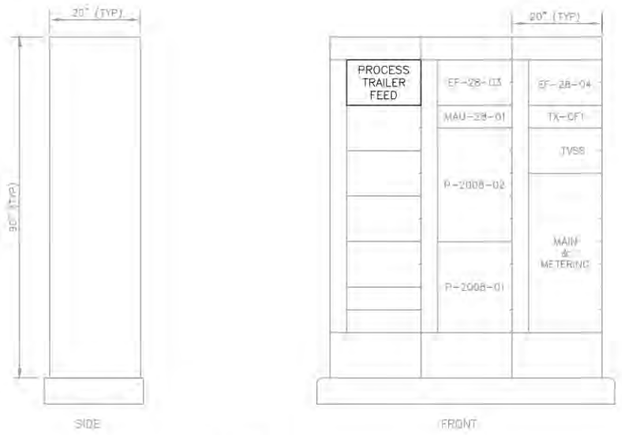
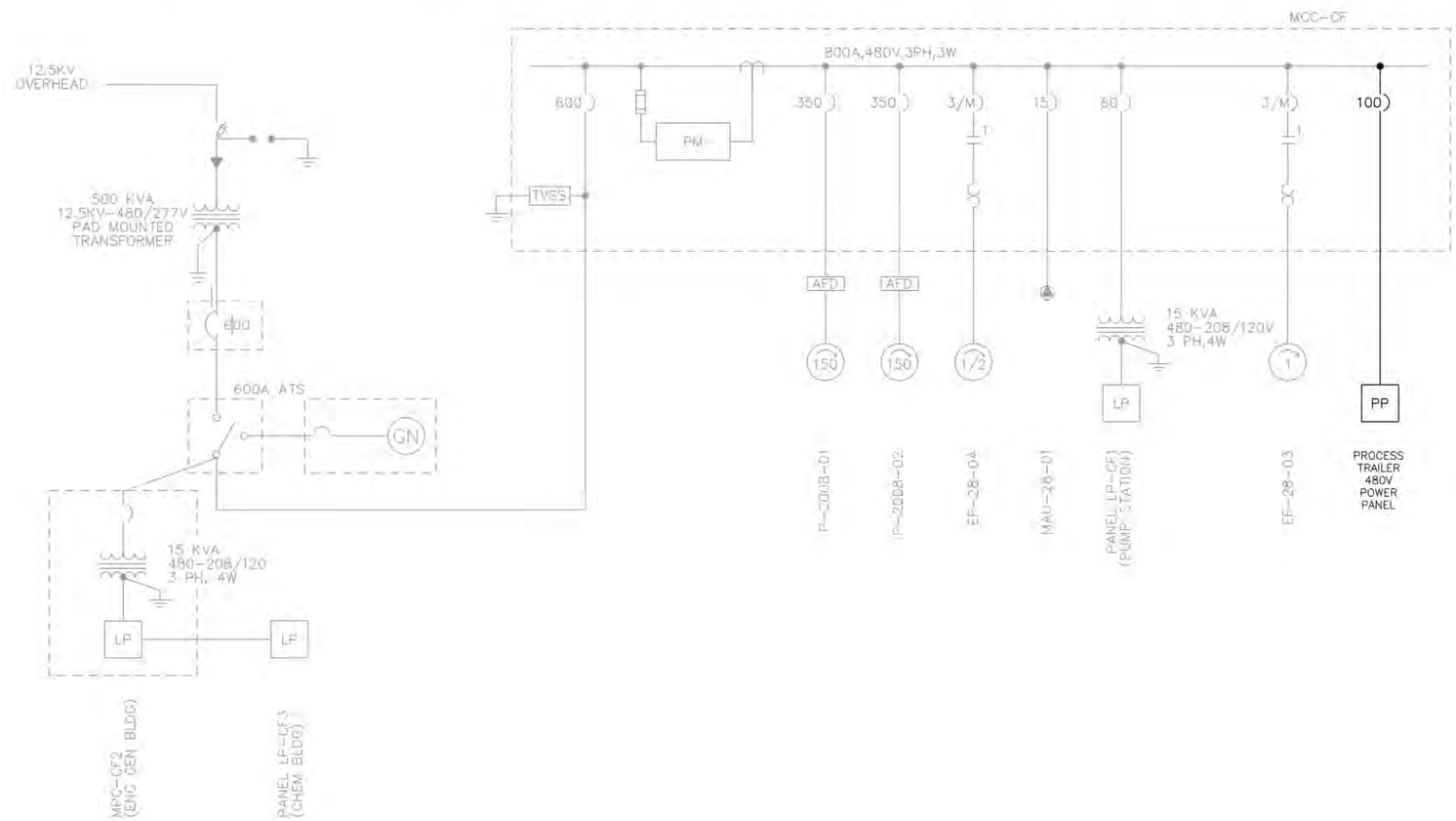


MCC-CF

ELEVATION

NTS



PUMP STATION ONE-LINE

REV. NO.	DATE	DRWN	CHKD	REMARKS

DESIGNED BY: DIS
DRAWN BY: WKT
SHEET CHK'D BY: JLJM
CROSS CHK'D BY: WJS
APPROVED BY: PJE
DATE: SEPT 2015

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ESTCP
United States Department of Defense
Environmental Security Technology Certification Program (ESTCP)

Project No. ER-201434: Anaerobic Membrane Bioreactor (AnMBR) for Sustainable Wastewater Treatment

ELECTRICAL ONE-LINE DIAGRAM

PROJECT NO. 144284-104485
FILE NAME: E-02

SHEET NO.
E-2

DESIGN DRAWINGS

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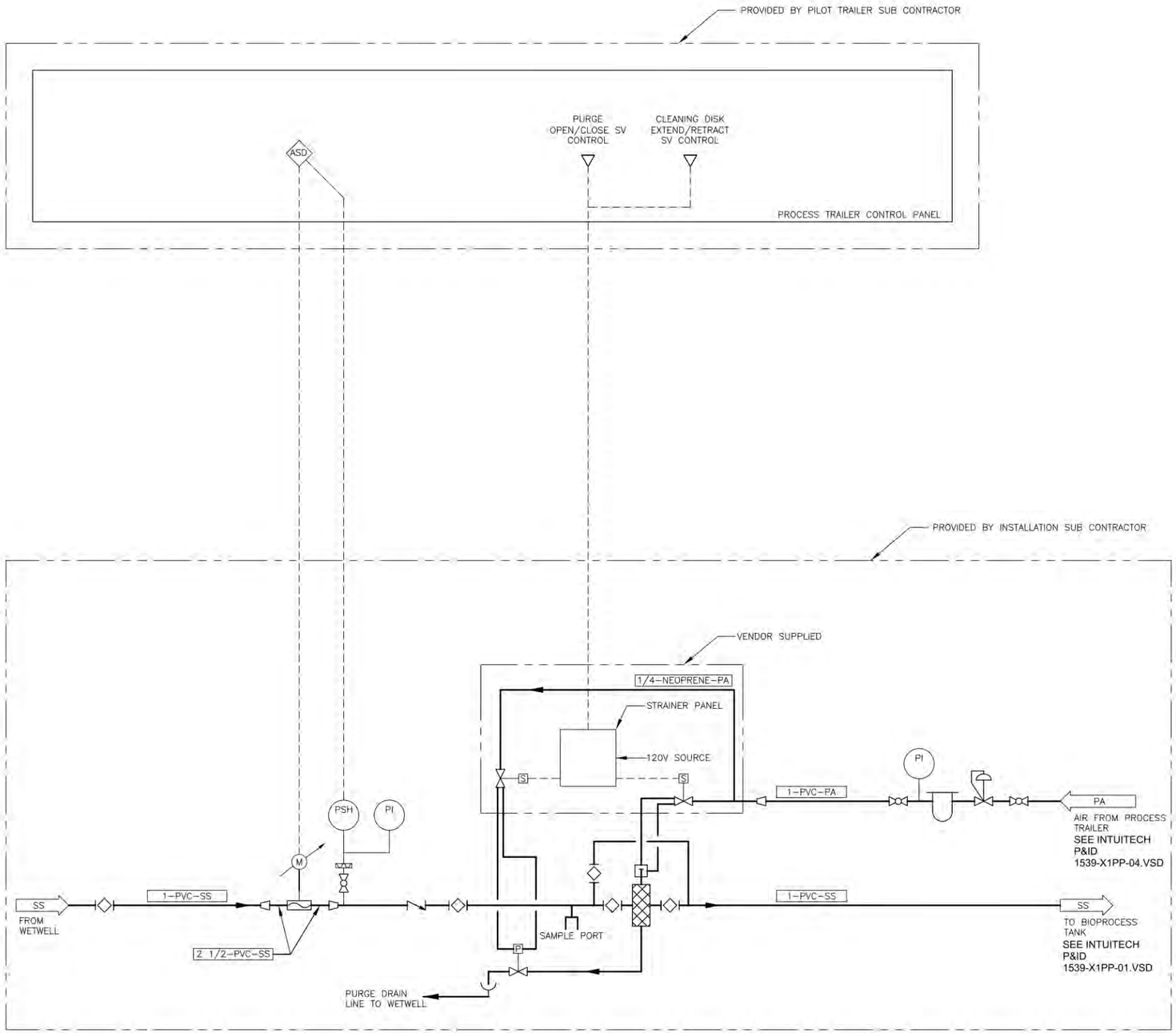

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REV. NO.	DATE	DRWN	CHK'D	REMARKS

DESIGNED BY: DIS
DRAWN BY: WKT
SHEET CHK'D BY: APS
CROSS CHK'D BY: WJS
APPROVED BY: PJE
DATE: DEC 2015

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Project No. ER-201434: Anaerobic Membrane Bioreactor (AnMBR) for Sustainable Wastewater Treatment

PROJECT NO. 144284-104485
FILE NAME: I-01

PROCESS & INSTRUMENTATION DIAGRAM

SHEET NO.
I-1

DESIGN DRAWINGS

Appendix D

Forms

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Field Observations Checklist

Date:

Observer:

Area	Equipment No.	Observation	Observation Location/ Instrument Number	Observed Value	Notes
Floor of Hazardous Room	N/A	water on the floor? source of leak? Yes/No	Hazardous Room		
Bioprocess Tank	Tank 1200	Headspace Pressure, PSI	PI 1200		
		Sludge Color Normal? Yes/No	Observe Thru Windows		
Recirculation & WAS/Mix Pump Area	Pump 1100 (Influent)	Discharge Flow, GPM	FIT 1100		
	Pump 1430 (Recirc)	Discharge Flow, GPM	FIT 1430		
	Pump 1440 (WAS/Mix)	Discharge Flow, GPM	FIT 1440		
Biogas Sparge Pump	Pump 1410	Suction Pressure, PSI	PI 1413		
		Discharge Pressure, PSI	PI 1423		
		Discharge Flow, LPM	FIT 1410		
		Condensate Trap Water Level (Suction)	Tank 1410		
		Condensate Trap Water Level (Discharge)	Tank 1420		
Effluent Gas Flow Meter	FIT 1230	Flow, LPM	FIT 1230		
		Condensate Trap Water Level	Tank 1220		
Membrane Tank	Tank 1300	Pressure, PSI	PI 1300		
		Sparge Gas Flow RH, CFM	FI 1425		
		Sparge Gas Flow LH, CFM	FI 1426		

Field Observations Checklist

Date:

Observer:

Area	Equipment No.	Observation	Observation Location/ Instrument Number	Observed Value	Notes
Pressure Relief Columns	Tank 1210, 1240, 1330	Water Column Level	Tank 1210		
		Water Column Level	Tank 1240		
		Water Column Level	Tank 1330		
Permeate Pump	Pump 1310	Discharge Flow, GPM	FIT 1310		
		Suction Pressure, PSI	PI 1310		
Vacuum Pump	Pump 1540	Suction Pressure, in Hg	PI 1540		
		Condensate Trap Water Level	Tank 1540		
Gas Transfer Membrane	Contactor 1500	Liquid Inlet Pressure, PSI	PI 1511		
		Gas Inlet Pressure, in Hg	PI 1530		
		Gas Flow, CFM	FI 1530		
CIP/Backpulse Tank	Tank 1320	Water Level	Tank 1320		
Non-Hazardous Room	N/A	Water on the floor? Source of Leak? Yes/No	Room, Chemical Storage Area		
Ambient Gas Monitor	AIT 1010, HSIT 1010	Methane Concentration, %LEL	AIT 1010		
		H2S Concentration, PPM	HSIT 1010		
Sedimentation Tank	Basin 1640, 1650	Water Level	Basin 1650		
		Sludge Level	Basin 1640		

Field Observations Checklist

Date:

Observer:

Area	Equipment No.	Observation	Observation Location/ Instrument Number	Observed Value	Notes
Rapid Mix/Flocculation Basin	Basin 1620, 31, 32, 33	Mixer On/Off	Mixer 1620		
		Mixer On/Off	Mixer 1631		
		Mixer On/Off	Mixer 1632		
		Mixer On/Off	Mixer 1633		
		Water Level	Basin 1620		
		Water Level	Basin 1631		
		Water Level	Basin 1632		
		Water Level	Basin 1633		
Chemical Storage & Metering	Pumps 1810, 20, 30, 40, 50	On/Off?	Pump 1810		
		On/Off?	Pump 1820		
		On/Off?	Pump 1830		
		On/Off?	Pump 1840		
		On/Off?	Pump 1850		
	Tanks 1810, 20, 30, 40, 50	Liquid Level	Tank 1810		
		Liquid Level	Tank 1820		
		Liquid Level	Tank 1830		
		Liquid Level	Tank 1840		
		Liquid Level	Tank 1850		

Field Observations Checklist

Date:

Observer:

Area	Equipment No.	Observation	Observation Location/ Instrument Number	Observed Value	Notes
IX Column	Vessel 1720	Media Height	Vessel 1720		
IX Column Pump	Pump 1710	Discharge Pressure, PSI	PI 1710		
		Flow, GPM	FI 1710		
Chemical Storage & Metering	Mixer 1810, 1820	On/Off?	Mixer 1810		
		On/Off?	Mixer 1820		
Air Compressor	Compressor 1910	Filter Element Pop-Up Indicator	Air Prep Module 1910		
		Pressure Indicator, PSI	Air Prep Module 1910		
Thermostat	N/A	Room Temp	N/A		
Gas Analyzer	AIT 1231, 32, N/A, N/A	% O2	AIT 1231		
		% CH4	AIT 1232		
		Gas Analyzer Pressure, PSI	Inside Gas Analyzer		
		Condenstation in trap or stainless steel valve? Yes/No	Inside Gas Analyzer		
Nitrogen Gas Cylindar	N/A	Pressure in Tank, PSI	Regulator on Cylinder		
Spec Gas Cylinder	N/A	Pressure in Tank, PSI	Regulator on Cylinder		
Pump Station	Pump 1100 (Feed)	Check for water leaks on the assoicated piping	Floor		
Pump Station	Strainer	Check for water leaks or air leaks on associated lines	Floor and Piping		
Feed Pump	N/A	Pressure, PSI	Pressure Gauge by Feed Pump		
Strainer	N/A	Pressure, PSI	Pressure Gauge by Strainer		

Field Observations Checklist

Date:

Observer:

Area	Equipment No.	Observation	Observation Location/ Instrument Number	Observed Value	Typical Range	Notes
Floor of Hazardous Room	N/A	Check for water on the floor, and source of leak	Room floor			
Bioprocess Tank	Tank 1200	Headspace Pressure, PSI	PI 1200			
		Sludge Color	Observe Thru Windows			
Recirculation & WAS/Mix Pump Area	Pump 1100 (Influent)	Discharge Flow, GPM	FIT 1100			
	Pump 1430 (Recirc)	Discharge Flow, GPM	FIT 1430			
	Pump 1440 (WAS/Mix)	Discharge Flow, GPM	FIT 1440			
Biogas Sparge Pump	Pump 1410	Suction Pressure, PSI	PI 1413			
		Discharge Pressure, PSI	PI 1423			
		Discharge Flow, LPM	FIT 1410			
		Condensate Trap Water Level (Suction)	Tank 1410			
		Condensate Trap Water Level (Discharge)	Tank 1420			
Effluent Gas Flow Meter	FIT 1230	Flow, LPM	FIT 1230			
		Condensate Trap Water Level	Tank 1220			
Membrane Tank	Tank 1300	Pressure, PSI	PI 1300			
		Sparge Gas Flow RH, CFM	FI 1425			
		Sparge Gas Flow LH, CFM	FI 1426			
Pressure Relief Columns	Tank 1210, 1240, 1330	Water Column Level	Tank 1210			
		Water Column Level	Tank 1240			
		Water Column Level	Tank 1330			

AnMBR Event Log

Date	Time	Initals	Event

WEEKLY MAINTENANCE LOG SHEET

Date	Equipment Tag	Maintenance Performed	Initials	Notes
	Strainer	Check Actuator Shaft Seal for Leaks		
	Tank 1210	Check level		
	Tank 1240	Check level		
	Tank 1330	Check level		
	PHT 1450	pH Calibration		
	PHT 1450	Calibration Test		
	Vent Fan	Clean Filter (louvers)		
	Biogas Pump 1410	Check Blower for Leaks		
	Biogas Pump 1410	Check Connections for Leaks		
	Pump 1810	Tubing Inspection		
	Pump 1820	Tubing Inspection		
	Pump 1830	Tubing Inspection		
	Pump 1840	Tubing Inspection		
	Pump 1850	Tubing Inspection		
	Pump 1810	Calibration Test		
	Pump 1820	Calibration Test		
	Pump 1830	Calibration Test		
	Pump 1840	Calibration Test		
	Pump 1850	Calibration Test		
	Biogas Analyzer	Analyzer Flow check		
	Biogas Analyzer	Analyzer Filter Inspection		

2 x Monthly MAINTENANCE LOG SHEET

Date	Equipment Tag	Maintenance Performed	Initials	Notes
	Vacuum Pump 1540	Clean Inlet Filter		
	Membrane Tank 1300	Maintenance Clean		
	Biogas Analyzer	Calibration		

MONTHLY MAINTENANCE LOG SHEET

Date	Equipment Tag	Maintenance Performed	Initials	Notes
	Pump 1430	Clean Exterior		
	Pump 1440	Clean Exterior		
	Pump 1710	Clean Exterior		
	Biogas Pump 1410	Check Pump for Leaks		
	Biogas Pump 1410	Check connects for leaks		
	Vacuum Pump 1540	Check Inlet Filter		
	Pump 1810	Clean tubing and exterior		
	Pump 1810	Replace Tubing		
	Pump 1810	Calibration		
	Pump 1820	Clean tubing and exterior		
	Pump 1820	Replace Tubing		
	Pump 1820	Calibration		
	Pump 1830	Clean tubing and exterior		
	Pump 1830	Replace Tubing		
	Pump 1830	Calibration		
	Pump 1840	Clean tubing and exterior		
	Pump 1840	Replace Tubing		
	Pump 1840	Calibration		
	Pump 1850	Clean tubing and exterior		
	Pump 1850	Replace Tubing		
	Pump 1850	Calibration		
	Air Compressor	Oil Level Check		
	TUT 1310	Clean		
	TUT 1310	Calibration Check		
	Pump 1100	Clean Exterior		
	Pump 1310	Clean Exterior		
	Strainer	Check Cleaning Disc for excessive wear		
	Strainer	Check inside of filter element for excessive wear		

QUARTERLY MAINTENANCE LOG SHEET

Date	Equipment Tag	Maintenance Performed	Initials	Notes
	Pump 1430	Coupling Inspection		
	Pump 1440	Coupling Inspection		
	Pump 1710	Coupling Inspection		
	Biogas Pump 1410	Clean Exterior		
	Vacuum Pump 1540	Clean Exterior		
	Membrane Tank 1300	Take Sample Fiber		
	Air Compressor	Compressor Air Filter Inspectiono		
	Air Compressor	Air Prep Module Inspection		
	TUT 1310	Calibration		
	PHT 1450	Sensor Buffer Replacement		
	Pump 1100	Coupling Inspection		
	Pump 1310	Coupling Inspection		

YEARLY MAINTENANCE LOG SHEET

Date	Equipment Tag	Maintenance Performed	Initials	Notes
	Air Compressor	Oil Replacement		
	Strainer	Inspect Actuator Assembly		

AS NEEDED MAINTENANCE LOG SHEET

Date	Equipment Tag	Maintenance Performed	Initials	Notes
	Pump 1430	Coupling Replacement		
	Pump 1430	Stator Replacement		
	Pump 1440	Coupling Replacement		
	Pump 1440	Stator Replacement		
	Pump 1710	Coupling Replacement		
	Pump 1710	Stator Replacement		
	Vacuum Pump 1540	Replace Inlet Filter		
	Membrane Tank 1300	Recovery Clean		
	Membrane Tank 1300	Check for leaks in the Fibers		
	Membrane Tank 1300	Clean Exterior		
	Membrane Contactor 1500	Clean Exterior		
	Membrane Contactor 1500	Flush Membrane with Ambient Air		
	Air Compressor	Air Prep Module Filter Replacement		
	Biogas Analyzer	Replacement of Oxygen sensor		
	Pump 1100	Coupling Replacement		
	Pump 1100	Stator Replacement		
	Pump 1310	Coupling Replacement		
	Pump 1310	Stator Replacement		
	Pressure Relief Column 1210	Fill to full line		
	Pressure Relief Column 1240	Fill to full line		
	Pressure Relief Column 1330	Fill to full line		
	Heat Tracing	Turn On/Off		

Membrane Sequence Control
Date: 12 JUL 2016

CONTROL	STEP NAME	EVENT		TRIGGER
Offline	**Offline**			Step Time Limit 600 SEC
Production	**Pre-Production Sparge**	Step Time 60 SEC		
	Pre-Production Flow	Step Time 60 SEC	Permeate Flow 0.5 GPM	
	Production	Permeate Flow 0 GPM		
Relax	**Relax**	Step Time 120 SEC		Frequency 0.2 HOUR
Defoam	**Defoam**	Step Time 70 SEC	Recirc. Flow 4 GPM	Frequency 5 HOUR
WAS to Waste	**WAS to Waste**	Waste Volume 15 GAL	Waste Flow 0 GPM	Frequency 1.3 HOUR
Backpulse	**Backpulse**	Step Time 65 SEC	Permeate Flow 1.3 GPM	Frequency 0.2 HOUR
	Backpulse - Relax	Step Time 45 SEC		

Date:

CONTROL	STEP NAME	EVENT		TRIGGER
Offline	**Offline**			Step Time Limit SEC
Production	**Pre-Production Sparge**	Step Time SEC		
	Pre-Production Flow	Step Time SEC	Permeate Flow GPM	
	Production	Feed Flow GPM	Permeate Flow GPM	
Relax	**Relax**	Step Time SEC		Frequency HOUR
Defoam	**Defoam**	Step Time SEC	Recirc. Flow GPM	Frequency HOUR
WAS to Waste	**WAS to Waste**	Waste Volume GAL	Waste Flow GPM	Frequency HOUR
Backpulse	**Backpulse**	Step Time SEC	Permeate Flow GPM	Frequency HOUR
	Backpulse - Relax	Step Time SEC		

Membrane Clean Sequence Control

Date: 12 JUL 2016

CONTROL	STEP NAME	EVENT		TRIGGER
Offline	**Offline**			
Maintenance Clean	**M.C. Permeate Off 1**	Step Time 5 SEC		Cleaning Freq. 4.3 HR
	M.C. Chem Backpulse 1	Step Time 5 SEC	Permeate Flow 1.20 GPM	Tank Fill Limit 29 GAL
	M.C Relax 1	Step Time 5 SEC		
# of Cycles 2	**M.C. Chem Backpulse 2**	Step Time 5 SEC	Permeate Flow 1.30 GPM	Cycle Number 0
	M.C. Relax 2	Step Time 10 SEC		
	M.C. Clean Backpulse	Waste Volume 500 SEC	Permeate Flow 1.40 GPM	
	M.C. Permeate Off 2	Step Time 5 SEC		

Date:

CONTROL	STEP NAME	EVENT		TRIGGER
Offline	**Offline**			
Maintenance Clean	**M.C. Permeate Off 1**	Step Time SEC		Cleaning Freq. HR
	M.C. Chem Backpulse 1	Step Time SEC	Permeate Flow GPM	Tank Fill Limit GAL
	M.C Relax 1	Step Time SEC		
# of Cycles	**M.C. Chem Backpulse 2**	Step Time SEC	Permeate Flow GPM	Cycle Number
	M.C. Relax 2	Step Time SEC		
	M.C. Clean Backpulse	Waste Volume SEC	Permeate Flow GPM	
	M.C. Permeate Off 2	Step Time SEC		

Recovery Clean Sequence Control

Date: 12 JUL 2016

CONTROL	STEP NAME	EVENT		TRIGGER
1 Offline	**Offline**			**Pushbutton**
Recovery Clean	**R.C. Permeate Off**	Step Time 115 SEC		
	R.C. Membrane Drain 1	Drain Limit 30 INCH		
	R.C. Membrane Fill	Fill Limit 29 GAL	Fill Flow Rate 1.00 GPM	
	R.C. Biogas Sparge	Step Time 140 SEC	Sparge Flow 50.0 SLPM	
	R.C. Membrane Drain to Waste 1	Drain Limit 30 INCH		
	R.C. Chem Backpulse Fill 1	Fill Limit 45 INCH		
	R.C. Permeate Backpulse Fill 1	Fill Limit 70 INCH		
	R.C. Soak 1	Step Time 240 SEC		
	R.C. Membrane Drain to Waste 2	Drain Limit 30 INCH		
	R.C. Chem Backpulse Fill 2	Fill Limit 45 INCH		
2	**R.C. Clean Backpulse Fill 2**	Fill Limit 70 INCH		
	R.C. Soak 2	Step Time 240 SEC		
	R.C. Membrane Drain to Waste 3	Drain Limit 30 INCH		
	R.C. Permeate Fill	Fill Limit 70 INCH		
	R.C. Soak	Step Time 240 SEC		
	R.C. Membrane Drain to Waste 4	Drain Limit 30 INCH		

Date:

CONTROL	STEP NAME	EVENT		TRIGGER
1 Offline	**Offline**			**Pushbutton**
Recovery Clean	**R.C. Permeate Off**	Step Time SEC		
	R.C. Membrane Drain 1	Drain Limit GAL		
	R.C. Membrane Fill	Fill Limit GAL	Fill Flow Rate GPM	
	R.C. Biogas Sparge	Step Time SEC	Sparge Flow SLPM	
	R.C. Membrane Drain to Waste 1	Drain Limit GAL		
	R.C. Chem Backpulse Fill 1	Fill Limit GAL		
	R.C. Permeate Backpulse Fill 1	Fill Limit GAL		
	R.C. Soak 1	Step Time HR		
	R.C. Membrane Drain to Waste 2	Drain Limit GAL		
	R.C. Chem Backpulse Fill 2	Fill Limit GAL		
2	**R.C. Clean Backpulse Fill 2**	Fill Limit GAL		
	R.C. Soak 2	Step Time HR		
	R.C. Membrane Drain to Waste 3	Drain Limit GAL		
	R.C. Permeate Fill	Fill Limit INCH		
	R.C. Soak	Step Time HR		
	R.C. Membrane Drain to Waste 4	Drain Limit GAL		

PID

NOTE: Turn Pump 1810 to PID control to access this screen.

Date: 11 JUL 2016

PID Infromation

Mode: Auto

Auto Setpoint
7.00 pH

Reverse: Acid

Device Control

Status: Off

Control: Off

PID Configurations

Gain	Reset
4.000	5.000
Rate	**Rate Delay**
0.000	0 SEC

PID Alarms

Alarm Deadband	Alarm Delay
0.50 pH	60 SEC

Hi Normal Lo Normal

Date:

PID Infromation

Mode: Auto

Auto Setpoint
pH

Reverse: Acid

Device Control

Status: Off

Control: Off

PID Configurations

Gain	Reset
Rate	**Rate Delay**
	SEC

PID Alarms

Alarm Deadband	Alarm Delay
pH	SEC

Hi		Lo	

Strainer Sequence Step

Date: 11 JUL 2016

Control

	Runtime Limit
Strain Interval	6.0 HOUR

	Runtime
Runtime	HOUR

Date:

Control

	Runtime Limit
Strain Interval	HOUR

	Runtime
Runtime	HOUR

Coallescing Tank Configuration

Date: 11 JUL 2016

Tank 1220 Level	Open Level	6.00 INCH
DV-1229 Drain	Close Level	2.00 INCH
Tank 1410 Level	Open Level	6.00 INCH
DV-1219 Drain	Close Level	2.00 INCH
Tank 1420 Level	Open Level	6.00 INCH
DV-1429 Drain	Close Level	2.00 INCH
Tank 1540 Level	Shutdown Level	6.00 INCH

Date:

Tank 1220 Level	Open Level	INCH
DV-1229 Drain	Close Level	INCH
Tank 1410 Level	Open Level	INCH
DV-1219 Drain	Close Level	INCH
Tank 1420 Level	Open Level	INCH
DV-1429 Drain	Close Level	INCH
Tank 1540 Level	Shutdown Level	INCH

Ventilation Fan Control

Date: 11 JUL 2016

Status: off

Control: Auto

	Fan Speed
Normal Operation	45 %
Alarm Operation	80 %

Date:

Status: off

Control: Auto

	Fan Speed
Normal Operation	%
Alarm Operation	%

Appendix E

Chemical Safety Data Sheets

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SAFETY DATA SHEET

Issuing Date January 5, 2015 **Revision Date** June 12, 2015 **Revision Number** 1

1. IDENTIFICATION OF THE SUBSTANCE/PREPARATION AND OF THE COMPANY/UNDERTAKING

Product identifier

Product Name **Clorox® Regular-Bleach$_1$**

Other means of identification

EPA Registration Number 5813-100

Recommended use of the chemical and restrictions on use

Recommended use Household disinfecting, sanitizing, and laundry bleach

Uses advised against No information available

Details of the supplier of the safety data sheet

Supplier Address
The Clorox Company
1221 Broadway
Oakland, CA 94612

Phone: 1-510-271-7000

Emergency telephone number

Emergency Phone Numbers For Medical Emergencies, call: 1-800-446-1014
For Transportation Emergencies, call Chemtrec: 1-800-424-9300

2. HAZARDS IDENTIFICATION

Classification

This chemical is considered hazardous by the 2012 OSHA Hazard Communication Standard (29 CFR 1910.1200).

Skin corrosion/irritation	Category 1
Serious eye damage/eye irritation	Category 1

GHS Label elements, including precautionary statements

Emergency Overview

Signal word **Danger**

Hazard Statements
Causes severe skin burns and eye damage
Causes serious eye damage

Appearance Clear, pale yellow **Physical State** Thin liquid **Odor** Bleach

Precautionary Statements - Prevention
Wash face, hands and any exposed skin thoroughly after handling.
Wear protective gloves, protective clothing, face protection, and eye protection such as safety glasses.

Precautionary Statements - Response
Immediately call a poison center or doctor.
If swallowed: Rinse mouth. Do NOT induce vomiting.
If on skin (or hair): Take off immediately all contaminated clothing. Rinse skin with water.
Wash contaminated clothing before reuse.
If inhaled: Remove person to fresh air and keep comfortable for breathing.
Specific treatment (see supplemental first aid instructions on this label).
If in eyes: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.

Precautionary Statements - Storage
Store locked up.

Precautionary Statements - Disposal
Dispose of contents in accordance with all applicable federal, state, and local regulations.

Hazards not otherwise classified (HNOC)
Although not expected, heart conditions or chronic respiratory problems such as asthma, chronic bronchitis, or obstructive lung disease may be aggravated by exposure to high concentrations of vapor or mist.

Product contains a strong oxidizer. Always flush drains before and after use.

Unknown Toxicity
Not applicable.

Other information
Very toxic to aquatic life with long lasting effects.

Interactions with Other Chemicals
Reacts with other household chemicals such as toilet bowl cleaners, rust removers, acids, or products containing ammonia to produce hazardous irritating gases, such as chlorine and other chlorinated compounds.

3. COMPOSITION/INFORMATION ON INGREDIENTS

Chemical Name	CAS-No	Weight %	Trade Secret
Sodium hypochlorite	7681-52-9	5 - 10	*

* The exact percentage (concentration) of composition has been withheld as a trade secret.

4. FIRST AID MEASURES

First aid measures

General Advice Call a poison control center or doctor immediately for treatment advice. Show this safety data sheet to the doctor in attendance.

Eye Contact Hold eye open and rinse slowly and gently with water for 15 - 20 minutes. Remove contact lenses, if present, after the first 5 minutes, then continue rinsing eye. Call a poison control center or doctor for treatment advice.

Skin Contact Take off contaminated clothing. Rinse skin immediately with plenty of water for 15-20 minutes. Call a poison control center or doctor for treatment advice.

Inhalation Move to fresh air. If breathing is affected, call a doctor.

Ingestion Have person sip a glassful of water if able to swallow. Do not induce vomiting unless told to do so by a poison control center or doctor. Do not give anything by mouth to an unconscious person. Call a poison control center or doctor immediately for treatment advice.

Protection of First-aiders Avoid contact with skin, eyes, and clothing. Use personal protective equipment as required. Wear personal protective clothing (see section 8).

Most important symptoms and effects, both acute and delayed

Most Important Symptoms and Effects Burning of eyes and skin.

Indication of any immediate medical attention and special treatment needed

Notes to Physician Treat symptomatically. Probable mucosal damage may contraindicate the use of gastric lavage.

5. FIRE-FIGHTING MEASURES

Suitable Extinguishing Media
Use extinguishing measures that are appropriate to local circumstances and the surrounding environment.

Unsuitable Extinguishing Media
CAUTION: Use of water spray when fighting fire may be inefficient.

Specific Hazards Arising from the Chemical
This product causes burns to eyes, skin, and mucous membranes. Thermal decomposition can release sodium chlorate and irritating gases and vapors.

Explosion Data

Sensitivity to Mechanical Impact None.

Sensitivity to Static Discharge None.

Protective equipment and precautions for firefighters
As in any fire, wear self-contained breathing apparatus pressure-demand, MSHA/NIOSH (approved or equivalent) and full protective gear.

6. ACCIDENTAL RELEASE MEASURES

Personal precautions, protective equipment and emergency procedures

Personal Precautions Avoid contact with eyes, skin, and clothing. Ensure adequate ventilation. Use personal protective equipment as required. For spills of multiple products, responders should evaluate the MSDSs of the products for incompatibility with sodium hypochlorite. Breathing protection should be worn in enclosed and/or poorly-ventilated areas until hazard assessment is complete.

Other Information Refer to protective measures listed in Sections 7 and 8.

Environmental precautions

Environmental Precautions This product is toxic to fish, aquatic invertebrates, oysters, and shrimp. Do not allow product to enter storm drains, lakes, or streams. See Section 12 for ecological Information.

Methods and material for containment and cleaning up

Methods for Containment Prevent further leakage or spillage if safe to do so.

Methods for Cleaning Up Absorb and containerize. Wash residual down to sanitary sewer. Contact the sanitary treatment facility in advance to assure ability to process washed-down material.

7. HANDLING AND STORAGE

Precautions for safe handling

Handling Handle in accordance with good industrial hygiene and safety practice. Avoid contact with skin, eyes, and clothing. Do not eat, drink, or smoke when using this product.

Conditions for safe storage, including any incompatibilities

Storage Store away from children. Reclose cap tightly after each use. Store this product upright in a cool, dry area, away from direct sunlight and heat to avoid deterioration. Do not contaminate food or feed by storage of this product.

Incompatible Products Toilet bowl cleaners, rust removers, acids, and products containing ammonia.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

Control parameters

Exposure Guidelines

Chemical Name	ACGIH TLV	OSHA PEL	NIOSH IDLH
Sodium hypochlorite 7681-52-9	None	None	None

ACGIH TLV: American Conference of Governmental Industrial Hygienists - Threshold Limit Value. OSHA PEL: Occupational Safety and Health Administration - Permissible Exposure Limits. NIOSH IDLH: Immediately Dangerous to Life or Health.

Appropriate engineering controls

Engineering Measures Showers
Eyewash stations
Ventilation systems

Individual protection measures, such as personal protective equipment

Eye/Face Protection If splashes are likely to occur: Wear safety glasses with side shields (or goggles) or face shield.

Skin and Body Protection Wear rubber or neoprene gloves and protective clothing such as long-sleeved shirt.

Respiratory Protection If irritation is experienced, NIOSH/MSHA approved respiratory protection should be worn. Positive-pressure supplied air respirators may be required for high airborne contaminant concentrations. Respiratory protection must be provided in accordance with current local regulations.

Hygiene Measures Handle in accordance with good industrial hygiene and safety practice. Wash hands after direct contact. Do not wear product-contaminated clothing for prolonged periods. Remove and wash contaminated clothing before re-use. Do not eat, drink, or smoke when using this product.

9. PHYSICAL AND CHEMICAL PROPERTIES

Physical and Chemical Properties

Physical State	Thin liquid		
Appearance	Clear	**Odor**	Bleach
Color	Pale yellow	**Odor Threshold**	No information available

Property	**Values**	**Remarks/ Method**
pH	~12	None known
Melting/freezing point	No data available	None known
Boiling point / boiling range	No data available	None known
Flash Point	Not flammable	None known
Evaporation rate	No data available	None known
Flammability (solid, gas)	No data available	None known
Flammability Limits in Air		
Upper flammability limit	No data available	None known
Lower flammability limit	No data available	None known
Vapor pressure	No data available	None known
Vapor density	No data available	None known
Specific Gravity	~1.1	None known
Water Solubility	Soluble	None known
Solubility in other solvents	No data available	None known
Partition coefficient: n-octanol/water	No data available	None known
Autoignition temperature	No data available	None known
Decomposition temperature	No data available	None known
Kinematic viscosity	No data available	None known
Dynamic viscosity	No data available	None known
Explosive Properties	Not explosive	
Oxidizing Properties	No data available	

Other Information

Softening Point	No data available
VOC Content (%)	No data available
Particle Size	No data available
Particle Size Distribution	No data available

10. STABILITY AND REACTIVITY

Reactivity
Reacts with other household chemicals such as toilet bowl cleaners, rust removers, acids, or products containing ammonia to produce hazardous irritating gases, such as chlorine and other chlorinated compounds.

Chemical stability
Stable under recommended storage conditions.

Possibility of Hazardous Reactions
None under normal processing.

Conditions to avoid
None known based on information supplied.

Incompatible materials
Toilet bowl cleaners, rust removers, acids, and products containing ammonia.

Hazardous Decomposition Products
None known based on information supplied.

11. TOXICOLOGICAL INFORMATION

Information on likely routes of exposure

Product Information .

Inhalation Exposure to vapor or mist may irritate respiratory tract and cause coughing. Inhalation of high concentrations may cause pulmonary edema.

Eye Contact Corrosive. May cause severe damage to eyes.

Skin Contact May cause severe irritation to skin. Prolonged contact may cause burns to skin.

Ingestion Ingestion may cause burns to gastrointestinal tract and respiratory tract, nausea, vomiting, and diarrhea.

Component Information

Chemical Name	LD50 Oral	LD50 Dermal	LC50 Inhalation
Sodium hypochlorite 7681-52-9	8200 mg/kg (Rat)	>10000 mg/kg (Rabbit)	-

Information on toxicological effects

Symptoms May cause redness and tearing of the eyes. May cause burns to eyes. May cause redness or burns to skin. Inhalation may cause coughing.

Delayed and immediate effects as well as chronic effects from short and long-term exposure

Sensitization No information available.

Mutagenic Effects No information available.

Carcinogenicity The table below indicates whether each agency has listed any ingredient as a carcinogen.

Chemical Name	ACGIH	IARC	NTP	OSHA
Sodium hypochlorite 7681-52-9	-	Group 3	-	-

IARC (International Agency for Research on Cancer)
Group 3 - Not Classifiable as to Carcinogenicity in Humans

Reproductive Toxicity No information available.

STOT - single exposure No information available.

STOT - repeated exposure No information available.
Chronic Toxicity Carcinogenic potential is unknown.
Target Organ Effects Respiratory system, eyes, skin, gastrointestinal tract (GI).

Aspiration Hazard No information available.

Numerical measures of toxicity - Product Information

The following values are calculated based on chapter 3.1 of the GHS document

ATEmix (oral)
54 g/kg
ATEmix (inhalation-dust/mist)
58 mg/L

12. ECOLOGICAL INFORMATION

Ecotoxicity
Very toxic to aquatic life with long lasting effects.

This product is toxic to fish, aquatic invertebrates, oysters, and shrimp. Do not allow product to enter storm drains, lakes, or streams.

Persistence and Degradability
No information available.

Bioaccumulation
No information available.

Other adverse effects
No information available.

13. DISPOSAL CONSIDERATIONS

Disposal methods
Dispose of in accordance with all applicable federal, state, and local regulations. Do not contaminate food or feed by disposal of this product.

Contaminated Packaging
Do not reuse empty containers. Dispose of in accordance with all applicable federal, state, and local regulations.

14. TRANSPORT INFORMATION

DOT	Not restricted.
TDG	Not restricted for road or rail.
ICAO	Not restricted, as per Special Provision A197, Environmentally Hazardous Substance exception.
IATA	Not restricted, as per Special Provision A197, Environmentally Hazardous Substance exception.
IMDG/IMO	Not restricted, as per IMDG Code 2.10.2.7, Marine Pollutant exception.

15. REGULATORY INFORMATION

Chemical Inventories

TSCA	All components of this product are either on the TSCA 8(b) Inventory or otherwise exempt from listing.
DSL/NDSL	All components are on the DSL or NDSL.

TSCA - United States Toxic Substances Control Act Section 8(b) Inventory
DSL/NDSL - Canadian Domestic Substances List/Non-Domestic Substances List

U.S. Federal Regulations

SARA 313
Section 313 of Title III of the Superfund Amendments and Reauthorization Act of 1986 (SARA). This product does not contain any chemicals which are subject to the reporting requirements of the Act and Title 40 of the Code of Federal Regulations, Part 372

SARA 311/312 Hazard Categories

Acute Health Hazard	Yes
Chronic Health Hazard	No
Fire Hazard	No
Sudden Release of Pressure Hazard	No
Reactive Hazard	No

Clean Water Act
This product contains the following substances which are regulated pollutants pursuant to the Clean Water Act (40 CFR 122.21 and 40 CFR 122.42)

Chemical Name	CWA - Reportable Quantities	CWA - Toxic Pollutants	CWA - Priority Pollutants	CWA - Hazardous Substances
Sodium hypochlorite 7681-52-9	100 lb			X

CERCLA
This material, as supplied, contains one or more substances regulated as a hazardous substance under the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) (40 CFR 302)

Chemical Name	Hazardous Substances RQs	Extremely Hazardous Substances RQs	RQ
Sodium hypochlorite 7681-52-9	100 lb	-	RQ 100 lb final RQ RQ 45.4 kg final RQ

EPA Statement
This chemical is a pesticide product registered by the Environmental Protection Agency and is subject to certain labeling requirements under federal pesticide law. These requirements differ from the classification criteria and hazard information required for safety data sheets and for workplace labels of non-pesticide chemicals. Following is the hazard information as required on the pesticide label:

> **DANGER: CORROSIVE.** Causes irreversible eye damage and skin burns. Harmful if swallowed. Do not get in eyes, on skin, or on clothing. Wear protective eyewear and rubber gloves when handling this product. Wash thoroughly with soap and water after handling and before eating, drinking, chewing gum, using tobacco, or using the restroom. Avoid breathing vapors and use only in a well-ventilated area.

US State Regulations

California Proposition 65
This product does not contain any Proposition 65 chemicals.

U.S. State Right-to-Know Regulations

Chemical Name	New Jersey	Massachusetts	Pennsylvania	Rhode Island	Illinois
Sodium hypochlorite 7681-52-9	X	X	X	X	
Sodium chlorate 7775-09-9	X	X	X		

International Regulations

Canada
WHMIS Hazard Class
E - Corrosive material

16. OTHER INFORMATION

NFPA	**Health Hazard**	3	**Flammability** 0	**Instability** 0	**Physical and Chemical Hazards**	-
HMIS	**Health Hazard**	3	**Flammability** 0	**Physical Hazard** 0	**Personal Protection**	B

Prepared By
Product Stewardship
23 British American Blvd.
Latham, NY 12110
1-800-572-6501

Revision Date June 12, 2015

Revision Note Revision Section 14.

Reference 1096036/164964.159

General Disclaimer
The information provided in this Safety Data Sheet is correct to the best of our knowledge, information and belief at the date of its publication. The information given is designed only as a guidance for safe handling, use, processing, storage, transportation, disposal, and release and is not to be considered a warranty or quality specification. The information relates only to the specific material designated and may not be valid for such material used in combination with any other materials or in any process, unless specified in the text.

End of Safety Data Sheet

SAFETY DATA SHEET

Section 1. Chemical Product and Company Identification

Product Name:	ChemTreat CL16
Product Use:	Reverse Osmosis and Resin Cleaner
Supplier's Name:	ChemTreat, Inc.
Emergency Telephone Number:	(800)424−9300 (Toll Free)
Address (Corporate Headquarters):	5640 Cox Road Glen Allen, VA 23060
Telephone Number for Information:	(800)648−4579
Date of MSDS:	September 14, 2015
Revision Date:	September 14, 2015
Revision Number:	15091401AN

Section 2. Hazard(s) Identification

Signal Word:	**DANGER**
GHS Classification(s):	Skin corrosion/irritation − Category 1b Eye damage/irritation − Category 1 Acute Toxicity Dermal − Category 4 Acute Toxicity Inhalation − Category 4 Acute Toxicity Oral − Category 4
Hazard Statement(s):	Causes severe skin burns and eye damage. Causes serious eye damage. Harmful in contact with skin. Harmful if inhaled. Harmful if swallowed.
Precautionary Statement(s):	Wear protective gloves/clothing and eye/face protection. Do not breathe dust/fume/gas/mist/vapors/spray. Do not eat, drink or smoke when using this product. Wash hands thoroughly after handling. Use only outdoors or in a well−ventilated area.
System of Classification Used:	Classification under 2012 OSHA Hazard Communication Standard (29 CFR 1910.1200).
Hazards Not Otherwise Classified:	None.

Section 3. Composition/Hazardous Ingredients

Component	CAS Registry #	Wt.%
Citric acid	77−92−9	10 − 30
1−Hydroxyethylidene−1,1−diphosphonic acid	2809−21−4	3 − 7

Comments If chemical identity and/or exact percentage of composition has been withheld, this information is considered to be a trade secret.

Section 4. First Aid Measures

Inhalation: Remove victim to fresh air and keep at rest in a position comfortable for breathing. Immediately call a poison center or doctor/physician.

Eyes: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. Immediately call a poison center or doctor/physician.

Skin: Immediately remove/take off all contaminated clothing. Rinse skin with water/shower. Wash contaminated clothing before re−use. Immediately call a poison center or doctor/physician.

Ingestion: DO NOT INDUCE VOMITING. Rinse mouth. Call a POISON CENTER or doctor/physician.

Notes to Physician: N/A

Additional First Aid Remarks: N/A

Section 5. Fire Fighting Measures

Flammability of the Product: Not flammable.

Suitable Extinguishing Media: Use extinguishing media suitable to surrounding fire.

Specific Hazards Arising from the Chemical: None known.

Protective Equipment: If product is involved in a fire, wear full protective clothing including a positive−pressure, NIOSH approved, self−contained breathing apparatus.

Section 6. Accidental Release Measures

Personal Precautions: Use appropriate Personal Protective Equipment (PPE).

Environmental Precautions: Avoid dispersal of spilled material and runoff and contact with soil, waterways, drains, and sewers.

Methods for Cleaning up: Contain and recover liquid when possible. Flush spill area with water spray.

Other Statements: None.

Section 7. Handling and Storage

Handling: Wear appropriate Personal Protective Equipment (PPE) when handling this product. Do not get in eyes, or on skin and clothing. Wash thoroughly after handling. Do not ingest. Avoid breathing vapors, mist or dust.

Storage: Store away from incompatible materials (see Section 10). Store at ambient temperatures. Keep container securely closed when not in use. Label precautions also apply to empty container. Recondition or dispose of empty containers in accordance with government regulations. For Industrial use only.
Store above Freeze Point.

Section 8. Exposure Controls/Personal Protection

Exposure Limits

Component	Source	Exposure Limits
Citric acid	N/E	N/E
1−Hydroxyethylidene−1,1−diphosphonic acid	N/E	N/E

Engineering Controls: Use only with adequate ventilation. The use of local ventilation is recommended to control emission near the source.

Personal Protection

Eyes:	Wear chemical splash goggles or safety glasses with full−face shield. Maintain eyewash fountain in work area.
Skin:	Maintain quick−drench facilities in work area. Wear butyl rubber or neoprene gloves. Wash them after each use and replace as necessary. If conditions warrant, wear protective clothing such as boots, aprons, and coveralls to prevent skin contact.
Respiratory:	If misting occurs, use NIOSH approved organic vapor/acid gas dual cartridge respirator with a dust/mist prefilter in accordance with 29 CFR 1910.134.

Section 9. Physical and Chemical Properties

Physical State and Appearance:	Liquid, Colorless, Clear
Specific Gravity:	1.093 @ 20°C
pH:	1.0 @ 20°C, 100.0%
Freezing Point:	32°F
Flash Point:	N/D
Odor:	Mild
Melting Point:	N/A
Initial Boiling Point and Boiling Range:	212°F
Solubility in Water:	Complete
Evaporation Rate:	N/A
Vapor Density:	N/D
Molecular Weight:	N/D
Viscosity:	N/A
Flammability (solid, gas):	N/D
Flammable Limits:	N/A
Autoignition Temperature:	N/A
Density:	9.12 LB/GA
Vapor Pressure:	N/D
% VOC:	N/D
Odor Threshold	N/D
n−octanol Partition Coefficient	N/D
Decomposition Temperature	N/D

Section 10. Stability and Reactivity

Chemical Stability: Stable at normal temperatures and pressures.

Incompatibility with Various Substances: Bases, Strong oxidizers.

Hazardous Decomposition Products: Oxides of carbon, Oxides of phosphorus.

Possibility of Hazardous Reactions: None known.

Section 11. Toxicological Information

Chemical Name	Exposure	Type of Effect	Concentration	Species
1−Hydroxyethylidene−1,1−diphosphonic acid	Oral	LD50	2400 MG/KG	Rat
	Dermal	LD50	7940 MG/KG	Rabbit

Carcinogenicity Category

Component	Source	Code	Brief Description
Citric acid	N/E	N/E	N/E
1−Hydroxyethylidene−1,1−diphosphonic acid	N/E	N/E	N/E

Comments: None.

Section 12. Ecological Information

Species	Duration	Type of Effect	Test Results
Ceriodaphnia dubia	48h	LC50	>1000 mg/l
Fathead Minnow	96h	LC50	>1000 mg/l
Rainbow Trout	96h	LC50	7906 mg/l

Comments: None.

Section 13. Disposal Considerations

Dispose of in accordance with local, state and federal regulations.
EPA corrosivity characteristic hazardous waste D002 when disposed of in the original product form.

Section 14. Transport Information

Controlling Regulation	UN/NA#:	Proper Shipping Name:	Technical Name:	Hazard Class:	Packing Group:
DOT	UN3265	CORROSIVE LIQUID, ACIDIC, ORGANIC, N.O.S.	(CITRIC ACID)	8	PGIII
IMDG	UN3265	CORROSIVE LIQUID, ACIDIC, ORGANIC, N.O.S.	(CITRIC ACID)	8	PGIII
TDG	UN3265	CORROSIVE LIQUID, ACIDIC, ORGANIC, N.O.S.	(CITRIC ACID)	8	PGIII
ICAO	UN3265	CORROSIVE LIQUID, ACIDIC, ORGANIC, N.O.S.	(CITRIC ACID)	8	PGIII

Note: N/A

Section 15. Regulatory Information

Inventory Status

United States (TSCA): All ingredients listed.
Canada (DSL/NDSL): All ingredients listed.

Federal Regulations

SARA Title III Rules

Sections 311/312 Hazard Classes

Fire Hazard: No
Reactive Hazard: No
Release of Pressure: No
Acute Health Hazard: Yes
Chronic Health Hazard: No

Other Sections

Component	Section 313 Toxic Chemical	Section 302 EHS TPQ	CERCLA RQ
Citric acid	N/A	N/A	N/A
1−Hydroxyethylidene−1,1−diphosphonic acid	N/A	N/A	N/A

Comments: None.

State Regulations

California Proposition 65: None known.

Special Regulations

Component	States
Citric acid	None.
1−Hydroxyethylidene−1,1−diphosphonic acid	None.

International Regulations

Canada

WHMIS Classification: D2B (Toxic Material)
E (Corrosive Material)

Controlled Product Regulations (CPR): This product has been classified in accordance with the hazard criteria of the Controlled Products Regulations (CPR) and the MSDS contains all the information required by the CPR.

Compliance Information

NSF:	Certified to NSF/ANSI Standard 60 This product ships as NSF from: Ashland, VA Eldridge, IA Nederland, TX Vernon, CA
FDA/USDA/GRAS:	Generally Recognized as Safe (GRAS) by the FDA at 21 CFR 184.1033.
KOSHER:	This product is certified by the Orthodox Union as Kosher for Passover and year−round use. Only when prepared by the following ChemTreat facilities: Ashland, VA; Eldridge, IA; Nederland, TX; Vernon, CA.
FIFRA:	N/A
Other:	None

Comments: None.

Section 16. Other Information

HMIS Hazard Rating

Health:	2
Flammability:	0
Physical Hazard:	1
PPE:	X

Notes: The PPE rating depends on circumstances of use. See Section 8 for recommended PPE.
The Hazardous Material Information System (HMIS) is a voluntary, subjective alpha−numeric symbolic system for recommending hazard risk and personal protection equipment information. It is a subjective rating system based on the evaluator's understanding of the chemical associated risks. The end−user must determine if the code is appropriate for their use.

Abbreviations

Abbreviation	Definition
<	Less Than
>	Greater Than
ACGIH	American Conference of Governmental Industrial Hygienists

Abbreviation	Definition
EHS	Environmental Health and Safety Dept
N/A	Not Applicable
N/D	Not Determined
N/E	Not Established
OSHA	Occupational Health and Safety Dept
PEL	Personal Exposure Limit
STEL	Short Term Exposure Limit
TLV	Threshold Limit Value
TWA	Time Weight Average
UNK	Unknown

Prepared by: Product Compliance Department; ProductCompliance@chemtreat.com

Revision Date: September 14, 2015

Disclaimer

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SAFETY DATA SHEET

Nitrogen

Section 1. Identification

GHS product identifier : Nitrogen

Chemical name : nitrogen

Other means of identification : nitrogen (dot); nitrogen gas; Nitrogen NF, Nitrogen FG

Product use : Synthetic/Analytical chemistry.

Synonym : nitrogen (dot); nitrogen gas; Nitrogen NF, Nitrogen FG

SDS # : 001040

Supplier's details : Airgas USA, LLC and its affiliates
259 North Radnor-Chester Road
Suite 100
Radnor, PA 19087-5283
1-610-687-5253

24-hour telephone : 1-866-734-3438

Section 2. Hazards identification

OSHA/HCS status : This material is considered hazardous by the OSHA Hazard Communication Standard (29 CFR 1910.1200).

Classification of the substance or mixture : GASES UNDER PRESSURE - Compressed gas

GHS label elements

Hazard pictograms :

Signal word : Warning

Hazard statements : Contains gas under pressure; may explode if heated.
May displace oxygen and cause rapid suffocation.

Precautionary statements

General : Read and follow all Safety Data Sheets (SDS'S) before use. Read label before use. Keep out of reach of children. If medical advice is needed, have product container or label at hand. Close valve after each use and when empty. Use equipment rated for cylinder pressure. Do not open valve until connected to equipment prepared for use. Use a back flow preventative device in the piping. Use only equipment of compatible materials of construction.

Prevention : Not applicable.

Response : Not applicable.

Storage : Protect from sunlight when ambient temperature exceeds 52°C/125°F. Store in a well-ventilated place.

Disposal : Not applicable.

Hazards not otherwise classified : In addition to any other important health or physical hazards, this product may displace oxygen and cause rapid suffocation.

Section 3. Composition/information on ingredients

Substance/mixture : Substance

Chemical name : nitrogen

Other means of identification : nitrogen (dot); nitrogen gas; Nitrogen NF, Nitrogen FG

CAS number/other identifiers

CAS number : 7727-37-9

Product code : 001040

Ingredient name	%	CAS number
Nitrogen	100	7727-37-9

Any concentration shown as a range is to protect confidentiality or is due to batch variation.

There are no additional ingredients present which, within the current knowledge of the supplier and in the concentrations applicable, are classified as hazardous to health or the environment and hence require reporting in this section.

Occupational exposure limits, if available, are listed in Section 8.

Section 4. First aid measures

Description of necessary first aid measures

Eye contact : Immediately flush eyes with plenty of water, occasionally lifting the upper and lower eyelids. Check for and remove any contact lenses. Continue to rinse for at least 10 minutes. Get medical attention if irritation occurs.

Inhalation : Remove victim to fresh air and keep at rest in a position comfortable for breathing. If not breathing, if breathing is irregular or if respiratory arrest occurs, provide artificial respiration or oxygen by trained personnel. It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation. Get medical attention if adverse health effects persist or are severe. If unconscious, place in recovery position and get medical attention immediately. Maintain an open airway. Loosen tight clothing such as a collar, tie, belt or waistband. In case of inhalation of decomposition products in a fire, symptoms may be delayed. The exposed person may need to be kept under medical surveillance for 48 hours.

Skin contact : Flush contaminated skin with plenty of water. Remove contaminated clothing and shoes. Get medical attention if symptoms occur. Wash clothing before reuse. Clean shoes thoroughly before reuse.

Ingestion : As this product is a gas, refer to the inhalation section.

Most important symptoms/effects, acute and delayed

Potential acute health effects

Eye contact : Contact with rapidly expanding gas may cause burns or frostbite.

Inhalation : No known significant effects or critical hazards.

Skin contact : Contact with rapidly expanding gas may cause burns or frostbite.

Frostbite : Try to warm up the frozen tissues and seek medical attention.

Ingestion : As this product is a gas, refer to the inhalation section.

Over-exposure signs/symptoms

Eye contact : No specific data.

Inhalation : No specific data.

Skin contact : No specific data.

Ingestion : No specific data.

Indication of immediate medical attention and special treatment needed, if necessary

Notes to physician : In case of inhalation of decomposition products in a fire, symptoms may be delayed. The exposed person may need to be kept under medical surveillance for 48 hours.

Section 4. First aid measures

Specific treatments : No specific treatment.

Protection of first-aiders : No action shall be taken involving any personal risk or without suitable training. It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation.

See toxicological information (Section 11)

Section 5. Fire-fighting measures

Extinguishing media

Suitable extinguishing media : Use an extinguishing agent suitable for the surrounding fire.

Unsuitable extinguishing media : None known.

Specific hazards arising from the chemical : Contains gas under pressure. In a fire or if heated, a pressure increase will occur and the container may burst or explode.

Hazardous thermal decomposition products : Decomposition products may include the following materials:
nitrogen oxides

Special protective actions for fire-fighters : Promptly isolate the scene by removing all persons from the vicinity of the incident if there is a fire. No action shall be taken involving any personal risk or without suitable training. Contact supplier immediately for specialist advice. Move containers from fire area if this can be done without risk. Use water spray to keep fire-exposed containers cool.

Special protective equipment for fire-fighters : Fire-fighters should wear appropriate protective equipment and self-contained breathing apparatus (SCBA) with a full face-piece operated in positive pressure mode.

Section 6. Accidental release measures

Personal precautions, protective equipment and emergency procedures

For non-emergency personnel : No action shall be taken involving any personal risk or without suitable training. Evacuate surrounding areas. Keep unnecessary and unprotected personnel from entering. Avoid breathing gas. Provide adequate ventilation. Wear appropriate respirator when ventilation is inadequate. Put on appropriate personal protective equipment.

For emergency responders : If specialised clothing is required to deal with the spillage, take note of any information in Section 8 on suitable and unsuitable materials. See also the information in "For non-emergency personnel".

Environmental precautions : Ensure emergency procedures to deal with accidental gas releases are in place to avoid contamination of the environment. Inform the relevant authorities if the product has caused environmental pollution (sewers, waterways, soil or air).

Methods and materials for containment and cleaning up

Small spill : Immediately contact emergency personnel. Stop leak if without risk.

Large spill : Immediately contact emergency personnel. Stop leak if without risk. Note: see Section 1 for emergency contact information and Section 13 for waste disposal.

Section 7. Handling and storage

Precautions for safe handling

Protective measures : Put on appropriate personal protective equipment (see Section 8). Contains gas under pressure. Avoid contact with eyes, skin and clothing. Avoid breathing gas. Empty containers retain product residue and can be hazardous. Do not puncture or incinerate container. Use equipment rated for cylinder pressure. Close valve after each use and when empty. Protect cylinders from physical damage; do not drag, roll, slide, or drop. Use a suitable hand truck for cylinder movement.

Section 7. Handling and storage

Advice on general occupational hygiene : Eating, drinking and smoking should be prohibited in areas where this material is handled, stored and processed. Workers should wash hands and face before eating, drinking and smoking. Remove contaminated clothing and protective equipment before entering eating areas. See also Section 8 for additional information on hygiene measures.

Conditions for safe storage, including any incompatibilities : Store in accordance with local regulations. Store in a segregated and approved area. Store away from direct sunlight in a dry, cool and well-ventilated area, away from incompatible materials (see Section 10). Keep container tightly closed and sealed until ready for use. Cylinders should be stored upright, with valve protection cap in place, and firmly secured to prevent falling or being knocked over. Cylinder temperatures should not exceed 52 °C (125 °F).

Section 8. Exposure controls/personal protection

Control parameters

Occupational exposure limits

Ingredient name	Exposure limits
Nitrogen	Oxygen Depletion [Asphyxiant]

Appropriate engineering controls : Good general ventilation should be sufficient to control worker exposure to airborne contaminants.

Environmental exposure controls : Emissions from ventilation or work process equipment should be checked to ensure they comply with the requirements of environmental protection legislation. In some cases, fume scrubbers, filters or engineering modifications to the process equipment will be necessary to reduce emissions to acceptable levels.

Individual protection measures

Hygiene measures : Wash hands, forearms and face thoroughly after handling chemical products, before eating, smoking and using the lavatory and at the end of the working period. Appropriate techniques should be used to remove potentially contaminated clothing. Wash contaminated clothing before reusing. Ensure that eyewash stations and safety showers are close to the workstation location.

Eye/face protection : Safety eyewear complying with an approved standard should be used when a risk assessment indicates this is necessary to avoid exposure to liquid splashes, mists, gases or dusts. If contact is possible, the following protection should be worn, unless the assessment indicates a higher degree of protection: safety glasses with side-shields.

Skin protection

Hand protection : Chemical-resistant, impervious gloves complying with an approved standard should be worn at all times when handling chemical products if a risk assessment indicates this is necessary. Considering the parameters specified by the glove manufacturer, check during use that the gloves are still retaining their protective properties. It should be noted that the time to breakthrough for any glove material may be different for different glove manufacturers. In the case of mixtures, consisting of several substances, the protection time of the gloves cannot be accurately estimated.

Body protection : Personal protective equipment for the body should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product.

Other skin protection : Appropriate footwear and any additional skin protection measures should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product.

Respiratory protection : Use a properly fitted, air-purifying or air-fed respirator complying with an approved standard if a risk assessment indicates this is necessary. Respirator selection must be based on known or anticipated exposure levels, the hazards of the product and the safe working limits of the selected respirator.

Section 9. Physical and chemical properties

Appearance

Physical state : Gas. [Compressed gas.]

Color : Colorless.

Molecular weight : 28.02 g/mole

Molecular formula : N2

Boiling/condensation point : -196°C (-320.8°F)

Melting/freezing point : -210.01°C (-346°F)

Critical temperature : -146.95°C (-232.5°F)

Odor : Odorless.

Odor threshold : Not available.

pH : Not available.

Flash point : [Product does not sustain combustion.]

Burning time : Not applicable.

Burning rate : Not applicable.

Evaporation rate : Not available.

Flammability (solid, gas) : Not available.

Lower and upper explosive (flammable) limits : Not available.

Vapor pressure : Not available.

Vapor density : 0.967 (Air = 1) Liquid Density@BP: 50.46 lb/ft3 (808.3 kg/m3)

Specific Volume (ft^3/lb) : 13.8889

Gas Density (lb/ft^3) : 0.072

Relative density : Not applicable.

Solubility : Not available.

Solubility in water : Not available.

Partition coefficient: n-octanol/water : 0.67

Auto-ignition temperature : Not available.

Decomposition temperature : Not available.

SADT : Not available.

Viscosity : Not applicable.

Section 10. Stability and reactivity

Reactivity : No specific test data related to reactivity available for this product or its ingredients.

Chemical stability : The product is stable.

Possibility of hazardous reactions : Under normal conditions of storage and use, hazardous reactions will not occur.

Conditions to avoid : No specific data.

Incompatible materials : No specific data.

Hazardous decomposition products : Under normal conditions of storage and use, hazardous decomposition products should not be produced.

Hazardous polymerization : Under normal conditions of storage and use, hazardous polymerization will not occur.

Section 10. Stability and reactivity

Irritation/Corrosion
Not available.

Sensitization
Not available.

Mutagenicity
Not available.

Carcinogenicity
Not available.

Reproductive toxicity
Not available.

Teratogenicity
Not available.

Specific target organ toxicity (single exposure)
Not available.

Specific target organ toxicity (repeated exposure)
Not available.

Aspiration hazard
Not available.

Information on the likely routes of exposure : Not available.

Potential acute health effects

Eye contact : Contact with rapidly expanding gas may cause burns or frostbite.

Inhalation : No known significant effects or critical hazards.

Skin contact : Contact with rapidly expanding gas may cause burns or frostbite.

Ingestion : As this product is a gas, refer to the inhalation section.

Symptoms related to the physical, chemical and toxicological characteristics

Eye contact : No specific data.

Inhalation : No specific data.

Skin contact : No specific data.

Ingestion : No specific data.

Delayed and immediate effects and also chronic effects from short and long term exposure

Short term exposure

Potential immediate effects : Not available.

Potential delayed effects : Not available.

Long term exposure

Potential immediate effects : Not available.

Potential delayed effects : Not available.

Potential chronic health effects
Not available.

General : No known significant effects or critical hazards.

Carcinogenicity : No known significant effects or critical hazards.

Section 11. Toxicological information

Mutagenicity : No known significant effects or critical hazards.

Teratogenicity : No known significant effects or critical hazards.

Developmental effects : No known significant effects or critical hazards.

Fertility effects : No known significant effects or critical hazards.

Numerical measures of toxicity

Acute toxicity estimates

Not available.

Section 12. Ecological information

Toxicity

Not available.

Persistence and degradability

Not available.

Bioaccumulative potential

Product/ingredient name	$LogP_{ow}$	BCF	Potential
Nitrogen	0.67	-	low

Mobility in soil

Soil/water partition coefficient (K_{OC}) : Not available.

Other adverse effects : No known significant effects or critical hazards.

Section 13. Disposal considerations

Disposal methods : The generation of waste should be avoided or minimized wherever possible. Disposal of this product, solutions and any by-products should at all times comply with the requirements of environmental protection and waste disposal legislation and any regional local authority requirements. Dispose of surplus and non-recyclable products via a licensed waste disposal contractor. Waste should not be disposed of untreated to the sewer unless fully compliant with the requirements of all authorities with jurisdiction. Empty Airgas-owned pressure vessels should be returned to Airgas. Waste packaging should be recycled. Incineration or landfill should only be considered when recycling is not feasible. This material and its container must be disposed of in a safe way. Empty containers or liners may retain some product residues. Do not puncture or incinerate container.

Section 14. Transport information

	DOT	TDG	Mexico	IMDG	IATA
UN number	UN1066	UN1066	UN1066	UN1066	UN1066
UN proper shipping name	NITROGEN, COMPRESSED	NITROGEN, COMPRESSED	NITROGEN, COMPRESSED	NITROGEN, COMPRESSED	NITROGEN, COMPRESSED
Transport hazard class(es)	2.2	2.2	2.2	2.2	2.2

Section 14. Transport information

Packing group	-	-	-	-	-
Environment	No.	No.	No.	No.	No.
Additional information	**Limited quantity** Yes. **Packaging instruction** **Passenger aircraft** Quantity limitation: 75 kg **Cargo aircraft** Quantity limitation: 150 kg	Product classified as per the following sections of the Transportation of Dangerous Goods Regulations: 2.13-2.17 (Class 2). **Explosive Limit and Limited Quantity Index** 0.125 **Passenger Carrying Road or Rail Index** 75	-	-	**Passenger and Cargo Aircraft**Quantity limitation: 75 kg **Cargo Aircraft Only** Quantity limitation: 150 kg

"Refer to CFR 49 (or authority having jurisdiction) to determine the information required for shipment of the product."

Special precautions for user : **Transport within user's premises:** always transport in closed containers that are upright and secure. Ensure that persons transporting the product know what to do in the event of an accident or spillage.

Transport in bulk according to Annex II of MARPOL 73/78 and the IBC Code : Not available.

Section 15. Regulatory information

U.S. Federal regulations : **TSCA 8(a) CDR Exempt/Partial exemption**: This material is listed or exempted.
United States inventory (TSCA 8b): This material is listed or exempted.

Clean Air Act Section 112 (b) Hazardous Air Pollutants (HAPs) : Not listed

Clean Air Act Section 602 Class I Substances : Not listed

Clean Air Act Section 602 Class II Substances : Not listed

DEA List I Chemicals (Precursor Chemicals) : Not listed

DEA List II Chemicals (Essential Chemicals) : Not listed

SARA 302/304

Composition/information on ingredients

No products were found.

SARA 304 RQ : Not applicable.

SARA 311/312

Classification : Sudden release of pressure

Composition/information on ingredients

Name	%	Fire hazard	Sudden release of pressure	Reactive	Immediate (acute) health hazard	Delayed (chronic) health hazard
Nitrogen	100	No.	Yes.	No.	No.	No.

Section 15. Regulatory information

State regulations

Massachusetts : This material is listed.

New York : This material is not listed.

New Jersey : This material is listed.

Pennsylvania : This material is listed.

International regulations

International lists

National inventory

Australia : This material is listed or exempted.

Canada : This material is listed or exempted.

China : This material is listed or exempted.

Europe : This material is listed or exempted.

Japan : Not determined.

Malaysia : Not determined.

New Zealand : This material is listed or exempted.

Philippines : This material is listed or exempted.

Republic of Korea : This material is listed or exempted.

Taiwan : This material is listed or exempted.

Canada

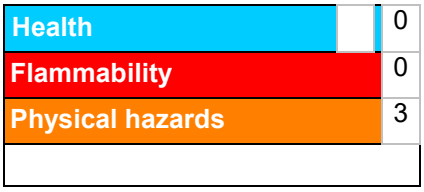
WHMIS (Canada) : Class A: Compressed gas.

CEPA Toxic substances: This material is not listed.
Canadian ARET: This material is not listed.
Canadian NPRI: This material is not listed.
Alberta Designated Substances: This material is not listed.
Ontario Designated Substances: This material is not listed.
Quebec Designated Substances: This material is not listed.

Section 16. Other information

Canada Label requirements : Class A: Compressed gas.

Hazardous Material Information System (U.S.A.)



Caution: HMIS® ratings are based on a 0-4 rating scale, with 0 representing minimal hazards or risks, and 4 representing significant hazards or risks Although HMIS® ratings are not required on SDSs under 29 CFR 1910. 1200, the preparer may choose to provide them. HMIS® ratings are to be used with a fully implemented HMIS® program. HMIS® is a registered mark of the National Paint & Coatings Association (NPCA). HMIS® materials may be purchased exclusively from J. J. Keller (800) 327-6868.

The customer is responsible for determining the PPE code for this material.

National Fire Protection Association (U.S.A.)

Reprinted with permission from NFPA 704-2001, Identification of the Hazards of Materials for Emergency Response Copyright ©1997, National Fire Protection Association, Quincy, MA 02269. This reprinted material is not the complete and official position of the National Fire Protection Association, on the referenced subject which is represented only by the standard in its entirety.

Section 16. Other information

Copyright ©2001, National Fire Protection Association, Quincy, MA 02269. This warning system is intended to be interpreted and applied only by properly trained individuals to identify fire, health and reactivity hazards of chemicals. The user is referred to certain limited number of chemicals with recommended classifications in NFPA 49 and NFPA 325, which would be used as a guideline only. Whether the chemicals are classified by NFPA or not, anyone using the 704 systems to classify chemicals does so at their own risk.

Procedure used to derive the classification

Classification	Justification
Press. Gas Comp. Gas, H280	Expert judgment

History

Date of printing : 5/26/2016

Date of issue/Date of revision : 5/26/2016

Date of previous issue : 8/7/2015

Version : 0.02

Key to abbreviations : ATE = Acute Toxicity Estimate
BCF = Bioconcentration Factor
GHS = Globally Harmonized System of Classification and Labelling of Chemicals
IATA = International Air Transport Association
IBC = Intermediate Bulk Container
IMDG = International Maritime Dangerous Goods
LogPow = logarithm of the octanol/water partition coefficient
MARPOL 73/78 = International Convention for the Prevention of Pollution From Ships, 1973 as modified by the Protocol of 1978. ("Marpol" = marine pollution)
UN = United Nations

References : Not available.

Indicates information that has changed from previously issued version.

Notice to reader

To the best of our knowledge, the information contained herein is accurate. However, neither the above-named supplier, nor any of its subsidiaries, assumes any liability whatsoever for the accuracy or completeness of the information contained herein.
Final determination of suitability of any material is the sole responsibility of the user. All materials may present unknown hazards and should be used with caution. Although certain hazards are described herein, we cannot guarantee that these are the only hazards that exist.

SAFETY DATA SHEET

Section 1. Chemical Product and Company Identification

Product Name:	ChemTreat P8281L
Product Use:	Water Clarification Agent
Supplier's Name:	ChemTreat, Inc.
Emergency Telephone Number:	(800)424−9300 (Toll Free)
Address (Corporate Headquarters):	5640 Cox Road Glen Allen, VA 23060
Telephone Number for Information:	(800)648−4579
Date of SDS:	May 9, 2016
Revision Date:	May 9, 2016
Revision Number:	16050901AN

Section 2. Hazard(s) Identification

Signal Word: **DANGER**

GHS Classification(s):

Skin corrosion/irritation − Category 1b
Eye damage/irritation − Category 1
Acute Toxicity Dermal − Category 4
Acute Toxicity Inhalation − Category 4
Acute Toxicity Oral − Category 4

Hazard Statement(s):

H314 Causes severe skin burns and eye damage.
H318 Causes serious eye damage.
H312 Harmful in contact with skin.
H332 Harmful if inhaled.
H302 Harmful if swallowed.

Precautionary Statement(s):

Prevention:

P260 Do not breathe dust/fume/gas/mist/vapors/spray.
P264 Wash thoroughly after handling.
P270 Do not eat, drink, or smoke when using this product.
P271 Use only outdoors or in a well−ventilated area.
P280 Wear protective gloves/protective clothing/eye protection/face protection.

Response:

P301 + P312 IF SWALLOWED: Call a POISON CENTER or doctor/physician if you feel unwell
P301 + 330 + 331 IF SWALLOWED: Rinse mouth. Do NOT induce vomiting.
P303 + P361 + P353 IF ON SKIN (or hair): Remove/take off immediately all contaminated clothing. Rinse skin with water/shower
P304 + P340 IF INHALED: Remove person to fresh air and keep comfortable for breathing
P305 + P351 + P388 IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.
P310 Immediately call a POISON CENTER/doctor.
P363 Wash contaminated clothing before reuse.

Storage:

P405 Store locked up.

Disposal:

P501 Dispose of contents and container in accordance with applicable local, regional, national, and/or international regulations.

System of Classification Used:

Classification under 2012 OSHA Hazard Communication Standard (29 CFR 1910.1200).

Hazards Not Otherwise Classified:

None.

Section 3. Composition/Hazardous Ingredients

Component	CAS Registry #	Wt.%
Ferric chloride	7705−08−0	30 − 60

Comments

If chemical identity and/or exact percentage of composition has been withheld, this information is considered to be a trade secret.

Section 4. First Aid Measures

Inhalation:

Remove victim to fresh air and keep at rest in a position comfortable for breathing. Immediately call a poison center or doctor/physician.

Eyes:

Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. Immediately call a poison center or doctor/physician.

Skin:	Immediately remove/take off all contaminated clothing. Rinse skin with water/shower. Wash contaminated clothing before re−use. Immediately call a poison center or doctor/physician.
Ingestion:	DO NOT INDUCE VOMITING. Rinse mouth. Call a POISON CENTER or doctor/physician.
Most Important Symptoms:	N/D
Indication of Immediate Medical Attention and Special Treatment Needed, If Necessary:	N/A

Section 5. Fire Fighting Measures

Flammability of the Product:	Not flammable.
Suitable Extinguishing Media:	Use extinguishing media suitable to surrounding fire.
Specific Hazards Arising from the Chemical:	None known.
Protective Equipment:	If product is involved in a fire, wear full protective clothing including a positive−pressure, NIOSH approved, self−contained breathing apparatus.

Section 6. Accidental Release Measures

Personal Precautions:	Use appropriate Personal Protective Equipment (PPE).
Environmental Precautions:	Avoid dispersal of spilled material and runoff and contact with soil, waterways, drains, and sewers.
Methods for Cleaning up:	Contain and recover liquid when possible. Flush spill area with water spray.
Other Statements:	If RQ (Reportable Quantity) is exceeded, report to National Spill Response Office at 1−800−424−8802. Reportable Quantity of the product is 215 Gal.

Section 7. Handling and Storage

Handling: Wear appropriate Personal Protective Equipment (PPE) when handling this product. Do not get in eyes, or on skin and clothing. Wash thoroughly after handling. Do not ingest. Avoid breathing vapors, mist or dust.

Storage: Store away from incompatible materials (see Section 10). Store at ambient temperatures. Keep container securely closed when not in use. Label precautions also apply to empty container. Recondition or dispose of empty containers in accordance with government regulations. For Industrial use only.
Protect from heat and sources of ignition.
Store in dry place.
Store above Freeze Point.

Section 8. Exposure Controls/Personal Protection

Exposure Limits

Component	Source	Exposure Limits
Ferric chloride	N/E	N/E

Engineering Controls: Use only with adequate ventilation. The use of local ventilation is recommended to control emission near the source.

Personal Protection

Eyes: Wear chemical splash goggles or safety glasses with full−face shield. Maintain eyewash fountain in work area.

Skin: Maintain quick−drench facilities in work area.
Wear butyl rubber or neoprene gloves. Wash them after each use and replace as necessary. If conditions warrant, wear protective clothing such as boots, aprons, and coveralls to prevent skin contact.

Respiratory: If misting occurs, use NIOSH approved organic vapor/acid gas dual cartridge respirator with a dust/mist prefilter in accordance with 29 CFR 1910.134.

Section 9. Physical and Chemical Properties

Physical State and Appearance:	Liquid, Brown, Clear
Specific Gravity:	1.395 @ 20°C
pH:	<1.0 @ 20°C, 100.0%
Freezing Point:	<−13°F
Flash Point:	N/D
Odor:	Mild
Melting Point:	N/A
Initial Boiling Point and Boiling Range:	223°F
Solubility in Water:	Complete
Evaporation Rate:	N/A
Vapor Density:	N/D
Molecular Weight:	N/D
Viscosity:	<100 CPS @ 20°C
Flammability (solid, gas):	N/D
Flammable Limits:	N/A
Autoignition Temperature:	N/A
Density:	11.63 LB/GA
Vapor Pressure:	40 mmHg @ 35C
% VOC:	N/D
Odor Threshold	N/D
n−octanol Partition Coefficient	N/D
Decomposition Temperature	N/D

Section 10. Stability and Reactivity

Chemical Stability:	Stable at normal temperatures and pressures.
Incompatibility with Various Substances:	Strong oxidizers, Bases, Aluminum/aluminum alloys, Carbon steel, Copper/copper alloys.
Hazardous Decomposition Products:	None known.
Possibility of Hazardous Reactions:	None known.
Reactivity:	N/D
Conditions To Avoid:	N/D

Section 11. Toxicological Information

Acute Toxicity

Chemical Name	Exposure	Type of Effect	Concentration	Species
N/D	N/D	N/D	N/D	N/D

Carcinogenicity Category

Component	Source	Code	Brief Description
Ferric chloride	N/E	N/E	N/E

Likely Routes of Exposure: N/D

Symptoms

Inhalation: N/D

Eye Contact: N/D

Skin Contact: N/D

Ingestion: N/D

Skin Corrosion/Irritation: N/D

Serious Eye Damage/Eye Irritation: N/D

Sensitization: N/D

Germ Cell Mutagenicity: N/D

Reproductive/Developmental Toxicity: N/D

Specific Target Organ Toxicity

Single Exposure: N/D

Repeated Exposure: N/D

Aspiration Hazard: N/D

Comments: None.

Section 12. Ecological Information

Ecotoxicity

Species	Duration	Type of Effect	Test Results
Ceriodaphnia dubia	48h	LC50	>1000 mg/l
Fathead Minnow	96h	LC50	7937 mg/l

Persistence and Biodegradability: N/D

Bioaccumulative Potential: N/D

Mobility In Soil: N/D

Other Adverse Effects: N/D

Comments: None.

Section 13. Disposal Considerations

Dispose of in accordance with local, state and federal regulations.
EPA corrosivity characteristic hazardous waste D002 when disposed of in the original product form.

Section 14. Transport Information

Controlling Regulation	UN/NA#:	Proper Shipping Name:	Technical Name:	Hazard Class:	Packing Group:
DOT	UN2582	FERRIC CHLORIDE SOLUTION	N/A	8	PGIII
Over 215 GA	UN2582	RQ FERRIC CHLORIDE SOLUTION	N/A	8	PGIII
IMDG	UN2582	FERRIC CHLORIDE SOLUTION	N/A	8	PGIII
TDG	UN2582	FERRIC CHLORIDE SOLUTION	N/A	8	PGIII
ICAO	UN2582	FERRIC CHLORIDE SOLUTION	N/A	8	PGIII

Note: N/A

Section 15. Regulatory Information

Inventory Status

United States (TSCA): All ingredients listed.
Canada (DSL/NDSL): All ingredients listed.

Federal Regulations

SARA Title III Rules

Sections 311/312 Hazard Classes

Fire Hazard: No
Reactive Hazard: No
Release of Pressure: No
Acute Health Hazard: Yes
Chronic Health Hazard: No

Other Sections

Component	Section 313 Toxic Chemical	Section 302 EHS TPQ	CERCLA RQ
Ferric chloride	N/A	N/A	1000

Comments: None.

State Regulations

California Proposition 65: None known.

Special Regulations

Component	States
Ferric chloride	MA, NY, PA

International Regulations

Canada

WHMIS Classification:	D2B (Toxic Material) E (Corrosive Material)
Controlled Product Regulations (CPR):	This product has been classified in accordance with the hazard criteria of the Controlled Products Regulations (CPR) and the MSDS contains all the information required by the CPR.

Compliance Information

NSF:	N/A
Food Regulations:	N/A
KOSHER:	This product has not been evaluated for Kosher approval.
FIFRA:	N/A
Other:	None

Comments: None.

Section 16. Other Information

HMIS Hazard Rating

Health:	3
Flammability:	0
Physical Hazard:	0
PPE:	X

Notes: The PPE rating depends on circumstances of use. See Section 8 for recommended PPE.
The Hazardous Material Information System (HMIS) is a voluntary, subjective alpha−numeric symbolic system for recommending hazard risk and personal protection equipment information. It is a subjective rating system based on the evaluator's understanding of the chemical associated risks. The end−user must determine if the code is appropriate for their use.

Abbreviations

Abbreviation	Definition
<	Less Than
>	Greater Than
ACGIH	American Conference of Governmental Industrial Hygienists
EHS	Environmental Health and Safety Dept
N/A	Not Applicable
N/D	Not Determined
N/E	Not Established
OSHA	Occupational Health and Safety Dept
PEL	Personal Exposure Limit
STEL	Short Term Exposure Limit
TLV	Threshold Limit Value
TWA	Time Weight Average
UNK	Unknown

Prepared by: Product Compliance Department; ProductCompliance@chemtreat.com

Revision Date: May 9, 2016

Disclaimer

Although the information and recommendations set forth herein (hereinafter "information") are presented in good faith and believed to be correct as of the date hereof, ChemTreat, Inc. makes no representations as to the completeness or accuracy thereof. Information is supplied upon the condition that the persons receiving same will make their own determination as to its suitability for their purposes prior to use. In no event will ChemTreat, Inc. be responsible for damages of any nature whatsoever resulting from the use or reliance upon information. No representation or warranties, either expressed or implied, of merchantability, fitness for a particular purpose, or of any other nature are made hereunder with respect to information or the product to which information refers.

29 CFR 1910.1200 (OSHA HazCom 2012)

SECTION 1. PRODUCT AND COMPANY IDENTIFICATION

Product identifier

Trade name : Drewplus™ ED750
FOAM CONTROL AGENT
™ Trademark, Solenis or its subsidiaries or affiliates, registered in various countries

Substance name : ALCOHOLS C16-18 PEG-PPG 2-30

Substance No.

Recommended use of the chemical and restrictions on use

Details of the supplier of the safety data sheet	**Emergency telephone number**
Solenis LLC 500 Hercules Road Wilmington, Delaware 19808 United States of America RegulatoryRequestsNA@solenis.com	1-844-SOLENIS (844-765-3647) / 606-329-5705 **Product Information** 1-844-SOLENIS (844-765-3647)

SECTION 2. HAZARDS IDENTIFICATION

GHS Classification

This material is not considered hazardous under the OSHA Hazard Communication Standard (HazCom 2012).

GHS Label element

This material is not considered hazardous under the OSHA Hazard Communication Standard (HazCom 2012).

Other hazards

None known.

SECTION 3. COMPOSITION/INFORMATION ON INGREDIENTS

Substance / Mixture : Substance

Hazardous components

No hazardous ingredients

SECTION 4. FIRST AID MEASURES

General advice	:	No hazards which require special first aid measures.
If inhaled	:	If breathed in, move person into fresh air. If unconscious place in recovery position and seek medical advice. If symptoms persist, call a physician.
In case of skin contact	:	First aid is not normally required. However, it is recommended that exposed areas be cleaned by washing with soap and water.
In case of eye contact	:	Remove contact lenses. Protect unharmed eye.
If swallowed	:	Do not give milk or alcoholic beverages. Never give anything by mouth to an unconscious person. If symptoms persist, call a physician.
Most important symptoms and effects, both acute and delayed	:	No symptoms known or expected.
Notes to physician	:	No hazards which require special first aid measures.

SECTION 5. FIREFIGHTING MEASURES

Suitable extinguishing media	:	Use extinguishing measures that are appropriate to local circumstances and the surrounding environment. Water spray Foam Carbon dioxide (CO2) Dry chemical
Specific hazards during firefighting	:	Do not allow run-off from fire fighting to enter drains or water courses.
Hazardous combustion products	:	acid vapors Aldehydes carbon dioxide and carbon monoxide

Ketones

Specific extinguishing methods : Product is compatible with standard fire-fighting agents.

Further information : Standard procedure for chemical fires.

Special protective equipment for firefighters : In the event of fire, wear self-contained breathing apparatus.

SECTION 6. ACCIDENTAL RELEASE MEASURES

Personal precautions, protective equipment and emergency procedures : Persons not wearing protective equipment should be excluded from area of spill until clean-up has been completed.

Environmental precautions : Prevent further leakage or spillage if safe to do so.

Methods and materials for containment and cleaning up : Soak up with inert absorbent material (e.g. sand, silica gel, acid binder, universal binder, sawdust).
Keep in suitable, closed containers for disposal.

Other information : Comply with all applicable federal, state, and local regulations.

SECTION 7. HANDLING AND STORAGE

Advice on safe handling : Smoking, eating and drinking should be prohibited in the application area.
For personal protection see section 8.

Conditions for safe storage : Electrical installations / working materials must comply with the technological safety standards.

Materials to avoid : No materials to be especially mentioned.

SECTION 8. EXPOSURE CONTROLS/PERSONAL PROTECTION

Components with workplace control parameters

Engineering measures : General room ventilation should be adequate for normal

conditions of use. However, if unusual operating conditions exist, provide sufficient mechanical (general and/or local exhaust) ventilation to maintain exposure below exposure guidelines (if applicable) or below levels that cause known, suspected or apparent adverse effects.

Personal protective equipment

Respiratory protection : No personal respiratory protective equipment normally required.

Eye protection : Not required under normal conditions of use. Wear splash-proof safety goggles if material could be misted or splashed into eyes.

Skin and body protection : Wear resistant gloves (consult your safety equipment supplier).
Wear as appropriate:
Safety shoes

Hygiene measures : General industrial hygiene practice.

SECTION 9. PHYSICAL AND CHEMICAL PROPERTIES

Physical state	:	liquid
Colour	:	colourless
Odour	:	odourless
Odour Threshold	:	No data available
pH	:	6.5 - 7.5
Melting point/freezing point	:	No data available
Boiling point/boiling range	:	> 392 °F / > 200 °C (1,013 hPa)
Flash point	:	> 212 °F / > 100 °C
Evaporation rate	:	No data available
Flammability (solid, gas)	:	No data available
Upper explosion limit	:	No data available

Lower explosion limit	:	No data available
Vapour pressure	:	No data available
		No data available
Relative vapour density	:	No data available
Relative density	:	No data available
Density	:	0.98 g/cm3
Solubility(ies)		
Water solubility	:	insoluble
Solubility in other solvents	:	No data available
Partition coefficient: n-octanol/water	:	No data available
Auto-ignition temperature	:	> 200 °C
Thermal decomposition	:	No data available
Viscosity		
Viscosity, dynamic	:	300 mPa.s
Viscosity, kinematic	:	No data available
Oxidizing properties	:	No data available

SECTION 10. STABILITY AND REACTIVITY

Reactivity	:	No decomposition if stored and applied as directed.
Chemical stability	:	Stable under recommended storage conditions.
Possibility of hazardous reactions	:	Product will not undergo hazardous polymerization.
Incompatible materials	:	Strong oxidizing agents
Hazardous decomposition products		No hazardous decomposition products are known.

SECTION 11. TOXICOLOGICAL INFORMATION

Information on likely routes of exposure : Inhalation
Skin contact
Eye Contact
Ingestion

Acute toxicity
Not classified based on available information.
Product:
Acute oral toxicity : LD 50 (Rat): > 10,000 mg/kg

Skin corrosion/irritation
Not classified based on available information.
Product:
Result: Not irritating to skin

Serious eye damage/eye irritation
Not classified based on available information.
Product:
Result: Not irritating to eyes

Remarks: Unlikely to cause eye irritation or injury.

Respiratory or skin sensitisation
Skin sensitisation: Not classified based on available information.
Respiratory sensitisation: Not classified based on available information.
Germ cell mutagenicity
Not classified based on available information.
Carcinogenicity
Not classified based on available information.
Reproductive toxicity
Not classified based on available information.
STOT - single exposure
Not classified based on available information.
STOT - repeated exposure
Not classified based on available information.
Aspiration toxicity
Not classified based on available information.
Further information
Product:
Remarks: No data available

Carcinogenicity:

IARC	No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.
OSHA	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.
NTP	No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

SECTION 12. ECOLOGICAL INFORMATION

Ecotoxicity

Product:

Toxicity to fish	:	LC 50 (Oncorhynchus mykiss (rainbow trout)): 140 mg/l Exposure time: 96 h Test Type: static test LC 50 (Cyprinodon variegatus (sheepshead minnow)): > 1,000 mg/l Exposure time: 96 h Test Type: static test
Toxicity to daphnia and other aquatic invertebrates	:	EC 50 (Water flea (Daphnia magna)): 610 mg/l Exposure time: 48 h Test Type: static test
Toxicity to bacteria	:	(Bacteria): > 2,000 mg/l

Persistence and degradability

Product:

Biochemical Oxygen Demand (BOD)	:	< 10 mg/g Incubation time: 5 d
Chemical Oxygen Demand (COD)	:	2,130 mg/g

No data available

Bioaccumulative potential

No data available

Mobility in soil

No data available

Other adverse effects

No data available

Product:

Additional ecological information : No data available

SECTION 13. DISPOSAL CONSIDERATIONS

Disposal methods

General advice : Dispose of in accordance with all applicable local, state and federal regulations.

Contaminated packaging : Empty remaining contents.

SECTION 14. TRANSPORT INFORMATION

International transport regulations

REGULATION

ID NUMBER	PROPER SHIPPING NAME	*HAZARD CLASS	SUBSIDIARY HAZARDS	PACKING GROUP	MARINE POLLUTANT / LTD. QTY.

U.S. DOT - ROAD

Not dangerous goods

U.S. DOT - RAIL

Not dangerous goods

U.S. DOT - INLAND WATERWAYS

Not dangerous goods

TRANSPORT CANADA - ROAD

Not dangerous goods

TRANSPORT CANADA - RAIL

Not dangerous goods

TRANSPORT CANADA - INLAND WATERWAYS

Not dangerous goods

INTERNATIONAL MARITIME DANGEROUS GOODS

Not dangerous goods

INTERNATIONAL AIR TRANSPORT ASSOCIATION - CARGO

Not dangerous goods

INTERNATIONAL AIR TRANSPORT ASSOCIATION - PASSENGER

Not dangerous goods

MEXICAN REGULATION FOR THE LAND TRANSPORT OF HAZARDOUS MATERIALS AND WASTES

Not dangerous goods

***ORM = ORM-D, CBL = COMBUSTIBLE LIQUID**

Marine pollutant		no

Dangerous goods descriptions (if indicated above) may not reflect quantity, end-use or region-specific exceptions that can be applied. Consult shipping documents for descriptions that are specific to the shipment.

SECTION 15. REGULATORY INFORMATION

SARA 311/312 Hazards : No SARA Hazards

SARA 313
Component(s)SARA 313 : This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

California Prop 65 Proposition 65 warnings are not required for this product based on the results of a risk assessment.

The components of this product are reported in the following inventories:

TSCA	:	On TSCA Inventory
DSL	:	All components of this product are on the Canadian DSL.
AUSTR	:	On the inventory, or in compliance with the inventory
ENCS	:	On the inventory, or in compliance with the inventory
KECL	:	On the inventory, or in compliance with the inventory
PHIL	:	On the inventory, or in compliance with the inventory
IECSC	:	On the inventory, or in compliance with the inventory

Inventories
AICS (Australia), DSL (Canada), IECSC (China), REACH (European Union), ENCS (Japan), ISHL (Japan), KECI (Korea), NZIoC (New Zealand), PICCS (Philippines), TSCA (USA)

SECTION 16. OTHER INFORMATION

Further information
Revision Date: 01/27/2016

Full text of H-Statements referred to under sections 2 and 3.

Further information

Sources of key data used to compile the Safety Data Sheet
Key literature references and sources of data
SOLENIS Internal data
SOLENIS internal data including own and sponsored test reports
The UNECE administers regional agreements implementing harmonised classification for labelling (GHS) and transport.

The information accumulated herein is believed to be accurate but is not warranted to be whether originating with the company or not. Recipients are advised to confirm in advance of need that the information is current, applicable, and suitable to their circumstances. This MSDS has been prepared by the Solenis Environmental Health and Safety Department.

List of abbreviations and acronyms that could be, but not necessarily are, used in this safety data sheet :

ACGIH : American Conference of Industrial Hygienists
BEI : Biological Exposure Index

CAS : Chemical Abstracts Service (Division of the American Chemical Society).
CMR : Carcinogenic, Mutagenic or Toxic for Reproduction
FG : Food grade
GHS : Globally Harmonized System of Classification and Labeling of Chemicals.
H-statement : Hazard Statement
IATA : International Air Transport Association.
IATA-DGR : Dangerous Goods Regulation by the “International Air Transport Association” (IATA).
ICAO : International Civil Aviation Organization
ICAO-TI (ICAO) : Technical Instructions by the “International Civil Aviation Organization”
IMDG : International Maritime Code for Dangerous Goods
ISO : International Organization for Standardization
logPow : octanol-water partition coefficient
LCxx : Lethal Concentration, for xx percent of test population
LDxx : Lethal Dose, for xx percent of test population.
ICxx : Inhibitory Concentration for xx of a substance
Ecxx : Effective Concentration of xx
N.O.S.: Not Otherwise Specified
OECD : Organization for Economic Co-operation and Development
OEL : Occupational Exposure Limit
P-Statement : Precautionary Statement
PBT : Persistent , Bioaccumulative and Toxic
PPE : Personal Protective Equipment
STEL : Short-term exposure limit
STOT : Specific Target Organ Toxicity
TLV : Threshold Limit Value
TWA : Time-weighted average
vPvB : Very Persistent and Very Bioaccumulative
WEL : Workplace Exposure Level

CERCLA : Comprehensive Environmental Response, Compensation, and Liability Act
DOT : Department of Transportation
FIFRA : Federal Insecticide, Fungicide, and Rodenticide Act
HMIRC : Hazardous Materials Information Review Commission
HMIS : Hazardous Materials Identification System
NFPA : National Fire Protection Association
NIOSH : National Institute for Occupational Safety and Health
OSHA : Occupational Safety and Health Administration
PMRA : Health Canada Pest Management Regulatory Agency
RTK : Right to Know
WHMIS : Workplace Hazardous Materials Information System

Appendix F

CDM Smith Health and Safety Plan

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General Information

This task-specific health and safety plan (HASP) provides safety-related information and requirements specific to the task and work location(s) described. General requirements of the CDM Smith Health and Safety Program along with those described in this task-specific HASP will be implemented except where noted. Significant changes to this HASP shall be documented and reviewed by the division HSM.

Project Name: Project No. ER-201434: Anaerobic Membrane Bioreactor for Sustainable Wastewater Treatment Pilot Project (AnMBR Pilot Project)

Client: U.S. Department of Defense, Environmental Security Technology Certification Program (ESTCP)

Project No.: 104485.6444.001.T2A.DEMOP Date: November 2, 2015

Performing Organization(s): CDM Smith

Planned Duration of Field Activities: February 2016 – October 2017

Project Location: Camp Forsyth Pump Station, Intersection of 3rd Street & I Street, Fort Riley, Kansas, 66442

Key Personnel

Project Manager: Eva Opitz Telephone: 312-780-7870

Project Health and Safety Contact: Shawn Oliveira Telephone: 406-293-2672

Project Field Personnel	Responsibilities	Telephone
Bill Schilling, CDM Smith	Pilot Plant Operations/Sample Collection	916-576-7513
Pat Evans, CDM Smith	Pilot Plant Operations/Sample Collection	206-351-0228
Meagan Malloy, CDM Smith	Pilot Plant Operations/Sample Collection	816-896-8563
Dustin Craig, CDM Smith	Pilot Plant Operations/Sample Collection	816-412-3158

Project Site Description

The project site is a wastewater pump station. Existing facilities at the site include a wet-well/dry-pit style pump station, a building with a wastewater screen in it, an abandoned ferric chloride storage and metering facility, and an electrical building with an outdoor generator. As part of this project, an air-conditioned trailer with pilot wastewater treatment equipment located inside it will be temporarily installed at the site. The treatment equipment includes of a 350 gal digester, a 45 gallon membrane tank, a gas transfer membrane contactor, a flocculation/sedimentation basin, a ion-exchange column, three 15 gal chemical storage tanks, and ancillary components including piping, valves, small pumps, small compressors, and monitoring equipment. The pilot system has been designed to meet NFPA 497 standards. The pilot unit will operate for 15 months. A small pump and strainer will be located in the pump station dry-pit to pump sewage from the pump station wet well to the pilot plant.

CDM Smith Activity Hazard Analysis							
Project Name:	AnMBR Pilot Project			**Project No.:**	104485.6444.001.T2A.DEMOP		
Analyzed by:	Bill Schilling	**Date:**	11/3/2015	**Reviewed by:**	Shawn Oliveira	**Date:**	11/6/2015

Description of Work Activity

CDM Smith staff will periodically perform inspections of site activity and participate in operating the pilot plant. CDM Smith staff will also periodically visit the site to collect samples and trouble shoot operational issues. This HASP is intended only for CDM Smith personnel

Potential Hazards (Examples provided at this link)	**Hazard Controls**
Slip/Fall	Floor drains to prevent slippery surfaces; daily maintenance to reduce tripping hazards.
Hazardous Chemicals (hydrochloric acid, citric acid, sodium hypochlorite, magnesium hydroxide, ferric chloride)	Small volumes onsite; double containment; emergency shower/eyewash stations; O&M Manual and MSDS on site; ventilation; smoke/fire alarms; fire sprinklers
Exposure to toxic/explosive gases (methane and hydrogen sulfide)	O&M Manual and MSDS on site; Use of 4 gas meter to confirm safe atmosphere prior to entering. Action levels are 10% of LEL for CH4 and 5 ppm for H2S. All personnel working in trailer will receive H2S awareness training
Exposure to raw or treated sewage	O&M Manual, use of PPE during sampling, small volumes of samples collected
Electrical	All equipment and outlets ground-fault protected; lock out/tag out procedures; fire extinguisher onsite.
Work near loud mechanical equipment	Use of hearing protection

Training Required	**Equipment Required**
H2S awareness, Pilot system SOP's	Hard hat, safety glasses, steel-toe boots, lab coats, cut-resistant gloves for work with tools, latex gloves for sample collection.

Emergency Information	NAME	PHONE

Police: Ft. Riley Police Dept.	Ft. Riley Police Dept. 911 / 785-239-6767 Non-Emergency
Fire: Ft. Riley Fire Dept.	Ft. Riley Station: 911/785-239-4257 Non-Emergency
CDM H & S Manager	Shawn Oliveira: 406-293-2672
CDM Emergency Phone	Eva Opitz: 312-780-7870
Poison Control Center	800-222-1222
State Spill Number:	800-852-7550
24-Hr. First Aid/Non-Emergency Medical Services:	1. Call AllOne Health at 1.800.350.4511, PRESS 1, and tell them you are reporting an injury for CDM Smith. Supply requested information. 2. Follow AllOne Health instructions 3. After care, follow-up with AllOne at the 1-800 #.
Ambulance:	911
Ft. Riley Point of Contact:	Chris Otto, 785-313-7234
Nearest Medical Facility:	Irwin Army Community Hospital
Address:	600 Caisson Hill Road, Fort Riley, KS 66442
Telephone:	785-239-7000
Driving Directions:	See Attached Map

Reviews

Project Manager opitzem@cdmsmith.com Digitally signed by opitzem@cdmsmith.com DN: cn=opitzem@cdmsmith.com Date: 2016.08.04 10:47:14 -05'00' Date: _____

Health & Safety Manager: Shawn Oliveira Date: 8/26/16

from I St & 3rd St, Fort Riley, KS 66442
to Irwin Army Community Hospital, 600 Caisson Hill R...

9 min (4.1 miles)

via McCormick Rd and Huebner Rd

9 min without traffic

This route has restricted usage or private roads

I St & 3rd St
Fort Riley, KS 66442

Take H St to Trooper Dr
1 min (0.4 mi)

Follow McCormick Rd and Huebner Rd to Caisson Hill Rd
7 min (3.7 mi)

Turn left onto Caisson Hill Rd
Destination will be on the right
41 s (499 ft)

Irwin Army Community Hospital
600 Caisson Hill Road, Fort Riley, KS 66442

These directions are for planning purposes only. You may find that construction projects, traffic, weather, or other events may cause conditions to differ from the map results, and you should plan your route accordingly. You must obey all signs or notices regarding your route.

Question	Answer	Comments
Process designers qualified?	Y or N	
Facility designers qualified?	Y or N	
Facility appears to meet building code?	Y or N	
Should CDM engineers inspect the facility?	Y or N	Inspected by Bill Schilling & Pat Evans in March 2015
Documentation of the design available?	Y or N	Draft design drawings available in Sacramento
Does safe operation of the process require:	Y or N	
Mechanical ventilation?	Y or N	
Ventilation is working?	Y or N	
Electrical power?	Y or N	
Lighting?	Y or N	
Heating?	Y or N	
Cooling?	Y or N	
Fuel or fuel gas?	Y or N	
Fire detection?	Y or N	
Fire suppression?	Y or N	
Is each of these working safely?	Y or N	
Was process built in accord with design?	Y or N	Process not yet built
Any modifications that affect safety?	Y or N	Additional site security.
Did design team agreed to modification?	Y or N	N/A
Does facility continue to meet design?	Y or N	
Changes or modifications without appropriate review?	Y or N	
Are any component parts damaged?	Y or N	
If no design, does its configuration allow and encourage safe operation?	Y or N	

Question	Answer	Comments
Materials of construction appropriate for	Y or N	
Physical location?	Y or N	
Temperature?	Y or N	
Pressure?	Y or N	Low pressures.
Chemical activity?	Y or N	Common chemicals
Velocity?	Y or N	Typical of treatment plants.
Appropriate pressure & temperature relief?	Y or N	
Has the facility been properly maintained?	Y or N	
How will facility receive process chemicals?	Mail, UPS or hand delivered from subcontractor or CDM Smith offices	
Who can buy them, and from where?	CDM Smith staff or subcontractors from local vendors or mail order	
How are process chemicals moved?	Small metering pumps.	
How are they stored at the facility?	Enclosed cabinets; acids and bases separated; liquids and solids separated; liquids double contained.	
Do the materials on site bear proper labels?	Y or N	
Are chemical safety data sheets in hand?	Y or N	
Are appropriate warnings visible?	Y or N	
Do warnings specify appropriate PPE?	Y or N	
Are standard operating procedures handy?	Y or N	
Secondary containment present?	Y or N	
Enough emergency resources available?	Y or N	
Emergency shower and eyewash?	Y or N	
Emergency contact list?	Y or N	
Communications equipment?	Y or N	
First aid kit?	Y or N	
Spill response equipment?	Y or N	
Fire extinguishers?	Y or N	

Team Member Signature Form

All site personnel must sign this form indicating receipt or review of the H&SP. Keep this original on site. It becomes part of the permanent project files. Send a copy to the Health and Safety Manager (HSM).

SITE NAME/NUMBER: **AnMBR Pilot Plant**

DIVISION/LOCATION: **Camp Forsyth, Fort Riley, Kansas**

CERTIFICATION: I understand, and agree to comply with, the provisions of the above referenced H&SP for work activities on this project. I agree to report any injuries, illnesses or exposure incidents to the project Health and Safety Coordinator (PHSC). I agree to inform the PHSC about any drugs (legal and illegal) that I take within three days of site work.

PRINTED NAME	SIGNATURE	DATE
Pat Evans		
Bill Schilling		
Meagan Malloy		
Dustin Craig		

Attachments

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APPENDIX C. TECHNICAL DATA SHEETS FOR CHEMICALS

SAFETY DATA SHEET

Section 1. Chemical Product and Company Identification

Product Name:	ChemTreat P8281L
Product Use:	Water Clarification Agent
Supplier's Name:	ChemTreat, Inc.
Emergency Telephone Number:	(800)424−9300 (Toll Free)
Address (Corporate Headquarters):	5640 Cox Road Glen Allen, VA 23060
Telephone Number for Information:	(800)648−4579
Date of SDS:	May 9, 2016
Revision Date:	May 9, 2016
Revision Number:	16050901AN

Section 2. Hazard(s) Identification

Signal Word: **DANGER**

GHS Classification(s):

Skin corrosion/irritation − Category 1b
Eye damage/irritation − Category 1
Acute Toxicity Dermal − Category 4
Acute Toxicity Inhalation − Category 4
Acute Toxicity Oral − Category 4

Hazard Statement(s):

H314 Causes severe skin burns and eye damage.
H318 Causes serious eye damage.
H312 Harmful in contact with skin.
H332 Harmful if inhaled.
H302 Harmful if swallowed.

Precautionary Statement(s):

Prevention:

P260 Do not breathe dust/fume/gas/mist/vapors/spray.
P264 Wash thoroughly after handling.
P270 Do not eat, drink, or smoke when using this product.
P271 Use only outdoors or in a well−ventilated area.
P280 Wear protective gloves/protective clothing/eye protection/face protection.

Response:

P301 + P312 IF SWALLOWED: Call a POISON CENTER or doctor/physician if you feel unwell
P301 + 330 + 331 IF SWALLOWED: Rinse mouth. Do NOT induce vomiting.
P303 + P361 + P353 IF ON SKIN (or hair): Remove/take off immediately all contaminated clothing. Rinse skin with water/shower
P304 + P340 IF INHALED: Remove person to fresh air and keep comfortable for breathing
P305 + P351 + P388 IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.
P310 Immediately call a POISON CENTER/doctor.
P363 Wash contaminated clothing before reuse.

Storage:

P405 Store locked up.

Disposal:

P501 Dispose of contents and container in accordance with applicable local, regional, national, and/or international regulations.

System of Classification Used:

Classification under 2012 OSHA Hazard Communication Standard (29 CFR 1910.1200).

Hazards Not Otherwise Classified:

None.

Section 3. Composition/Hazardous Ingredients

Component	CAS Registry #	Wt.%
Ferric chloride	7705−08−0	30 − 60

Comments

If chemical identity and/or exact percentage of composition has been withheld, this information is considered to be a trade secret.

Section 4. First Aid Measures

Inhalation:

Remove victim to fresh air and keep at rest in a position comfortable for breathing. Immediately call a poison center or doctor/physician.

Eyes:

Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. Immediately call a poison center or doctor/physician.

Skin:	Immediately remove/take off all contaminated clothing. Rinse skin with water/shower. Wash contaminated clothing before re−use. Immediately call a poison center or doctor/physician.
Ingestion:	DO NOT INDUCE VOMITING. Rinse mouth. Call a POISON CENTER or doctor/physician.
Most Important Symptoms:	N/D
Indication of Immediate Medical Attention and Special Treatment Needed, If Necessary:	N/A

Section 5. Fire Fighting Measures

Flammability of the Product:	Not flammable.
Suitable Extinguishing Media:	Use extinguishing media suitable to surrounding fire.
Specific Hazards Arising from the Chemical:	None known.
Protective Equipment:	If product is involved in a fire, wear full protective clothing including a positive−pressure, NIOSH approved, self−contained breathing apparatus.

Section 6. Accidental Release Measures

Personal Precautions:	Use appropriate Personal Protective Equipment (PPE).
Environmental Precautions:	Avoid dispersal of spilled material and runoff and contact with soil, waterways, drains, and sewers.
Methods for Cleaning up:	Contain and recover liquid when possible. Flush spill area with water spray.
Other Statements:	If RQ (Reportable Quantity) is exceeded, report to National Spill Response Office at 1−800−424−8802. Reportable Quantity of the product is 215 Gal.

Section 7. Handling and Storage

Handling: Wear appropriate Personal Protective Equipment (PPE) when handling this product. Do not get in eyes, or on skin and clothing. Wash thoroughly after handling. Do not ingest. Avoid breathing vapors, mist or dust.

Storage: Store away from incompatible materials (see Section 10). Store at ambient temperatures. Keep container securely closed when not in use. Label precautions also apply to empty container. Recondition or dispose of empty containers in accordance with government regulations. For Industrial use only.
Protect from heat and sources of ignition.
Store in dry place.
Store above Freeze Point.

Section 8. Exposure Controls/Personal Protection

Exposure Limits

Component	Source	Exposure Limits
Ferric chloride	N/E	N/E

Engineering Controls: Use only with adequate ventilation. The use of local ventilation is recommended to control emission near the source.

Personal Protection

Eyes: Wear chemical splash goggles or safety glasses with full−face shield. Maintain eyewash fountain in work area.

Skin: Maintain quick−drench facilities in work area.
Wear butyl rubber or neoprene gloves. Wash them after each use and replace as necessary. If conditions warrant, wear protective clothing such as boots, aprons, and coveralls to prevent skin contact.

Respiratory: If misting occurs, use NIOSH approved organic vapor/acid gas dual cartridge respirator with a dust/mist prefilter in accordance with 29 CFR 1910.134.

Section 9. Physical and Chemical Properties

Physical State and Appearance:	Liquid, Brown, Clear
Specific Gravity:	1.395 @ 20°C
pH:	<1.0 @ 20°C, 100.0%
Freezing Point:	<−13°F
Flash Point:	N/D
Odor:	Mild
Melting Point:	N/A
Initial Boiling Point and Boiling Range:	223°F
Solubility in Water:	Complete
Evaporation Rate:	N/A
Vapor Density:	N/D
Molecular Weight:	N/D
Viscosity:	<100 CPS @ 20°C
Flammability (solid, gas):	N/D
Flammable Limits:	N/A
Autoignition Temperature:	N/A
Density:	11.63 LB/GA
Vapor Pressure:	40 mmHg @ 35C
% VOC:	N/D
Odor Threshold	N/D
n−octanol Partition Coefficient	N/D
Decomposition Temperature	N/D

Section 10. Stability and Reactivity

Chemical Stability:	Stable at normal temperatures and pressures.
Incompatibility with Various Substances:	Strong oxidizers, Bases, Aluminum/aluminum alloys, Carbon steel, Copper/copper alloys.
Hazardous Decomposition Products:	None known.
Possibility of Hazardous Reactions:	None known.
Reactivity:	N/D
Conditions To Avoid:	N/D

Section 11. Toxicological Information

Acute Toxicity

Chemical Name	Exposure	Type of Effect	Concentration	Species
N/D	N/D	N/D	N/D	N/D

Carcinogenicity Category

Component	Source	Code	Brief Description
Ferric chloride	N/E	N/E	N/E

Likely Routes of Exposure: N/D

Symptoms

Inhalation: N/D

Eye Contact: N/D

Skin Contact: N/D

Ingestion: N/D

Skin Corrosion/Irritation: N/D

Serious Eye Damage/Eye Irritation: N/D

Sensitization: N/D

Germ Cell Mutagenicity: N/D

Reproductive/Developmental Toxicity: N/D

Specific Target Organ Toxicity

Single Exposure: N/D

Repeated Exposure: N/D

Aspiration Hazard: N/D

Comments: None.

Section 12. Ecological Information

Ecotoxicity

Species	Duration	Type of Effect	Test Results
Ceriodaphnia dubia	48h	LC50	>1000 mg/l
Fathead Minnow	96h	LC50	7937 mg/l

Persistence and Biodegradability: N/D

Bioaccumulative Potential: N/D

Mobility In Soil: N/D

Other Adverse Effects: N/D

Comments: None.

Section 13. Disposal Considerations

Dispose of in accordance with local, state and federal regulations.
EPA corrosivity characteristic hazardous waste D002 when disposed of in the original product form.

Section 14. Transport Information

Controlling Regulation	UN/NA#:	Proper Shipping Name:	Technical Name:	Hazard Class:	Packing Group:
DOT	UN2582	FERRIC CHLORIDE SOLUTION	N/A	8	PGIII
Over 215 GA	UN2582	RQ FERRIC CHLORIDE SOLUTION	N/A	8	PGIII
IMDG	UN2582	FERRIC CHLORIDE SOLUTION	N/A	8	PGIII
TDG	UN2582	FERRIC CHLORIDE SOLUTION	N/A	8	PGIII
ICAO	UN2582	FERRIC CHLORIDE SOLUTION	N/A	8	PGIII

Note: N/A

Section 15. Regulatory Information

Inventory Status

United States (TSCA): All ingredients listed.
Canada (DSL/NDSL): All ingredients listed.

Federal Regulations

SARA Title III Rules

Sections 311/312 Hazard Classes

Fire Hazard: No
Reactive Hazard: No
Release of Pressure: No
Acute Health Hazard: Yes
Chronic Health Hazard: No

Other Sections

Component	Section 313 Toxic Chemical	Section 302 EHS TPQ	CERCLA RQ
Ferric chloride	N/A	N/A	1000

Comments: None.

State Regulations

California Proposition 65: None known.

Special Regulations

Component	States
Ferric chloride	MA, NY, PA

International Regulations

Canada

WHMIS Classification:	D2B (Toxic Material) E (Corrosive Material)
Controlled Product Regulations (CPR):	This product has been classified in accordance with the hazard criteria of the Controlled Products Regulations (CPR) and the MSDS contains all the information required by the CPR.

Compliance Information

NSF:	N/A
Food Regulations:	N/A
KOSHER:	This product has not been evaluated for Kosher approval.
FIFRA:	N/A
Other:	None

Comments: None.

Section 16. Other Information

HMIS Hazard Rating

Health:	3
Flammability:	0
Physical Hazard:	0
PPE:	X

Notes: The PPE rating depends on circumstances of use. See Section 8 for recommended PPE.
The Hazardous Material Information System (HMIS) is a voluntary, subjective alpha−numeric symbolic system for recommending hazard risk and personal protection equipment information. It is a subjective rating system based on the evaluator's understanding of the chemical associated risks. The end−user must determine if the code is appropriate for their use.

Abbreviations

Abbreviation	Definition
<	Less Than
>	Greater Than
ACGIH	American Conference of Governmental Industrial Hygienists
EHS	Environmental Health and Safety Dept
N/A	Not Applicable
N/D	Not Determined
N/E	Not Established
OSHA	Occupational Health and Safety Dept
PEL	Personal Exposure Limit
STEL	Short Term Exposure Limit
TLV	Threshold Limit Value
TWA	Time Weight Average
UNK	Unknown

Prepared by: Product Compliance Department; ProductCompliance@chemtreat.com

Revision Date: May 9, 2016

Disclaimer

Although the information and recommendations set forth herein (hereinafter "information") are presented in good faith and believed to be correct as of the date hereof, ChemTreat, Inc. makes no representations as to the completeness or accuracy thereof. Information is supplied upon the condition that the persons receiving same will make their own determination as to its suitability for their purposes prior to use. In no event will ChemTreat, Inc. be responsible for damages of any nature whatsoever resulting from the use or reliance upon information. No representation or warranties, either expressed or implied, of merchantability, fitness for a particular purpose, or of any other nature are made hereunder with respect to information or the product to which information refers.

Certificate of Analysis

October 10, 2016

Laboratory No. Q16−10−10−12
Customer ID 66734−00
Sales Order 1692154A

KANSAS STATE UNIVERSITY
2118 FIELDER HALL
1701 C. PLATT STREET
MANHATTAN, KS 66506

Lot Information	
Product	P8281L
Product Description	Chemical Treatment
Date Shipped	07/01/2016
Quantity Shipped	59x5 Gal Pails
Purchase Order Number	CREDIT CARD
Specification Effective Date	10/10/2016
Date of Analysis	06/30/2016
Lot Number	3207910$P6F08FPF

Analysis	Results	Specifications
Ferrous Iron, wt.%	0.3	− 3.0
Ferric Iron, wt.%	38.8	36.0 − 41.0
Clarity	Clear	Clear
Color	Brown	Brown
Specific Gravity @ 20° C	1.411	1.380 − 1.430

Respectfully Submitted,

Frank Blackshear
Quality Control Lab Manager
ChemTreat, Inc.

This report certifies that this batch was tested and found to be in accordance with product specifications. This report does not constitute a guarantee nor does it relieve the purchaser of responsibility for inspection of material upon delivery or prior to actual use.

Product Data

WATER CLARIFICATION AGENT
COAGULATION AND
CLARIFICATION AID

CHEMTREAT P891L

GENERAL DESCRIPTION

CHEMTREAT P891L is a concentrated solution of inorganic polyaluminum chlorides which is applicable to many commercial and industrial solids recovery and clarification systems. **CHEMTREAT P891L** is an extremely economical clarification and settling aid.

CHEMTREAT P891L is certified NSF/ANSI Standard 60 shipped from Vernon, California; Eldridge, Iowa; Nederland, Texas; and Ashland, Virginia. **CHEMTREAT P891L** is certified for coagulation and flocculation at a maximum use level of 250 mg/L.

TYPICAL PHYSICAL PROPERTIES

Form	Clear to slightly hazy, colorless to yellow liquid
Odor	Odorless
pH	~3.7
Specific Gravity @ 20°C	1.335
Density	11.13 pounds/gallon
Freeze Point	27°F / -3°C

DOSAGE AND FEEDING

CHEMTREAT P891L may be fed directly from the drum or from any convenient aqueous dilution and should be fed to the water to be treated at a point of good mixing. **CHEMTREAT P891L** compatibilities with materials of construction are available upon request from a ChemTreat representative. For optimum performance, **CHEMTREAT P891L** should be applied in accordance with the control parameters established by a ChemTreat representative for the specific application.

SAFETY PRECAUTIONS

For specific information on handling, safety and first aid, please review the product's Material Safety Data Sheet.

SHIPPING

CHEMTREAT P891L is available in 55-gallon drums, 275-gallon nonreturnable totes, and bulk.

SAFETY DATA SHEET

Section 1. Chemical Product and Company Identification

Product Name:	ChemTreat P891L
Product Use:	Water Clarification Agent
Supplier's Name:	ChemTreat, Inc.
Emergency Telephone Number:	(800)424−9300 (Toll Free)
Address (Corporate Headquarters):	5640 Cox Road Glen Allen, VA 23060
Telephone Number for Information:	(800)648−4579
Date of MSDS:	January 5, 2015
Revision Date:	January 5, 2015
Revision Number:	15010501AN

Section 2. Hazard(s) Identification

Signal Word: **WARNING**

GHS Classification(s): Acute Toxicity Dermal − Category 5
Acute Toxicity Inhalation − Category 5
Acute Toxicity Oral − Category 5

Hazard Statement(s): May be harmful in contact with skin.
May be harmful if inhaled.
May be harmful if swallowed.

Precautionary Statement(s): No significant health risks are expected from exposures under normal conditions of use.

Section 3. Composition/Hazardous Ingredients

Component	CAS Registry #	Wt.%
Aluminum chlorohydrate	12042−91−0	30 − 60

Comments N/A

Section 4. First Aid Measures

Inhalation:	Remove to fresh air and keep at rest in a position comfortable for breathing. Call a poison center or doctor/physician if you feel unwell.
Eyes:	Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. If eye irritation persists, get medical advice/attention.
Skin:	Wash with plenty of soap and water. Call a poison center or doctor/physician if you feel unwell.
Ingestion:	DO NOT INDUCE VOMITING. Rinse mouth. Call a POISON CENTER or doctor/physician if you feel unwell.
Notes to Physician:	N/A
Additional First Aid Remarks:	N/A

Section 5. Fire Fighting Measures

Flammability of the Product:	Not flammable.
Suitable Extinguishing Media:	Use extinguishing media suitable to surrounding fire.
Specific Hazards Arising from the Chemical:	None known.
Protective Equipment:	If product is involved in a fire, wear full protective clothing including a positive−pressure, NIOSH approved, self−contained breathing apparatus.

Section 6. Accidental Release Measures

Personal Precautions:	Use appropriate Personal Protective Equipment (PPE).
Environmental Precautions:	Avoid dispersal of spilled material and runoff and contact with soil, waterways, drains, and sewers.

Methods for Cleaning up: Contain and recover liquid when possible. Flush spill area with water spray.

Other Statements: None.

Section 7. Handling and Storage

Handling: Wear appropriate Personal Protective Equipment (PPE) when handling this product. Do not get in eyes, or on skin and clothing. Wash thoroughly after handling. Do not ingest. Avoid breathing vapors, mist or dust.

Storage: Store away from incompatible materials (see Section 10). Store at ambient temperatures. Keep container securely closed when not in use. Label precautions also apply to empty container. Recondition or dispose of empty containers in accordance with government regulations.
For Industrial use only.
Protect from heat and sources of ignition.
Store in corrosive resistant container with a resistant inliner.
Do not freeze. Store above Freeze Point. If freezes, then mechanical mixing is required.

Section 8. Exposure Controls/Personal Protection

Exposure Limits

Component	Source	Exposure Limits
Aluminum chlorohydrate	N/E	N/E

Engineering Controls: Use only with adequate ventilation. The use of local ventilation is recommended to control emission near the source.

Personal Protection

Eyes: Wear chemical splash goggles or safety glasses with full−face shield. Maintain eyewash fountain in work area.

Skin: Maintain quick−drench facilities in work area.
Wear butyl rubber or neoprene gloves. Wash them after each use and replace as necessary. If conditions warrant, wear protective clothing such as boots, aprons, and coveralls to prevent skin contact.

Respiratory:	If misting occurs, use NIOSH approved organic vapor/acid gas dual cartridge respirator with a dust/mist prefilter in accordance with 29 CFR 1910.134.

Section 9. Physical and Chemical Properties

Physical State and Appearance:	Liquid, Colorless, Clear
Specific Gravity:	1.335 @ 20°C
pH:	3.7 @ 20°C, 100.0%
Freezing Point:	27°F
Flash Point:	N/D
Odor:	Mild
Melting Point:	N/A
Boiling Point:	212°F
Solubility in Water:	Complete
Evaporation Rate:	N/D
Vapor Density:	N/D
Molecular Weight:	N/D
Viscosity:	N/A
Flammable Limits:	N/A
Autoignition Temperature:	N/A
Density:	11.13 LB/GA
Vapor Pressure:	N/D
% VOC:	0
Odor Threshold	N/D
n−octanol Partition Coefficient	N/D
Decomposition Temperature	N/D

Section 10. Stability and Reactivity

Chemical Stability:	Stable at normal temperatures and pressures.
Incompatibility with Various Substances:	Strong oxidizers, Strong bases.
Hazardous Decomposition Products:	Hydrochloric acid.
Possibility of Hazardous Reactions:	None known.

Section 11. Toxicological Information

Chemical Name	Exposure	Type of Effect	Concentration	Species
N/D	N/D	N/D	N/D	N/D

Carcinogenicity Category

Component	Source	Code	Brief Description
Aluminum chlorohydrate	N/E	N/E	N/E

Comments: None.

Section 12. Ecological Information

Species	Duration	Type of Effect	Test Results
Ceriodaphnia dubia	48h	LC50	>2000 mg/l
Daphnia pulex	48h	LC50	7071 mg/l
Fathead Minnow	96h	LC50	>1000 mg/l
	48h	LC50	3675 mg/l

Comments: None.

Section 13. Disposal Considerations

Dispose of in accordance with local, state and federal regulations.

Section 14. Transport Information

Controlling Regulation	Proper Shipping Name:	Technical Name:	Hazard Class:	UN/NA#:	Packing Group:
DOT	COMPOUND, INDUSTRIAL WATER TREATMENT, LIQUID	N/A	Not D.O.T. Regulated	N/A	N/A
IMDG	CORROSIVE LIQUID, ACIDIC, INORGANIC, N.O.S.	(ALUMINUM CHLORHYDRATE)	Corrosive	UN3264	PGIII
ICAO	CORROSIVE LIQUID, ACIDIC, INORGANIC, N.O.S.	(ALUMINUM CHLORHYDRATE)	Corrosive	UN3264	PGIII
TDG	COMPOUND, INDUSTRIAL WATER TREATMENT, LIQUID	N/A	Not D.O.T. Regulated	N/A	N/A

Note: When shipped by ground in the U.S., by exception 49 CFR 173.154 (d) (1) not subject to transport as a hazardous material when in authorized packaging that will not react dangerously or be degraded by the corrosive material.

Section 15. Regulatory Information

Inventory Status

United States (TSCA): All ingredients listed.
Canada (DSL/NDSL): All ingredients listed.

Federal Regulations

SARA Title III Rules

Sections 311/312 Hazard Classes

Fire Hazard: No
Reactive Hazard: No
Release of Pressure: No
Acute Health Hazard: Yes
Chronic Health Hazard: No

Other Sections

Component	Section 313 Toxic Chemical	Section 302 EHS TPQ	CERCLA RQ
Aluminum chlorohydrate	N/A	N/A	N/A

Comments: None.

State Regulations

California Proposition 65: None known.

Special Regulations

Component	States
Aluminum chlorohydrate	None.

International Regulations

Canada

WHMIS Classification:	E (Corrosive Material)
Controlled Product Regulations (CPR):	This product has been classified in accordance with the hazard criteria of the Controlled Products Regulations (CPR) and the MSDS contains all the information required by the CPR.

Section 16. Other Information

HMIS Hazard Rating

Health:	1
Flammability:	0
Physical Hazard:	0
PPE:	X

Notes: The PPE rating depends on circumstances of use. See Section 8 for recommended PPE.
The Hazardous Material Information System (HMIS) is a voluntary, subjective alpha−numeric symbolic system for recommending hazard risk and personal protection equipment information. It is a subjective rating system based on the evaluator's understanding of the chemical associated risks. The end−user must determine if the code is appropriate for their use.

NSF: Certified to NSF/ANSI Standard 60
Maximum use rate for potable water − 250 mg/L
This product ships as NSF from:
Ashland, VA
Eldridge, IA
Nederland, TX
Vernon, CA
Facility #4 USA
Facility #7 USA
Facility #8 USA
Facility #14 Canada
Facility #22 USA
Facility #23 USA
Facility #24 USA
Facility #25 USA

FDA/USDA/GRAS: GRAS − Using the Eligibility for Classification outlined in 21 CFR 170.30, ChemTreat has determined that this product is considered Generally Recognized as Safe (GRAS) and complies with 21 CFR 182.90, "Substance migrating to food from paper and paperboard products."

KOSHER: This product has not been evaluated for Kosher approval.

FIFRA: N/A

Other: None

Abbreviations

Abbreviation	Definition
<	Less Than
>	Greater Than
ACGIH	American Conference of Governmental Industrial Hygienists
EHS	Environmental Health and Safety Dept
N/A	Not Applicable
N/D	Not Determined
N/E	Not Established
OSHA	Occupational Health and Safety Dept
PEL	Personal Exposure Limit
STEL	Short Term Exposure Limit
TLV	Threshold Limit Value
TWA	Time Weight Average
UNK	Unknown

Prepared by: Product Compliance Department; ProductCompliance@chemtreat.com

Disclaimer

Although the information and recommendations set forth herein (hereinafter "information") are presented in good faith and believed to be correct as of the date hereof, ChemTreat, Inc. makes no representations as to the completeness or accuracy thereof. Information is supplied upon the condition that the persons receiving same will make their own determination as to its suitability for their purposes prior to use. In no event will ChemTreat, Inc. be responsible for damages of any nature whatsoever resulting from the use or reliance upon information. No representation or warranties, either expressed or implied, of merchantability, fitness for a particular purpose, or of any other nature are made hereunder with respect to information or the product to which information refers.

CERTIFICATE OF ANALYSIS

CHEMTREAT P891L

Date of Manufacture: XXXXXX **Chemtreat PO# XXXXXX**

Date of Analysis: XXXXXX **Customer PO # XXXXXX**

Shipping Date: XXXXXX

LOT# 3204H16XXXXX

Parameters	Analysis	Specifications
Specific Gravity @ 20C	1.3403	1.330 - 1.350
% Aluminum	12.65	12.18 - 13.00
% Chloride	8.11	7.90 - 8.40
Al:Cl (Mol.Wt.)	2.050:1	1.90 - 2.10
pH 30% (15% solids) w/v, 20 C	3.5	3.5 - 4.5
Iron (as Fe) ppm	68.2	<300
TURBIDITY	10.5	<50 NTU
APPEARANCE	Colorless	Report

THE ABOVE ANALYSIS IS BASED ON A RANDOM SAMPLE OF THE LOT.

Quantity Shipped: XXXXXX LBS

Carrier: XXXXXXXX

Shipped to: XXXXXX
XXXXXX
XXXXXX
XXXXXX

Product Data

FLOCCULANT AND SLUDGE CONDITIONER

CHEMTREAT P-847E

GENERAL DESCRIPTION

CHEMTREAT P-847E is a medium to high molecular weight, low charged cationic emulsion polymer for use in flocculation and sludge conditioning. **CHEMTREAT P-847E** is particularly applicable in flocculating, thickening, and dewatering many waste treatment processes where liquid-solids separation needs exist. **CHEMTREAT P-847E** is effective for enhancing liquid/solids separation in DAF and clarification units. Additionally, **CHEMTREAT P-847E** is effective for dewatering sludge on a belt and screw press, centrifuge, and vacuum filter.

TYPICAL PHYSICAL PROPERTIES

Form	Milky white, opaque liquid
Odor	Mild
Density	8.79 lbs./gallon

DOSAGE AND FEEDING

For best results, a 1% feed solution should be prepared. Further dilution at the application point may prove to be advantageous. For detailed information on applying this product, consult your local ChemTreat representative.

SAFETY PRECAUTIONS

For specific information on handling, safety and first aid, please review the product's Material Safety Data Sheet.

SHIPPING

CHEMTREAT P-847E is available in 55-gallon drums, 275-gallon totes, and in bulk.

SAFETY DATA SHEET

Section 1. Chemical Product and Company Identification

Product Name:	ChemTreat P847E
Product Use:	Water Clarification/Solids Conditioning Agent
Supplier's Name:	ChemTreat, Inc.
Emergency Telephone Number:	(800)424−9300 (Toll Free)
Address (Corporate Headquarters):	5640 Cox Road Glen Allen, VA 23060
Telephone Number for Information:	(800)648−4579
Date of SDS:	March 7, 2017
Revision Date:	March 7, 2017
Revision Number:	17030701AN

Section 2. Hazard(s) Identification

Signal Word: **WARNING**

GHS Classification(s): Eye damage/irritation − Category 2a

Hazard Statement(s): H319 Causes serious eye irritation.

Precautionary Statement(s):

Prevention: P280 Wear protective gloves/protective clothing/eye protection/face protection.
P264 Wash thoroughly after handling.

Response: P305 + P351 + P338 IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.
P337 + P313 If eye irritation persists, get medical advice/attention.

Storage: None.

Disposal: P501 Dispose of contents and container in accordance with applicable local, regional, national, and/or international regulations.

System of Classification Used: Classification under 2012 OSHA Hazard Communication Standard (29 CFR 1910.1200).

Hazards Not Otherwise Classified: None.

Section 3. Composition/Hazardous Ingredients

Component	CAS Registry #	Wt.%
Petroleum distillate hydrotreated light	64742−47−8	20 − 24
Alcohols (C12−16) ethoxylated	68551−12−2	0 − 3
Alcohols (C12−C14) ethoxylated	68439−50−9	0 − 3
Alcohols (C10−16) ethoxylated	68002−97−1	0 − 3
Citric acid	77−92−9	2 − 3

Comments If chemical identity and/or exact percentage of composition has been withheld, this information is considered to be a trade secret. Components listed above that have a zero minimum and a common maximum range are interchangeably used components based on availability. Only one of these components is contained in the product up to the maximum amount noted.

Section 4. First Aid Measures

Inhalation: Call a POISON CENTER or doctor/physician if you feel unwell.

Eyes: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. If eye irritation persists, get medical advice/attention.

Skin: Wash with plenty of soap and water. Take off contaminated clothing and wash before re−use. If skin irritation occurs, seek medical advice/attention.

Ingestion: Rinse mouth. Call a poison center or doctor/physician if you feel unwell.

Most Important Symptoms: N/D

Indication of Immediate Medical Attention and Special Treatment Needed, If Necessary: N/A

Section 5. Fire Fighting Measures

Flammability of the Product:	Not flammable.
Suitable Extinguishing Media:	Use extinguishing media suitable to surrounding fire.
Specific Hazards Arising from the Chemical:	None known.
Protective Equipment:	If product is involved in a fire, wear full protective clothing including a positive−pressure, NIOSH approved, self−contained breathing apparatus.

Section 6. Accidental Release Measures

Personal Precautions:	Use appropriate Personal Protective Equipment (PPE).
Environmental Precautions:	Avoid dispersal of spilled material and runoff and contact with soil, waterways, drains, and sewers.
Methods for Cleaning up:	Contain and recover liquid when possible. Flush spill area with water spray.
Other Statements:	None.

Section 7. Handling and Storage

Handling:	Wear appropriate Personal Protective Equipment (PPE) when handling this product. Do not get in eyes, or on skin and clothing. Wash thoroughly after handling. Do not ingest. Avoid breathing vapors, mist or dust.
Storage:	Store away from incompatible materials (see Section 10). Store at ambient temperatures. Keep container securely closed when not in use. Label precautions also apply to empty container. Recondition or dispose of empty containers in accordance with government regulations. For Industrial use only. Do not store or handle in aluminum, zinc, copper, or their alloys. Do not freeze. Store above Freeze Point. If freezes, then product is unusable.

Section 8. Exposure Controls/Personal Protection

Exposure Limits

Component	Source	Exposure Limits
Petroleum distillate hydrotreated light	N/E	N/E
Alcohols (C12−16) ethoxylated	N/E	N/E
Alcohols (C12−C14) ethoxylated	N/E	N/E
Alcohols (C10−16) ethoxylated	N/E	N/E
Citric acid	N/E	N/E

Engineering Controls: Use only with adequate ventilation. The use of local ventilation is recommended to control emission near the source.

Personal Protection

Eyes: Wear chemical splash goggles or safety glasses with full−face shield. Maintain eyewash fountain in work area.

Skin: Maintain quick−drench facilities in work area.
Wear butyl rubber or neoprene gloves. Wash them after each use and replace as necessary. If conditions warrant, wear protective clothing such as boots, aprons, and coveralls to prevent skin contact.

Respiratory: If misting occurs, use NIOSH approved organic vapor/acid gas dual cartridge respirator with a dust/mist prefilter in accordance with 29 CFR 1910.134.

Section 9. Physical and Chemical Properties

Physical State and Appearance: Liquid, White, Opaque
Specific Gravity: 1.054 @ 20°C
pH: N/A
Freezing Point: 32°F
Flash Point: >212°F
Odor: Mild
Melting Point: N/A
Initial Boiling Point and Boiling Range: 212°F
Solubility in Water: Limited by viscosity
Evaporation Rate: N/A
Vapor Density: Similar to water
Molecular Weight: N/D
Viscosity: N/A

Flammability (solid, gas):	N/D
Flammable Limits:	N/A
Autoignition Temperature:	N/A
Density:	8.79 LB/GA
Vapor Pressure:	Similar to water
% VOC:	N/D
Odor Threshold	N/D
n−octanol Partition Coefficient	N/D
Decomposition Temperature	N/D

Section 10. Stability and Reactivity

Chemical Stability: Stable at normal temperatures and pressures.

Incompatibility with Various Substances: Strong oxidizers.

Hazardous Decomposition Products: Carbon dioxide, Carbon monoxide, Ammonia, Oxides of nitrogen, Hydrochloric acid.

Possibility of Hazardous Reactions: None known.

Reactivity: N/D

Conditions To Avoid: N/D

Section 11. Toxicological Information

Acute Toxicity

Chemical Name	Exposure	Type of Effect	Concentration	Species
N/D	N/D	N/D	N/D	N/D

Carcinogenicity Category

Component	Source	Code	Brief Description
Petroleum distillate hydrotreated light	N/E	N/E	N/E
Alcohols (C12−16) ethoxylated	N/E	N/E	N/E
Alcohols (C12−C14) ethoxylated	N/E	N/E	N/E
Alcohols (C10−16) ethoxylated	N/E	N/E	N/E
Citric acid	N/E	N/E	N/E

Likely Routes of Exposure: N/D

Symptoms

Inhalation: N/D

Eye Contact: N/D

Skin Contact: N/D

Ingestion: N/D

Skin Corrosion/Irritation: N/D

Serious Eye Damage/Eye Irritation: N/D

Sensitization: N/D

Germ Cell Mutagenicity: N/D

Reproductive/Developmental Toxicity: N/D

Specific Target Organ Toxicity

Single Exposure: N/D

Repeated Exposure: N/D

Aspiration Hazard: N/D

Comments: None.

Section 12. Ecological Information

Ecotoxicity

Species	Duration	Type of Effect	Test Results
Fathead Minnow	96h	LC50	3.66 mg/l
Ceriodaphnia dubia	48h	LC50	0.88 mg/l

Persistence and Biodegradability: N/D

Bioaccumulative Potential: N/D

Mobility In Soil: N/D

Other Adverse Effects: N/D

Comments: Water clarification polymers function by multipoint adsorption and charge neutralization with suspended solids. Polymers inherently migrate with solids in the separation process and with the exception of uneconomic overdose do not remain in the clarified waters. Aquatic toxicity determinations in test method protocol waters without suspended solids overestimate the toxicity compared to natural receiving waters.

Section 13. Disposal Considerations

Dispose of in accordance with local, state and federal regulations.

Section 14. Transport Information

Controlling Regulation	UN/NA#:	Proper Shipping Name:	Technical Name:	Hazard Class:	Packing Group:
DOT	N/A	COMPOUND, INDUSTRIAL WATER TREATMENT, LIQUID	N/A	N/A	N/A
IMDG	N/A	COMPOUND, INDUSTRIAL WATER TREATMENT, LIQUID	N/A	N/A	N/A
ICAO	N/A	COMPOUND, INDUSTRIAL WATER TREATMENT, LIQUID	N/A	N/A	N/A
TDG	N/A	COMPOUND, INDUSTRIAL WATER TREATMENT, LIQUID	N/A	N/A	N/A

Note: N/A

Section 15. Regulatory Information

Inventory Status

United States (TSCA): All ingredients listed.
Canada (DSL/NDSL): All ingredients listed.

Federal Regulations

SARA Title III Rules

Sections 311/312 Hazard Classes

Fire Hazard:	No
Reactive Hazard:	No
Release of Pressure:	No
Acute Health Hazard:	Yes
Chronic Health Hazard:	No

Other Sections

Component	Section 313 Toxic Chemical	Section 302 EHS TPQ	CERCLA RQ
Petroleum distillate hydrotreated light	N/A	N/A	N/A
Alcohols (C12−16) ethoxylated	N/A	N/A	N/A
Alcohols (C12−C14) ethoxylated	N/A	N/A	N/A
Alcohols (C10−16) ethoxylated	N/A	N/A	N/A
Citric acid	N/A	N/A	N/A

Comments: None.

State Regulations

California Proposition 65: This product contains chemical(s) known to the State of California to cause cancer and/or to cause birth defects or other reproductive harm.

Special Regulations

Component	States
Petroleum distillate hydrotreated light	None.
Alcohols (C12−16) ethoxylated	None.
Alcohols (C12−C14) ethoxylated	None.
Alcohols (C10−16) ethoxylated	None.
Citric acid	None.

International Regulations

Canada

WHMIS Classification:	D2B (Toxic Material)
Controlled Product Regulations (CPR):	This product has been classified in accordance with the hazard criteria of the Controlled Products Regulations (CPR) and the MSDS contains all the information required by the CPR.

Compliance Information

NSF:	N/A
Food Regulations:	N/A
KOSHER:	This product has not been evaluated for Kosher approval.
FIFRA:	N/A
Other:	None

Comments: None.

Section 16. Other Information

HMIS Hazard Rating

Health:	2
Flammability:	1
Physical Hazard:	0
PPE:	X

Notes: The PPE rating depends on circumstances of use. See Section 8 for recommended PPE.
The Hazardous Material Information System (HMIS) is a voluntary, subjective alpha−numeric symbolic system for recommending hazard risk and personal protection equipment information. It is a subjective rating system based on the evaluator's understanding of the chemical associated risks. The end−user must determine if the code is appropriate for their use.

Abbreviations

Abbreviation	Definition
<	Less Than
>	Greater Than
ACGIH	American Conference of Governmental Industrial Hygienists
EHS	Environmental Health and Safety Dept
N/A	Not Applicable
N/D	Not Determined
N/E	Not Established
OSHA	Occupational Health and Safety Dept
PEL	Personal Exposure Limit
STEL	Short Term Exposure Limit
TLV	Threshold Limit Value
TWA	Time Weight Average
UNK	Unknown

Prepared by: Product Compliance Department; ProductCompliance@chemtreat.com

Revision Date: March 7, 2017

Disclaimer

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APPENDIX D. QUALITY ASSURANCE

Calibration of Analytical Equipment

At Kansas State University, Hach spectrophotometric methods were measured using a DR3900 spectrophotometer, which was subject to annual maintenance and calibration check by the manufacturer. Additionally, select standards for each parameter were analyzed periodically to verify the validity of the calibration curves. Other instruments were calibrated for each analytical run, in accordance with manufacturer recommendations. A five-point standard with triplicate runs was performed, each time the respective equipment was used to analyze a batch of samples.

At Inha University, instruments were similarly calibrated. pH, ion-selective (i.e., sulfide), and dissolved oxygen meters will be calibrated before each use in accordance with manufacturer instructions. Analytical instruments were calibrated for each analytical run (4- or 5-point standard curves). Instrumentation was maintained based on manufacturer recommendations at a frequency not less than annually.

At CERL, spectrophotometric analyses were performed on a Thermo Scientific GENESYS 20 visible spectrophotometer. A five-point calibration was performed weekly using ammonia standards. Preventative maintenance was performed as recommended by the manufacturer. The Dionex ICS-3000 used for ammonia analysis was calibrated during each batch run of samples using a standard solution diluted to obtain five points in concentration range of interest. Annual maintenance was performed by a service technician. Tip meters used to measure hydrogen production were calibrated weekly using a known volume of gas. Instrumentation was maintained based on manufacturer recommendations at a frequency no less than annually.

Other analyses were conducted by contract laboratories (see Table 5.7) including Katahdin Analytical Services (Scarborough, Maine), ALS Environmental (Simi Valley, California), and Biological Consulting Services of North Florida, Inc. (Gainsville, Florida).

Quality Assurance Sampling

The types of QA samples collected during the demonstration included field and laboratory replicates. Field duplicate samples were collected on an as-needed basis to determine whether samples were representative. Kansas State University and Inha University completed analyses either in duplicate or triplicate and averages and standard deviations were calculated and reported. Continuous evaluation of data was conducted by CDM Smith and the project team. Multiple lines of evidence were used to assess data quality and representativeness as is consistent with a scientific research approach to data collection and interpretation. These lines of evidence are described in detail in Section 5.7.

Sample Documentation

During sample collection, field personnel completed sampling forms and noted any deficiencies, unusual conditions, or operating issues. All data obtained was maintained in log books as well as dedicated folders in the respective equipment's computers. Compilation of all data into spreadsheet for review, analysis, and further data interpretation was performed by the respective parties

collecting the data and by CDM Smith. Laboratory reports and data spreadsheets were maintained in CDM Smith's Bentley Systems ProjectWise Explorer (version 08.11.11.590) network (pw.cdmsmith.com:PW_EXT\Documents\9998\108689\).

Chain-of-Custody (COC) forms were filled out for all samples submitted to contract laboratories. Sample date, location, and analyses requested were noted on each COC. COC forms were placed in a Ziploc bag inside the sample cooler for shipment to the laboratory. Copies of all COC forms were kept with field notes.

APPENDIX E. AWC LABORATORY REPORTS

awc

Membrane Autopsy Report

Date:

01-17-2018

Tests Performed For:

Manufacturer: Suez
Model: ZeeWeed 500D UF
Position: N/A
Serial #: N/A
AWC LSA#: 02-17206

Tests Performed By:

Vana Abbas
Joshua Utter
Sang Ah Bare

Table of Contents

Introduction 3

Membrane Information 3

Shipping and Handling Condition 4

Inspection of Fibers 5

Top 5

Middle 6

Bottom 7

Contact Angle Testing 8

Results 8

Hollow Fiber Cleaning Study 9

Results 9

Loss on Ignition Test with Foulant 10

Results 10

Electron Microscopy and X-Ray Spectroscopy Analysis 12

Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS) with Superimposed Elemental Imaging (SEI™) 12

Results 12

Top 13

Middle 33

Bottom 43

Post cleaning 52

Membrane Surface Analysis 56

Results 56

FTIR analysis 59

Results: Dehydrated Foulant 59

Results: LOI residue 62

Raman Spectroscopy 64

Results 64

Results and Discussion 65

Release of Liability 66

Introduction

This report describes the membrane autopsy procedures performed for **CDM Smith Katahdin Analytical Services.**
The observed findings are presented herein.

Membrane Information

Manufacturer	Model Number	Serial Number	Membrane Type
Suez	**ZeeWeed 500D**	**N/A**	**UF**

Table 1: Membrane Information.

Shipping and Handling Condition

Figure 1: The fibers arrived packaged in cooler.

Figure 2: The fibers were packaged in a cardboard box, sealed with bubble wrap and duct tape.

Figure 3: Fibers packaged in white plastic bags.

Inspection of Fibers

Black and brown foulants were found on all the fibers.

Top

Figure 4: Black and brown foulants found on the fibers.

Figure 5: Black and brown foulants found on the fibers.

Middle

Figure 6: Black and brown foulants found on the fibers.

Bottom

Figure 7: Black and brown foulants were found on the fibers.

Contact Angle Testing

Contact angle testing is used to determine the hydrophobicity of a membrane. Higher contact angles are directly correlated with a more hydrophobic surface. Membranes are less prone to fouling and have better productivity when they are less hydrophobic.

Results

Meniscus contact angle could not be measured due to the large diameter of the fibers.

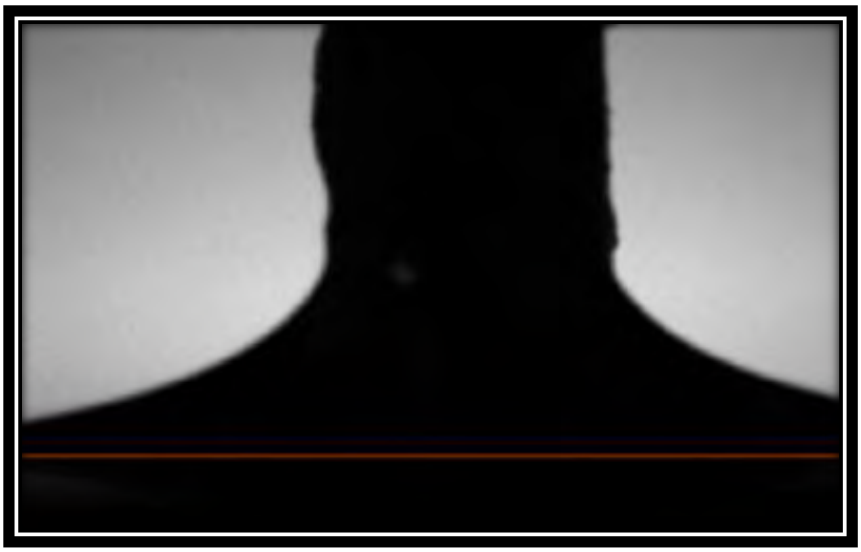


Figure 8: Contact angle could not be measured due to the large diameter of the fibers.

Hollow Fiber Cleaning Study

A hollow fiber cleaning study is performed to identify a cleaning regimen that will restore membrane performance. A set of representative fibers are collected from the module and soaked in deionized water for 24 hours. They are then potted into a small benchtop module manufactured by AWC. The module is then tested under the same conditions as a full module. Membrane flux measurements are made, and then a cleaning performed, with an additional performance test after each individual cleaning step determine the efficacy of the cleaning.

Results

Initial results showed the flux to be ~5% below the manufacture's specification. High pH cleaning with AWC UF-426 for 6 hours increased the permeability by ~3% when compared with the initial results. After high pH cleaning with AWC UF-429, the permeability increased by 5% above initial performance.

Model	**SHU-2024**
# of fibers	**6**
Filtration Mode	**Outside in**
Membrane area (ft^2)	**0.195**
Maximum TMP (PSI)	**14.5**

	Virgin Fiber	**Initial Module Performance**	**Post High pH 2% AWC UF-426 pH 10.5, 6 hrs**	**Post High pH 2% AWC UF-429 pH 10.4, 6 hrs**
Permeability (GFD/PSI)*	7.776	7.373	7.562	7.956
%Difference from Virgin performance	-	-5%	-3%	2%
%Difference from initial performance	-	-	3%	5%

* All values normalized for 20°C

Loss on Ignition Test with Foulant

A Loss on Ignition (LOI) test is performed to determine the organic/inorganic content of the foulant. The collected foulant samples are first heated at 105 °C overnight to remove moisture and volatile compounds. The dehydrated samples are then fired at 450 °C for 8 hours to combust any organic materials. The percentages of moisture, organics and inorganics are then calculated based on the loss of mass. This test is limited to material that can be scraped from the surface using a spatula, and the results should be considered within that context.

Results

The foulant on the membrane surface consisted of ~59% organic matter and ~41% inorganic matter.

	Foulant from membrane	Calculated Without Moisture
Moisture and Volatiles	89.03%	--
Organic Content	6.47%	59.03%
Inorganic Content	4.49%	40.97%

Table 2: LOI results for foulant from the membrane surface.

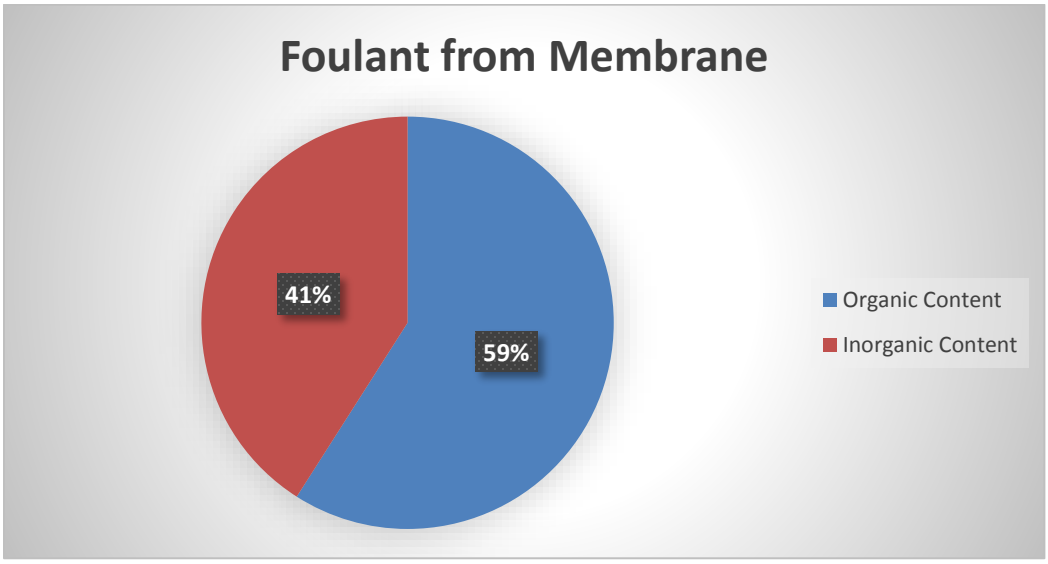


Figure 9: LOI results chart from table 2.

Figure 10: LOI residue.

Electron Microscopy and X-Ray Spectroscopy Analysis

Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS) with Superimposed Elemental Imaging (SEI™)

Scanning Electron Microscopy (SEM) analysis is used to determine the topography and morphology of a sample. The SEM shows very detailed 3-dimensional images at much higher magnification than an optical microscope.

Energy Dispersive X-ray Spectroscopy (EDS) analysis is generally performed together with electron microscopy to identify and quantify the elemental composition of a sample surface. The sample material is bombarded with electrons from an SEM which produce X-rays. The produced X-rays are then measured by an X-ray dispersive spectrometer. Every chemical element has its own characteristic wavelength by which it can be identified. EDS spectra, together with composition (Weight percent and Atomic percent) are attached in the section.

Results

Top

The foulant found on the "Top" fibers consisted of organic based matter, calcium sulfate, silts and/or clays. Sporadic deposits of phosphate salts (aluminum, calcium and iron), iron hydroxide and titanium oxide were also identified.

Middle

The foulant found on the "Middle" fibers consisted of organic based matter, calcium sulfate, phosphate salts (calcium and iron), titanium oxide, silts and/or clays.

Bottom

The foulant found on the "Bottom" fibers consisted of organic based matter, calcium sulfate, silts/clays, phosphate salts (calcium and iron), iron hydroxide and titanium oxide. A zinc sulfate particle was found in one area. Organic filaments that were visible in some areas were likely to be filamentous bacteria.

Top

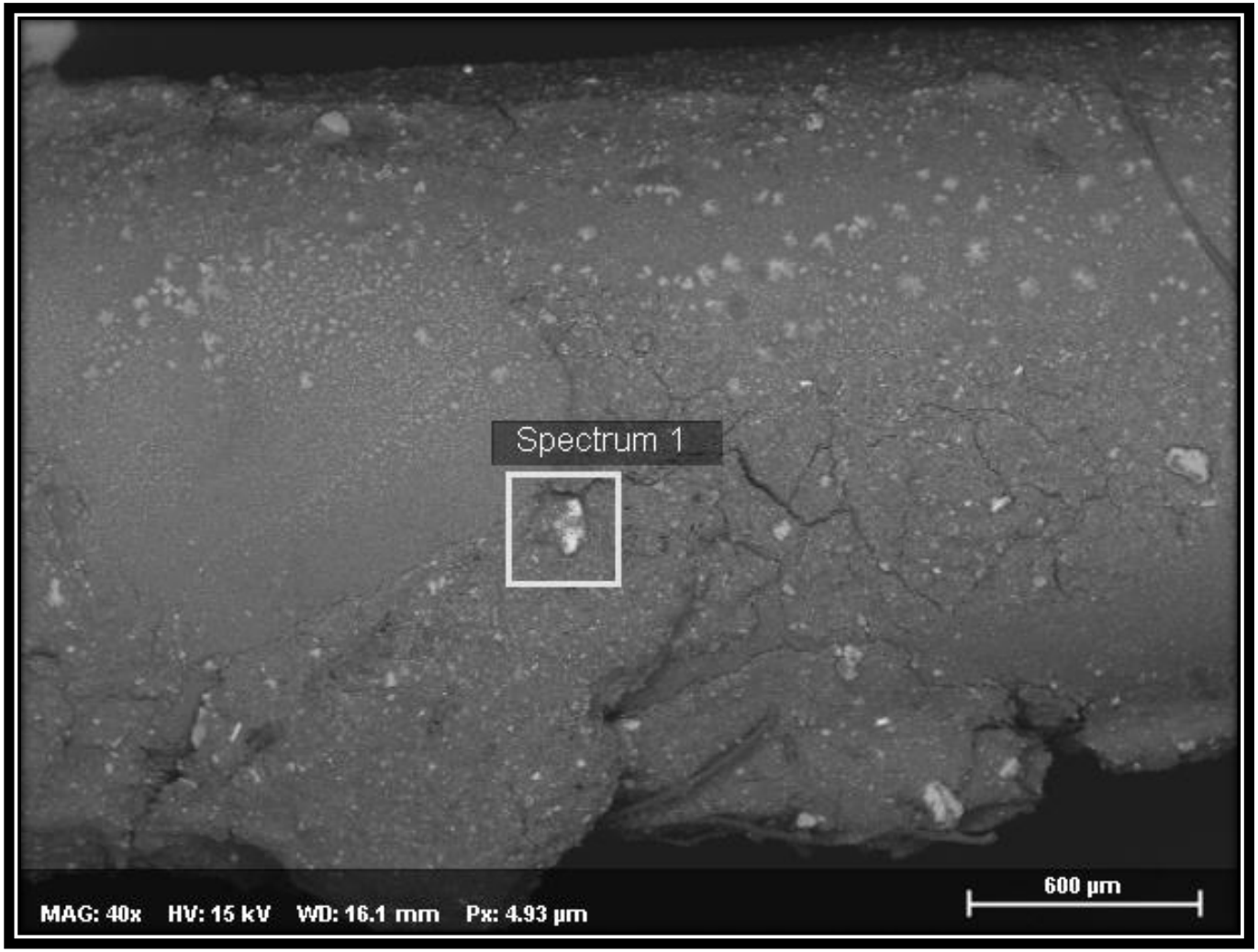


Figure 11: Electron micrograph of the membrane surface at 40X magnification (Spectrum 1).

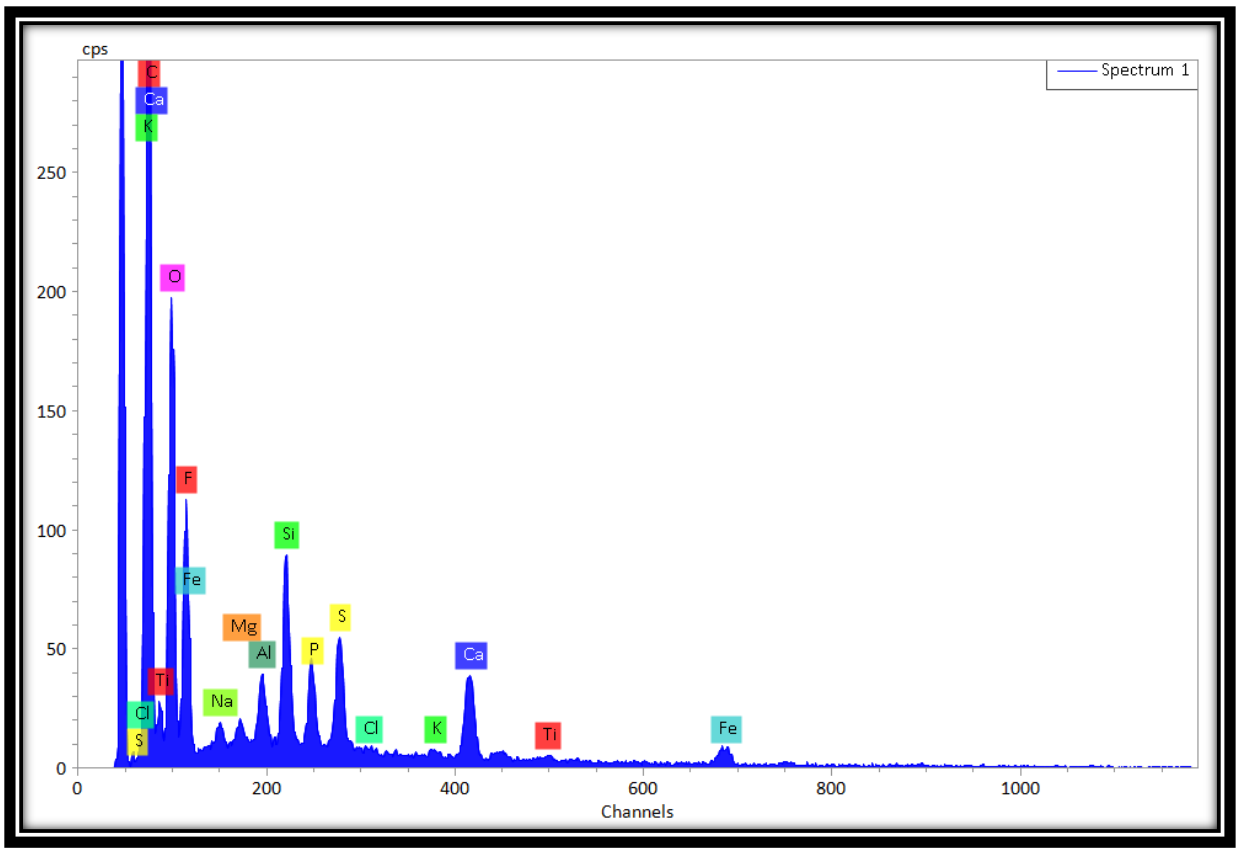


Figure 12: EDS and composition bar graph analysis of the membrane deposit from Spectrum 1.

Spectrum 1

Element	Atom [%]
Carbon	61.85
Oxygen	24.91
Fluorine	8.30
Silicon	1.08
Phosphorus	0.55
Sulfur	0.89
Calcium	1.13
Iron	0.75
Sodium	0.06
Aluminium	0.35
Titanium	0.07
Potassium	0.07
	100.00

Carbon and Oxygen Ignored

Spectrum 1

Element	Atom [%]
Fluorine	45.79
Silicon	10.93
Phosphorus	5.74
Sulfur	9.35
Calcium	12.21
Iron	8.78
Sodium	2.11
Aluminium	3.58
Titanium	0.78
Potassium	0.73
	100.00

Table 3: Composition table from the EDS spectrum of localized deposit from Spectrum 1.

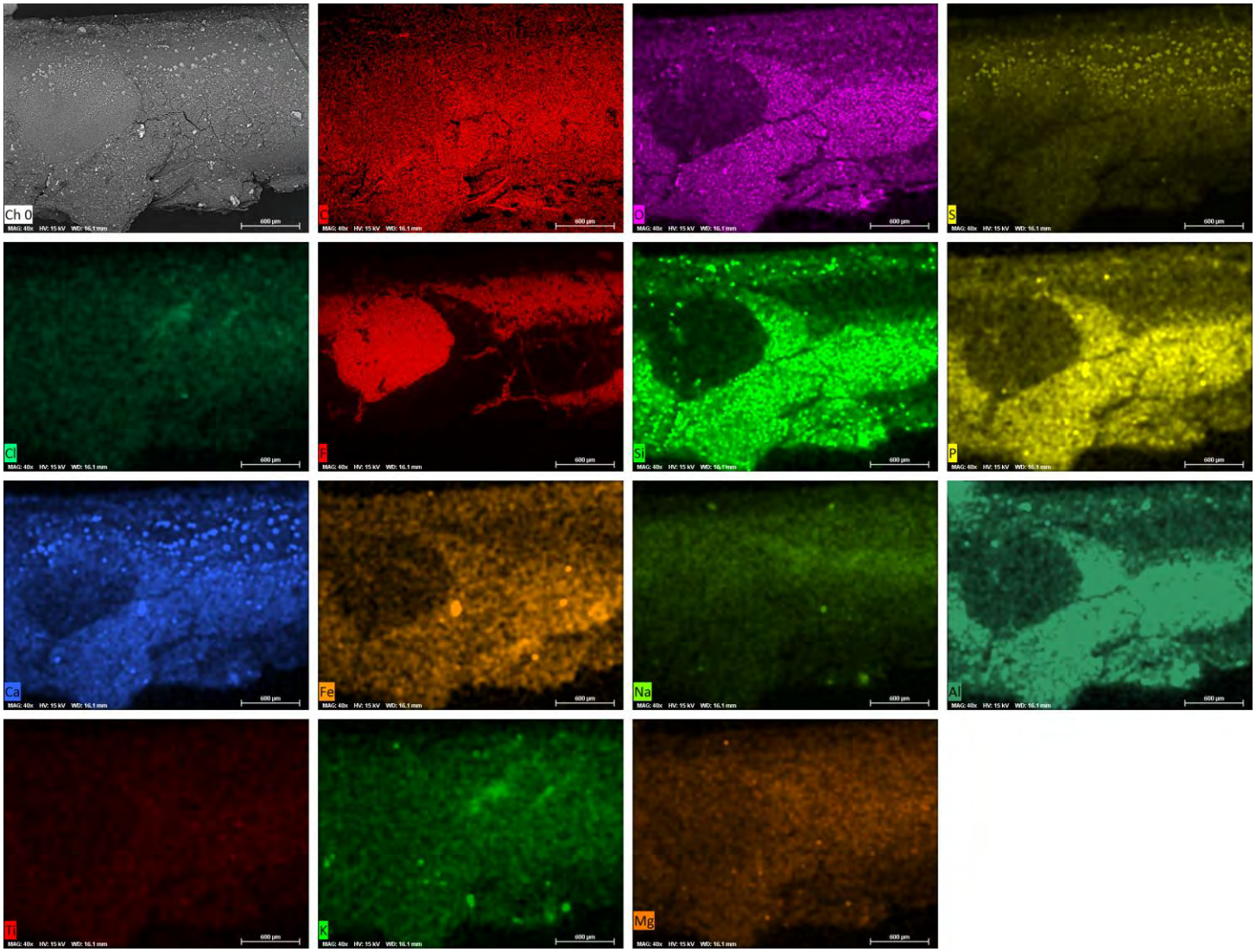


Figure 13: Prismatic Elemental Delineation (PED®) of membrane surface at 40X magnification. Deposits found: Organic based matter, silts/clays and calcium sulfate.

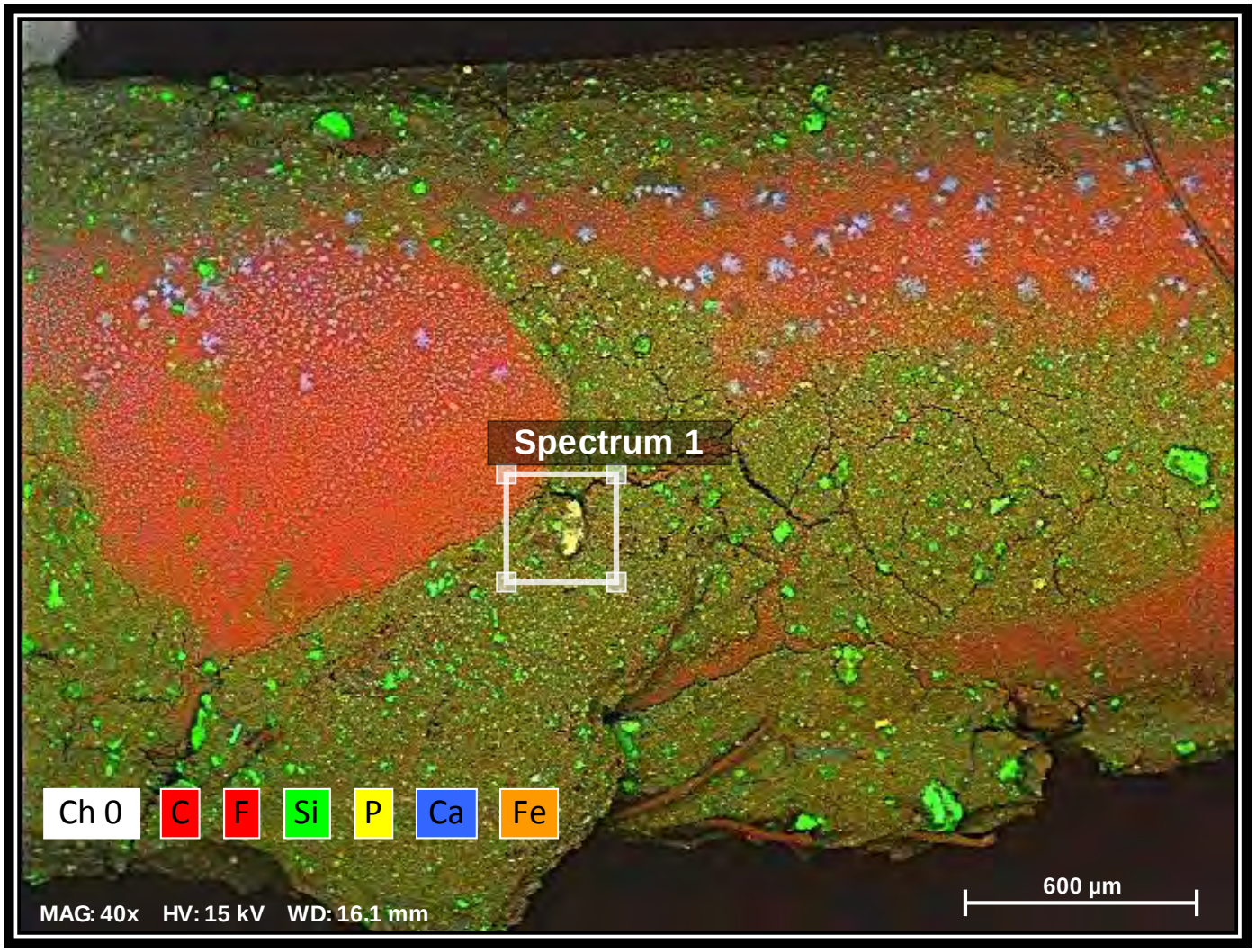


Figure 14: Superimposed Elemental Imaging (SEI®) of organic based matter, silts/clays and calcium sulfate.

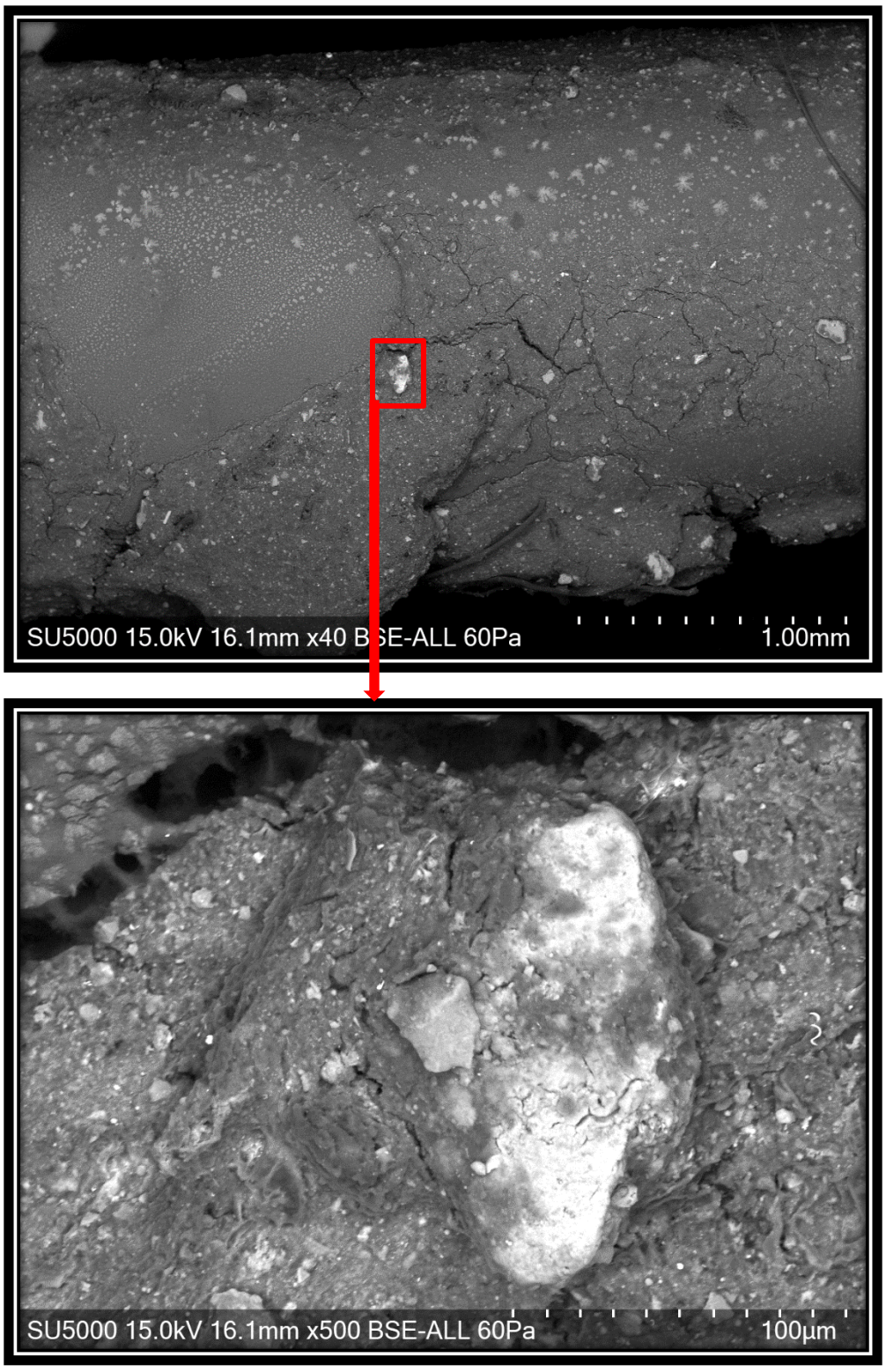

SU5000 15.0kV 16.1mm x40 BSE-ALL 60Pa
1.00mm
SU5000 15.0kV 16.1mm x500 BSE-ALL 60Pa
100µm

Figure 15: Electron micrograph of the membrane surface at 500X magnification (Spectrum 2, Spectrum 3 & Spectrum 4).

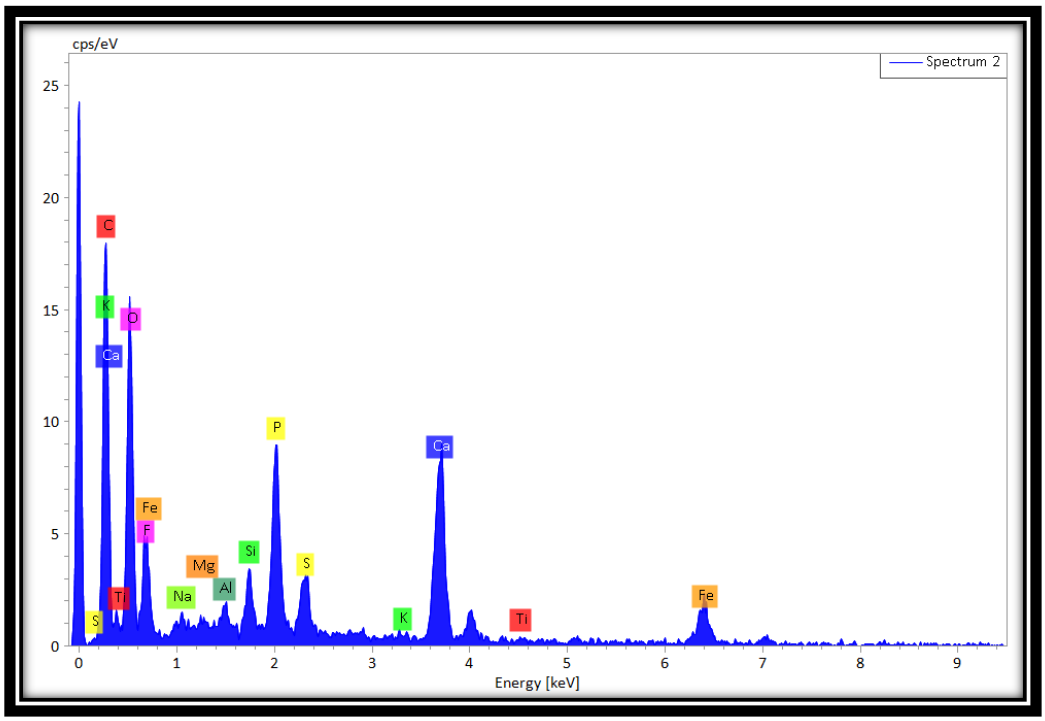


Figure 16: EDS and composition bar graph analysis of the membrane deposit from Spectrum 2.

Spectrum 2

Element	Atom [%]
Carbon	50.51
Oxygen	33.22
Fluorine	4.78
Calcium	4.66
Iron	2.78
Phosphorus	2.07
Sulfur	0.86
Silicon	0.52
Sodium	0.20
Aluminium	0.19
Magnesium	0.09
Titanium	0.08
Potassium	0.05
	100.00

Carbon and Oxygen Ignored

Spectrum 2

Element	Atom [%]
Calcium	32.68
Fluorine	20.35
Iron	20.19
Phosphorus	13.40
Sulfur	5.76
Silicon	3.38
Sodium	1.40
Aluminium	1.26
Magnesium	0.63
Titanium	0.57
Potassium	0.38
	100.00

Table 4: Composition table from the EDS spectrum of localized deposit from Spectrum 2.

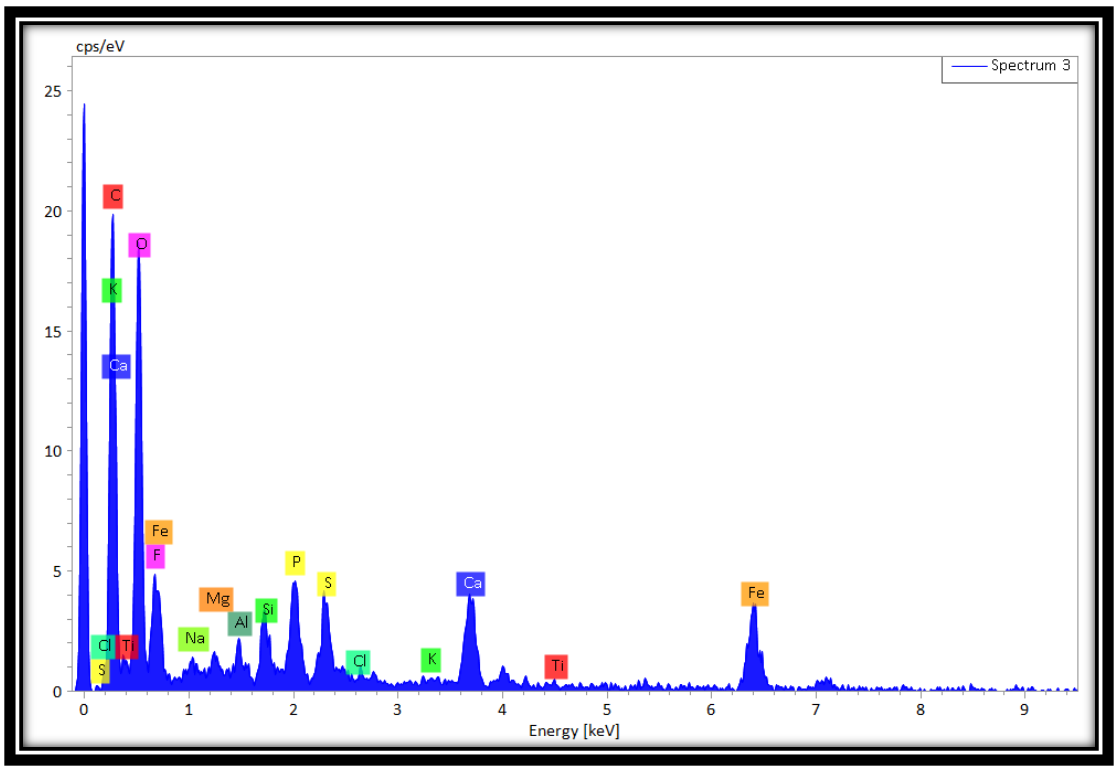


Figure 17: EDS and composition bar graph analysis of the membrane deposit from Spectrum 3.

Spectrum 3

Element	Atom [%]
Carbon	51.93
Oxygen	34.80
Iron	4.67
Fluorine	3.43
Calcium	2.14
Phosphorus	0.93
Sulfur	0.90
Silicon	0.50
Aluminium	0.23
Magnesium	0.19
Sodium	0.15
Potassium	0.06
Titanium	0.06
	100.00

Carbon and Oxygen Ignored

Spectrum 3

Element	Atom [%]
Iron	44.30
Calcium	19.27
Fluorine	10.68
Phosphorus	7.75
Sulfur	7.64
Silicon	4.21
Aluminium	1.96
Magnesium	1.68
Sodium	1.39
Potassium	0.58
Titanium	0.55
	100.00

Table 5: Composition table from the EDS spectrum of localized deposit from Spectrum 3.

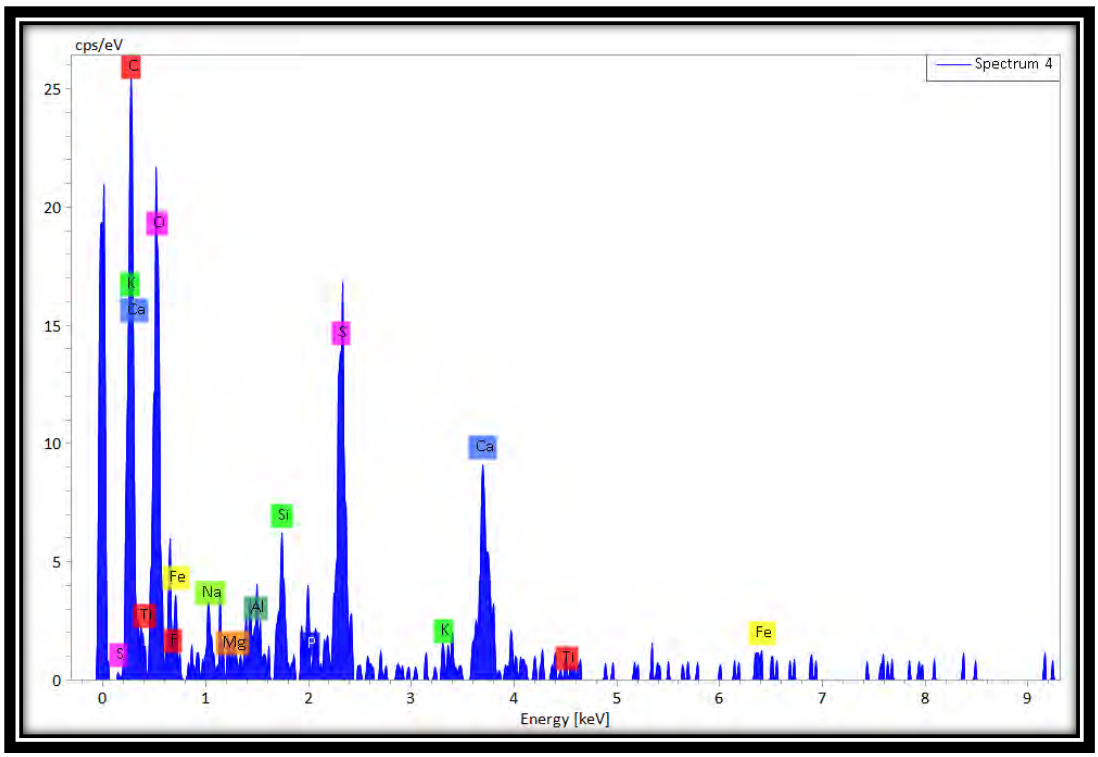


Figure 18: EDS and composition bar graph analysis of the membrane deposit from Spectrum 4.

Spectrum 4

Element	Atom [%]
Carbon	53.16
Oxygen	33.64
Fluorine	4.63
Calcium	2.95
Sulfur	2.78
Silicon	0.82
Iron	0.69
Sodium	0.67
Aluminium	0.27
Phosphorus	0.26
Potassium	0.13
	100.00

Carbon and Oxygen Ignored

Spectrum 4

Element	Atom [%]
Calcium	27.51
Sulfur	25.15
Fluorine	21.12
Silicon	7.32
Iron	6.84
Sodium	6.10
Aluminium	2.43
Phosphorus	2.34
Potassium	1.19
	100.00

Table 6: Composition table from the EDS spectrum of localized deposit from Spectrum 4.

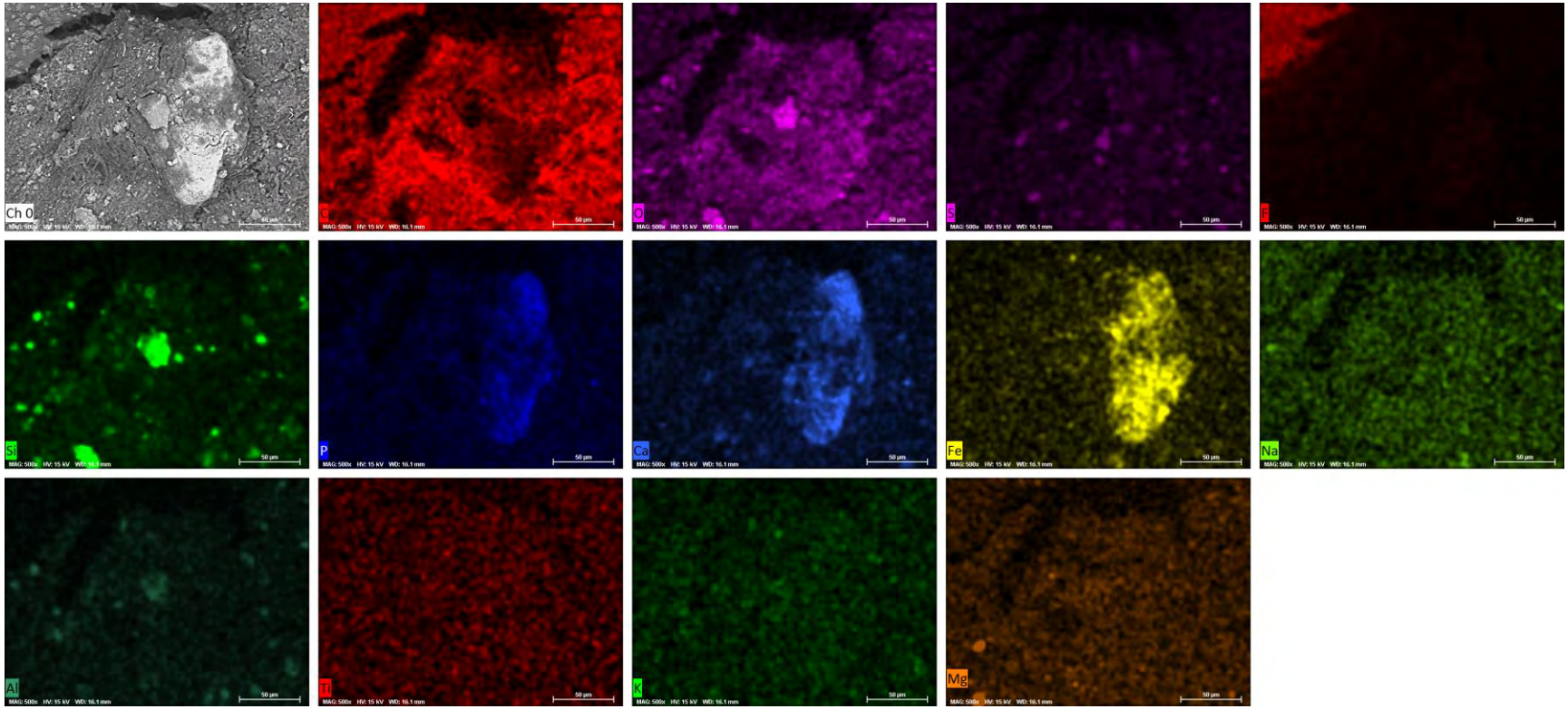


Figure 19: Prismatic Elemental Delineation (PED®) of membrane surface at 500X magnification. Deposits found: Organic based matter, phosphate salts (calcium and iron), calcium sulfate, silts and/or clays.

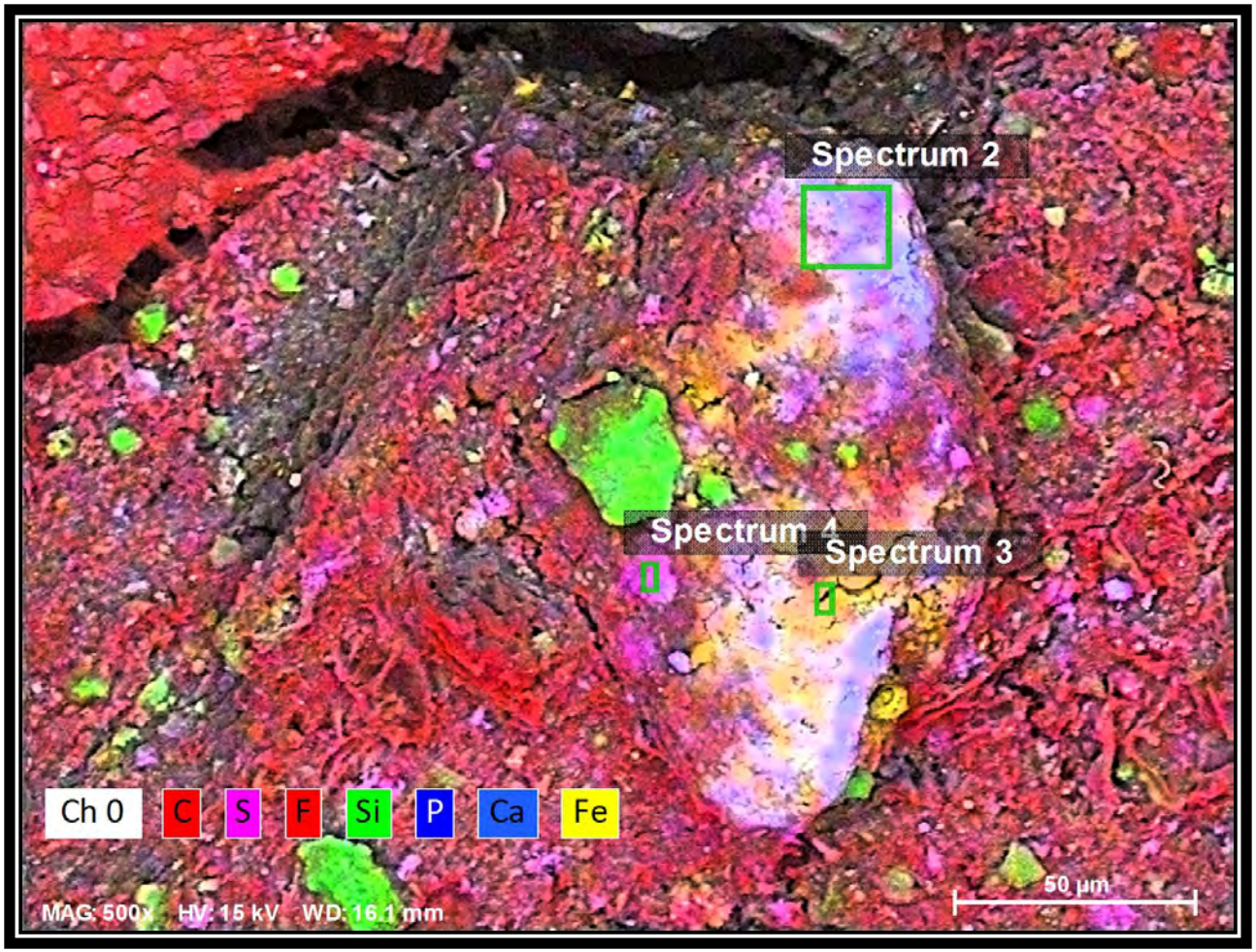


Figure 20: Superimposed Elemental Imaging (SEI®) of organic based matter, phosphate salts (calcium and iron), calcium sulfate, silts and/or clays.

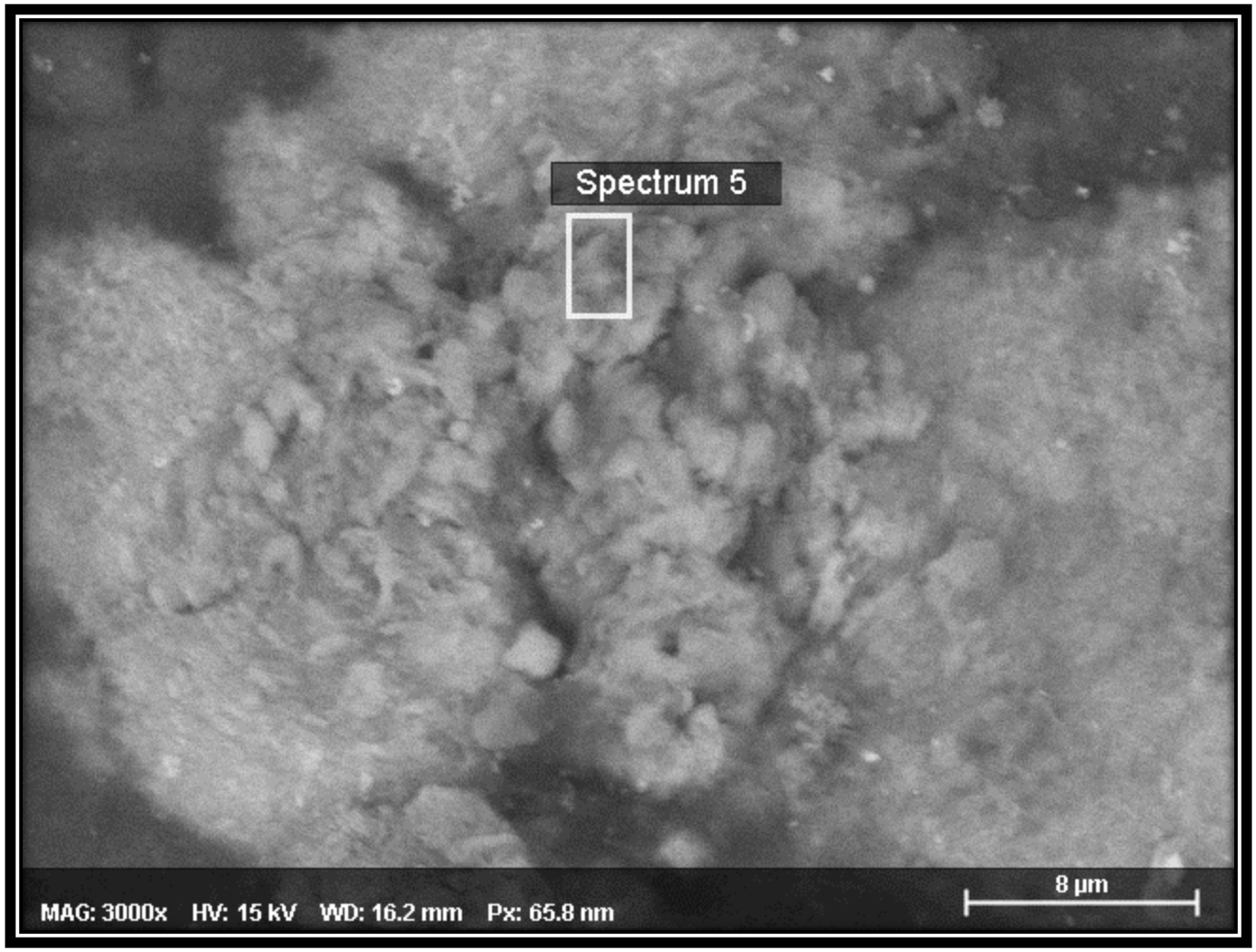


Figure 21: Electron micrograph of the membrane surface at 3000X magnification (Spectrum 5).

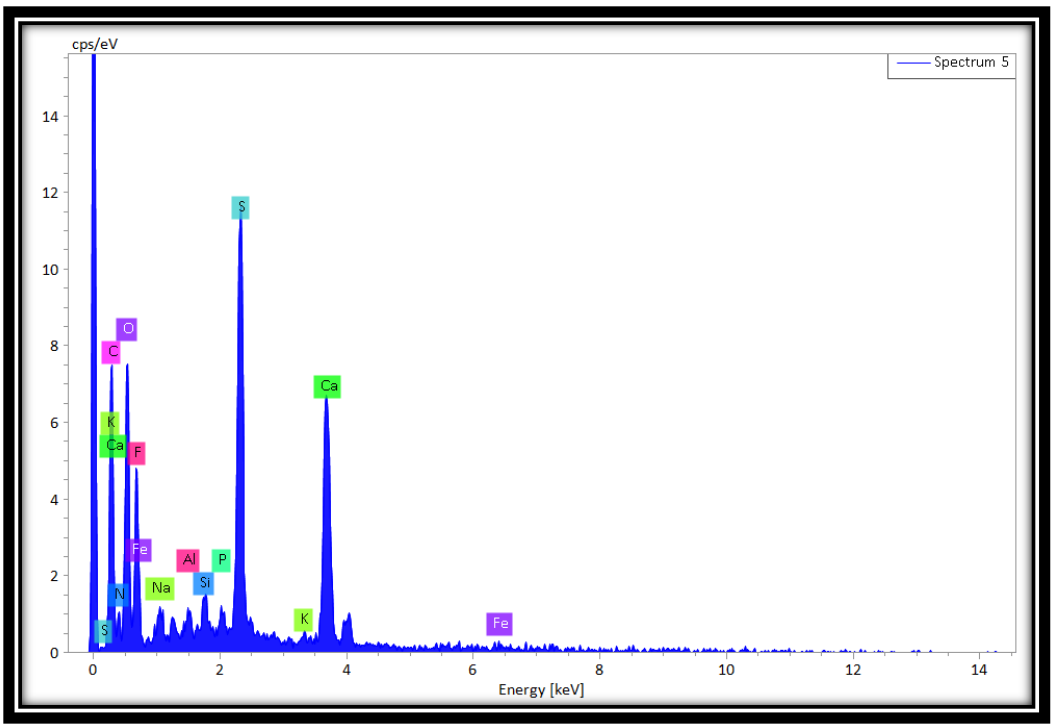


Figure 22: EDS and composition bar graph analysis of the membrane deposit from Spectrum 5.

Spectrum 5

Element	Atom [%]
Fluorine	10.89
Silicon	0.36
Phosphorus	0.21
Sulfur	5.24
Calcium	5.49
Iron	0.32
Sodium	0.39
Aluminium	0.24
Potassium	0.11
Nitrogen	6.67
Carbon	40.46
Oxygen	29.61
	100.00

Carbon, Nitrogen and Oxygen Ignored

Spectrum 5

Element	Atom [%]
Fluorine	39.30
Silicon	1.76
Phosphorus	1.01
Sulfur	25.33
Calcium	27.29
Iron	1.69
Sodium	1.92
Aluminium	1.18
Potassium	0.52
	100.00

Table 7: Composition table from the EDS spectrum of localized deposit from Spectrum 5.

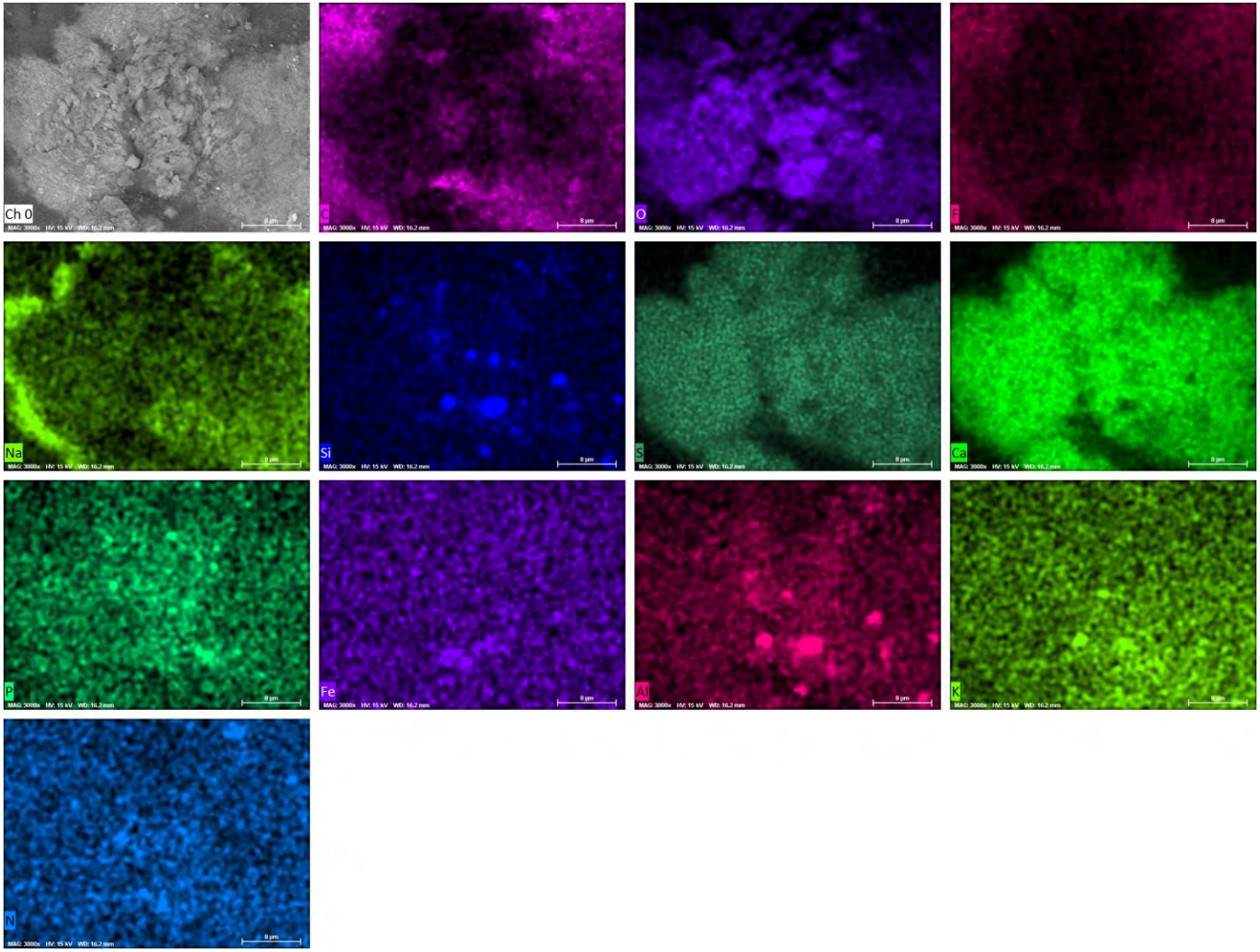


Figure 23: Prismatic Elemental Delineation (PED®) of membrane surface at 3000X magnification. Deposits found: Calcium sulfate, silts and/or clays.

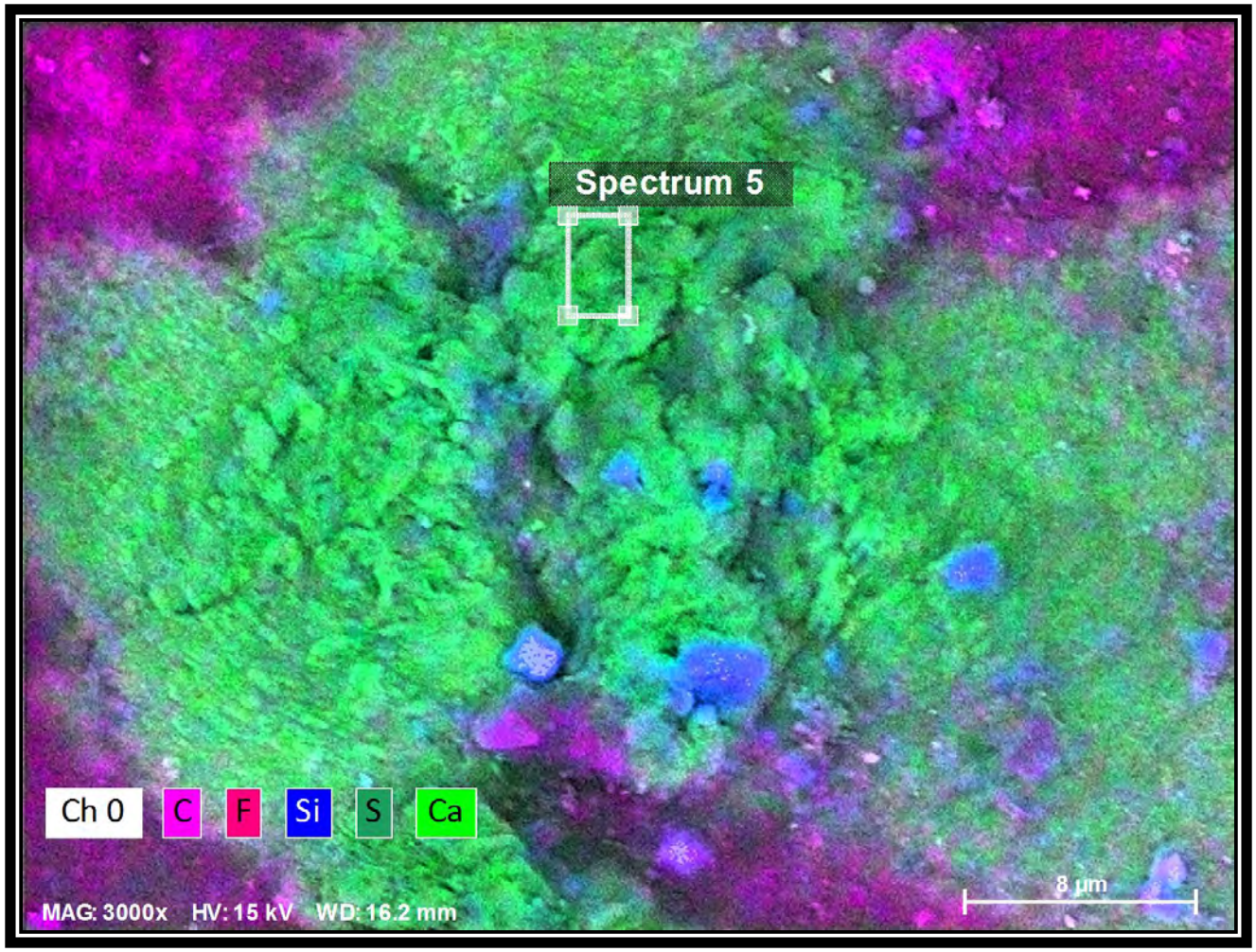
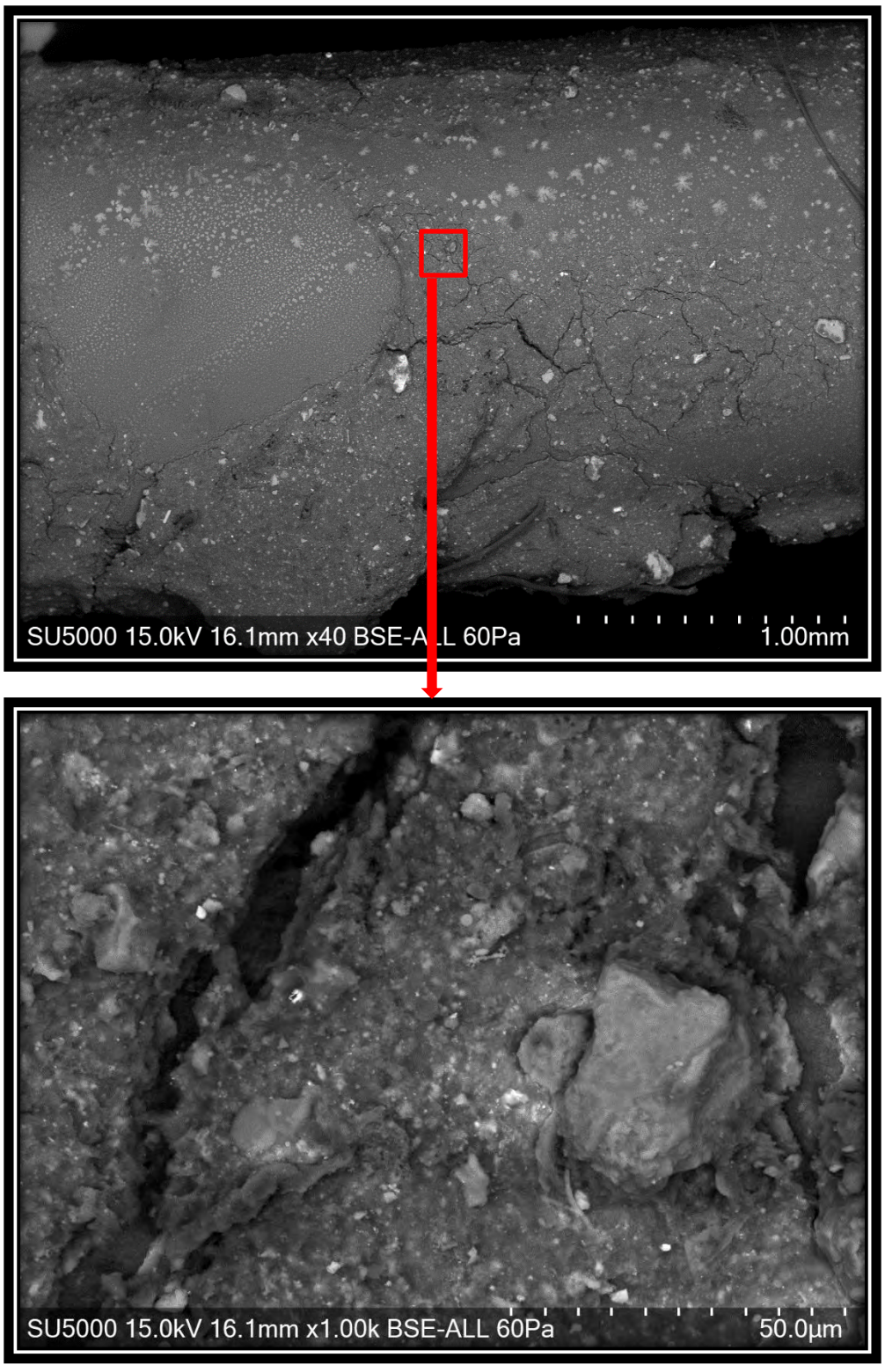


Figure 24: Superimposed Elemental Imaging (SEI®) of calcium sulfate, silts and/or clays.


SU5000 15.0kV 16.1mm x40 BSE-ALL 60Pa
1.00mm
SU5000 15.0kV 16.1mm x1.00k BSE-ALL 60Pa
50.0µm

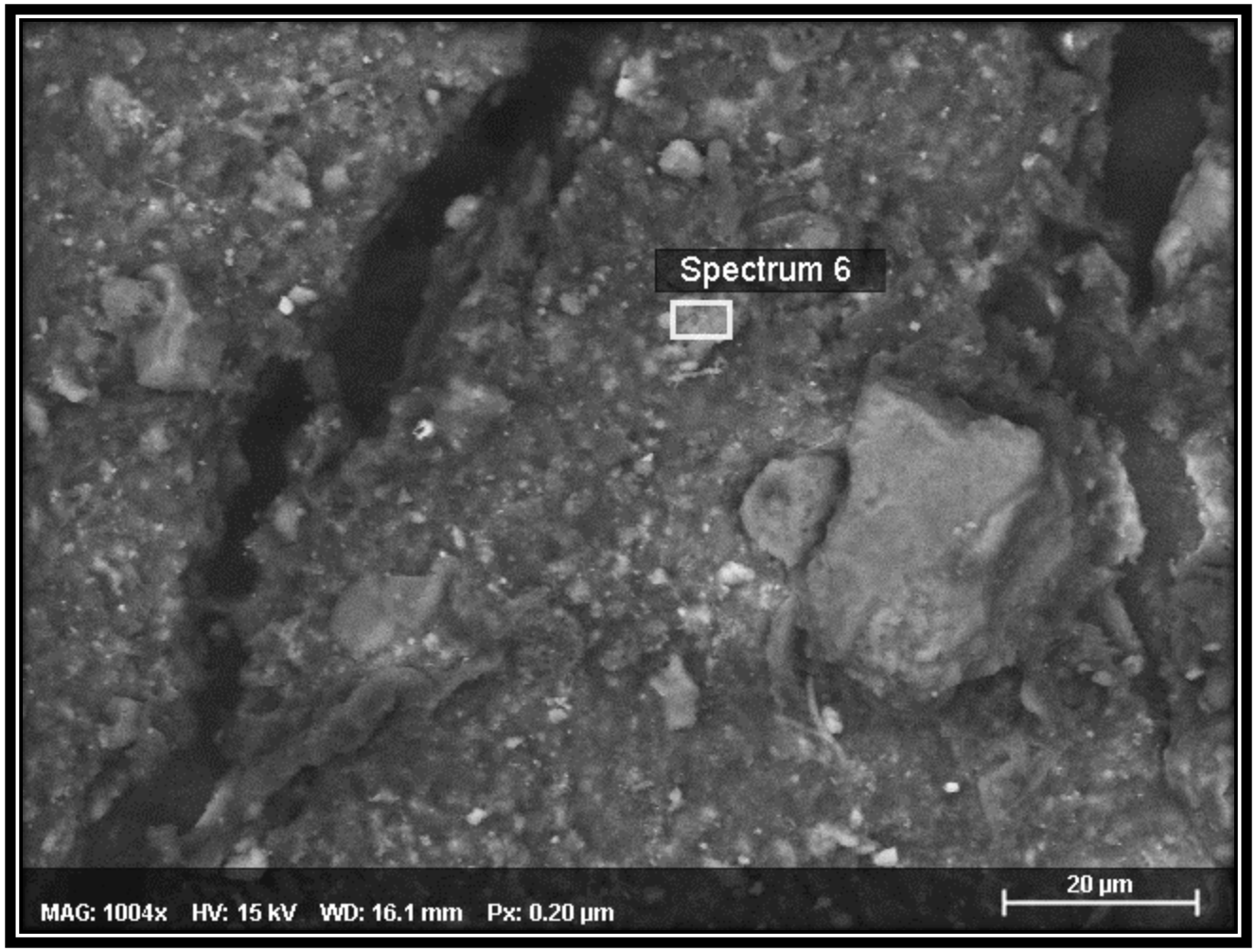


Figure 25: Electron micrograph of the membrane surface at 1000X magnification (Spectrum 6).

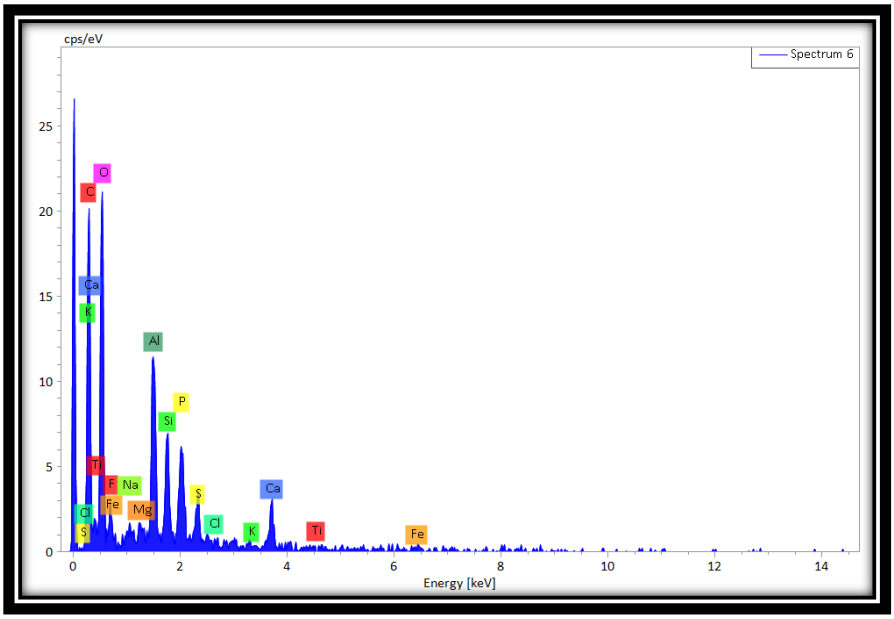


Figure 26: EDS and composition bar graph analysis of the membrane deposit from Spectrum 6.

Spectrum 6

Element	Atom [%]
Fluorine	2.78
Silicon	1.04
Phosphorus	1.38
Sulfur	0.76
Calcium	1.85
Iron	0.59
Sodium	0.11
Aluminium	1.97
Potassium	0.04
Nitrogen	4.79
Carbon	48.98
Oxygen	35.71
	100.00

Carbon, Nitrogen and Oxygen

Spectrum 6

Element	Atom [%]
Fluorine	13.57
Silicon	12.08
Phosphorus	16.35
Sulfur	9.16
Calcium	19.91
Iron	6.77
Sodium	1.19
Aluminium	20.54
Potassium	0.43
	100.00

Table 8: Composition table from the EDS spectrum of localized deposit from Spectrum 6.

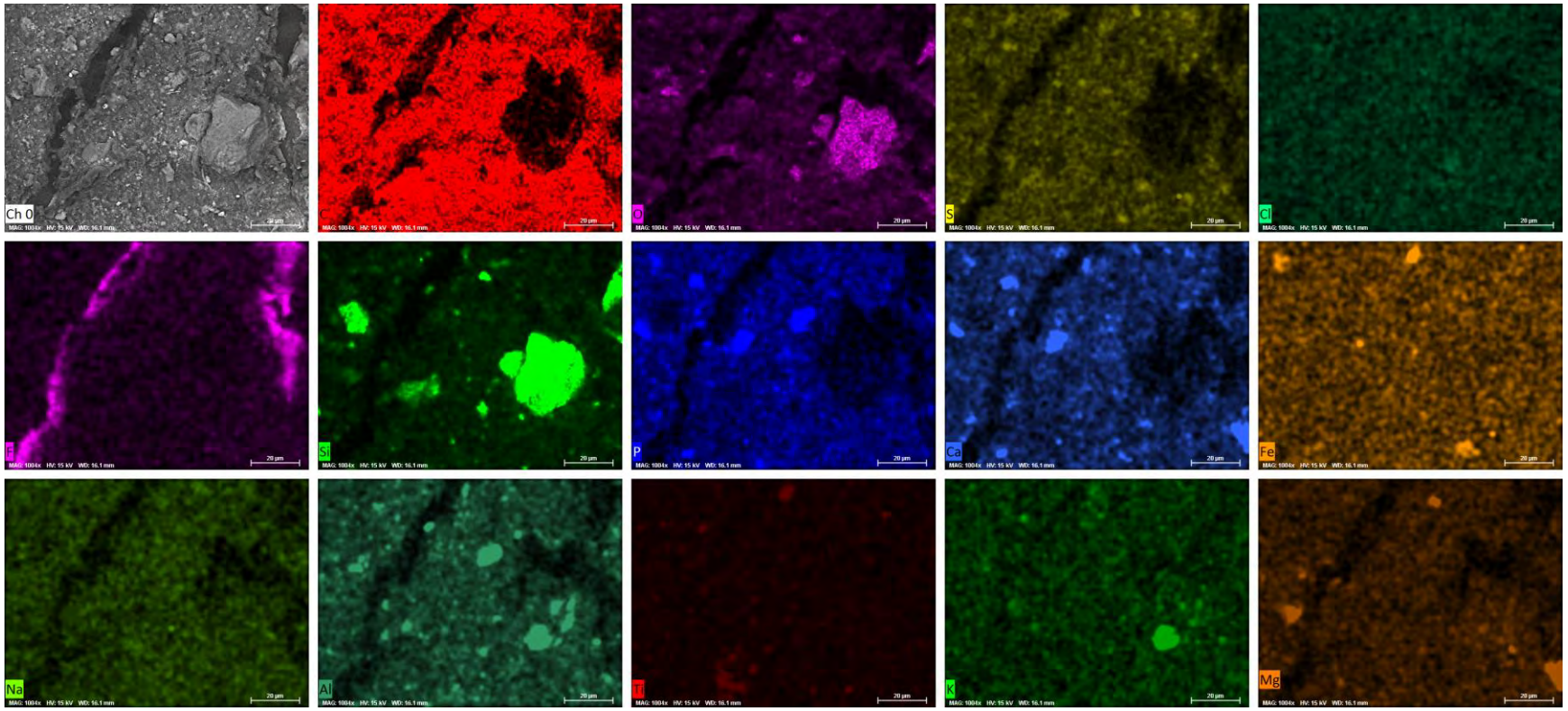


Figure 27: Prismatic Elemental Delineation (PED®) of membrane surface at 1000X magnification. Deposits found: Organic based matter, silts/clays, phosphate salts (aluminum, calcium and iron), iron hydroxide, calcium sulfate and titanium oxide.

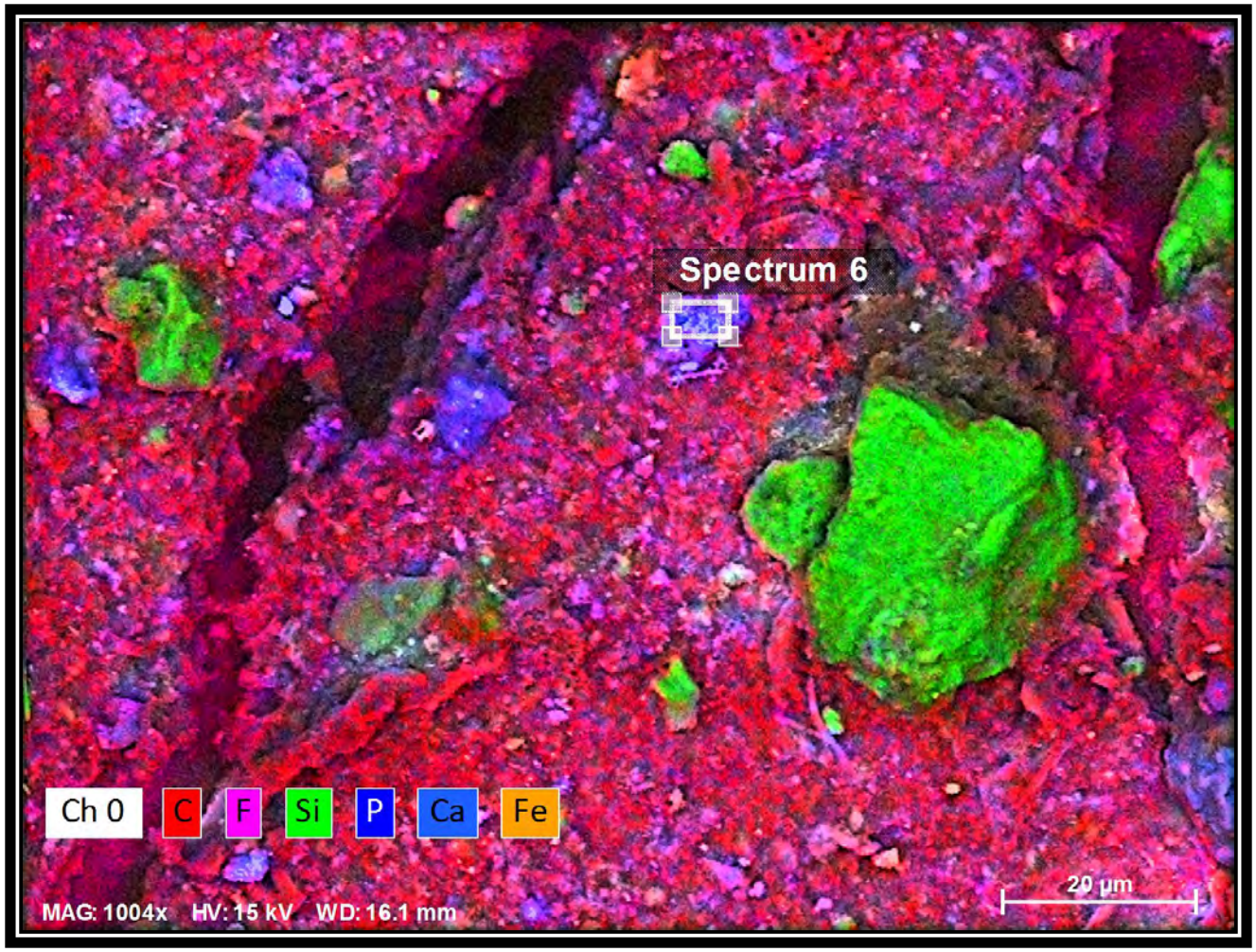


Figure 28: Superimposed Elemental Imaging (SEI®) of Organic based matter, silts/clays, phosphate salts (aluminum, calcium and iron), iron hydroxide, calcium sulfate and titanium oxide.

Middle

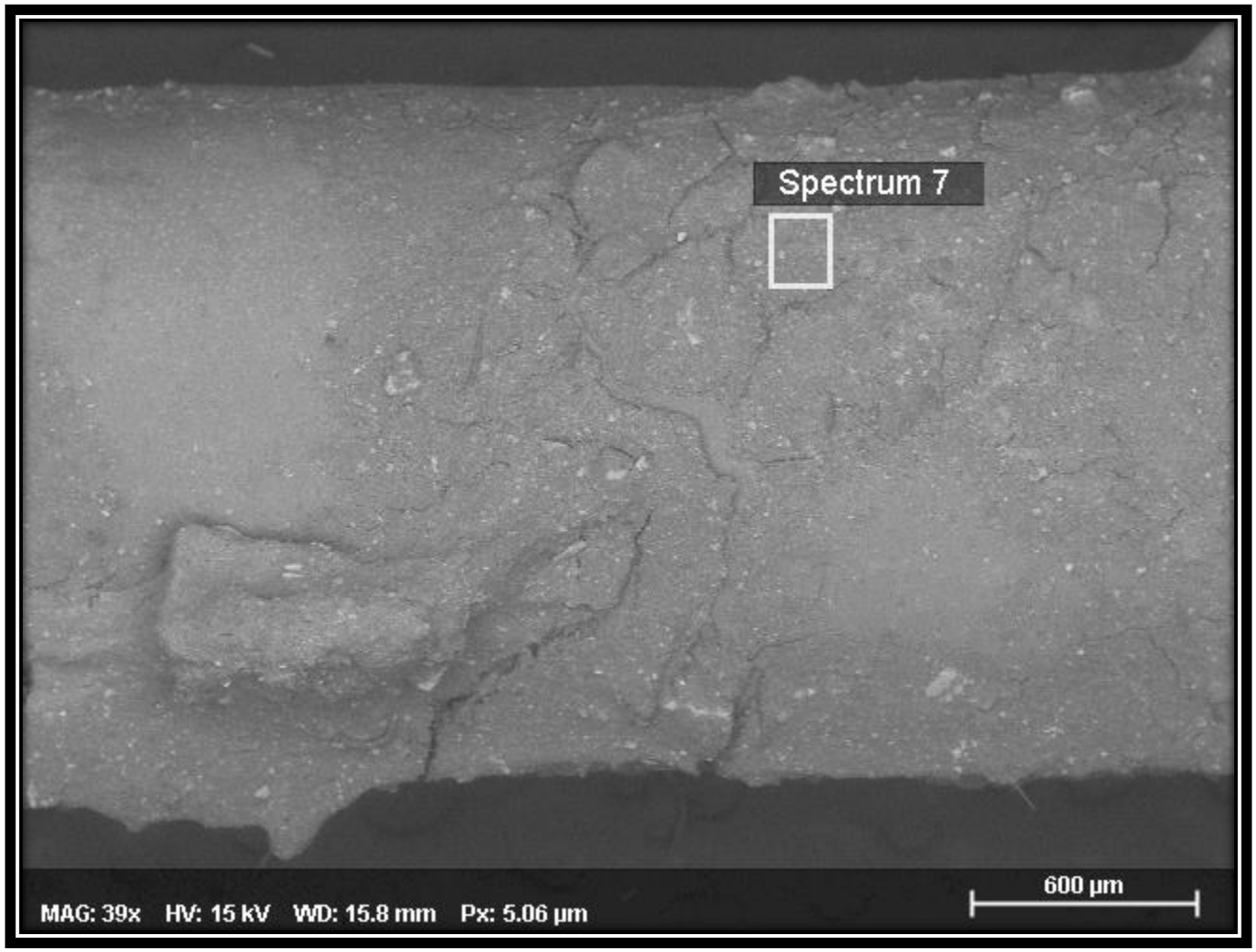


Figure 29: Electron micrograph of the membrane surface at 40X magnification (Spectrum 7).

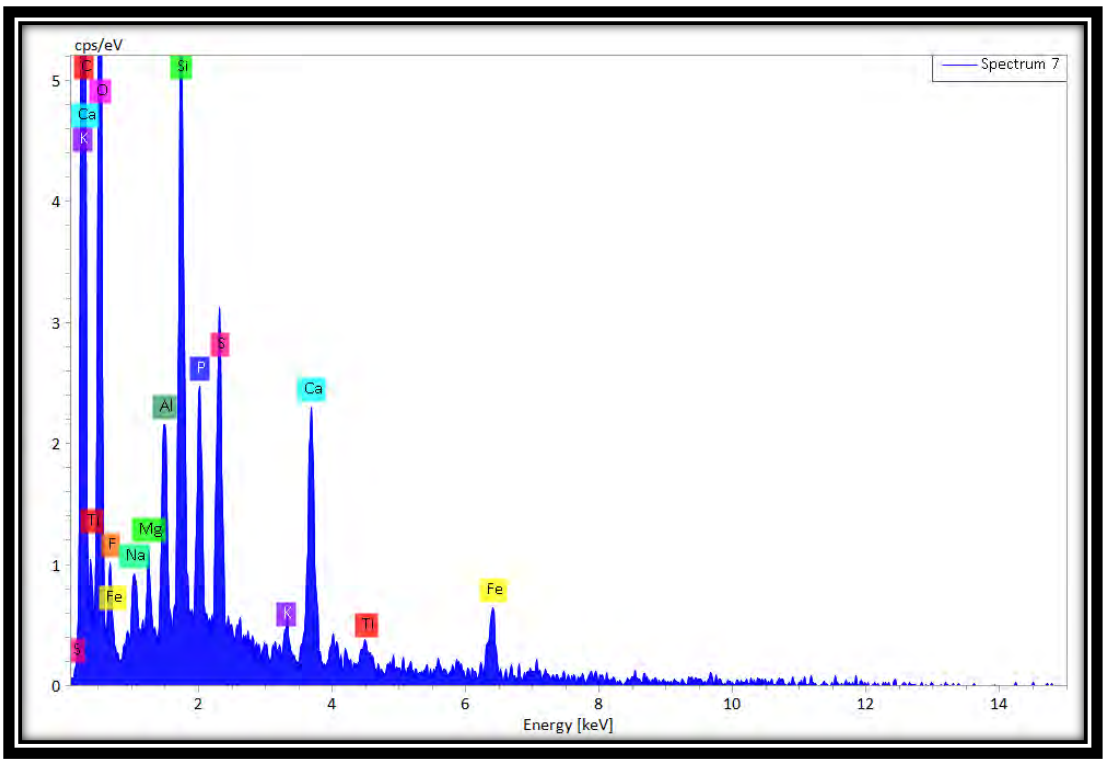


Figure 30: EDS and composition bar graph analysis of the membrane deposit from Spectrum 7.

Spectrum 7

Element	Atom [%]
Fluorine	1.58
Silicon	2.00
Phosphorus	0.91
Sulfur	1.36
Calcium	1.59
Iron	1.20
Sodium	0.37
Aluminium	0.62
Potassium	0.16
Carbon	62.26
Oxygen	27.49
Titanium	0.21
Magnesium	0.25
	100.00

Carbon and Oxygen Ignored

Spectrum 7

Element	Atom [%]
Fluorine	7.19
Silicon	20.46
Phosphorus	9.92
Sulfur	14.83
Calcium	17.25
Iron	13.58
Sodium	3.80
Aluminium	6.28
Potassium	1.66
Titanium	2.40
Magnesium	2.63
	100.00

Table 9: Composition table from the EDS spectrum of localized deposit from Spectrum 7.

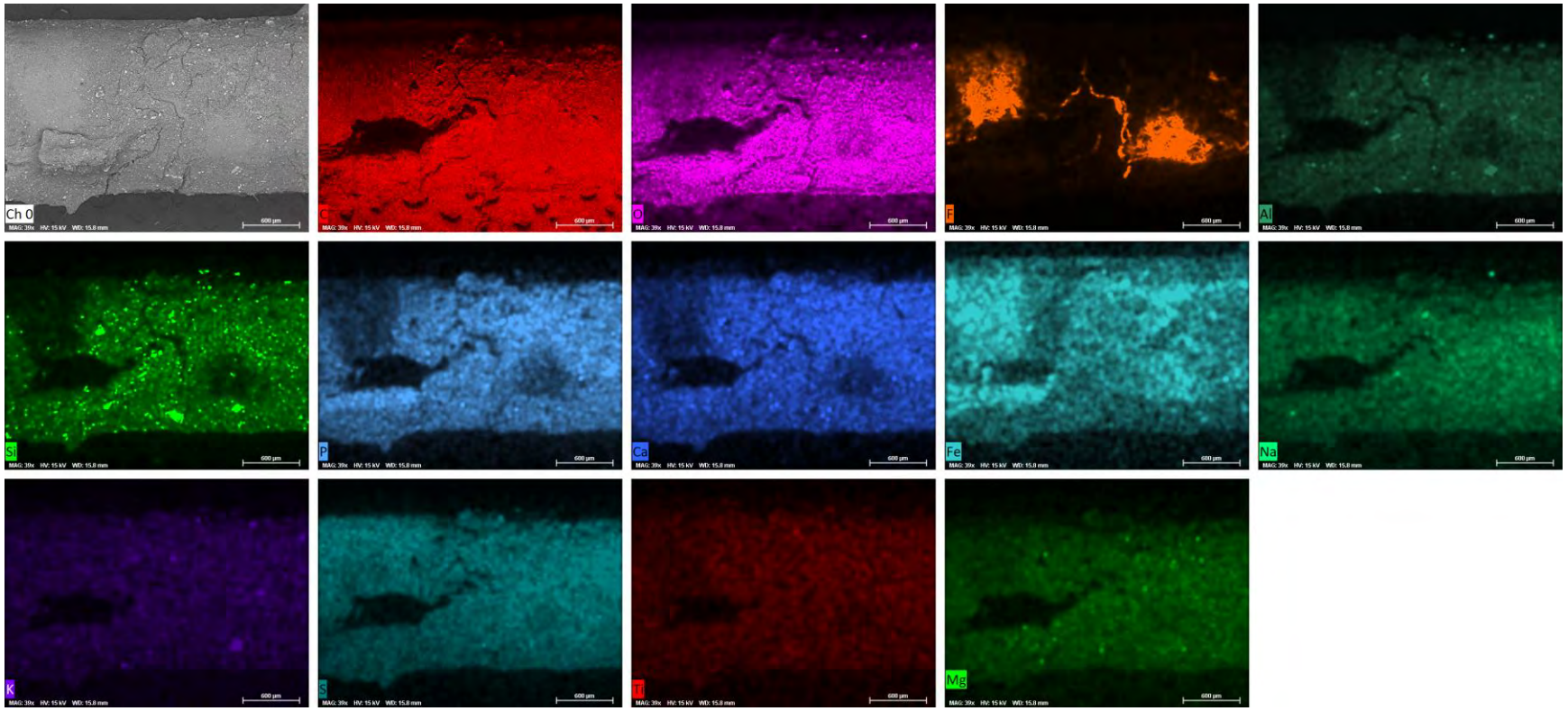


Figure 31: Prismatic Elemental Delineation (PED®) of membrane surface at 1000X magnification. Deposits found: Organic based matter, calcium sulfate, phosphate salts (calcium and iron), titanium dioxide, silts and/or clays.

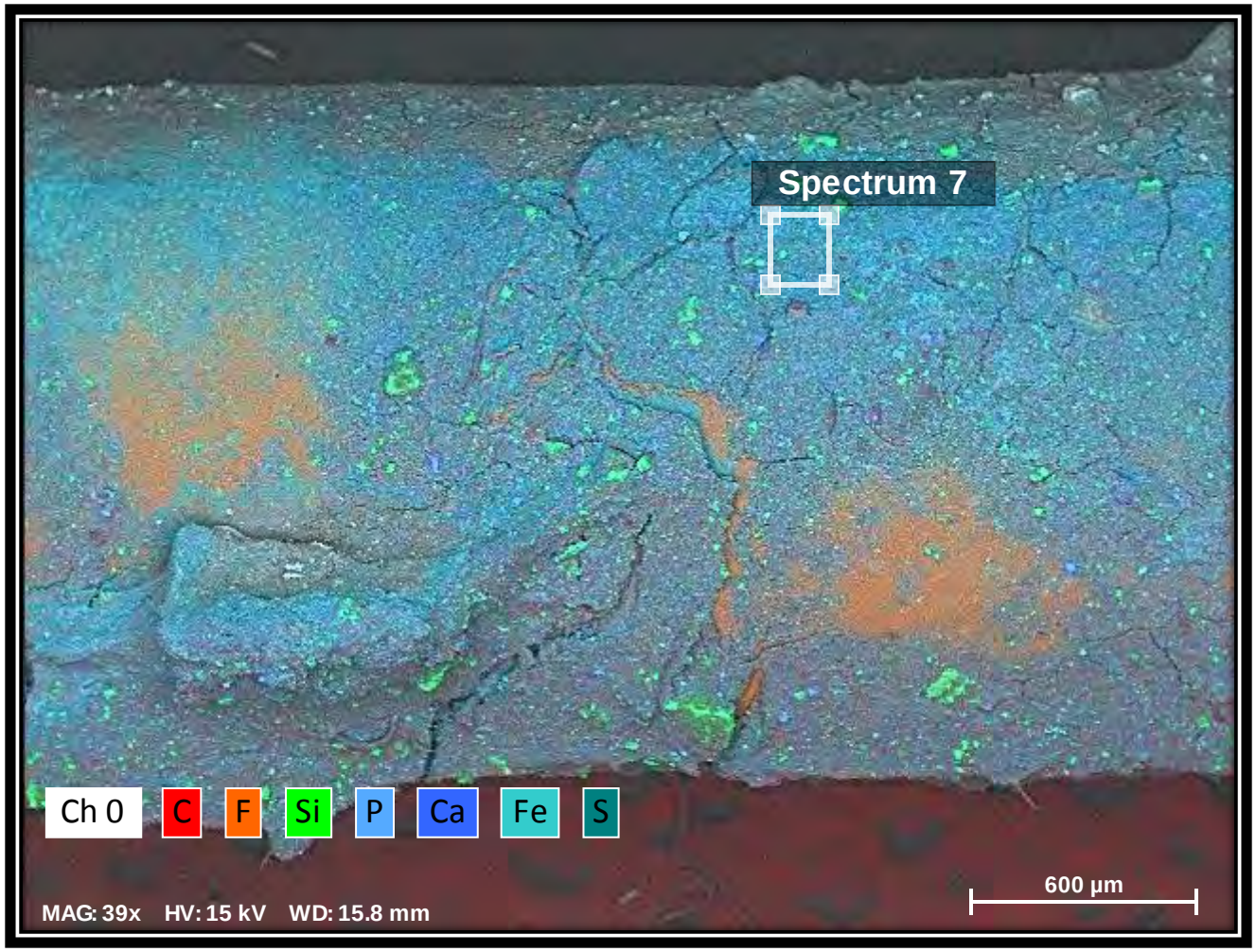
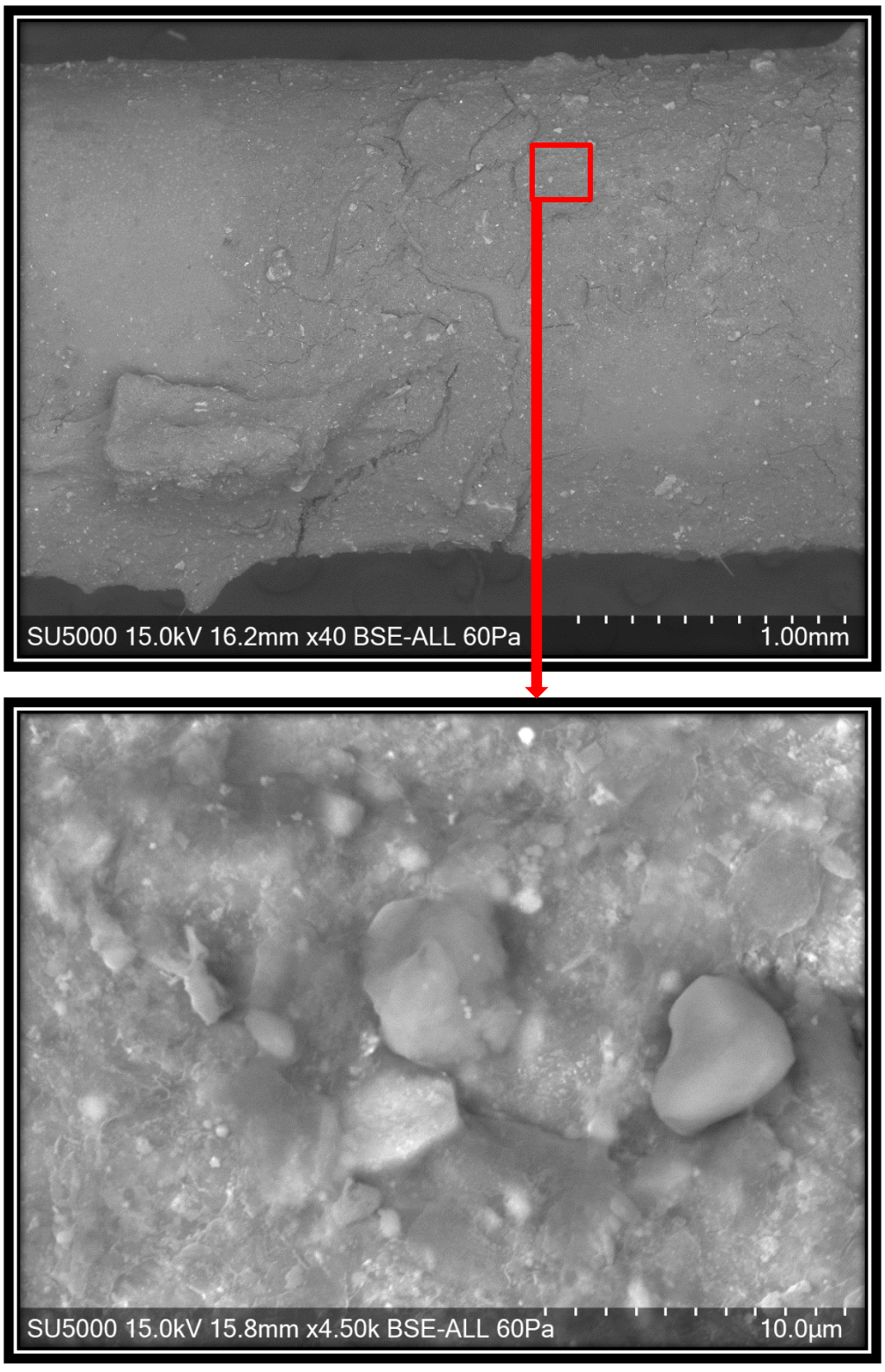


Figure 32: Superimposed Elemental Imaging (SEI®) of organic based matter, calcium sulfate, phosphate salts (calcium and iron), titanium oxide, silts and/or clays.


SU5000 15.0kV 16.2mm x40 BSE-ALL 60Pa
1.00mm
SU5000 15.0kV 15.8mm x4.50k BSE-ALL 60Pa
10.0µm

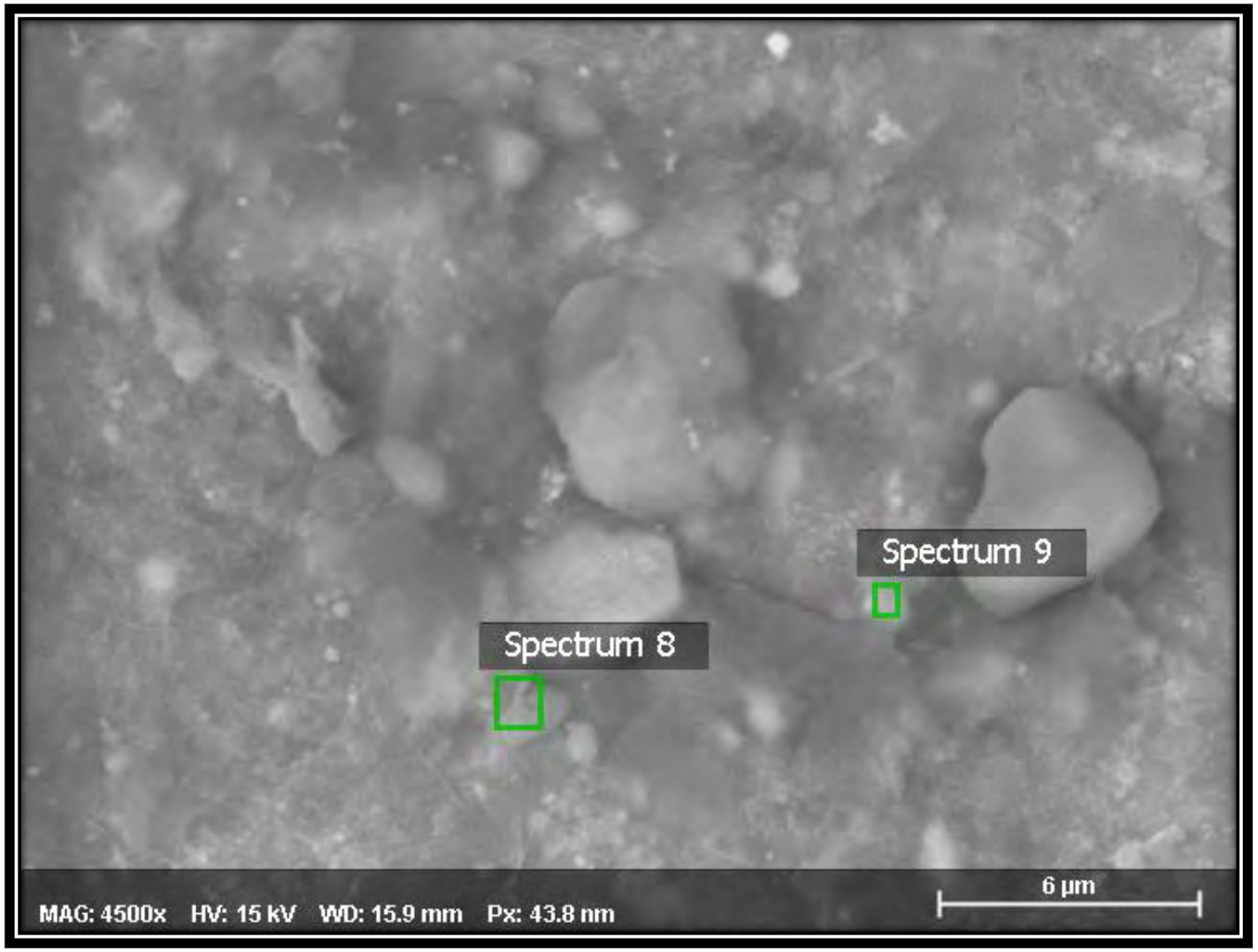


Figure 33: Electron micrograph of the membrane surface at 4500X magnification (Spectrum 8 & Spectrum 9).

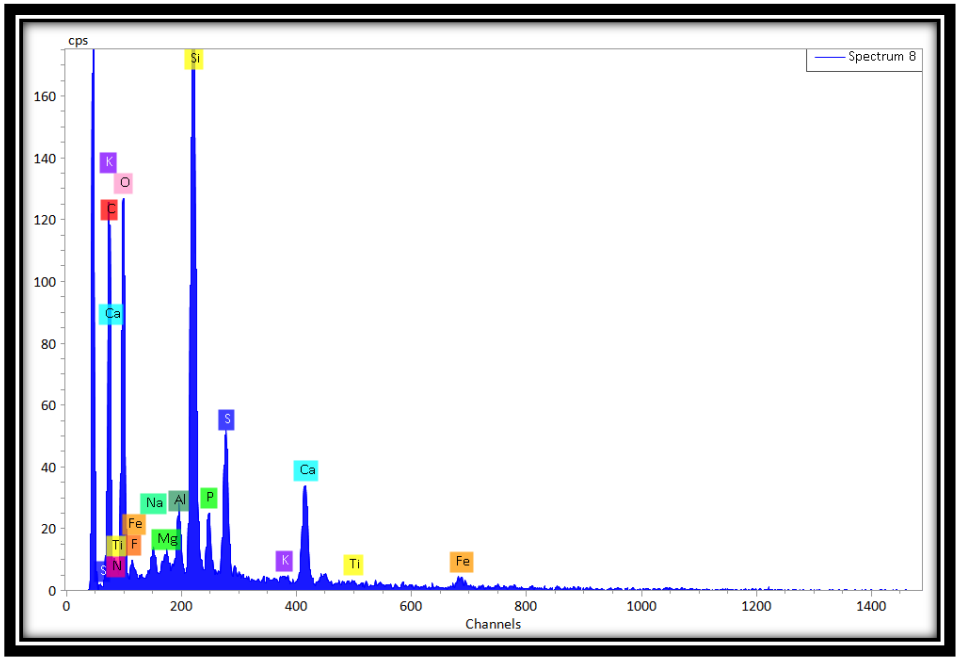


Figure 34: EDS and composition bar graph analysis of the membrane deposit from Spectrum 8.

Spectrum 8

Element	Atom [%]
Fluorine	0.77
Silicon	5.78
Phosphorus	0.77
Sulfur	2.20
Calcium	2.53
Iron	0.57
Sodium	0.43
Aluminium	0.48
Potassium	0.08
Titanium	0.08
Magnesium	0.12
Carbon	55.07
Oxygen	31.11
	100.00

Carbon and Oxygen Ignored

Spectrum 8

Element	Atom [%]
Fluorine	1.84
Silicon	42.62
Phosphorus	6.65
Sulfur	17.64
Calcium	18.31
Iron	4.53
Sodium	2.99
Aluminium	3.36
Potassium	0.58
Titanium	0.63
Magnesium	0.85
	100.00

Table 10: Composition table from the EDS spectrum of localized deposit from Spectrum 8.

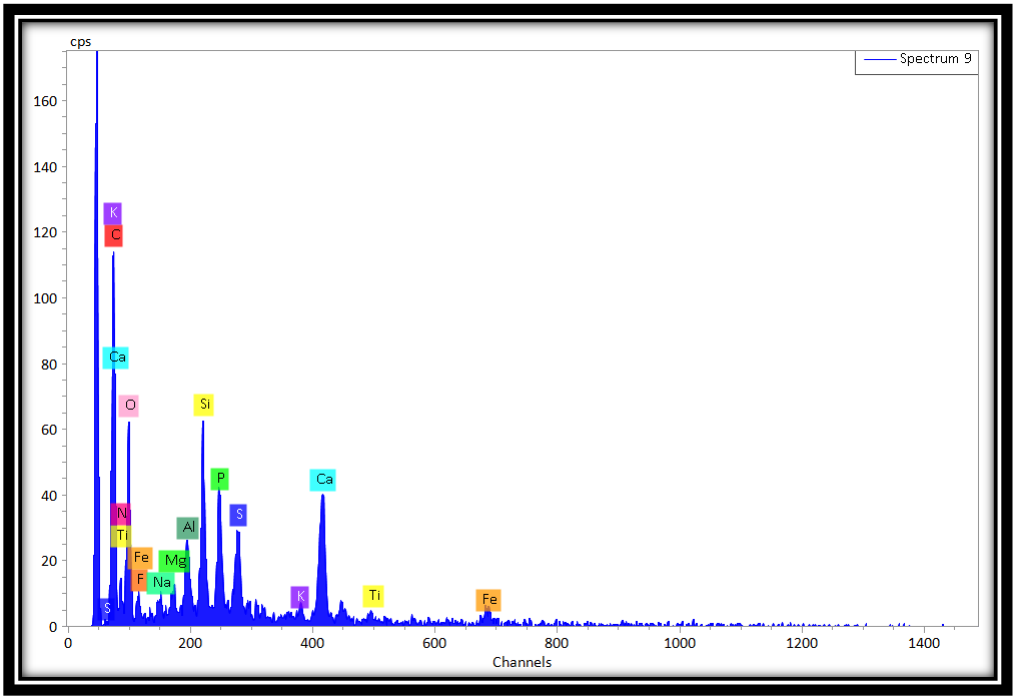


Figure 35: EDS and composition bar graph analysis of the membrane deposit from Spectrum 9.

Spectrum 9

Element	Atom [%]
Fluorine	1.56
Silicon	2.01
Phosphorus	1.64
Sulfur	1.35
Calcium	3.75
Iron	1.12
Sodium	0.36
Aluminium	0.86
Potassium	0.17
Titanium	0.22
Magnesium	0.37
Carbon	55.66
Nitrogen	6.98
Oxygen	23.96
	100.00

Carbon, Nitrogen and Oxygen Ignored

Spectrum 9

Element	Atom [%]
Fluorine	6.59
Silicon	15.49
Phosphorus	13.16
Sulfur	11.09
Calcium	29.26
Iron	9.17
Sodium	2.76
Aluminium	6.50
Potassium	1.30
Titanium	1.79
Magnesium	2.86
	100.00

Table 11: Composition table from the EDS spectrum of localized deposit from Spectrum 1.

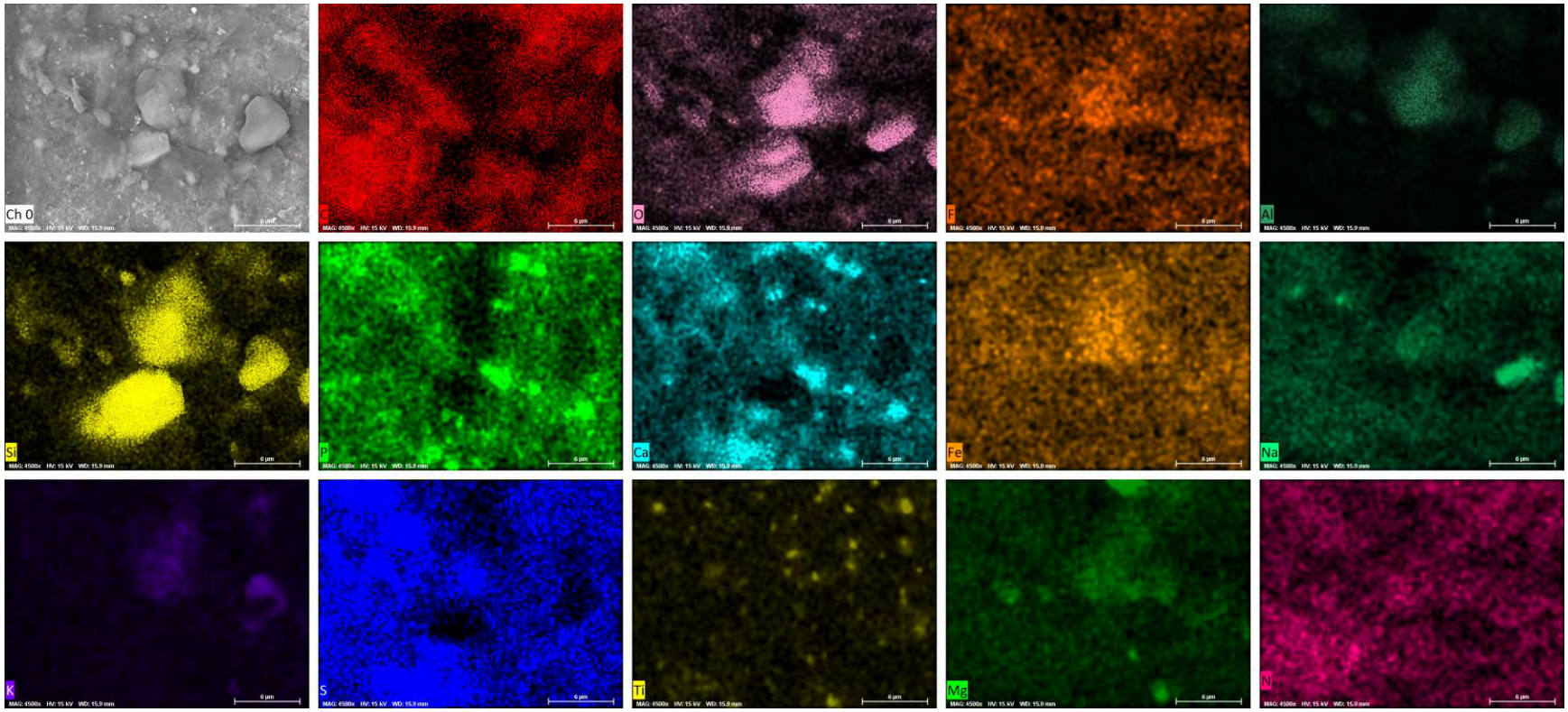


Figure 36: Prismatic Elemental Delineation (PED®) of membrane surface at 4500X magnification. Deposits found: Organic based matter, silts/clays, calcium sulfate, calcium phosphate, and titanium oxide.

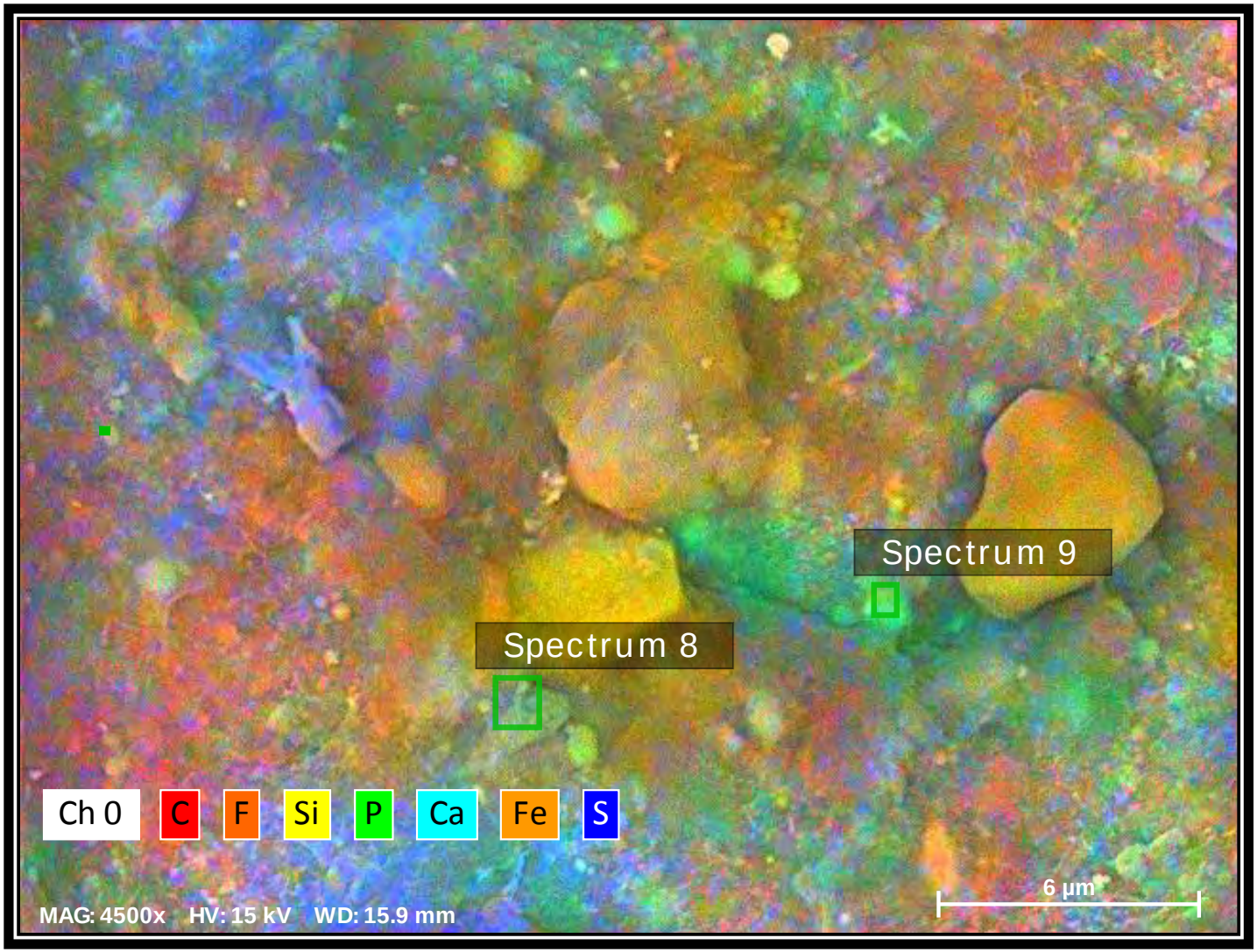


Figure 37: Superimposed Elemental Imaging (SEI®) of organic based matter, silts/clays, calcium sulfate, calcium phosphate, and titanium oxide.

Bottom

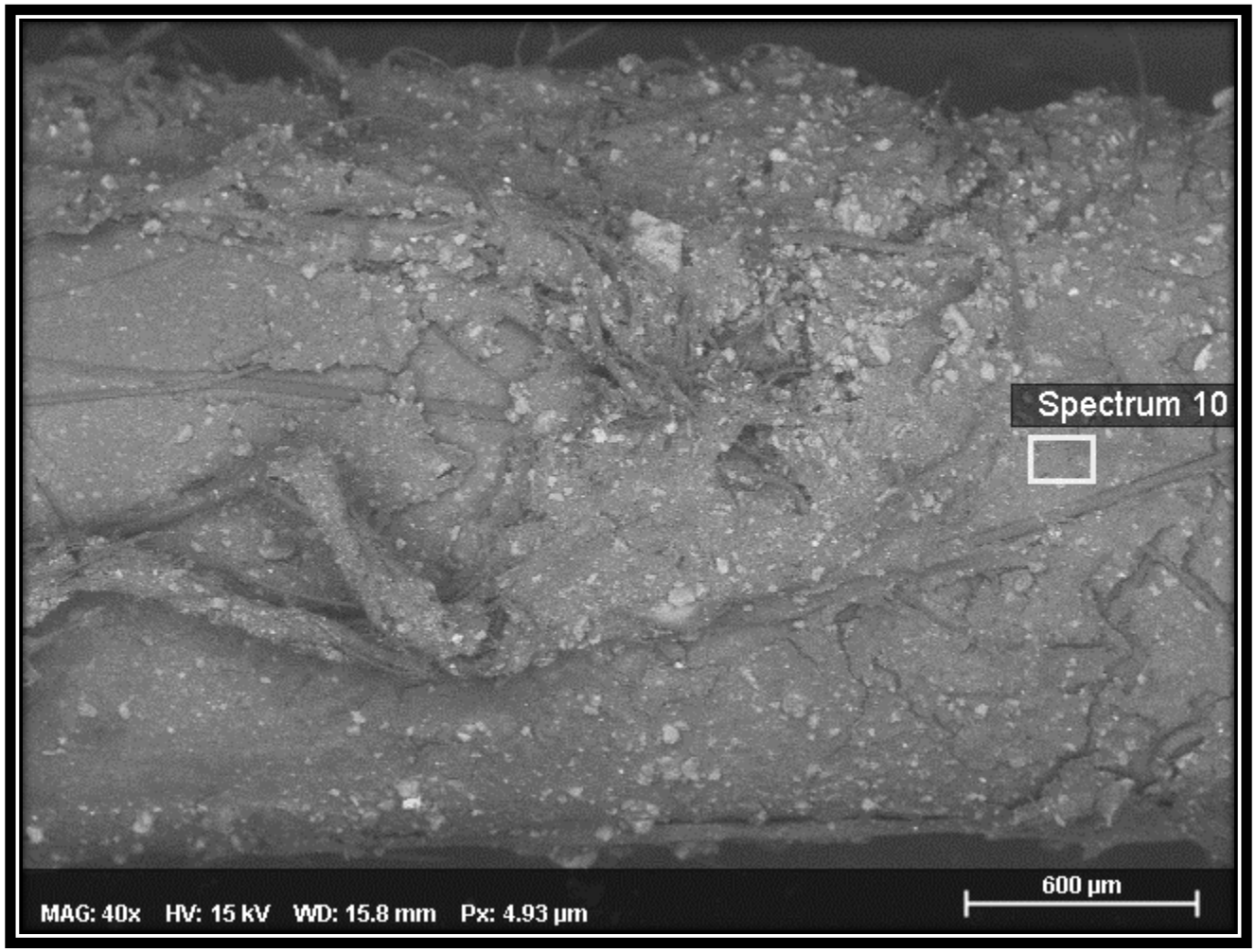


Figure 38: Electron micrograph of the membrane surface at 40X magnification (Spectrum 10).

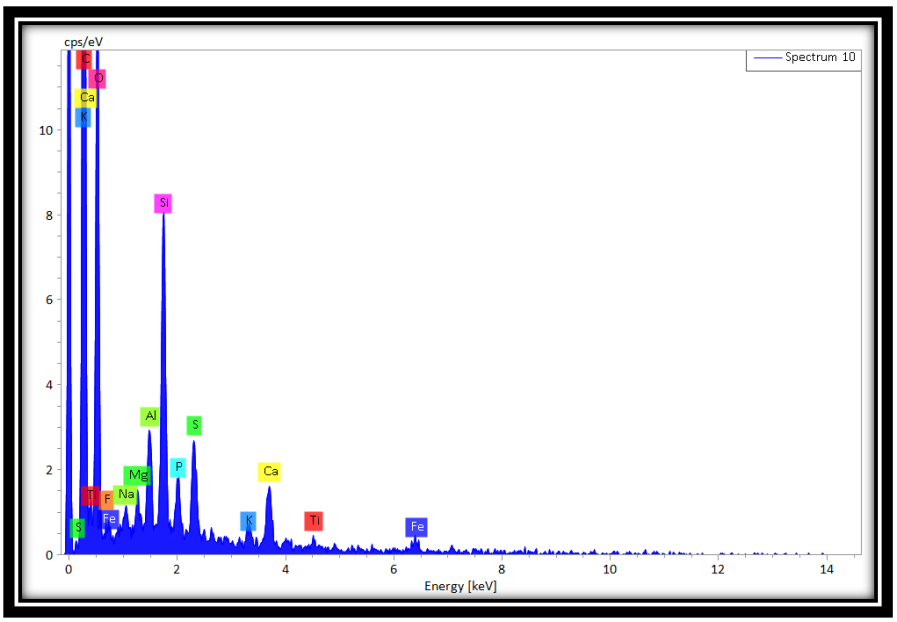


Figure 39: EDS and composition bar graph analysis of the membrane deposit from Spectrum 10.

Spectrum 10

Element	Atom [%]
Fluorine	0.30
Silicon	1.75
Phosphorus	0.38
Sulfur	0.89
Calcium	0.73
Iron	0.54
Sodium	0.15
Aluminium	0.47
Potassium	0.20
Titanium	0.19
Magnesium	0.17
Carbon	62.66
Oxygen	31.57
	100.00

Carbon, Nitrogen and Oxygen Ignored

Spectrum 10

Element	Atom [%]
Fluorine	0.00
Silicon	30.79
Phosphorus	7.78
Sulfur	16.87
Calcium	13.31
Iron	10.43
Sodium	2.56
Aluminium	7.96
Potassium	3.72
Titanium	3.62
Magnesium	2.95
	100.00

Table 12: Composition table from the EDS spectrum of localized deposit from Spectrum 10.

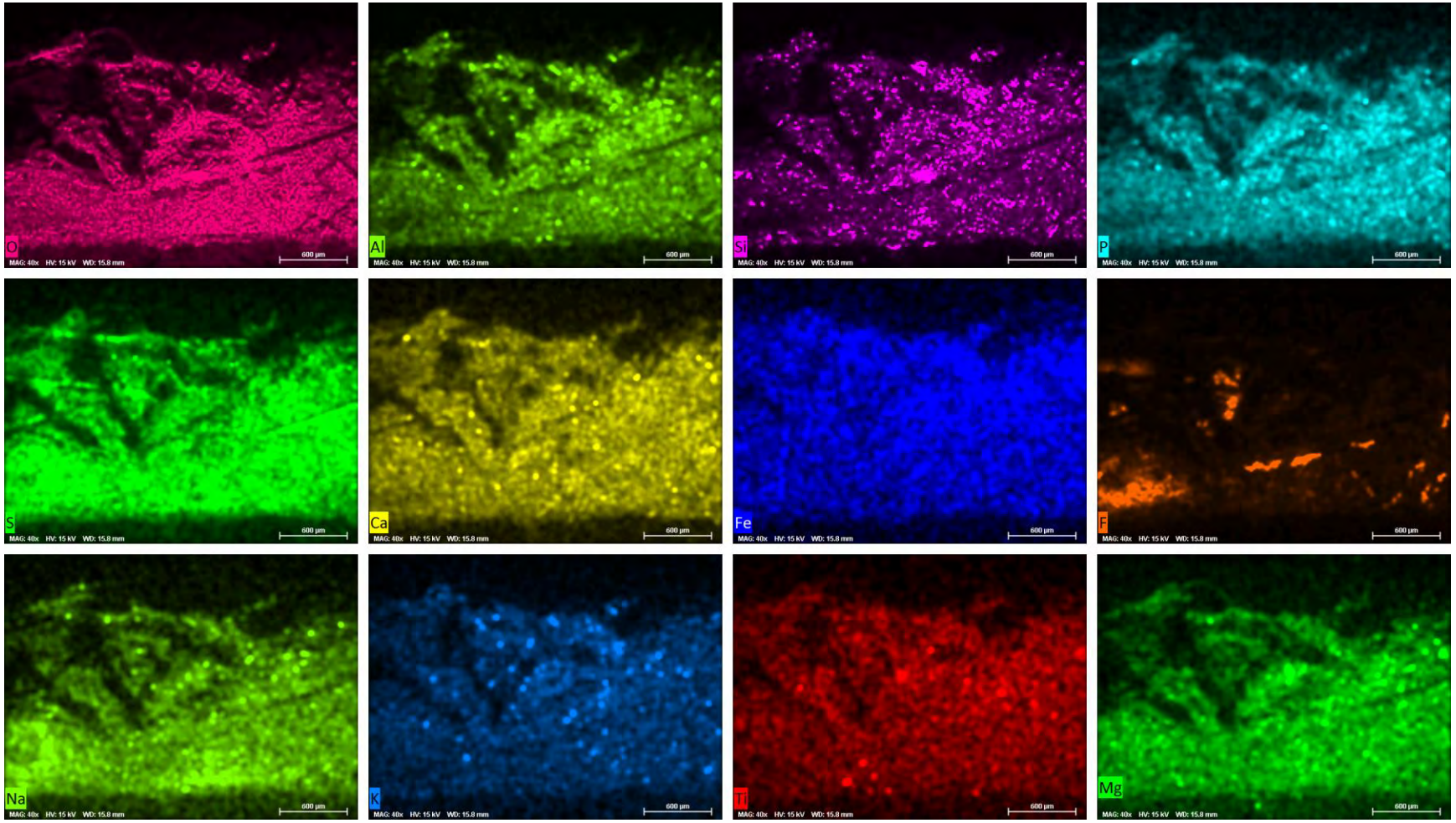


Figure 40: Prismatic Elemental Delineation (PED®) of membrane surface at 40X magnification. Deposits found: Organic based matter, calcium sulfate, silts/clays, iron hydroxide and titanium oxide.

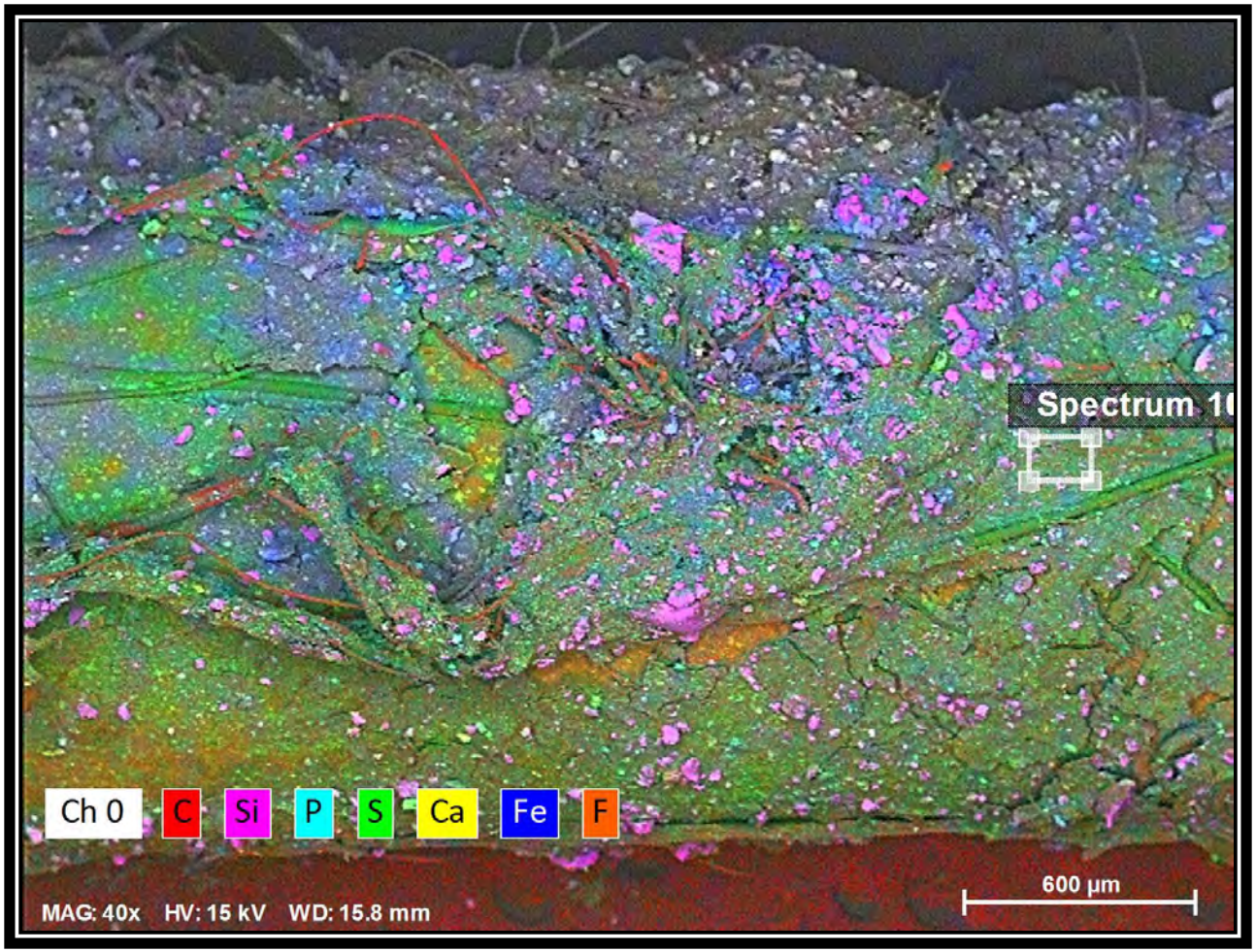
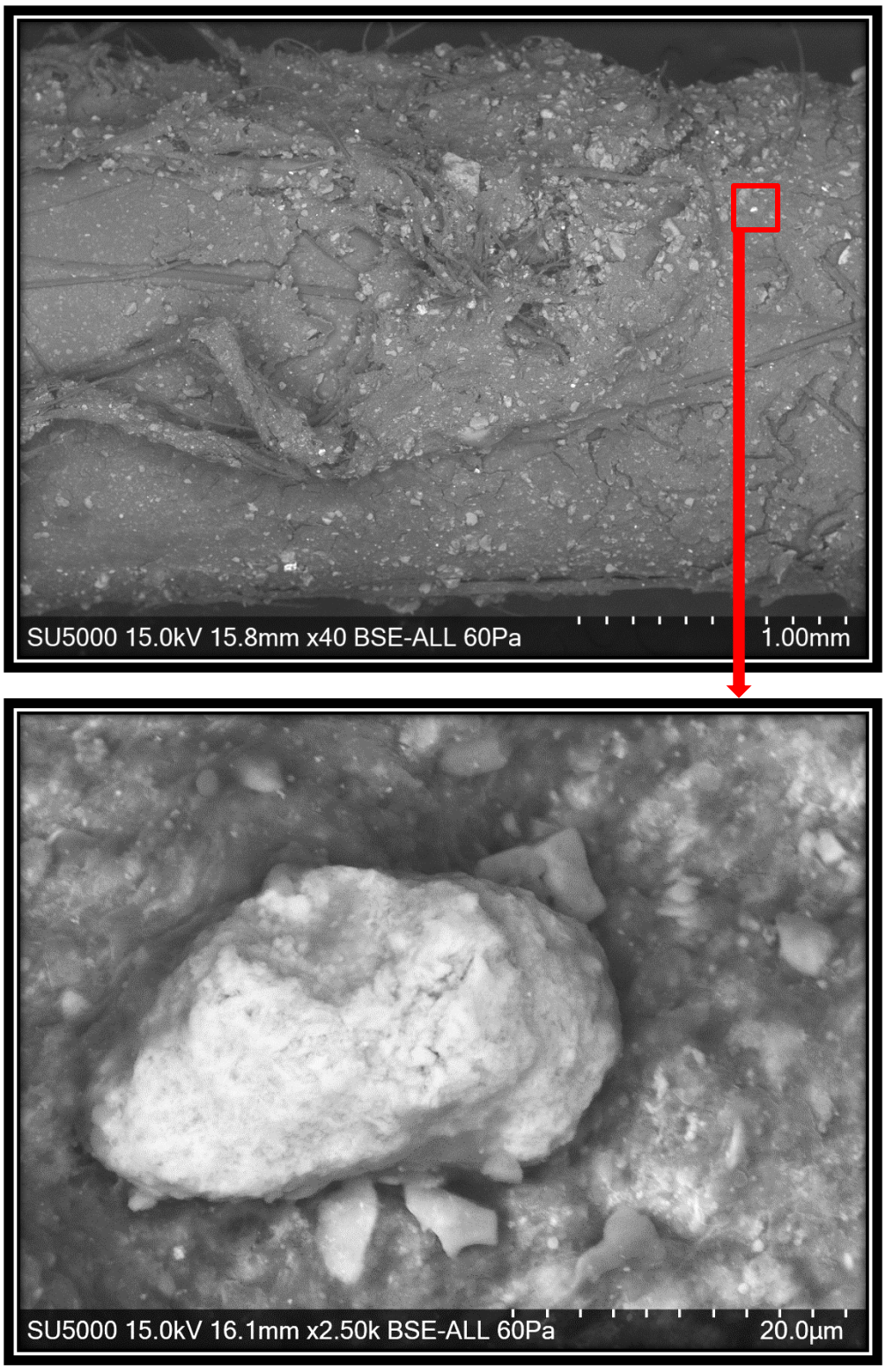


Figure 41: Superimposed Elemental Imaging (SEI®) of organic based matter, calcium sulfate, silts/clays, iron hydroxide and titanium oxide.


SU5000 15.0kV 15.8mm x40 BSE-ALL 60Pa
1.00mm
SU5000 15.0kV 16.1mm x2.50k BSE-ALL 60Pa
20.0µm

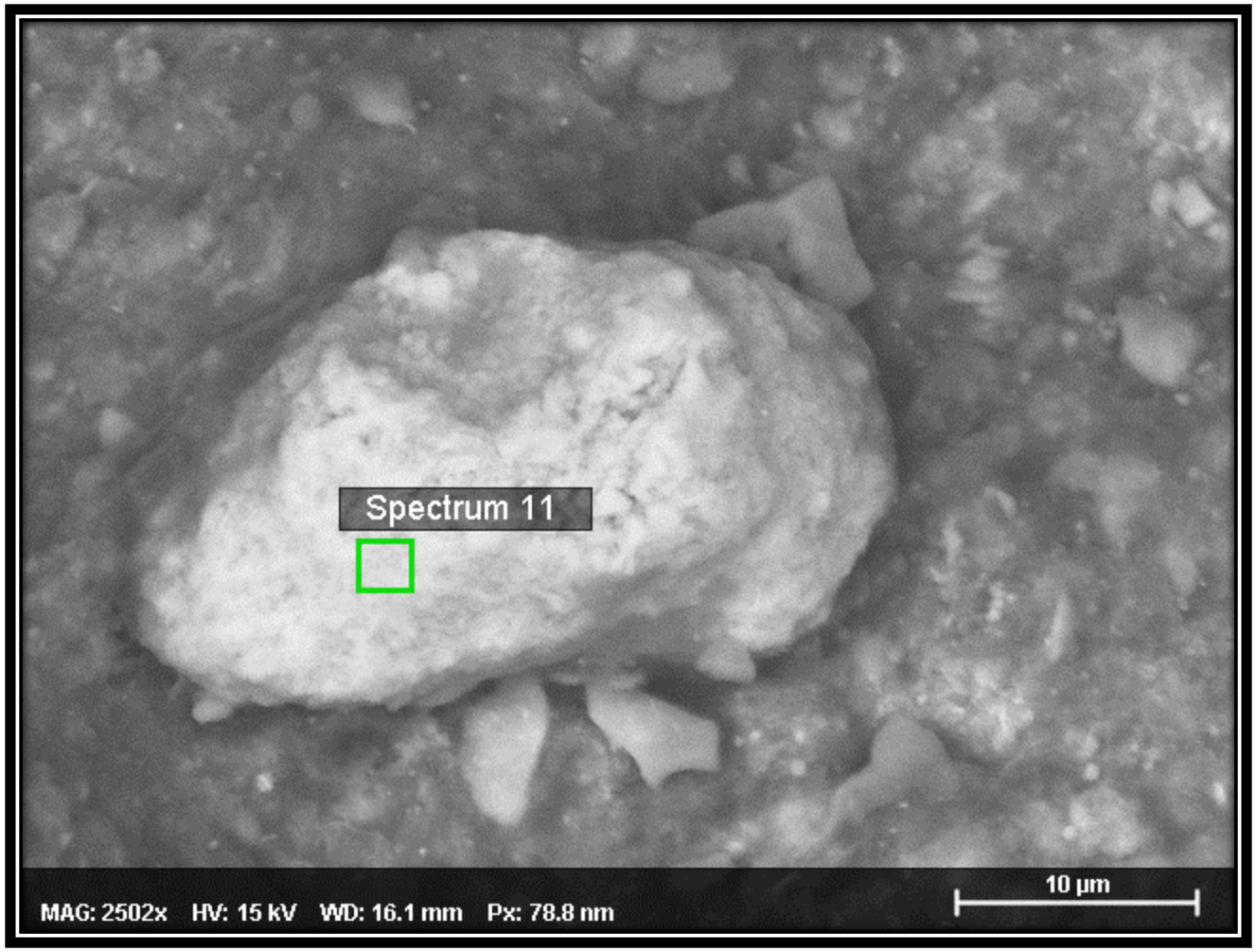


Figure 42: Electron micrograph of the membrane surface at 2500X magnification (Spectrum 11).

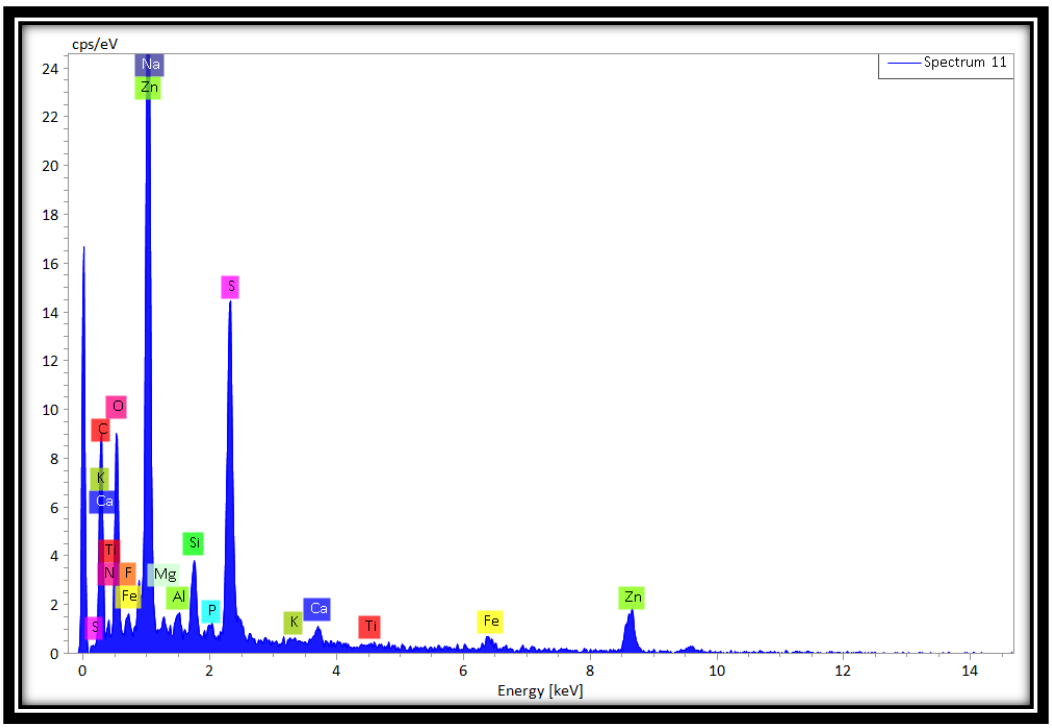


Figure 43: EDS and composition bar graph analysis of the membrane deposit from Spectrum 11.

Spectrum 11

Element	Atom [%]
Silicon	1.45
Phosphorus	0.35
Sulfur	7.99
Calcium	0.63
Iron	1.07
Sodium	6.24
Aluminium	0.36
Potassium	0.14
Magnesium	0.05
Titanium	0.05
Zinc	6.77
Carbon	53.20
Oxygen	21.70
	100.00

Carbon and Oxygen Ignored

Spectrum 11

Element	Atom [%]
Silicon	5.52
Phosphorus	1.29
Sulfur	29.43
Calcium	2.59
Iron	4.60
Sodium	24.63
Aluminium	1.41
Potassium	0.56
Magnesium	0.23
Titanium	0.20
Zinc	29.54
	100.00

Table 13: Composition table from the EDS spectrum of localized deposit from Spectrum 11.

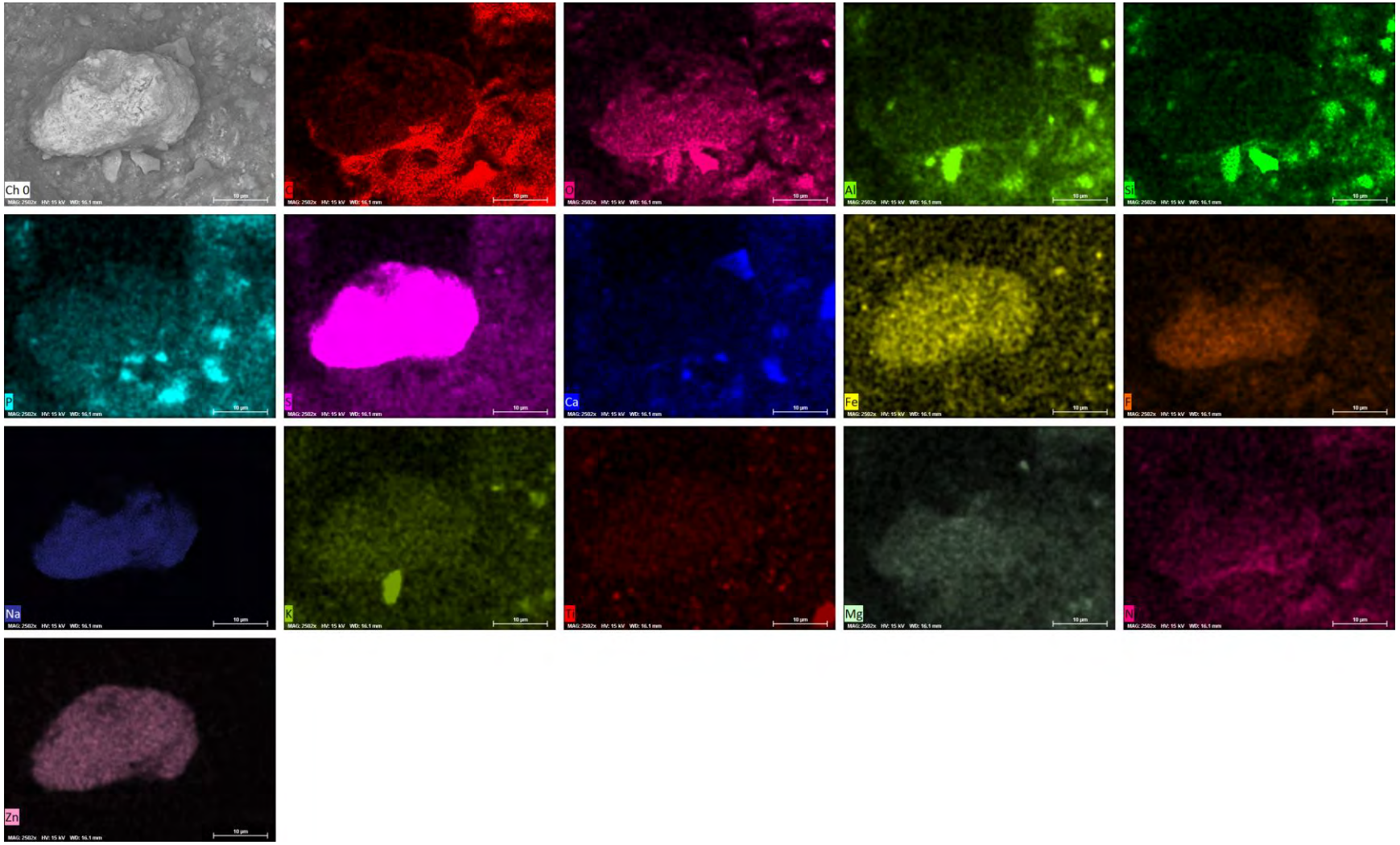


Figure 44: Prismatic Elemental Delineation (PED®) of membrane surface at 1000X magnification. Deposits found: Zinc sulfate, phosphate salts (calcium and iron), silts/clays and titanium dioxide.

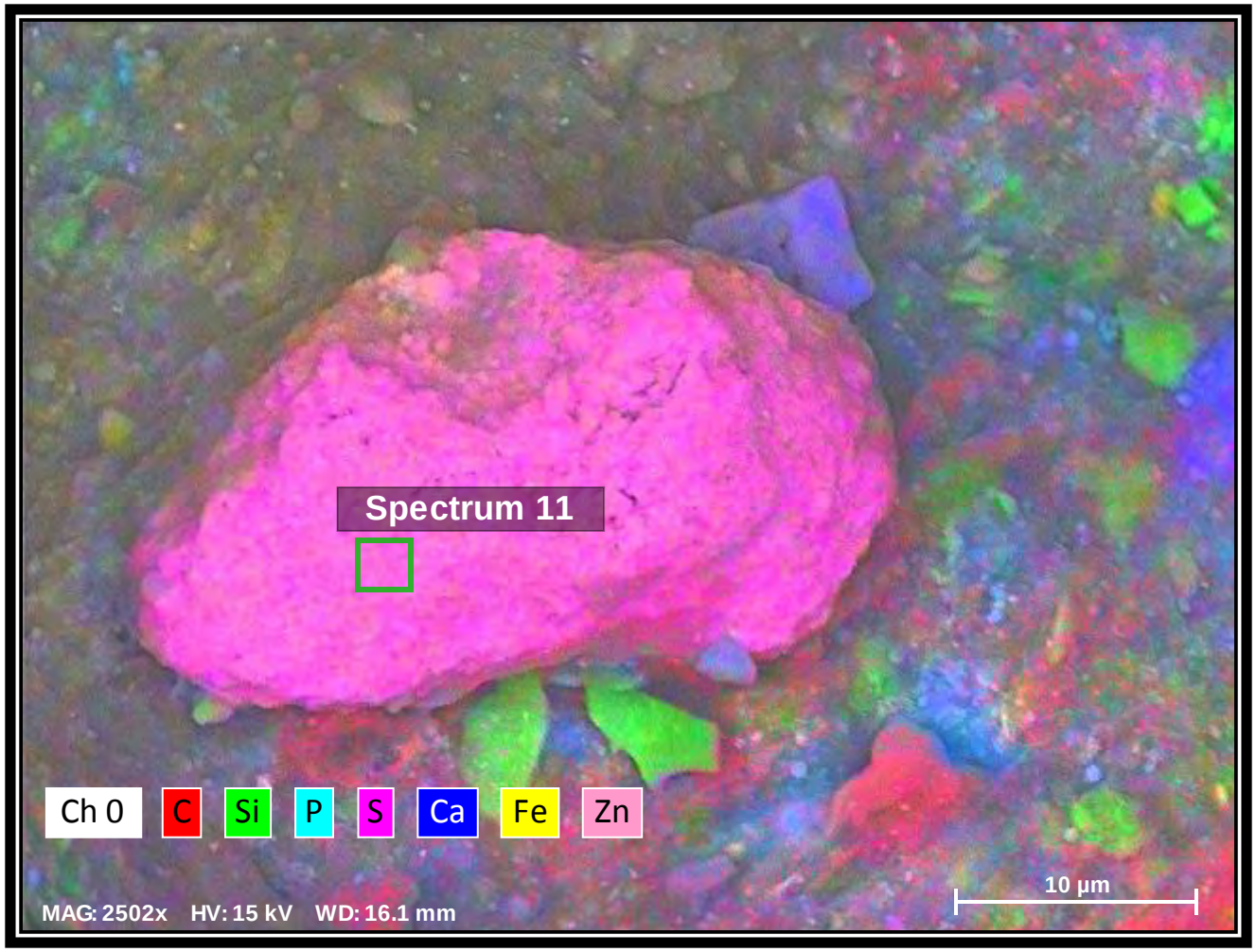


Figure 45: Superimposed Elemental Imaging (SEI®) of zinc sulfate, phosphate salts (calcium and iron), silts/clays and titanium oxide.

Post cleaning

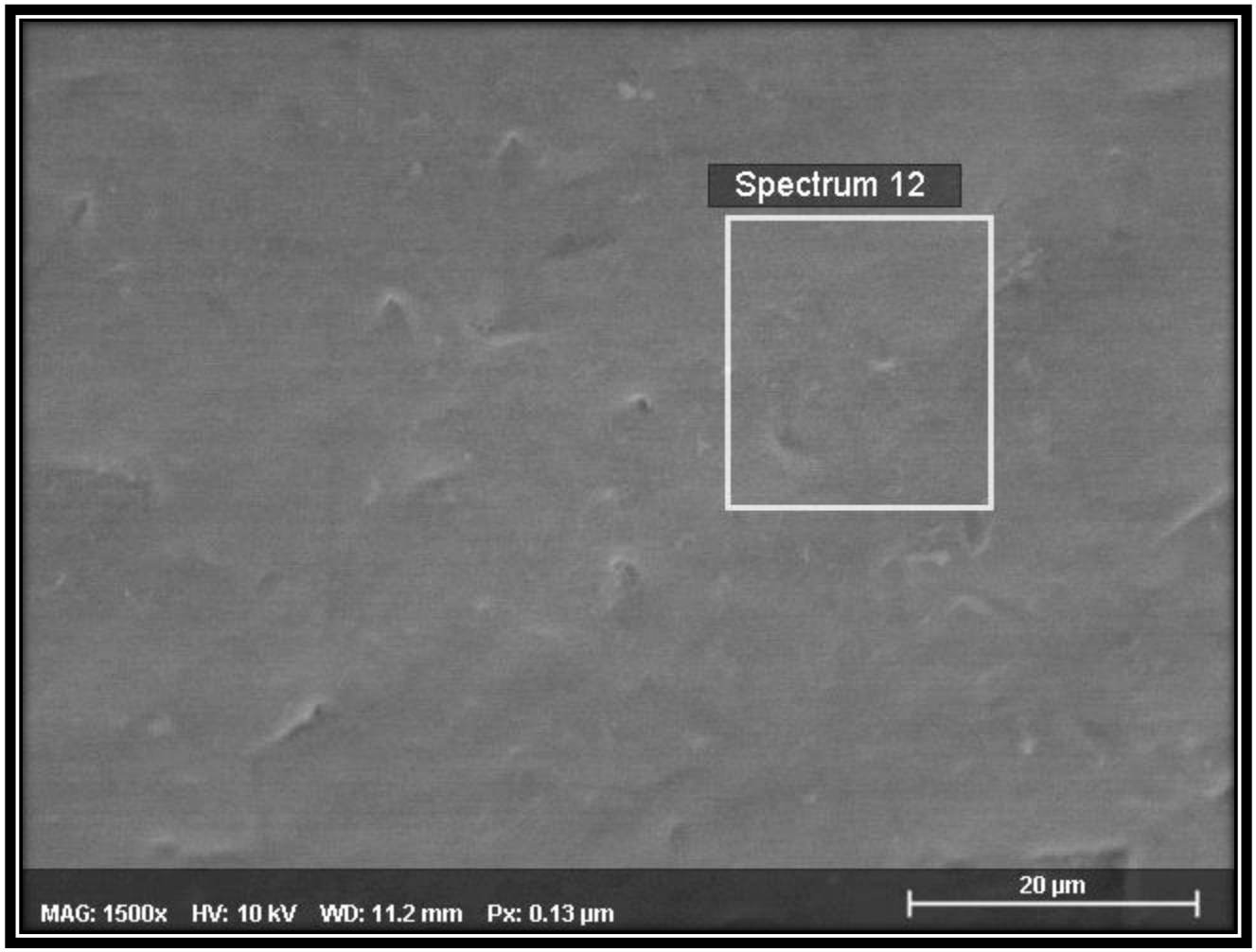
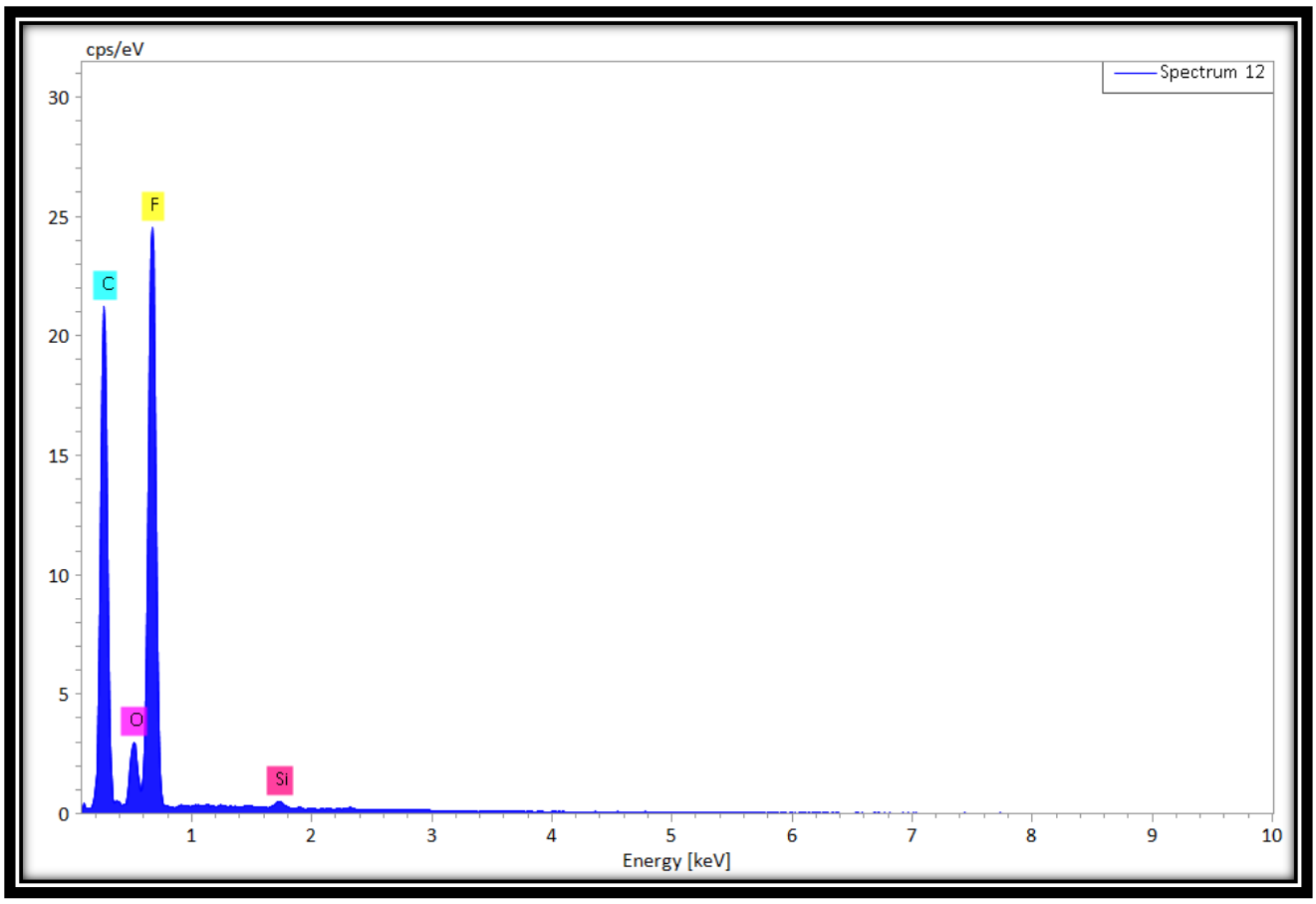


Figure 46: Electron micrograph of the cleaned membrane surface at 1500X magnification (Spectrum 12).



EDS and composition bar graph analysis of the membrane deposit from Spectrum 12.

Spectrum 12

Element	Atom [%]
Carbon	55.59
Oxygen	6.58
Silicon	0.21
Fluorine	37.61
	100.00

Table 14: Composition table from the EDS spectrum of localized deposit from Spectrum 12.

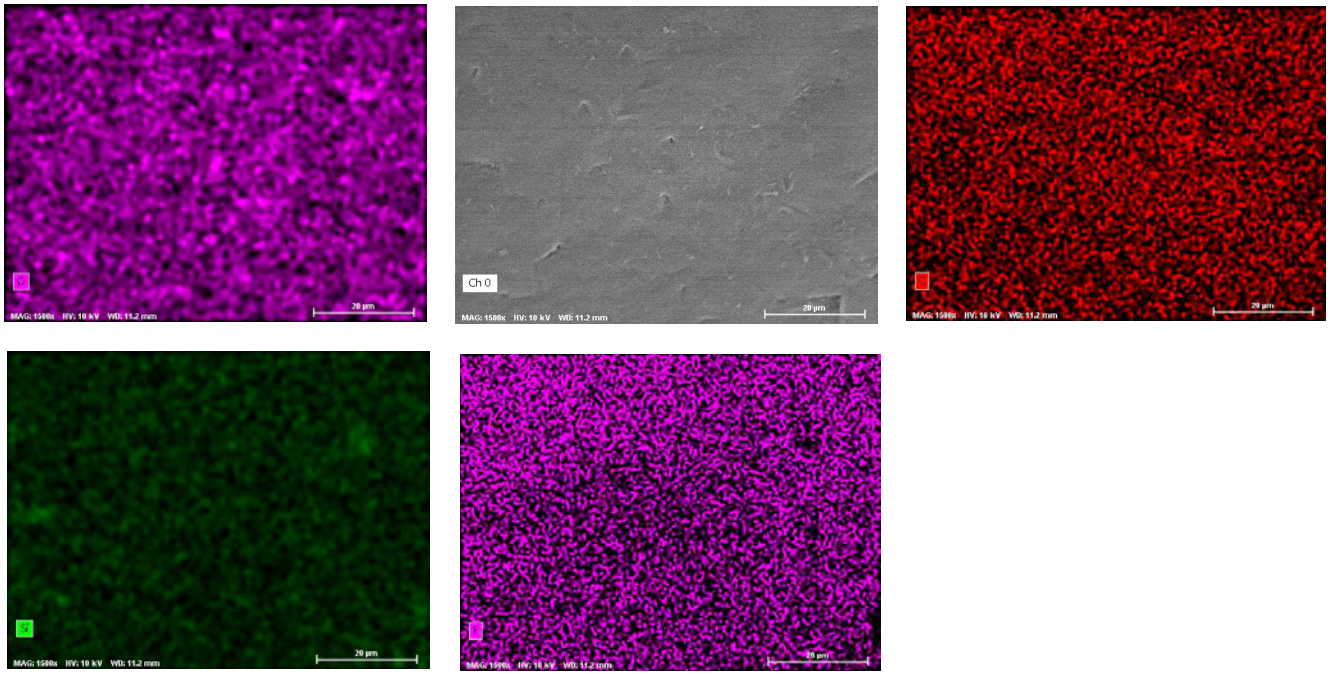


Figure 47: Prismatic Elemental Delineation (PED®) of the cleaned membrane surface at 1500X magnification. Sporadic deposits of silts/clays were found.

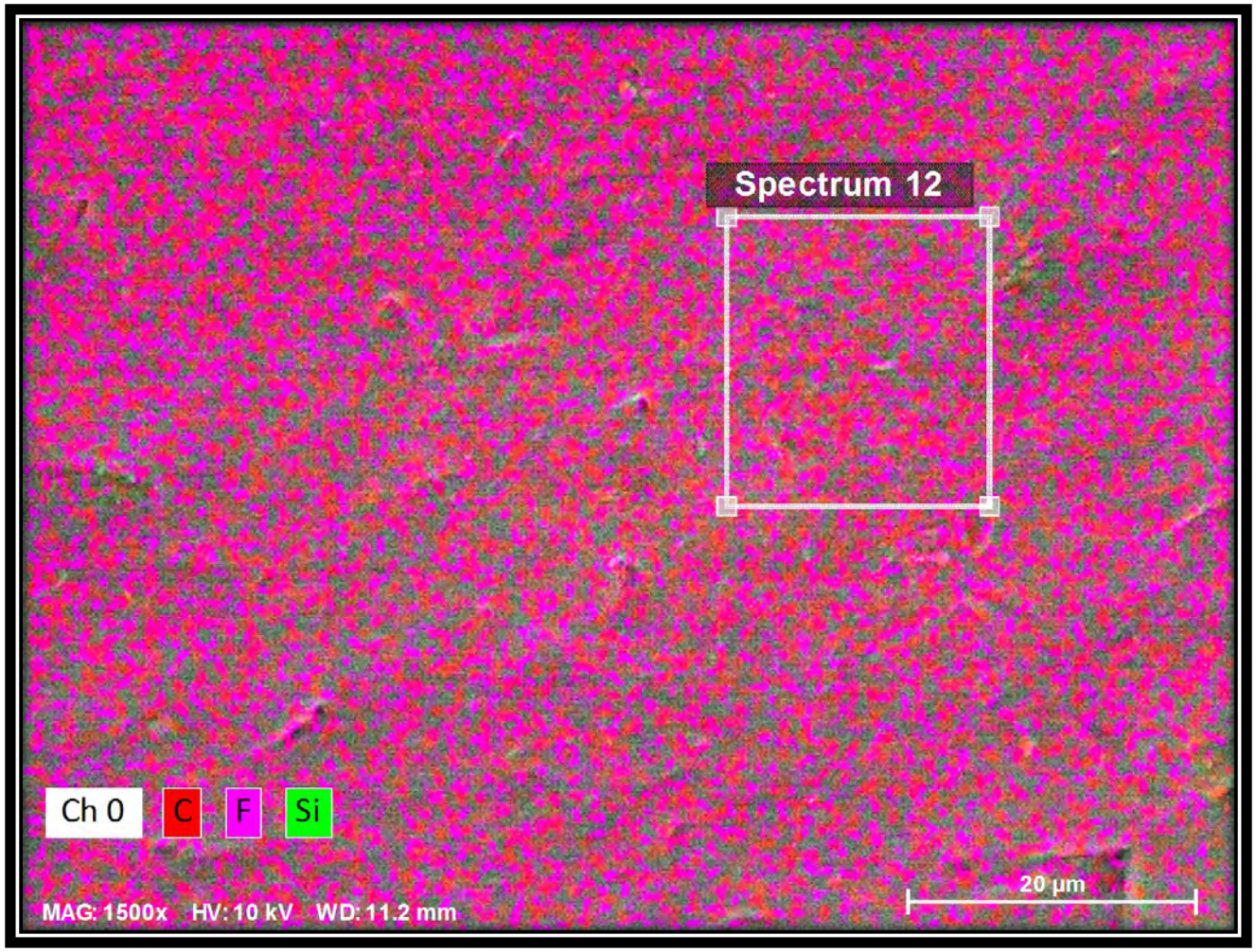


Figure 48: Superimposed Elemental Imaging (SEI®) of the cleaned membrane surface.

Membrane Surface Analysis

Low Voltage Secondary Electron Imaging can be used to determine the condition of the membrane surface. The samples are sputtered with a thin layer of gold to decrease “charging” and allow observation at higher resolutions. Membrane artifacts and surface tears on a cleaned membrane are measured and characterized.

Results

Surface damage was observed on the fiber surface. The size of the damage ranged from <1.5 μm to ~6 μm.

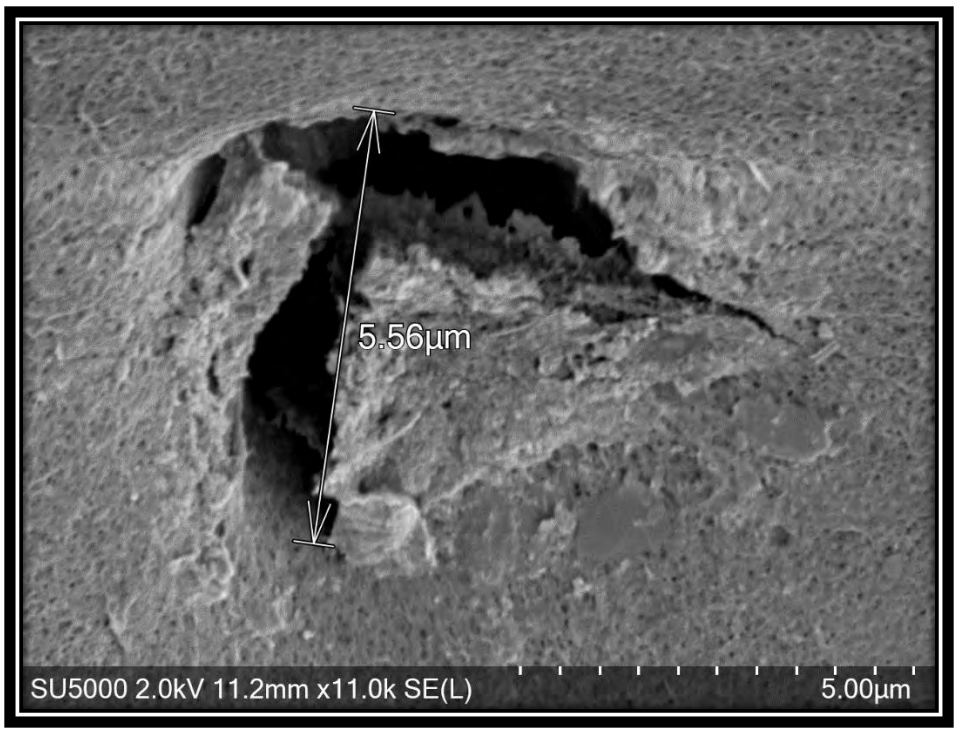


Figure 49: Electron micrograph of the damaged membrane surface at 11000X magnification. The size of the damage was ~5.6 µm.

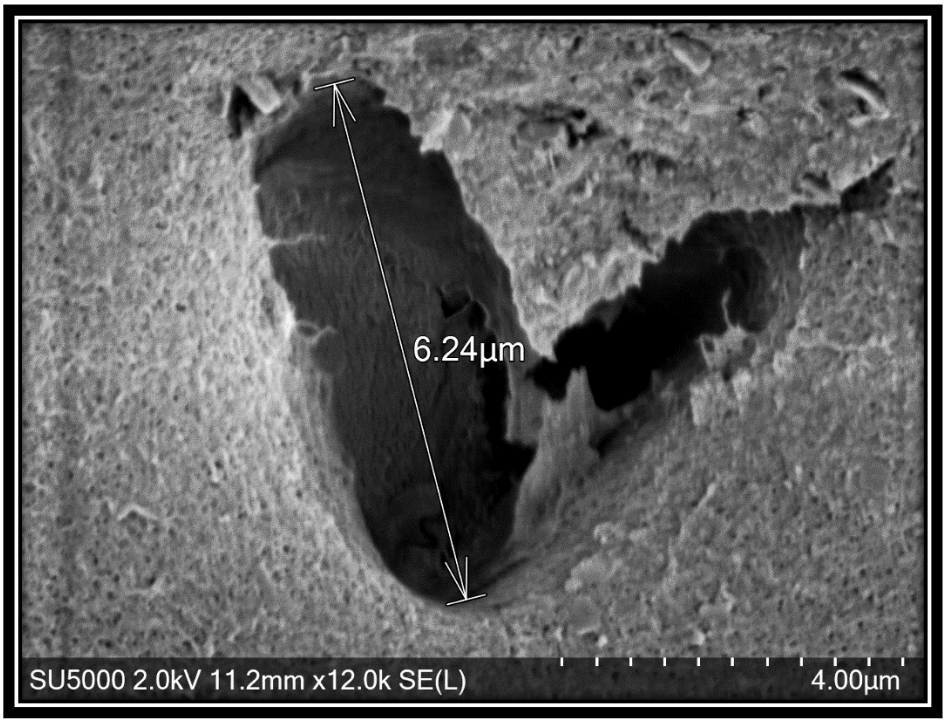


Figure 50: Electron micrograph of the damaged membrane surface at 12000X magnification. The size of the damage was ~5.6 µm.

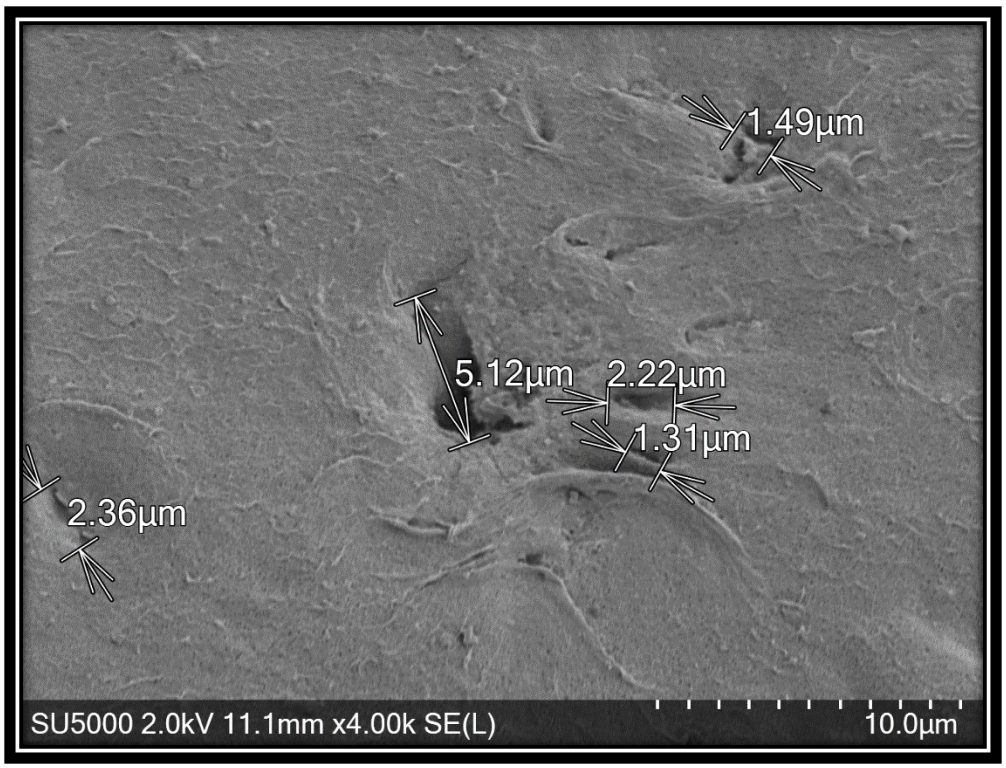


Figure 51: Electron micrograph of the damaged membrane surface at 4000X magnification. The size of the damage ranged from <1.5 µm to ~ 5 µm.

FTIR analysis

Fourier Transform Infrared spectrometer (FTIR) is a powerful tool for identifying types of chemical bonds (functional groups). The wavelength of light absorbed is characteristic to the chemical bond. The tested material can be identified by comparing its spectrum to the spectra of documented compounds in the database.

The following samples were analyzed with FTIR:

- The membrane foulant dehydrated at 105°C for 8 hours (see Figure 52).
- The LOI residue of the foulant collected from the membrane surface (see Figure 57).

Results: Dehydrated Foulant

The spectrum of the dehydrated foulant had peaks that were associated with biofilm. A library search found matches to proteins and yeast. A search in AWC's database found a high correlation to a known biofilm sample.

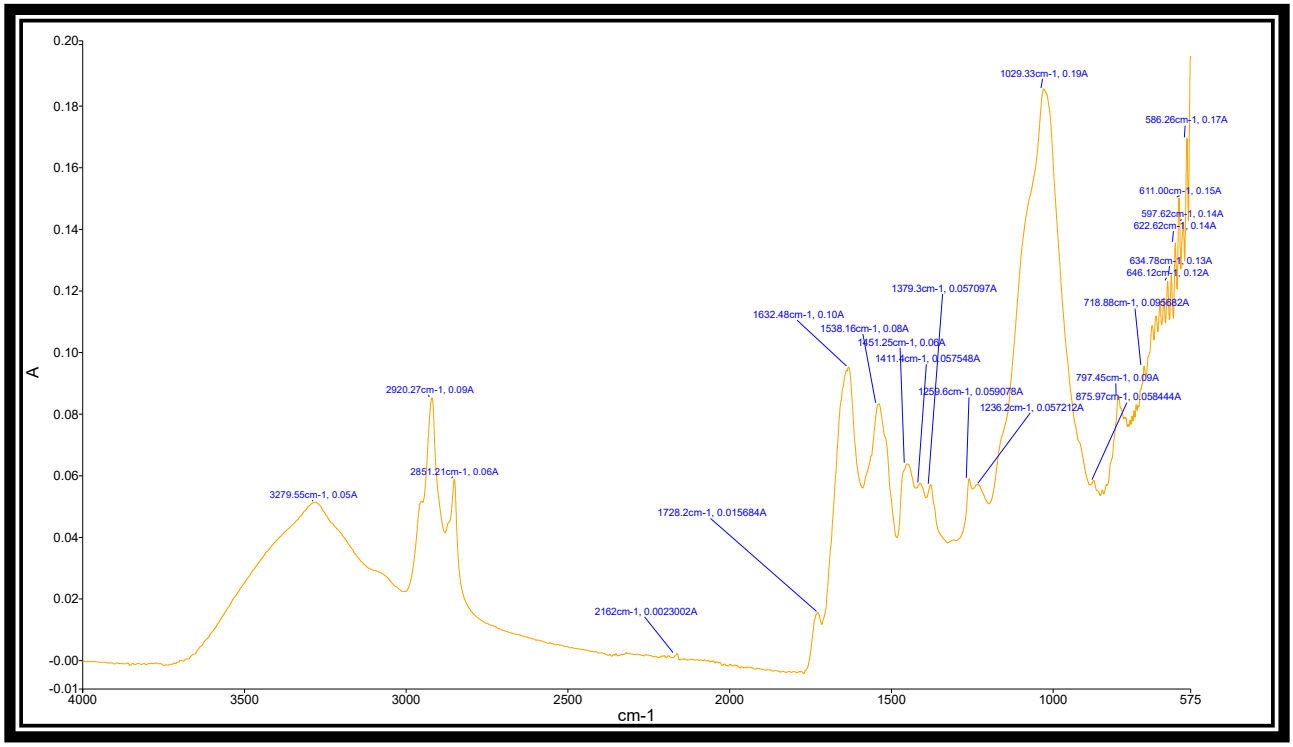


Figure 52: FTIR spectrum of the dehydrated foulant.

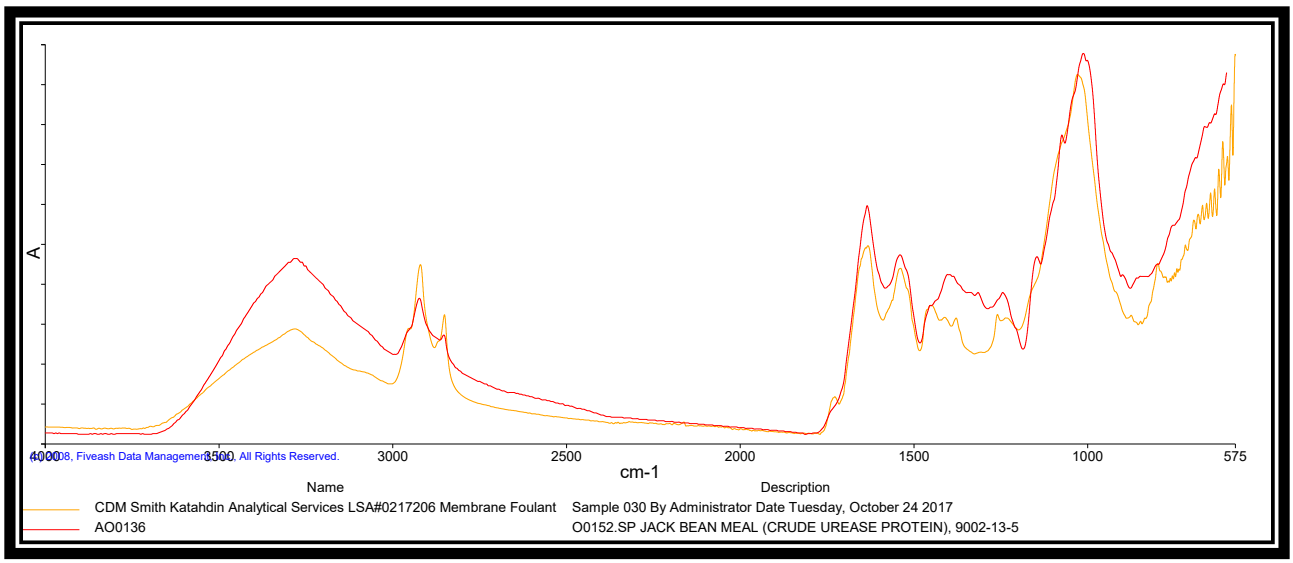


Figure 53: The spectrum of the dehydrated foulant had a ~86% correlation to protein.

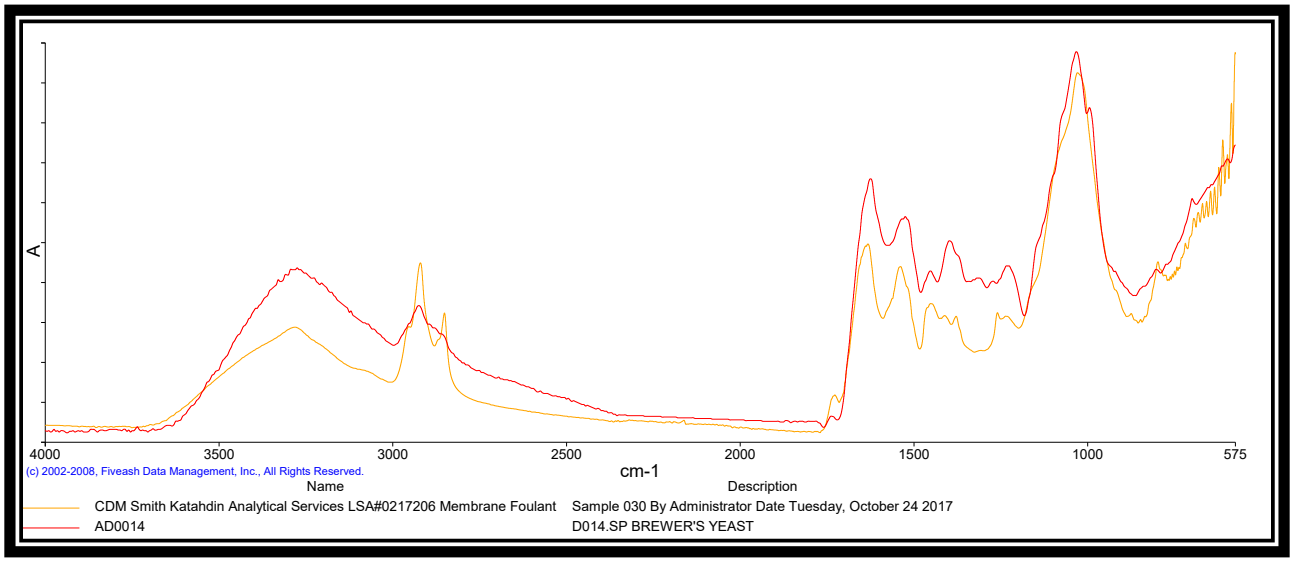


Figure 54: The spectrum of the dehydrated foulant had a ~80% correlation to yeast.

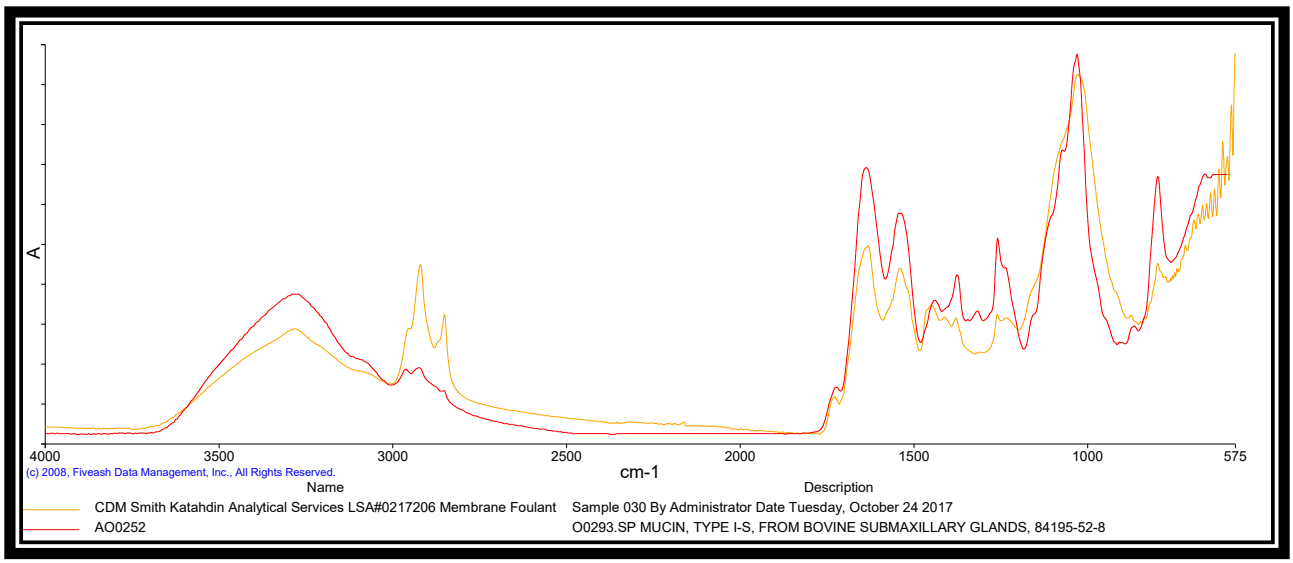


Figure 55: The spectrum of the dehydrated foulant had a ~79% correlation to mucin.

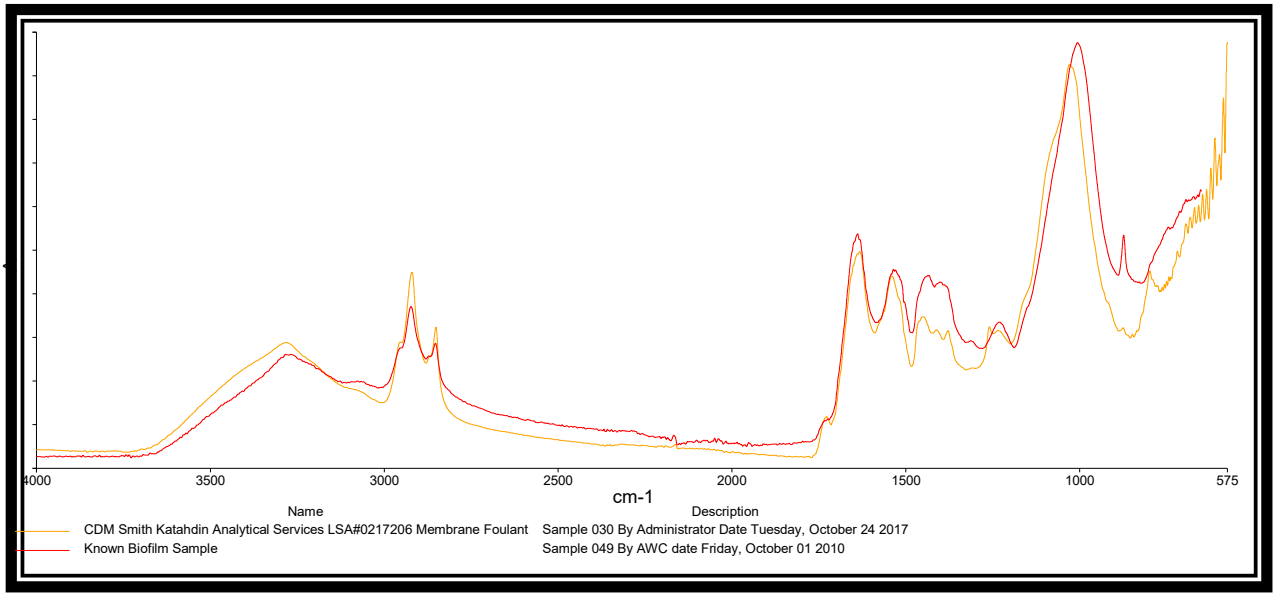


Figure 56: The spectrum of the dehydrated foulant had a ~89% correlation to a known biofilm sample.

Results: LOI residue

The spectrum of the LOI residue had peaks that were associated with crystalline silica. A library search found correlations to aluminosilicate minerals.

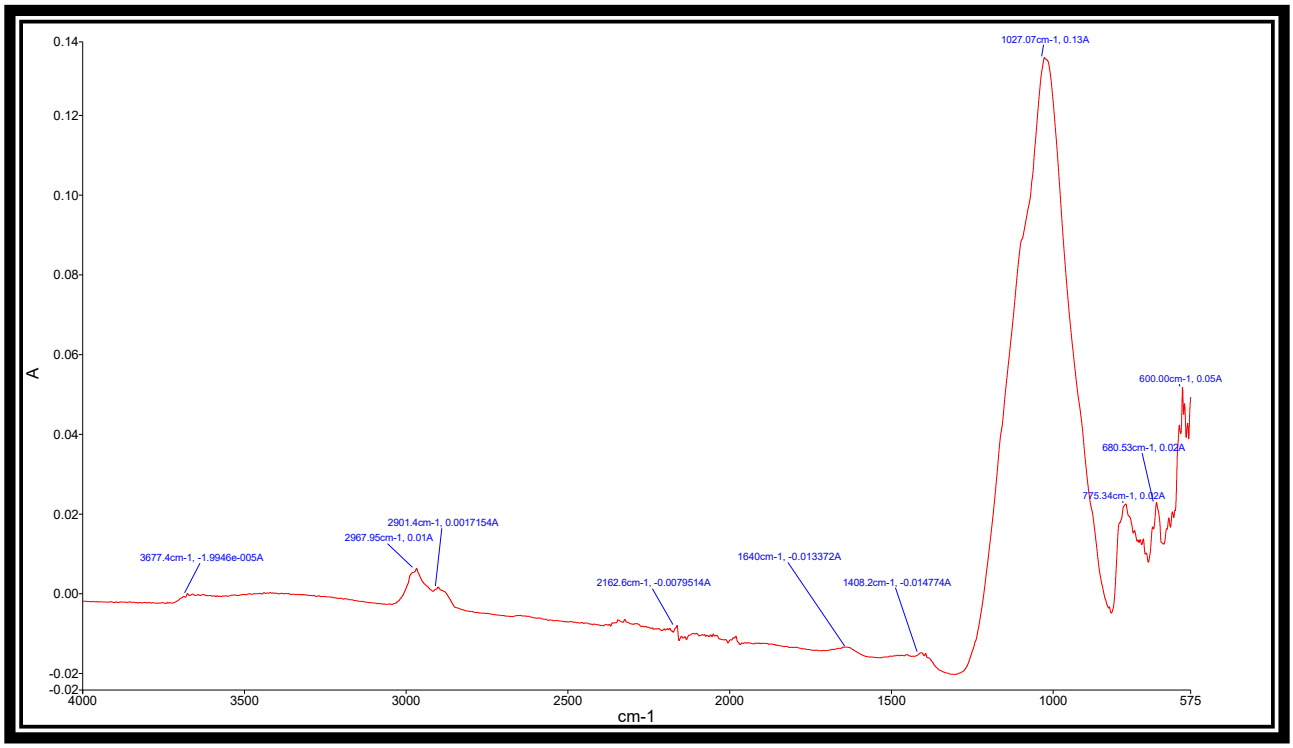


Figure 57: FTIR spectrum of the of the LOI residue.

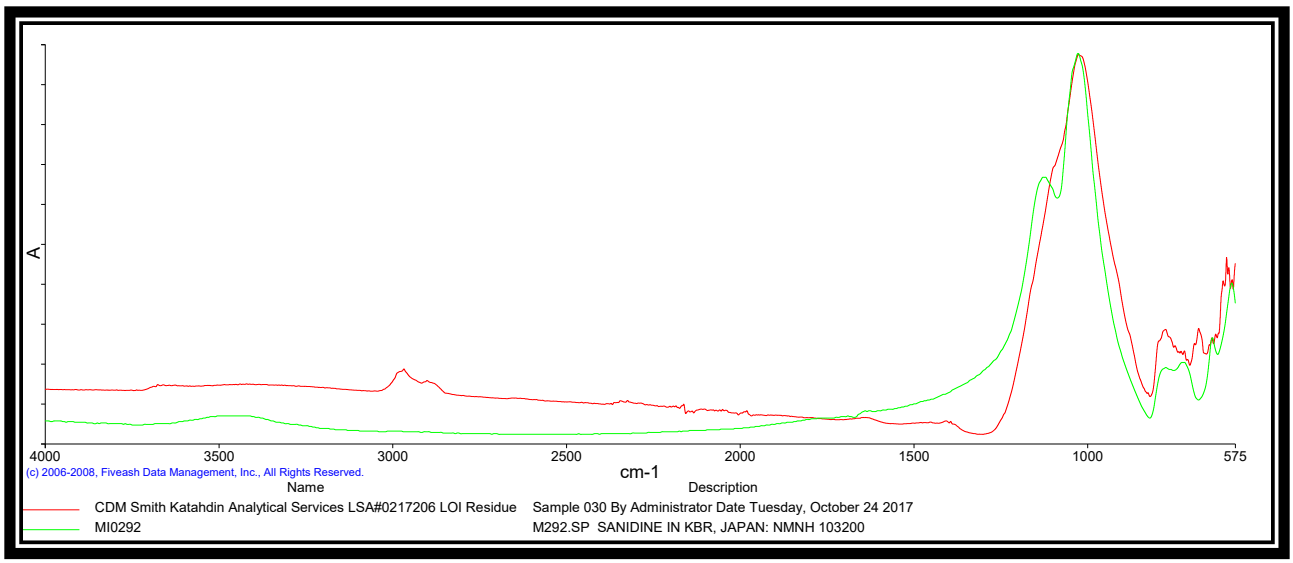


Figure 58: The spectrum of the LOI residue had a 68% correlation to Sanidine (aluminosilicate mineral).

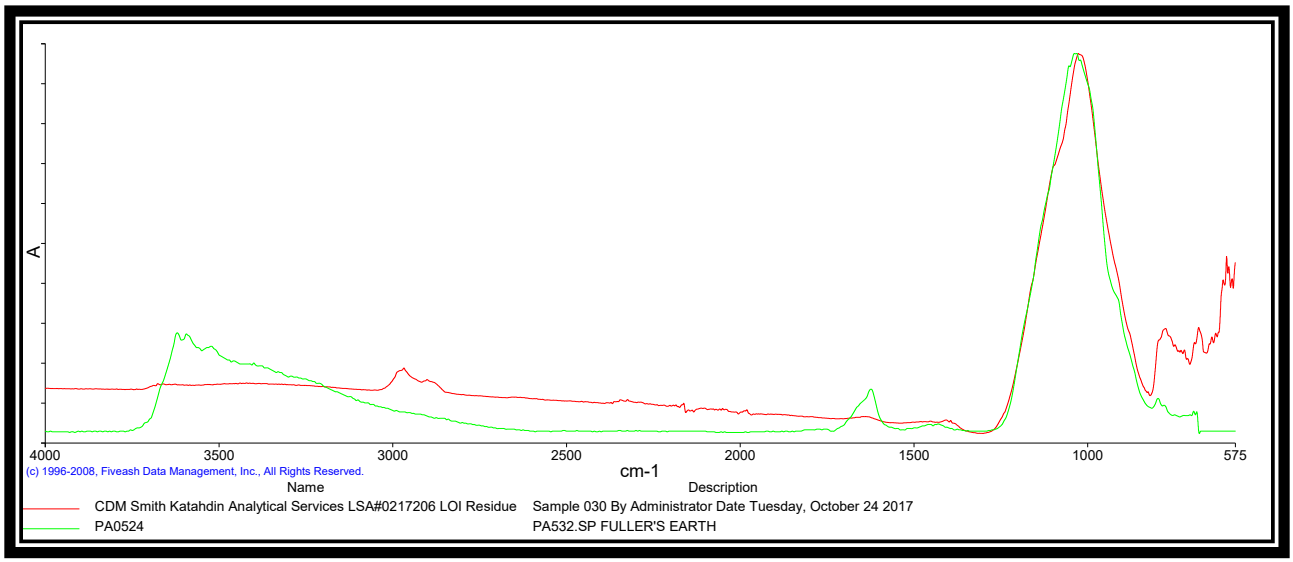


Figure 59: The spectrum of the LOI residue had a ~67% correlation to Fuller's earth (aluminosilicate mineral).

Raman Spectroscopy

Raman spectroscopy is used to identify molecules and study chemical bonding through the inelastic scattering of light caused by the vibrations of molecules. A laser beam is used to irradiate a sample, and the resulting scattered radiation provides information about vibrational frequencies that are specific to a molecule's chemical bonds and symmetry. The unknown material can be identified by comparing its spectrum to the spectra of known compounds in a database.

Results

The Raman spectrum of the foulant did not match any spectra in the AWC database.

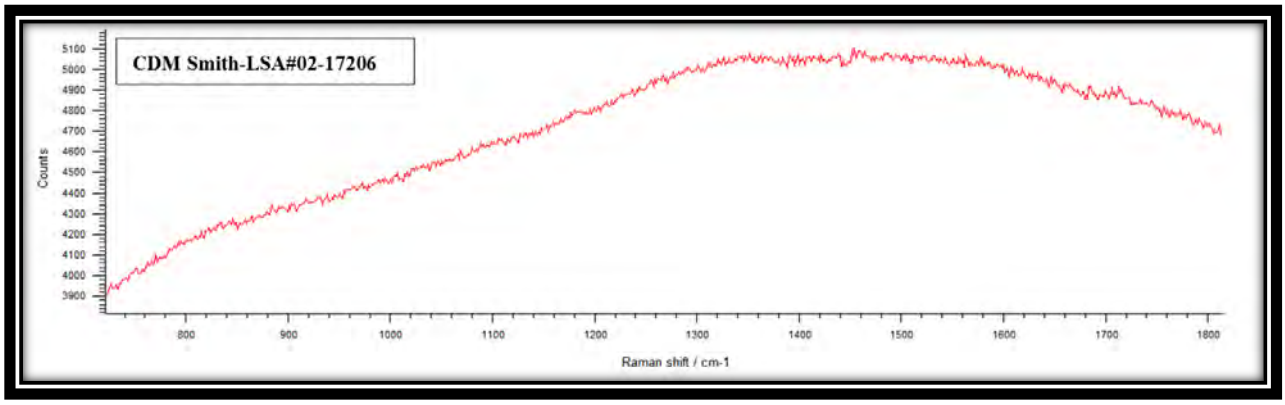


Figure 60: Raman spectrum of the foulant.

Results and Discussion

Black and brown foulant were found on the fibers. The LOI test determined the foulant to consist of ~59% organic matter and ~41% inorganic matter.

Initial results showed the flux to be ~5% below the manufacture's specification. High pH cleaning with AWC UF-426 for 6 hours increased the permeability by ~3% when compared with the initial results. After high pH cleaning with AWC UF-429, the permeability increased by 5% above initial performance.

SEM/EDS/SEI/PED analysis of the membrane surface found the foulant to consist of organic based matter, calcium sulfate, silts and/or clays, phosphate salts (aluminum, calcium and iron), iron hydroxide and titanium oxide. Filamentous bacteria or morphologically similar organisms were also present.

Post cleaning membrane surface analysis found tears on the fiber.

FTIR analysis of the foulant found spectra associated with biofilm and silts/clays.

Release of Liability

The Membrane Autopsy Service (The Service) was performed in accordance with the standards of care, skill, and diligence normally provided by a professional in the performance of similar services. American Water Chemicals, Inc. makes no warranty of any kind with the respect to The Service and will not be liable for any damages resulting from the use or misuse of The Service. In no event shall American Water Chemicals, Inc. have any liability for The Service, including, but not limited to, special, indirect, incidental, consequential, or other direct damages whether such liability arises in contract, negligence, strict liability, or otherwise, and the Client hereby agrees to release and indemnify American Water Chemicals, Inc. against same.

awc

Membrane Autopsy Report

Date:

11-16-2017

Tests Performed For:

Manufacturer:
Model:
Position:
Serial #: SM-1015 UF
AWC LSA#: 02-17151

Tests Performed By:

Vana Abbas
Joshua Utter
Sang Ah Bare
Nicholas Raymond

Table of Contents

Introduction 3

Membrane Information 3

Shipping and Handling Condition 4

Inspection of Fibers 5

- **Top** 5
- **Middle** 6
- **Bottom** 7

Contact Angle Testing 8

- **Results** 8

Hollow Fiber Cleaning Study 9

- **Results** 9

Loss on Ignition Test with Foulant 10

- **Results** 10

Electron Microscopy and X-Ray Spectroscopy Analysis 12

Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS) with Superimposed Elemental Imaging (SEI™) 12

- **Results** 12
- **Top** 13
- **Middle** 33
- **Bottom** 47
- **Post Cleaning** 56

Membrane Surface Analysis 60

- **Results** 60

FTIR analysis 62

- **Results: Dehydrated Foulant** 62
- **Results: LOI residue** 65

Raman Spectroscopy 67

- **Results** 67

Results and Discussion 68

Release of Liability 69

Introduction

This report describes the membrane autopsy procedures performed for **CDM Smith Katahdin Analytical Services.**
The observed findings are presented herein.

Membrane Information

Product Code	Main Application	Membrane Type	Filtration Mode	Serial Number
SHU-2024	**MBR**	**Hollow Fiber-PVDF**	**Outside-in**	**N/A**

Figure 1: Membrane Information.

Figure 2: Module #1.

Shipping and Handling Condition

Figure 3: The fibers arrived packaged in a cardboard box and sealed.

Figure 4: The fibers were found inside plastic containers.

Figure 5: Fibers packaged in clear plastic bags.

Inspection of Fibers

Black deposits were found on the fibers.

Top

Figure 6: Black deposit found on the fibers.

Middle

Figure 7: Black deposits were found on the fibers. Some fibers had heavier black deposits than others.

Bottom

Figure 8: Black deposits found on the fibers.

Contact Angle Testing

Contact angle testing is used to determine the hydrophobicity of a membrane. Higher contact angles are directly correlated with a more hydrophobic surface. Membranes are less prone to fouling and have better productivity when they are less hydrophobic.

Results

Contact angle could not be measured due to the large diameter of the fibers.

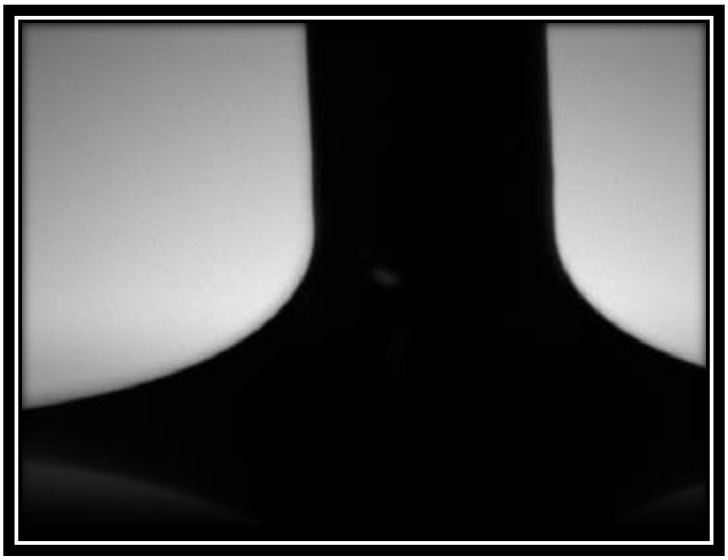


Figure 9: Contact angle could not be measured due to the large diameter of the fibers

Hollow Fiber Cleaning Study

A hollow fiber cleaning study is performed to identify a cleaning regimen that will restore membrane performance. A set of representative fibers are collected from the module and soaked in deionized water for 24 hours. They are then potted into a small benchtop module manufactured by AWC. The module is then tested under the same conditions as a full module. Membrane flux measurements are made, and then a cleaning performed, with an additional performance test after each individual cleaning step determine the efficacy of the cleaning.

Results

Initial results showed the flux to be ~1.04% above the manufacture's specification. High pH cleaning with AWC UF-426 for 6 hours showed no notable improvement in permeability. After high pH cleaning with AWC UF-429, the permeability increased to 2.53% above initial performance; this was insignificant.

Since the client had reported a decline in permeability, it can be assumed that the foulant that had caused the permeability decline was removed during the 24 hour deionized water soak.

Model	**SHU-2024**
# of fibers	**3 fibers**
Filtration Mode	**Outside in**
Membrane area (ft^2)	**0.1055**
Maximum TMP (PSI)	**14.5**

	Virgin Fiber	**Initial Module Performance**	**Post High pH 2% AWC UF-426 pH 10.5, 6hr**	**Post High pH 2% AWC UF-429 pH 10.5, 6hr**
Permeability (GFD/PSI)*	7.776	7.857	7.756	8.056
%Difference from Specification	-	1.04%	-0.25%	3.6%
%Difference from initial	-	-	-1.28%	2.53%

* All values normalized for 20°C

Loss on Ignition Test with Foulant

A Loss on Ignition (LOI) test is performed to determine the organic/inorganic content of the foulant. The collected foulant samples are first heated at 105 °C overnight to remove moisture and volatile compounds. The dehydrated samples are then fired at 450 °C for 8 hours to combust any organic materials. The percentages of moisture, organics and inorganics are then calculated based on the loss of mass. This test is limited to material that can be scraped from the surface using a spatula, and the results should be considered within that context.

Results

The foulant on the membrane surface consisted of ~66% organic matter and ~34% inorganic matter.

	Foulant from membrane	Calculated Without Moisture
Moisture and Volatiles	99.25%	--
Organic Content	0.50%	65.73%
Inorganic Content	0.26%	34.27%

Table 1: LOI results for foulant from the membrane surface.

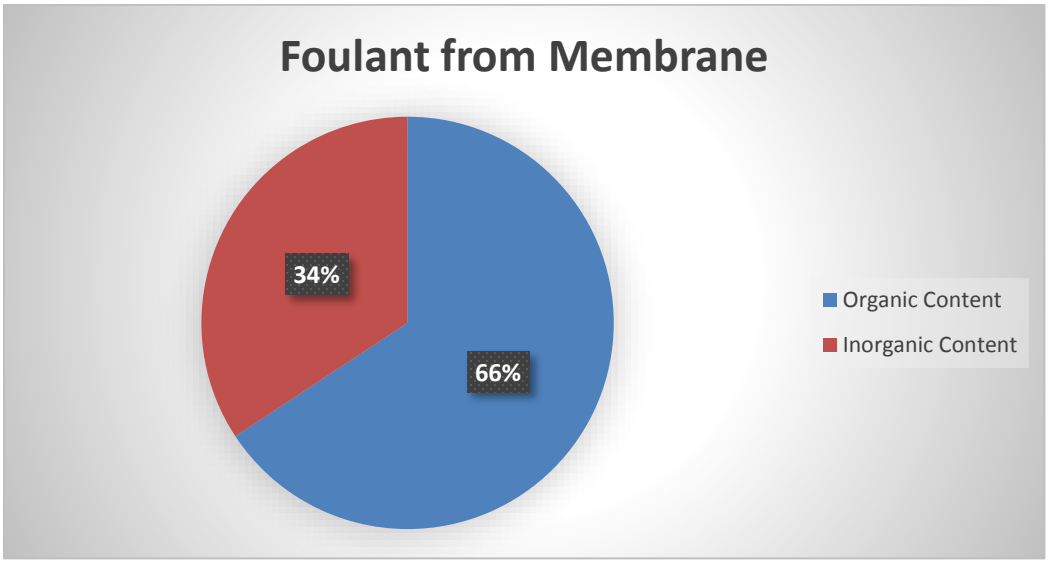


Figure 10: LOI results chart from table 1.

Figure 11: LOI residue.

Electron Microscopy and X-Ray Spectroscopy Analysis

Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS) with Superimposed Elemental Imaging (SEI™)

Scanning Electron Microscopy (SEM) analysis is used to determine the topography and morphology of a sample. The SEM shows very detailed 3-dimensional images at much higher magnification than an optical microscope.

Energy Dispersive X-ray Spectroscopy (EDS) analysis is generally performed together with electron microscopy to identify and quantify the elemental composition of a sample surface. The sample material is bombarded with electrons from an SEM which produce X-rays. The produced X-rays are then measured by an X-ray dispersive spectrometer. Every chemical element has its own characteristic wavelength by which it can be identified. EDS spectra, together with composition (Weight percent and Atomic percent) are attached in the section.

Results

Top

The deposit on the top fibers consisted of organic based matter, elemental sulfur, calcium phosphate, iron hydroxide, titanium dioxide, silts and/or clays. Inorganic carbon was identified based on its geometric morphology. A single iron disulfide (pyrite) particle was identified.

Middle

The deposit on the middle fibers consisted of calcium sulfate, organic based matter, iron hydroxide, silts and/or clays.

Bottom

The deposit on the bottom fibers consisted of calcium sulfate, organic based matter, iron hydroxide and silts/clays.

Top

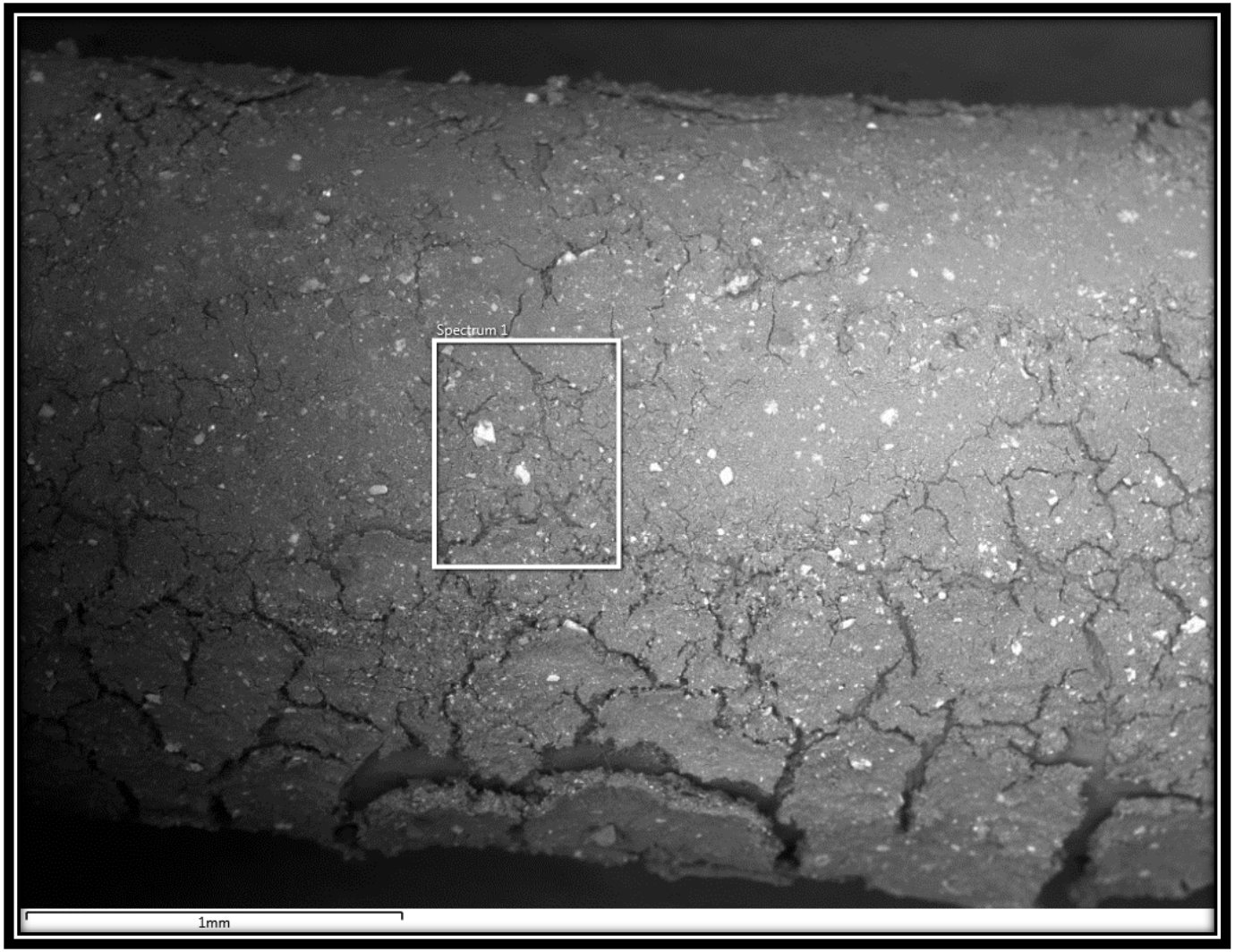


Figure 12: Electron micrograph of the membrane surface at 40X magnification (Spectrum 1).

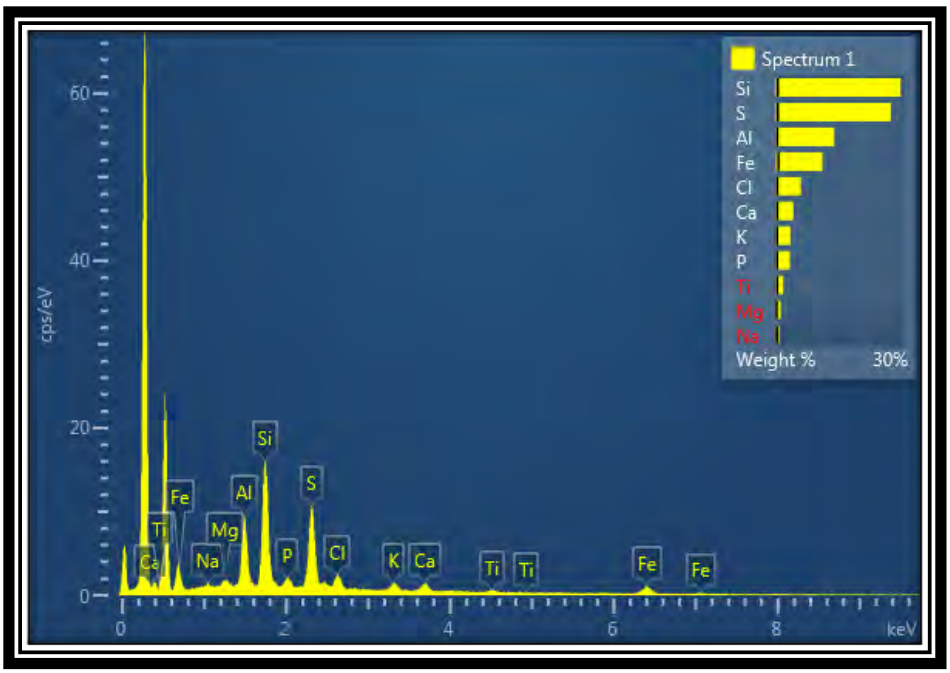


Figure 13: EDS and composition bar graph analysis of the membrane deposit from Spectrum 1.

Spectrum 1	Atomic %
C	69.28
N	3.77
O	20.13
F	1.84
Na	0.06
Mg	0.09
Al	0.92
Si	1.67
P	0.14
S	1.19
Cl	0.22
K	0.13
Ca	0.16
Ti	0.06
Fe	0.35
Total	100.00

Spectrum 1	Atomic %
Carbon, Oxygen, Nitrogen and Fluorine Ignored	
Na	1.06
Mg	1.50
Al	16.04
Si	32.99
P	3.32
S	26.63
Cl	5.20
K	2.73
Ca	3.23
Ti	1.10
Fe	6.19
Total	100.00

Table 2: Composition table from the EDS spectrum of localized deposit from Spectrum 1.

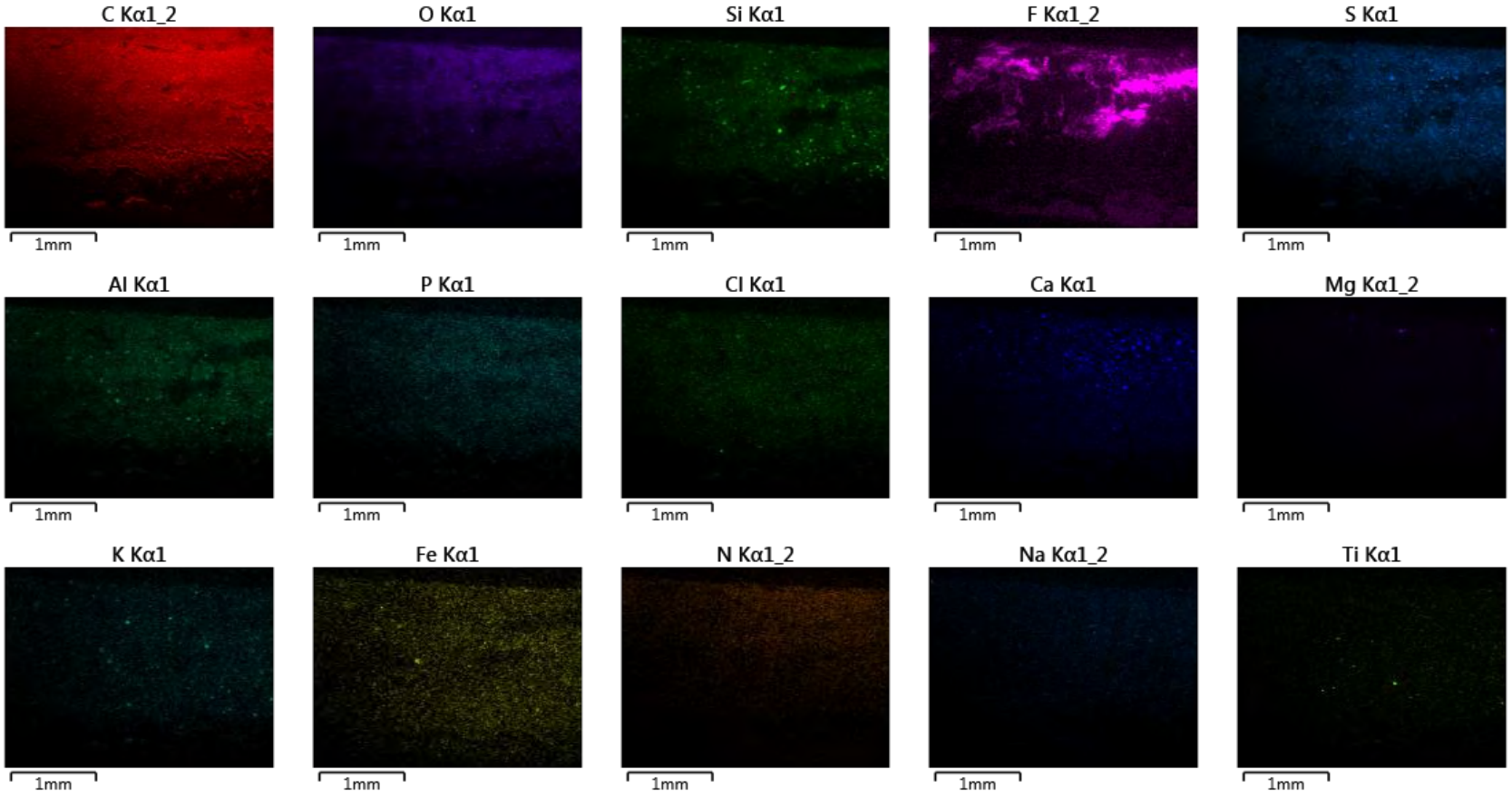


Figure 14: Prismatic Elemental Delineation (PED®) of membrane surface at 40X magnification. Deposits found: Organic based matter, elemental sulfur, titanium dioxide and silts/clays.

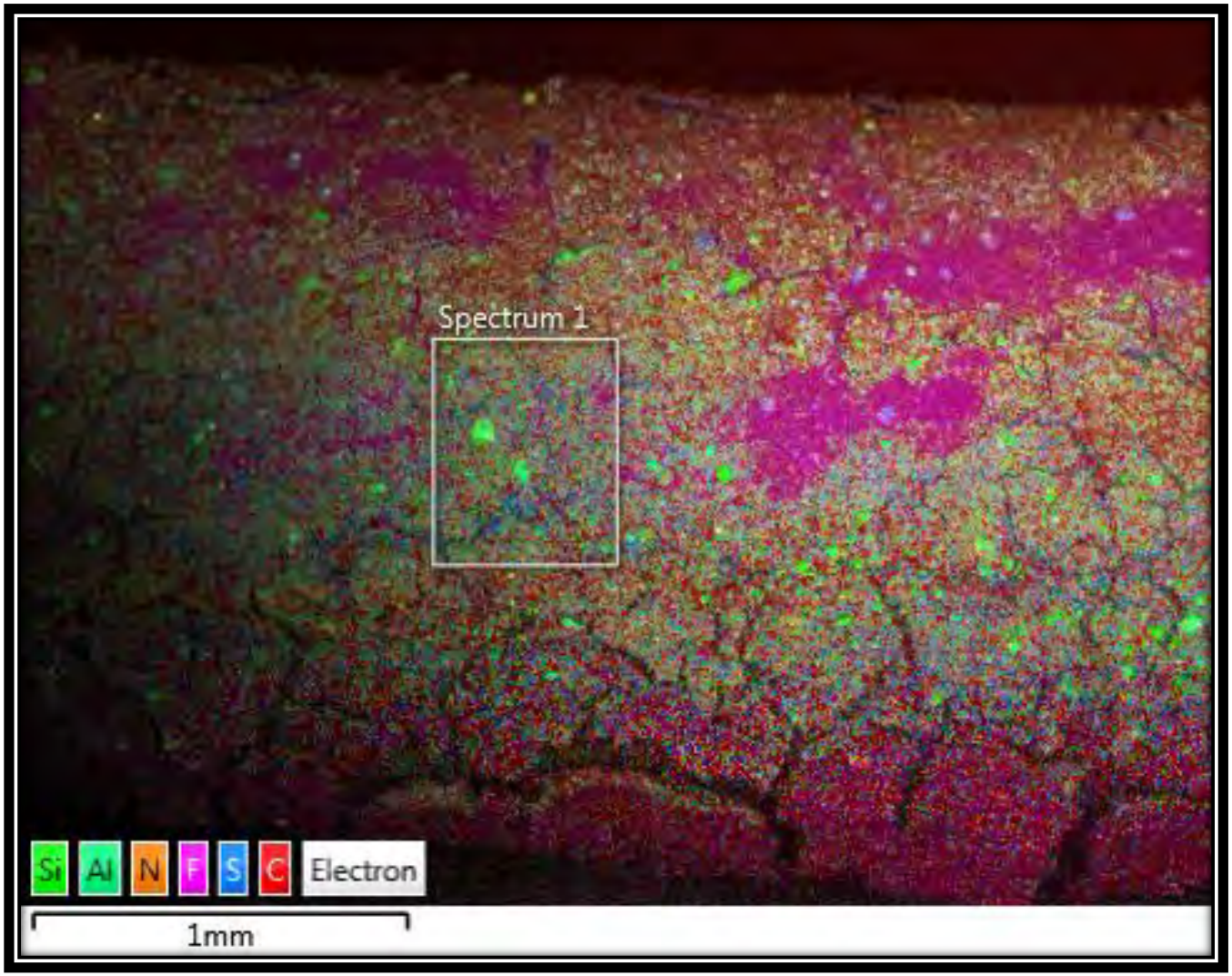
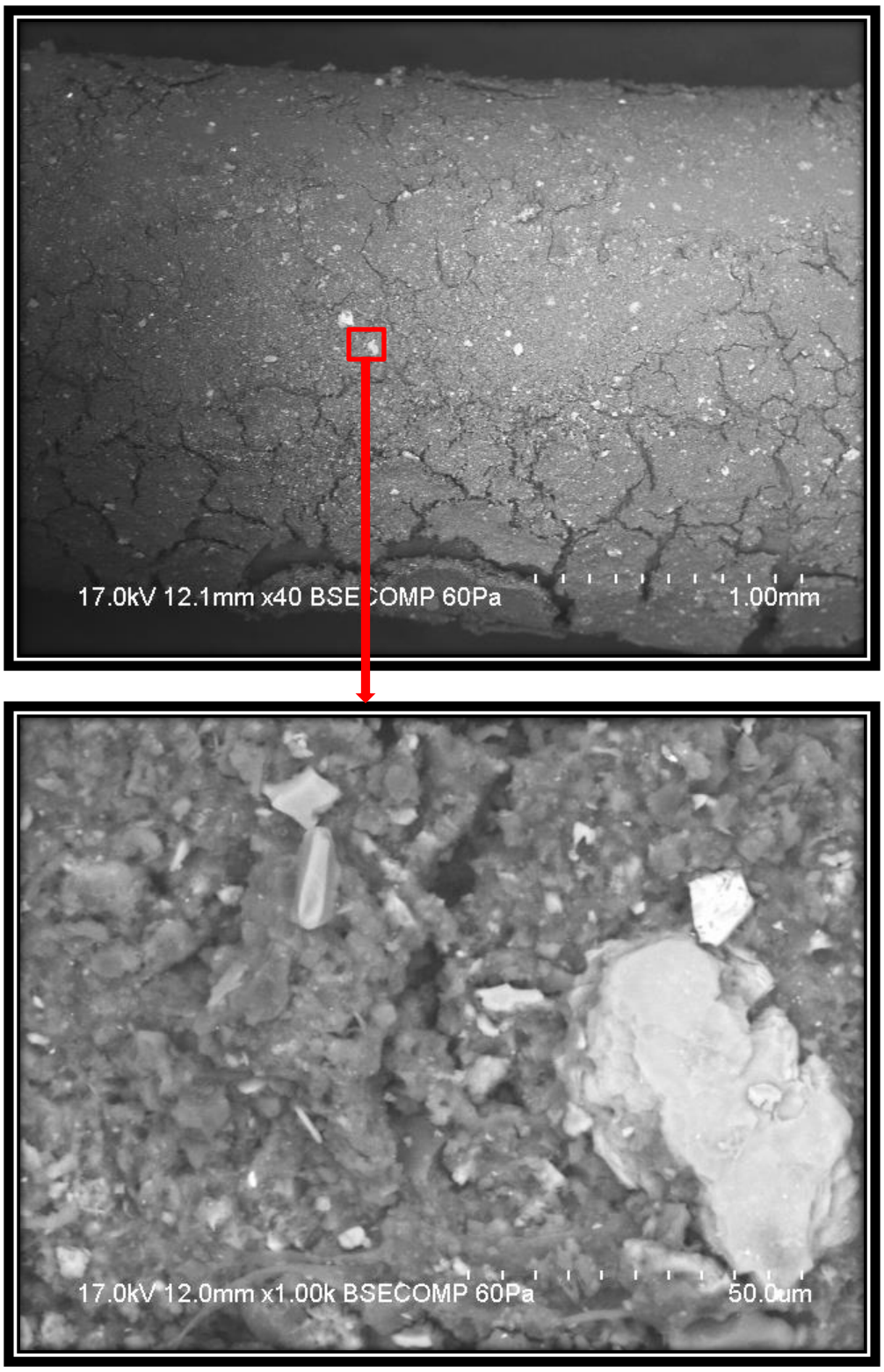


Figure 15: Superimposed Elemental Imaging (SEI®) of organic based matter, elemental sulfur, titanium oxide and silts/clays.


17.0kV 12.1mm x40 BSECOMP 60Pa
1.00mm
17.0kV 12.0mm x1.00k BSECOMP 60Pa
50.0um

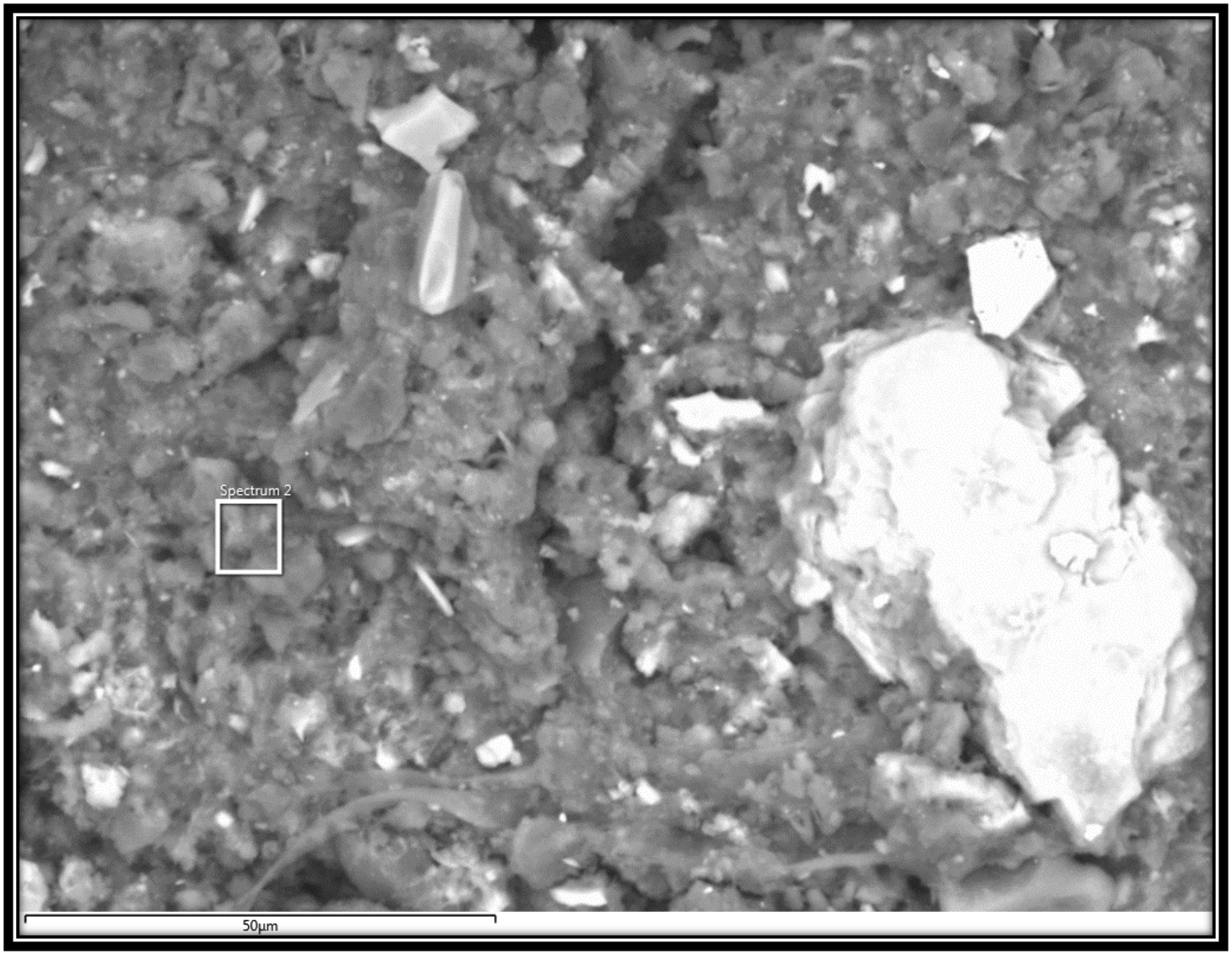


Figure 16: Electron micrograph of the membrane surface at 1000X magnification (Spectrum 2).

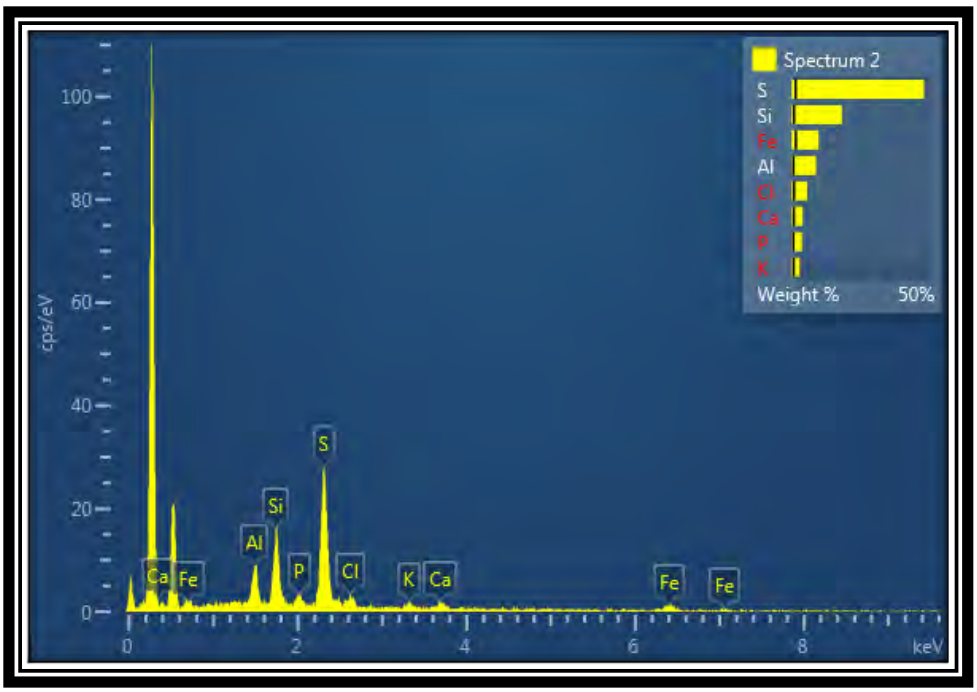


Figure 17: EDS and composition bar graph analysis of the membrane deposit from Spectrum 2.

Spectrum 2	Atomic %
C	76.73
N	3.29
O	15.31
Al	0.56
Si	1.03
P	0.17
S	2.16
Cl	0.19
K	0.10
Ca	0.14
Fe	0.30
Total	100.00

Spectrum 2	Atomic %
Carbon, Nitrogen and Oxygen Ignored	
Al	10.59
Si	20.96
P	3.90
S	48.20
Cl	5.16
K	2.37
Ca	3.19
Fe	5.62
Total	100.00

Table 3: Composition table from the EDS spectrum of localized deposit from Spectrum 2.

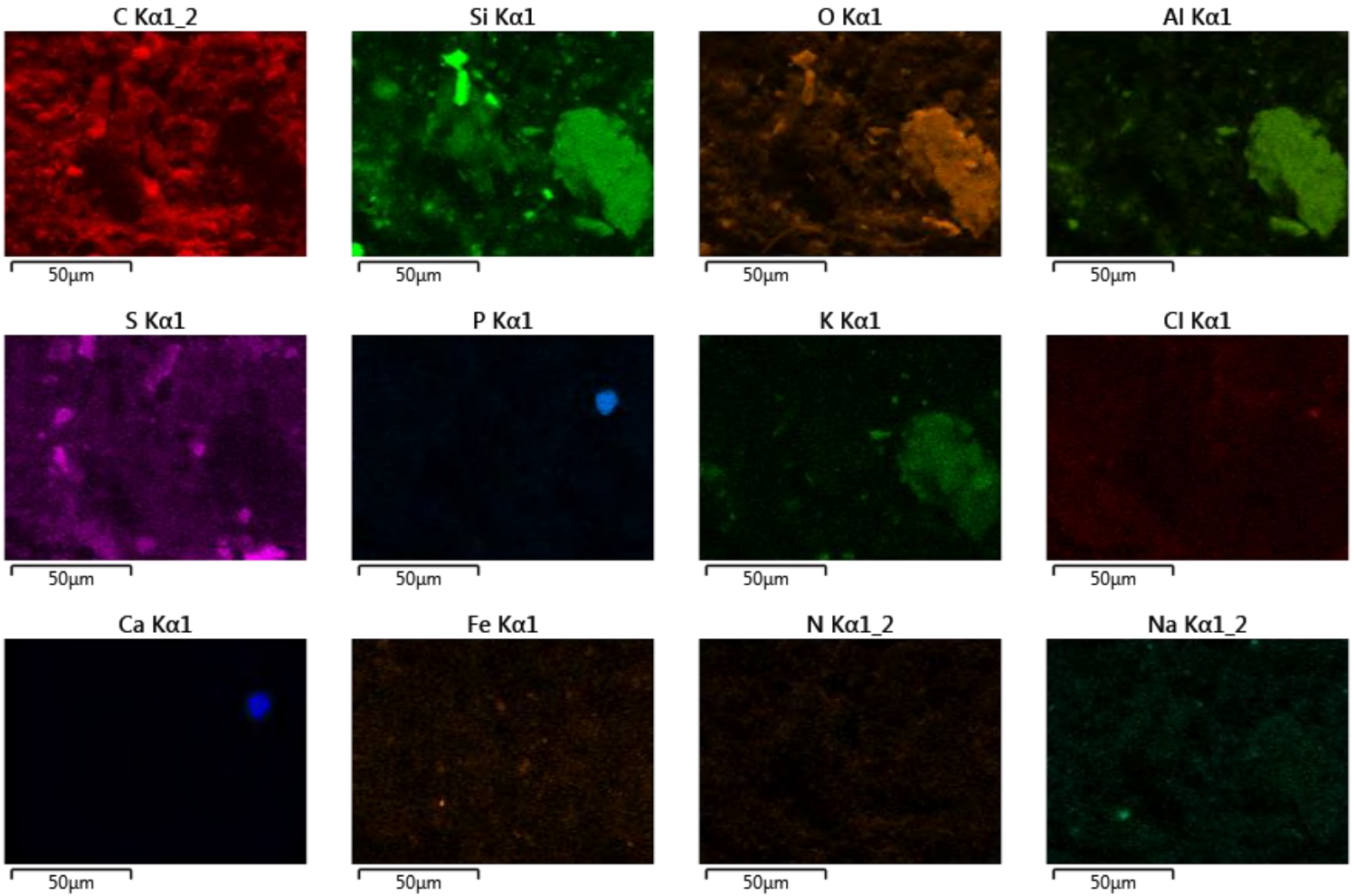


Figure 18: Prismatic Elemental Delineation (PED®) of membrane surface at 1000X magnification. Deposits found: Organic based matter, elemental sulfur, calcium phosphate, silts and/or clays.

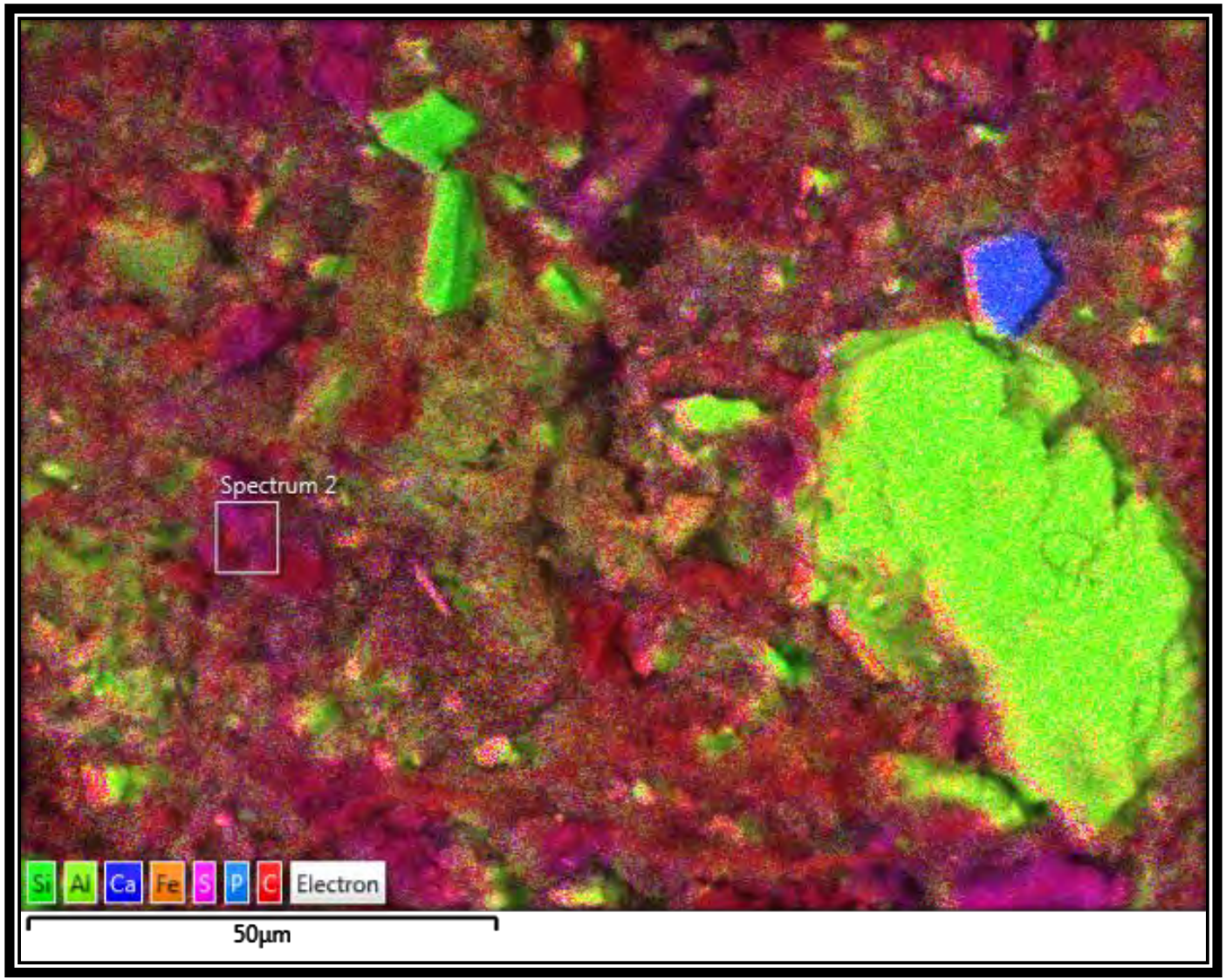


Figure 19: Superimposed Elemental Imaging (SEI®) of organic based matter, elemental sulfur, calcium phosphate, silts and/or clays.

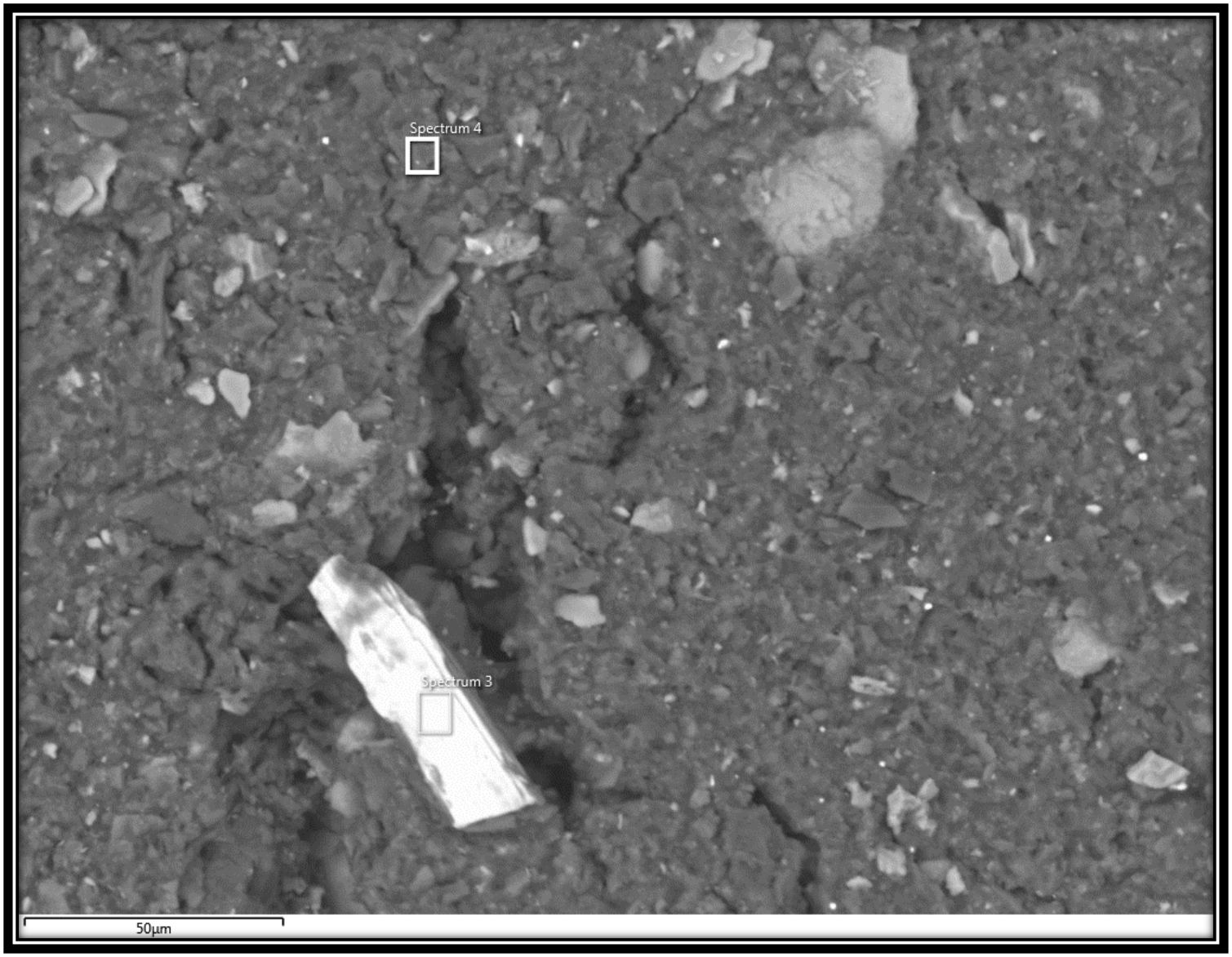


Figure 20: Electron micrograph of the membrane surface at 550X magnification (Spectrum 3 & Spectrum 4).

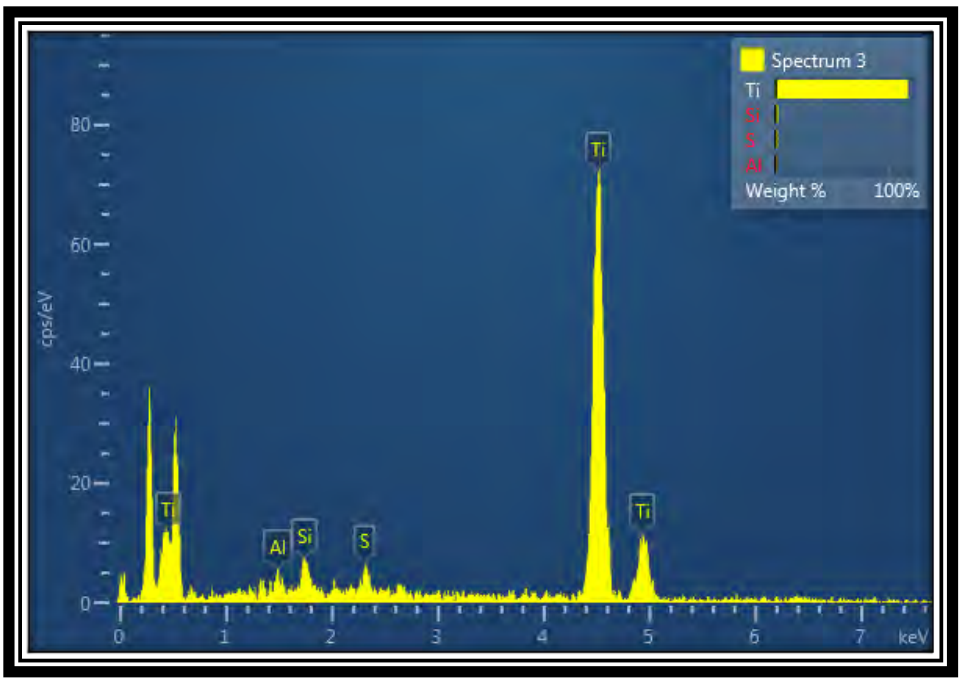


Figure 21: EDS and composition bar graph analysis of the membrane deposit from Spectrum 3.

Spectrum 3	Atomic %
C	37.08
O	41.97
Al	0.48
Si	0.74
S	0.61
Ti	19.11
Total	100.00

Spectrum 3	Atomic %
Carbon and Oxygen Ignored	
Al	2.57
Si	3.93
S	3.09
Ti	90.41
Total	100.00

Table 4: Composition table from the EDS spectrum of localized deposit from Spectrum 3.

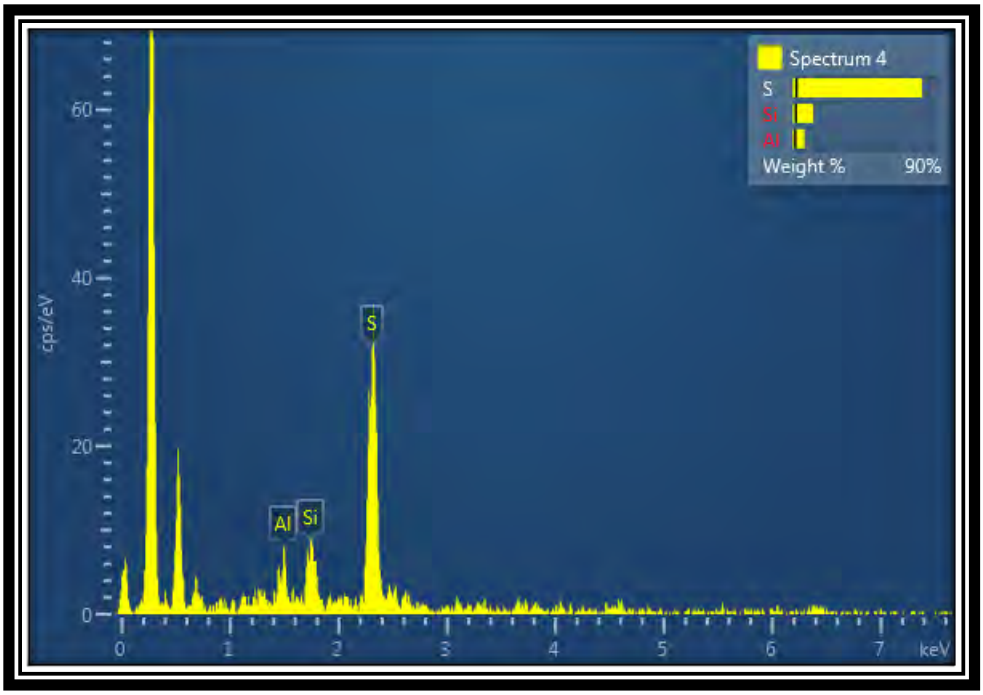


Figure 22: EDS and composition bar graph analysis of the membrane deposit from Spectrum 4.

Spectrum 4	Atomic %
C	80.51
O	13.99
F	1.22
Al	0.41
Si	0.64
S	3.23
Total	100.00

Spectrum 4	Atomic %
Carbon, Oxygen and Fluorine Ignored	
Al	8.30
Si	14.07
S	77.64
Total	100.00

Table 5: Composition table from the EDS spectrum of localized deposit from Spectrum 4.

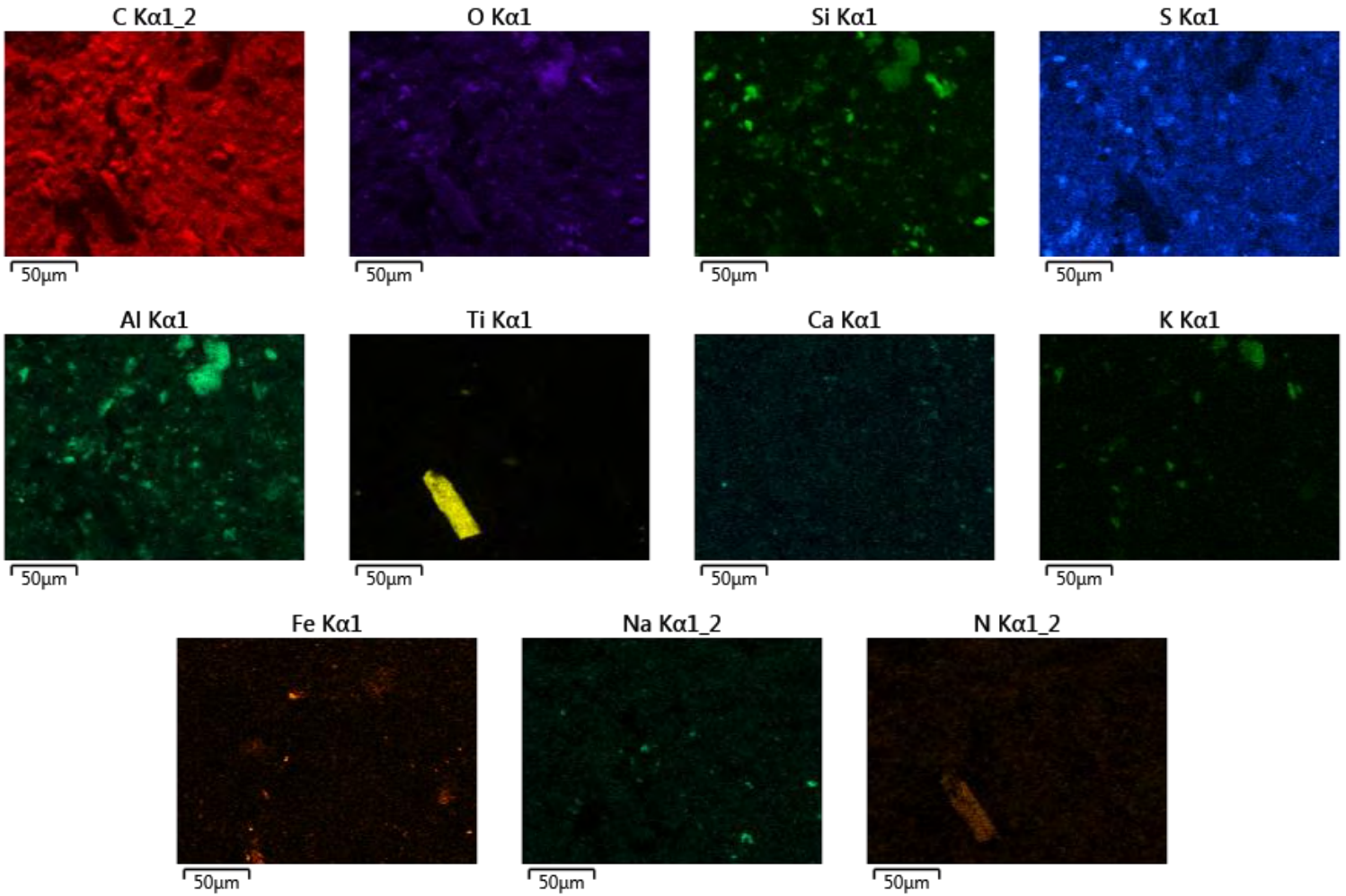


Figure 23: Prismatic Elemental Delineation (PED®) of membrane surface at 550X magnification. Deposits found: Organic based matter, titanium oxide, elemental sulfur, iron hydroxide, silts and/or clays.

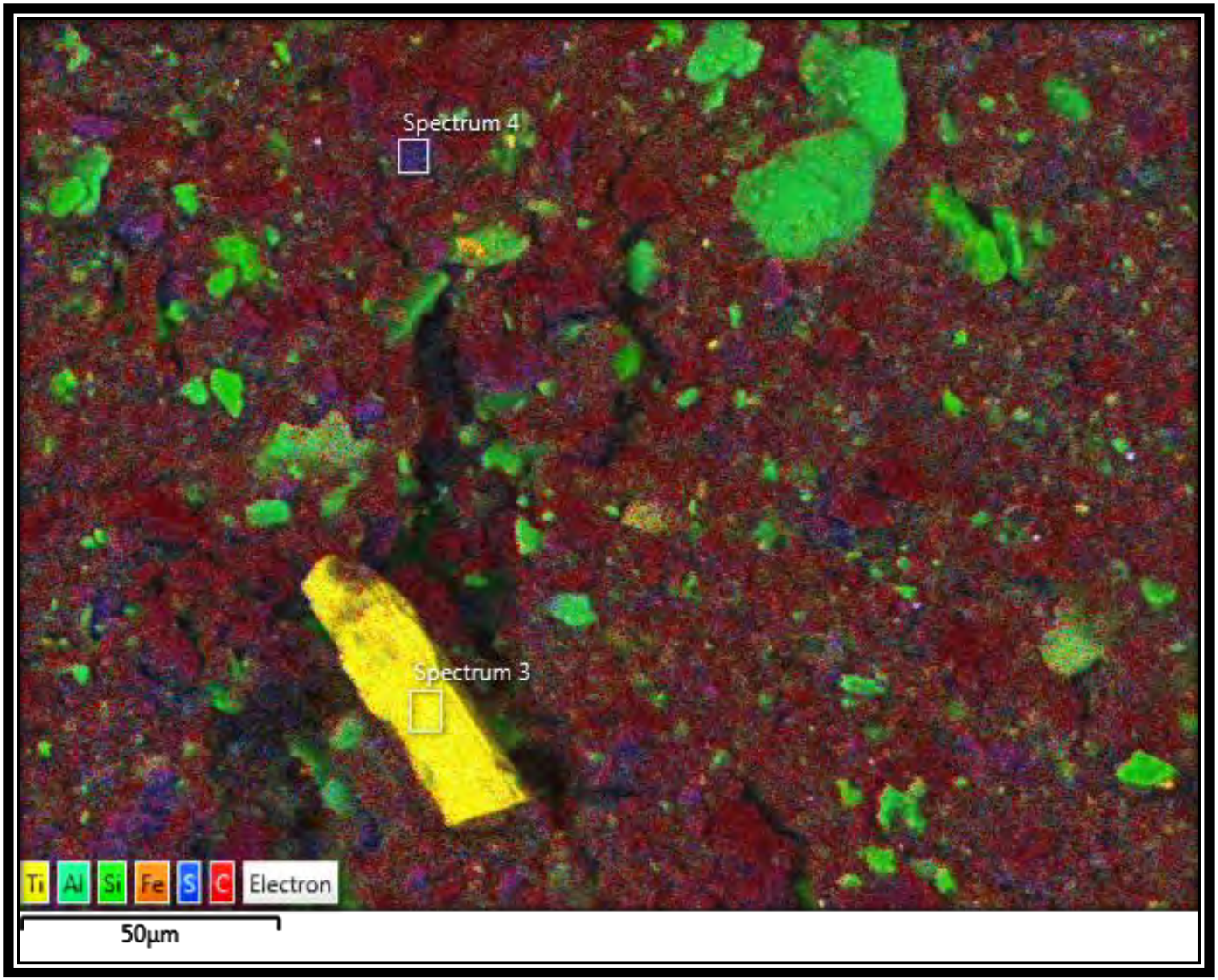
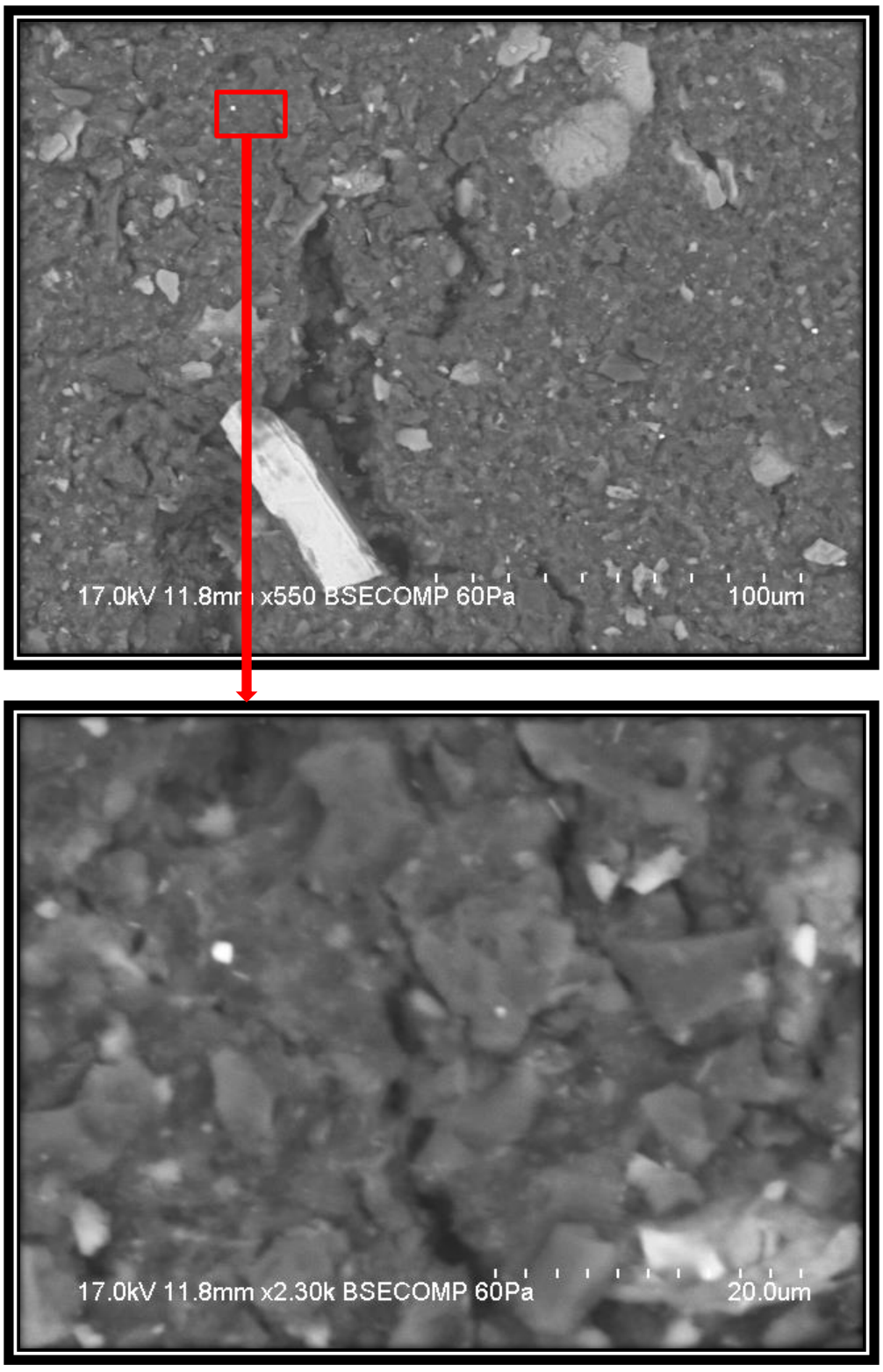


Figure 24: Superimposed Elemental Imaging (SEI®) of organic based matter, titanium oxide, elemental sulfur, iron hydroxide, silts and/or clays.


17.0kV 11.8mm x550 BSECOMP 60Pa
100um
17.0kV 11.8mm x2.30k BSECOMP 60Pa
20.0um

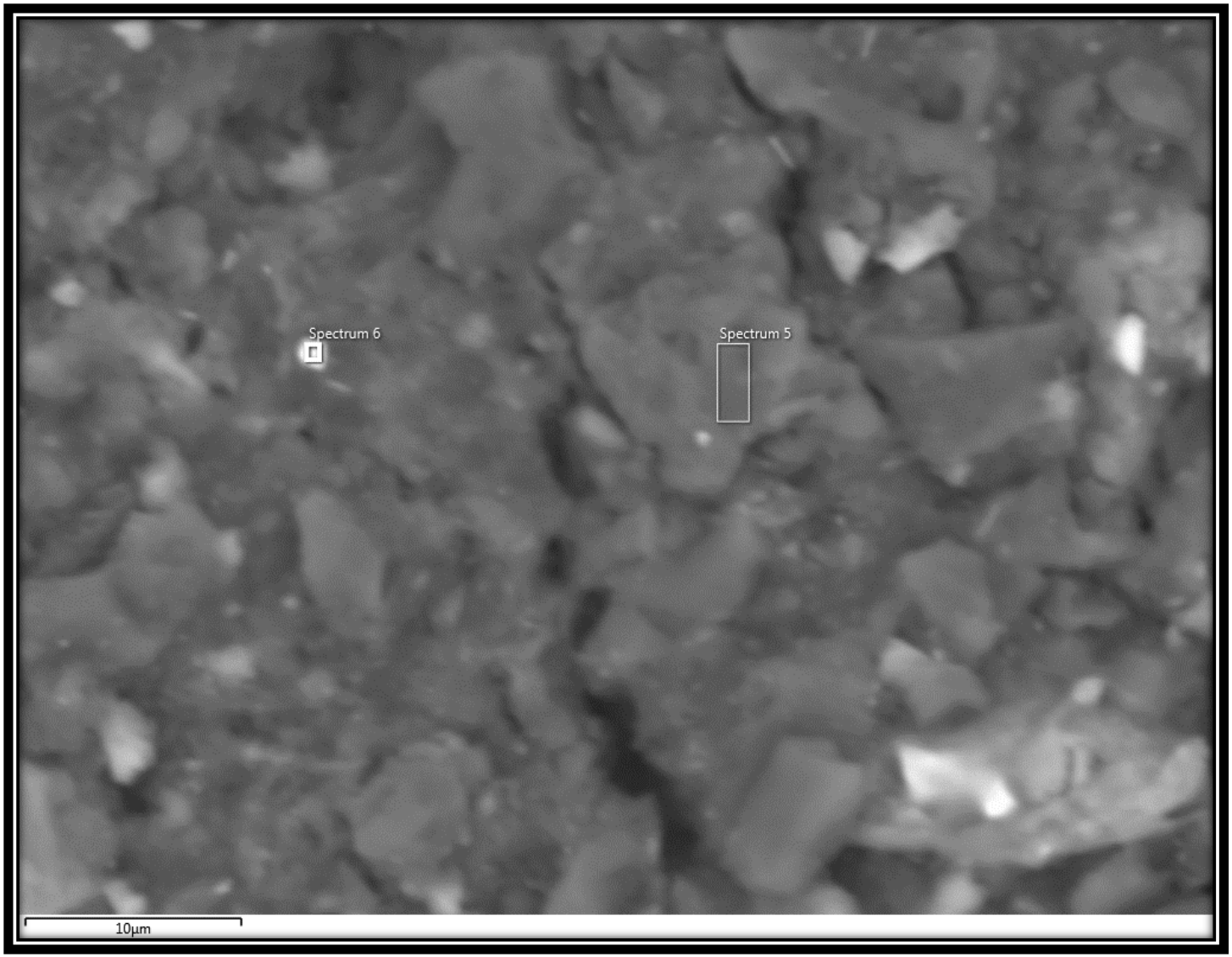


Figure 25: Electron micrograph of the membrane surface at 2300X magnification (Spectrum 5 & Spectrum 6).

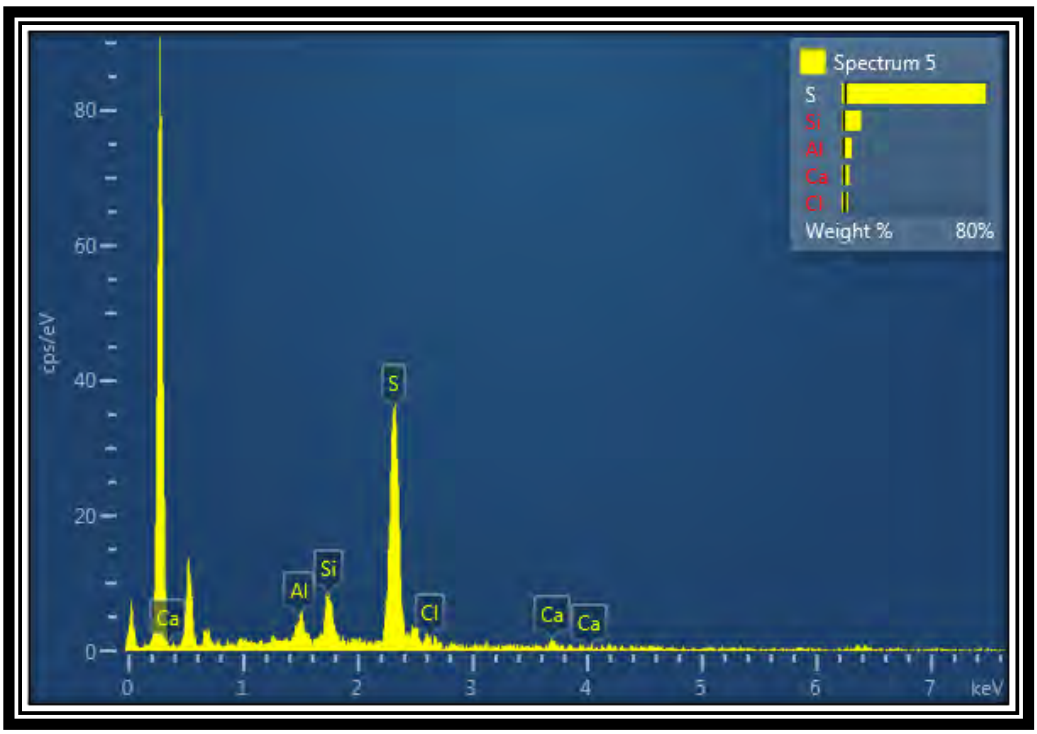


Figure 26: EDS and composition bar graph analysis of the membrane deposit from Spectrum 5.

Spectrum 5	Atomic %
C	83.31
O	10.68
F	1.26
Al	0.33
Si	0.59
S	3.61
Cl	0.09
Ca	0.13
Total	100.00

Spectrum 5	Atomic %
Carbon, Oxygen and Fluorine Ignored	
Al	6.19
Si	11.67
S	76.25
Cl	2.85
Ca	3.05
Total	100.00

Table 6: Composition table from the EDS spectrum of localized deposit from Spectrum 5.

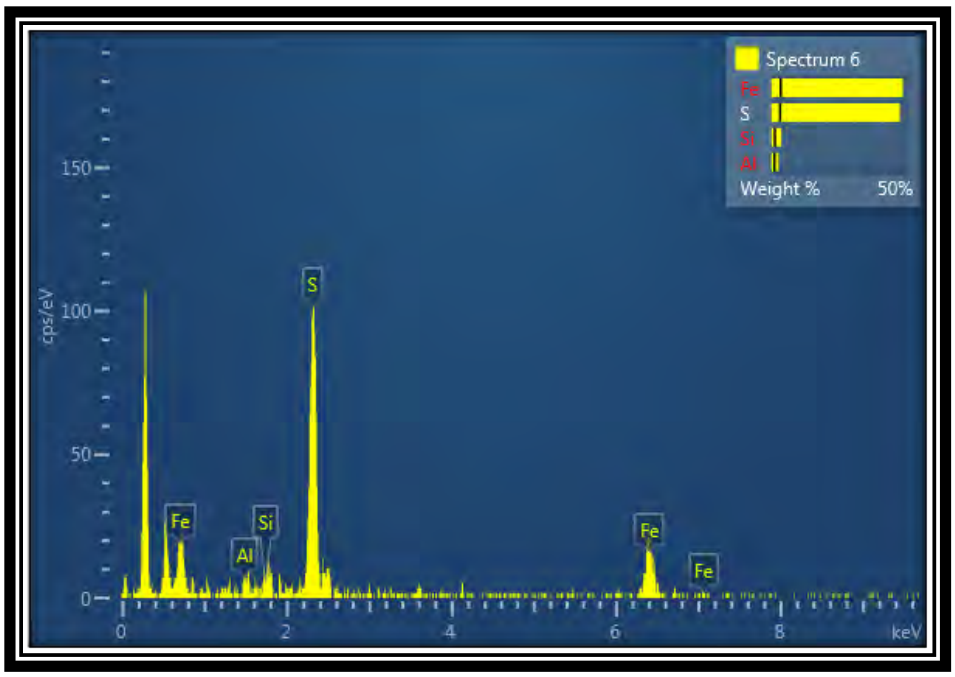


Figure 27: EDS and composition bar graph analysis of the membrane deposit from Spectrum 6.

Spectrum 6	Atomic %
C	78.03
O	11.11
Al	0.35
Si	0.48
S	6.02
Fe	4.00
Total	100.00

Spectrum 6	Atomic %
Carbon and Oxygen Ignored	
Al	3.82
Si	4.96
S	57.44
Fe	33.77
Total	100.00

Table 7: Composition table from the EDS spectrum of localized deposit from Spectrum 6.

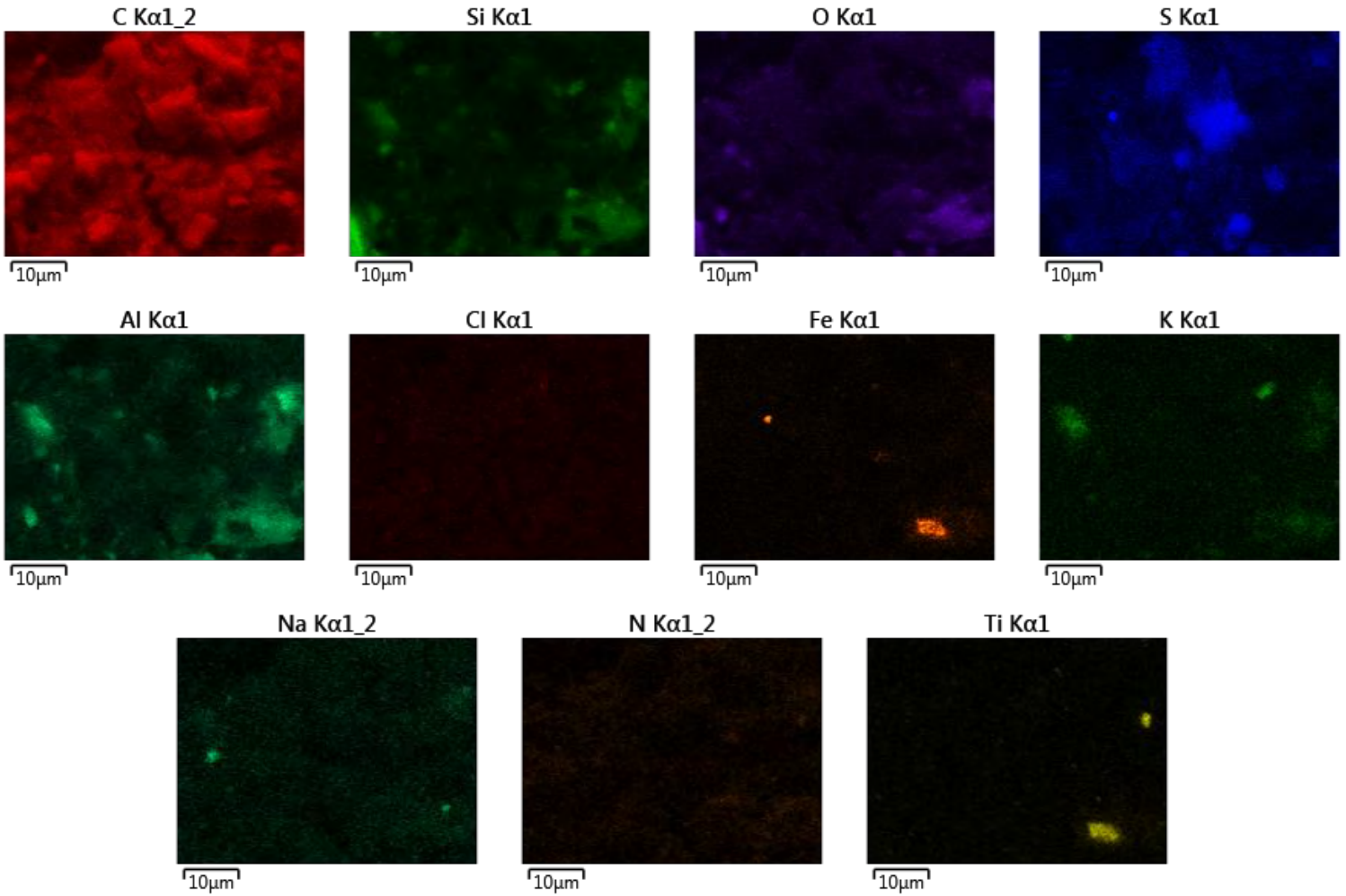


Figure 28: Prismatic Elemental Delineation (PED®) of membrane surface at 2300X magnification. Deposits found: Organic based matter, silts/clays, elemental sulfur, an iron disulfide (pyrite) particle and titanium oxide. Geometric carbon-based deposits are likely to be inorganic carbon.

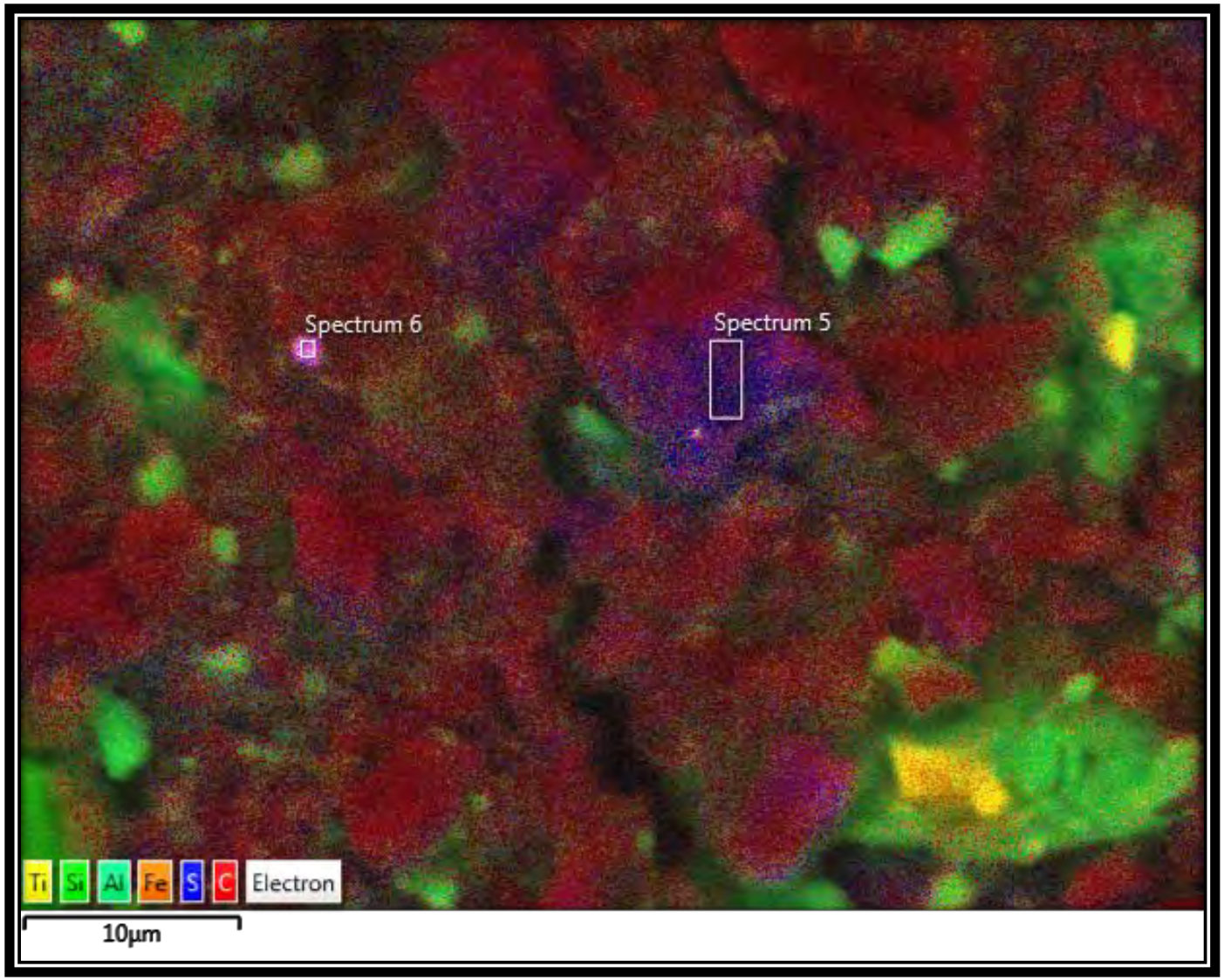


Figure 29: Superimposed Elemental Imaging (SEI®) of organic based matter, silts/clays, elemental sulfur, iron disulfide (pyrite) and titanium oxide.

Middle

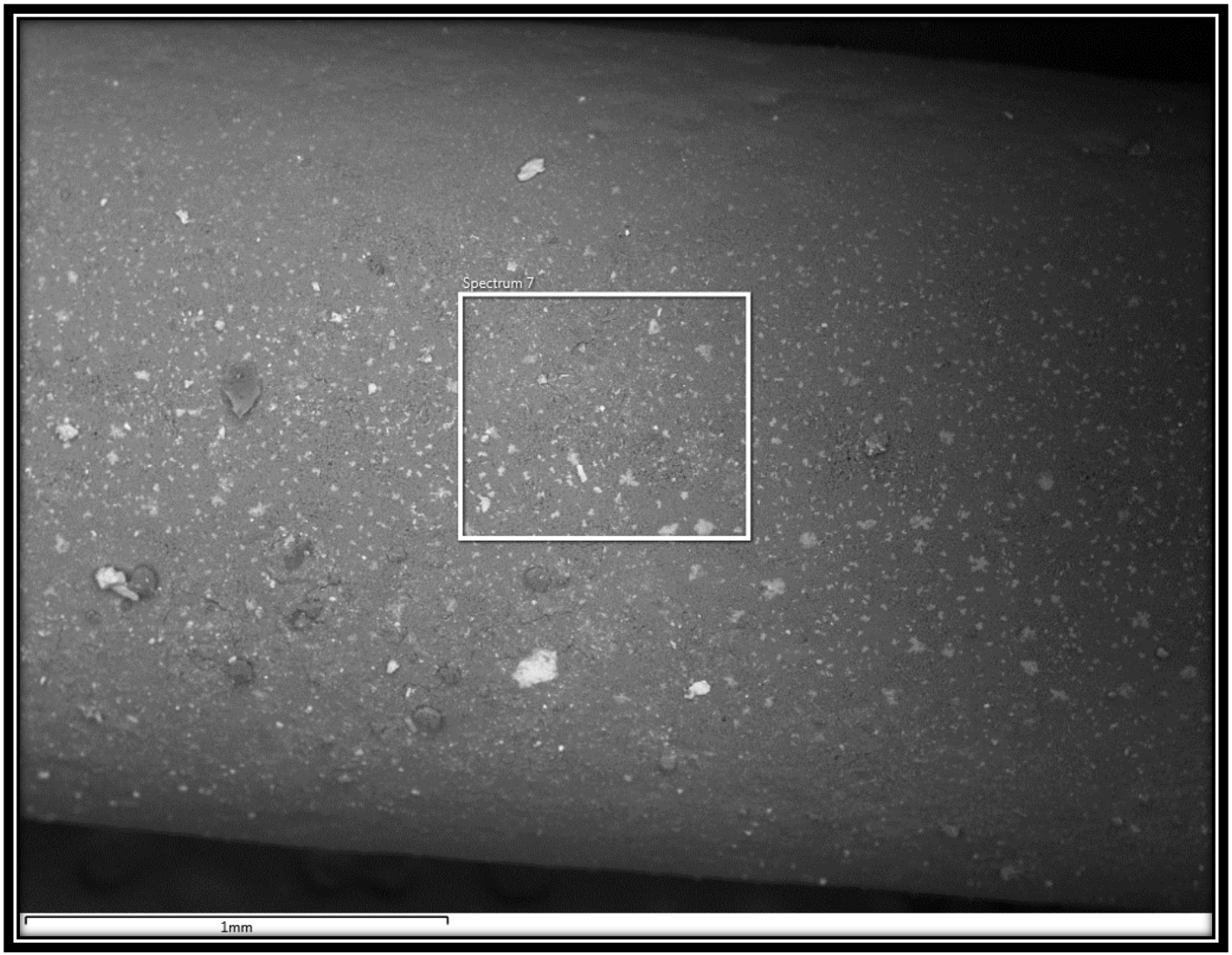


Figure 30: Electron micrograph of the membrane surface at 45X magnification (Spectrum 7).

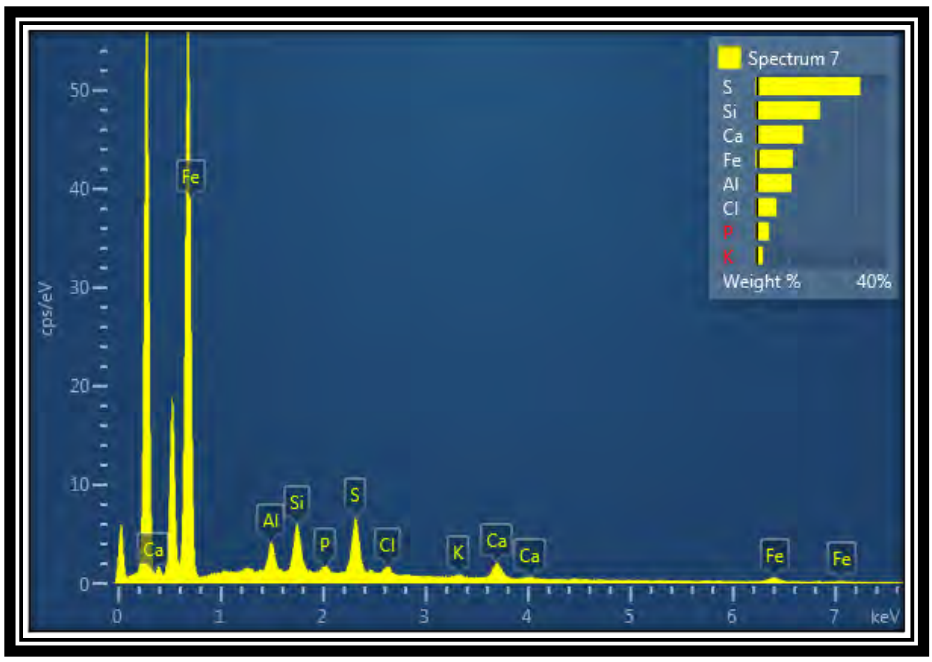


Figure 31: EDS and composition bar graph analysis of the membrane deposit from Spectrum 7.

Spectrum 7	Atomic %
C	56.75
N	2.46
O	12.18
F	26.36
Al	0.37
Si	0.55
P	0.09
S	0.69
Cl	0.11
K	0.04
Ca	0.26
Fe	0.16
Total	100.00

Spectrum 7	Atomic %
Carbon, Nitrogen, Oxygen and Fluorine Ignored	
Al	13.40
Si	22.95
P	4.43
S	32.73
Cl	5.97
K	1.92
Ca	11.92
Fe	6.69
Total	100.00

Table 8: Composition table from the EDS spectrum of localized deposit from Spectrum 7.

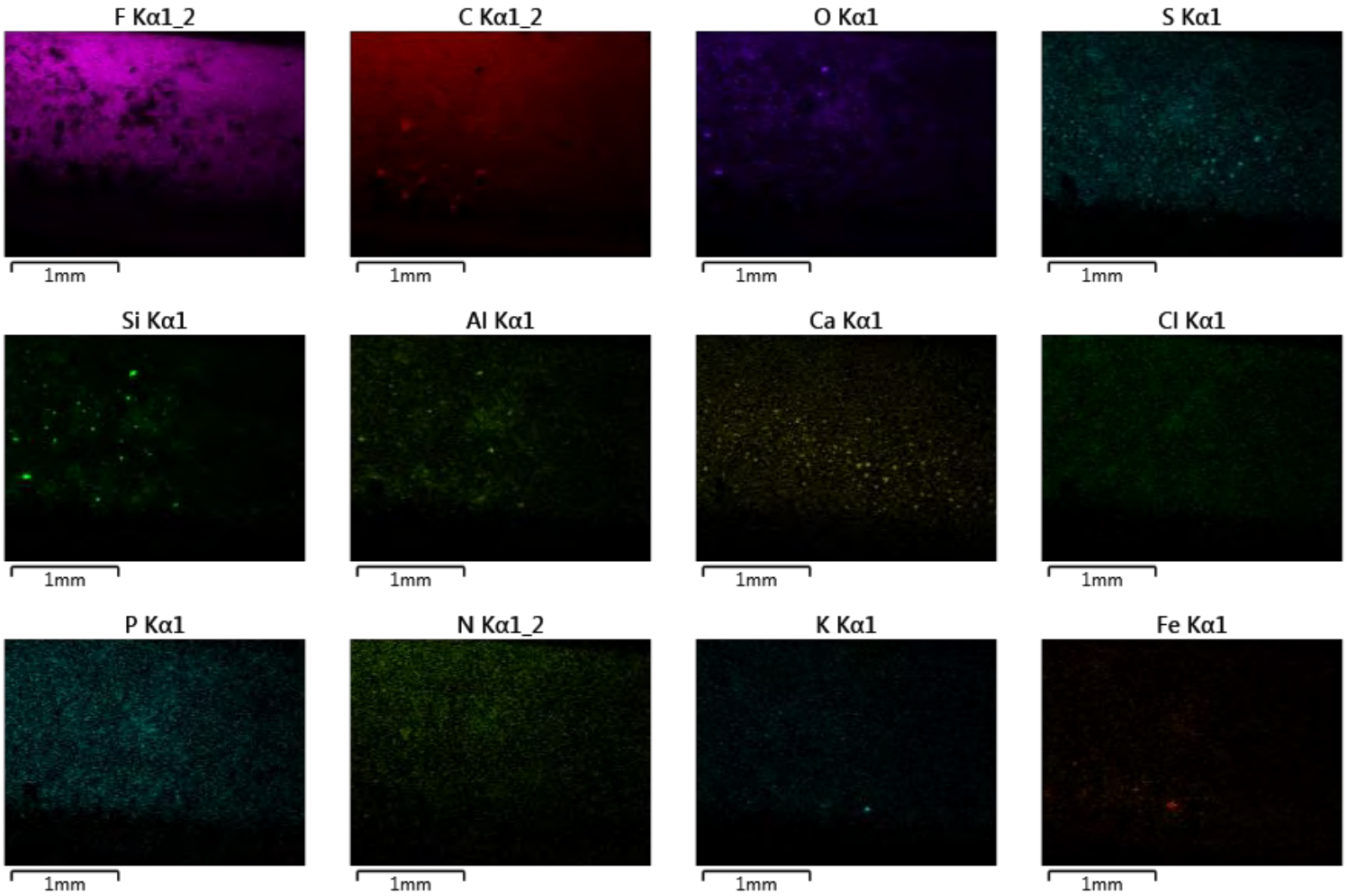


Figure 32: Prismatic Elemental Delineation (PED®) of membrane surface at 45X magnification. Deposits found: Organic based matter, calcium sulfate, iron hydroxide, silts and/or clays.

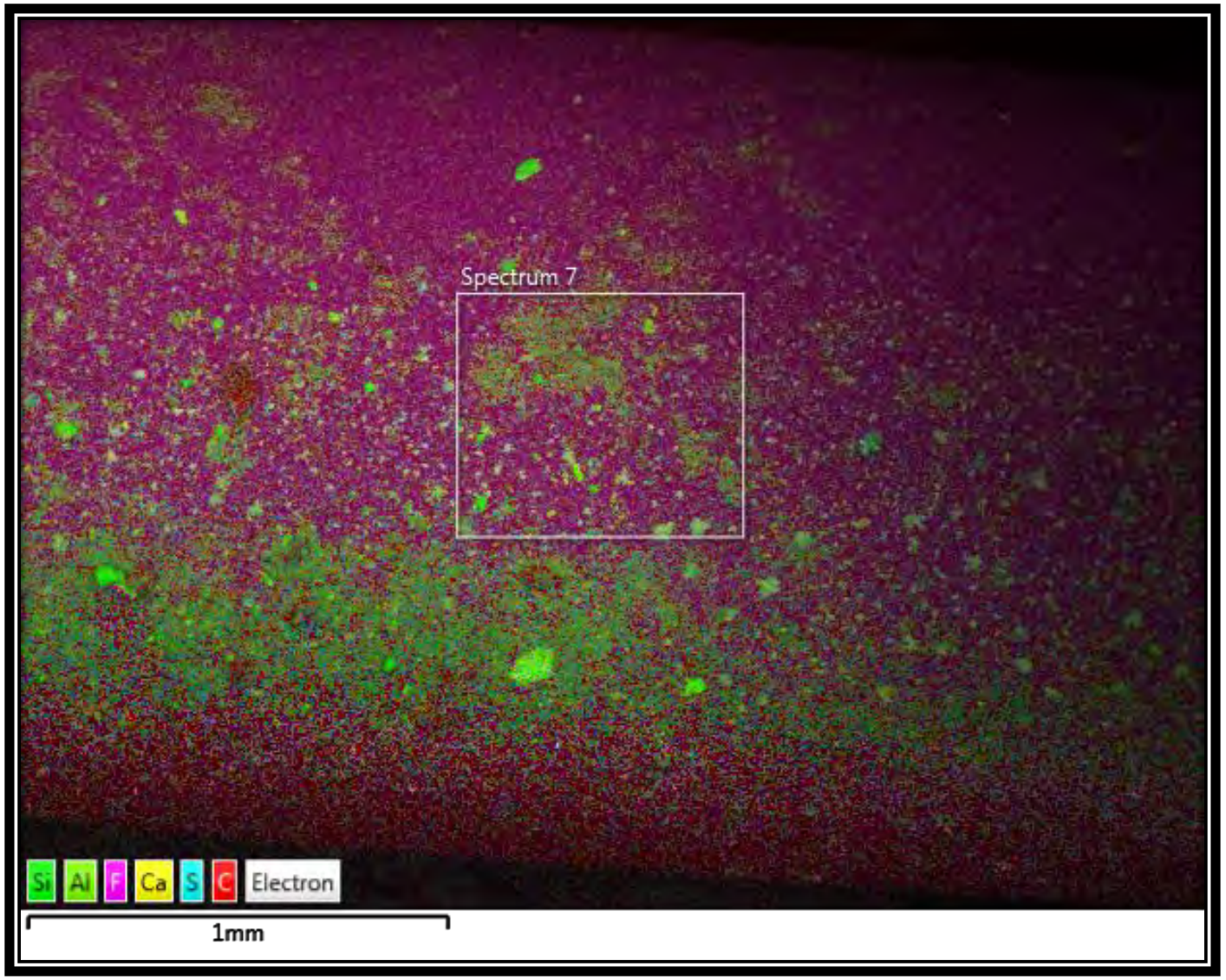
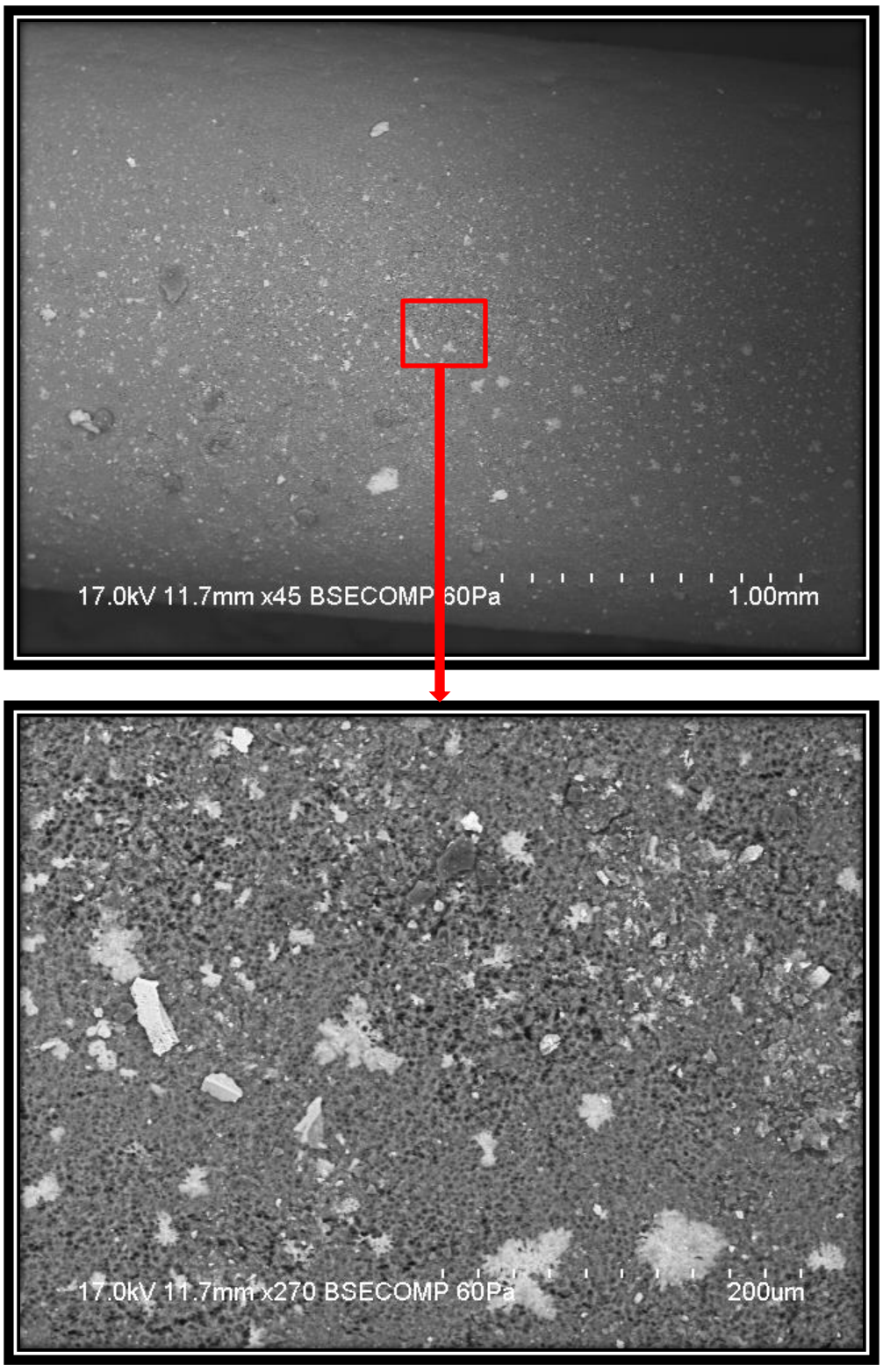


Figure 33: Superimposed Elemental Imaging (SEI®) of organic based matter, calcium sulfate, iron hydroxide, silts and/or clays.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1.00mm
17.0kV 11.7mm x270 BSECOMP 60Pa
200um

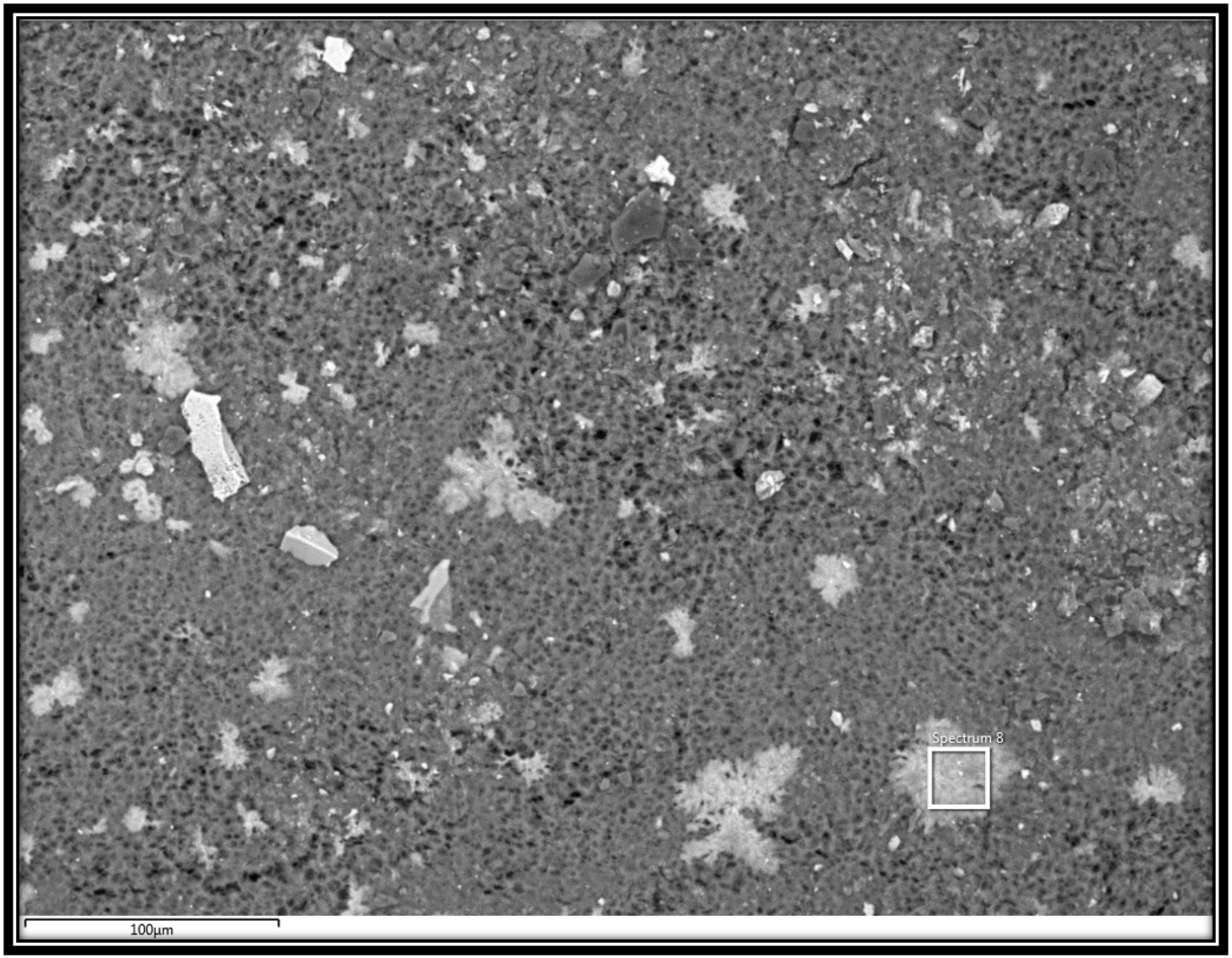


Figure 34: Electron micrograph of the membrane surface at 270X magnification (Spectrum 8).

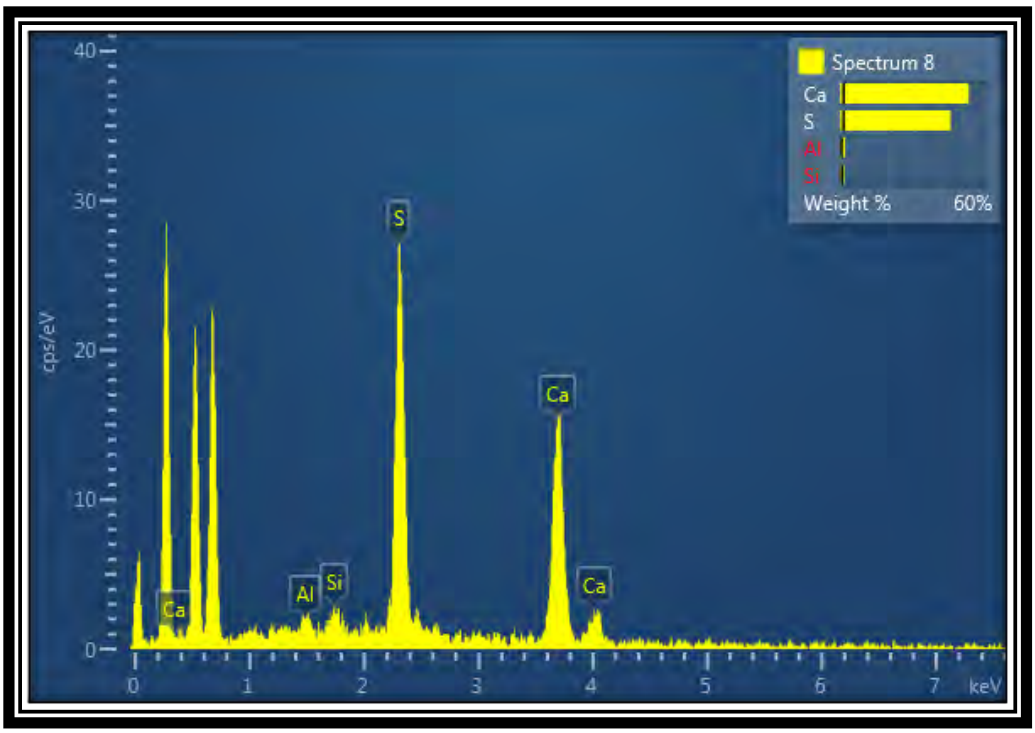


Figure 35: EDS and composition bar graph analysis of the membrane deposit from Spectrum 8.

Spectrum 8	Atomic %
C	49.90
N	2.26
O	22.05
F	17.68
Al	0.22
Si	0.17
S	4.17
Ca	3.55
Total	100.00

Spectrum 8	Atomic %
Carbon, Nitrogen, Oxygen and Fluorine Ignored	
Al	2.55
Si	2.02
S	49.33
Ca	46.10
Total	100.00

Table 9: Composition table from the EDS spectrum of localized deposit from Spectrum 8.

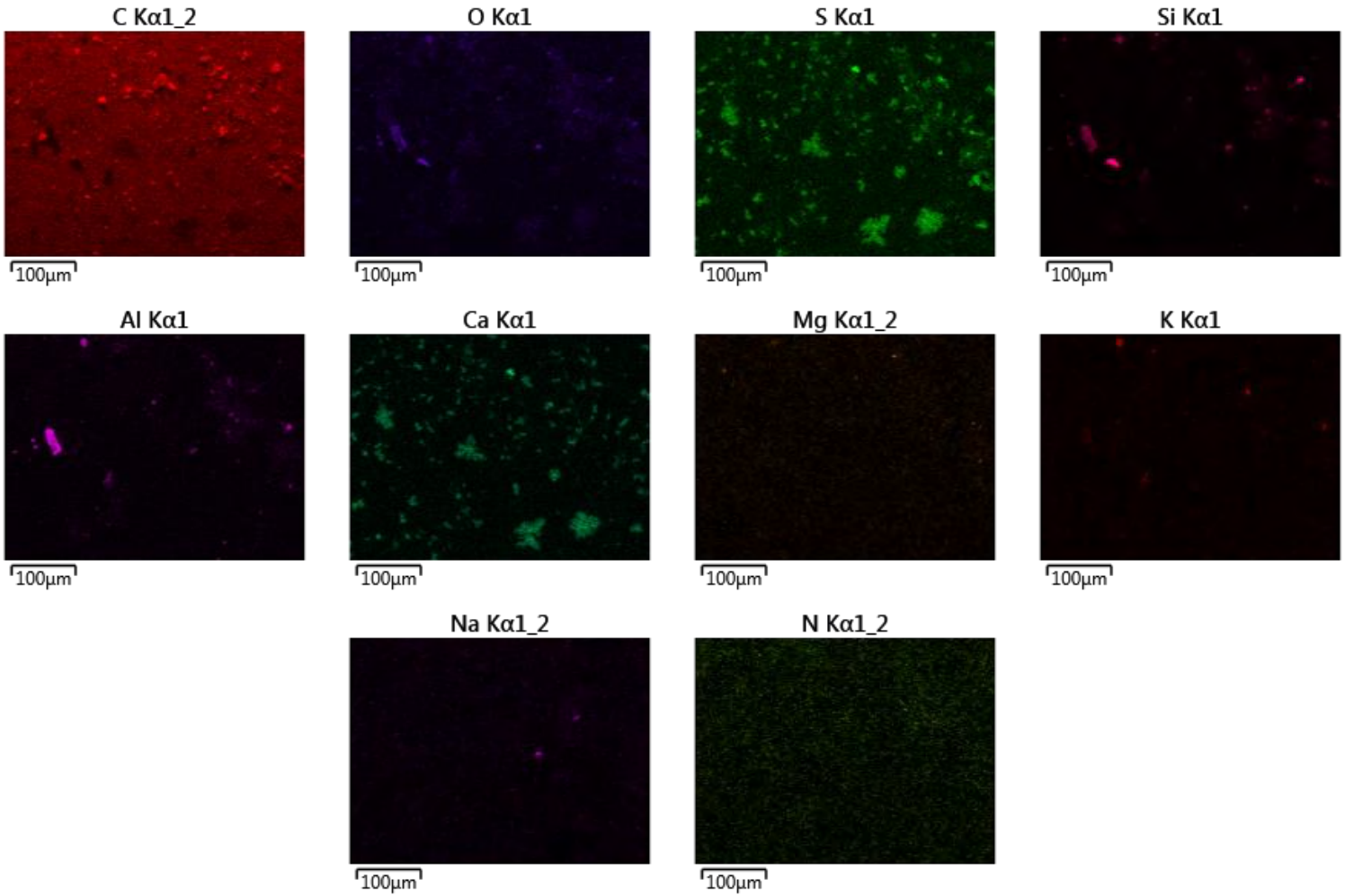


Figure 36: Prismatic Elemental Delineation (PED®) of membrane surface at 270X magnification. Deposits found: Calcium sulfate, silts/clays and organic based matter.

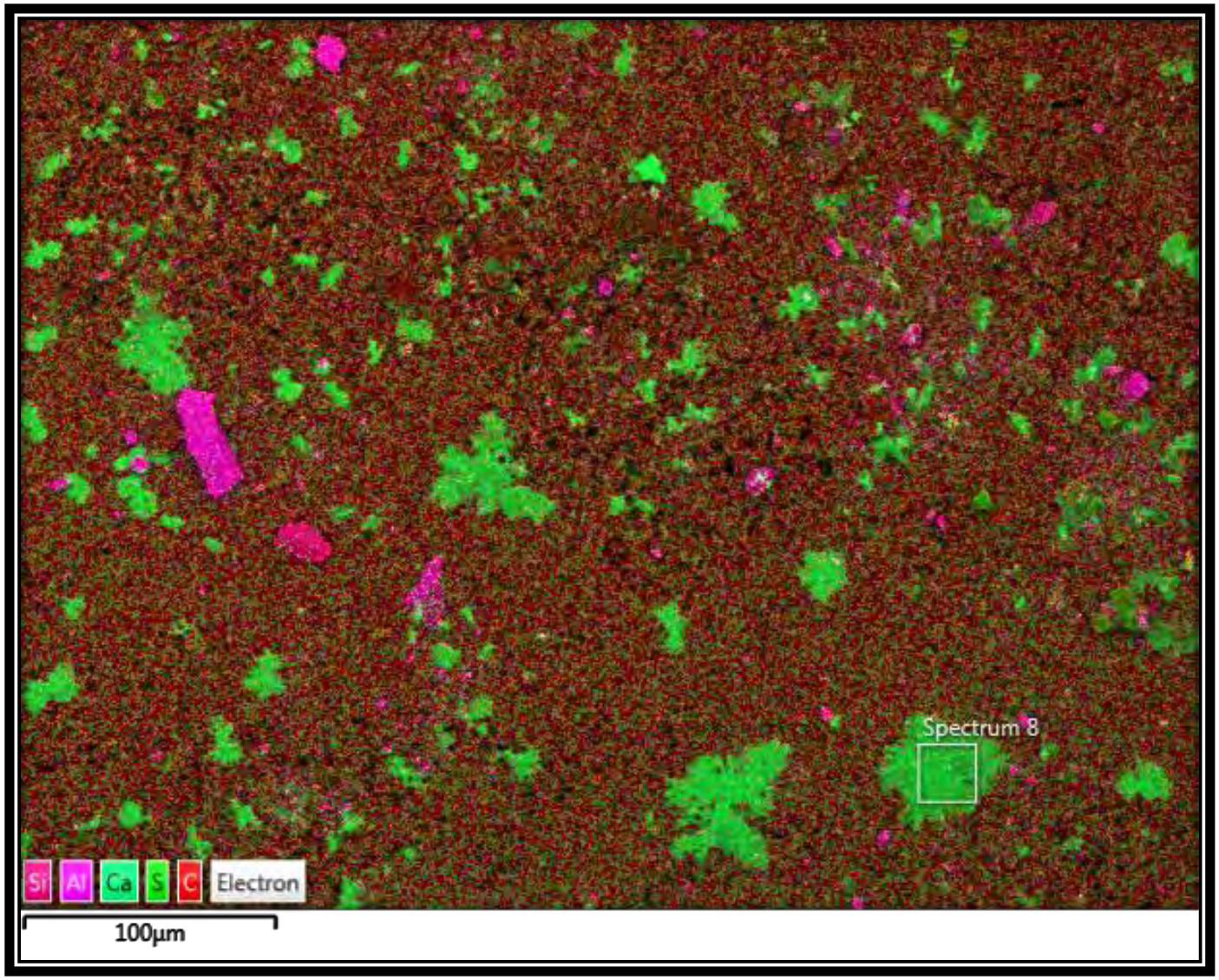
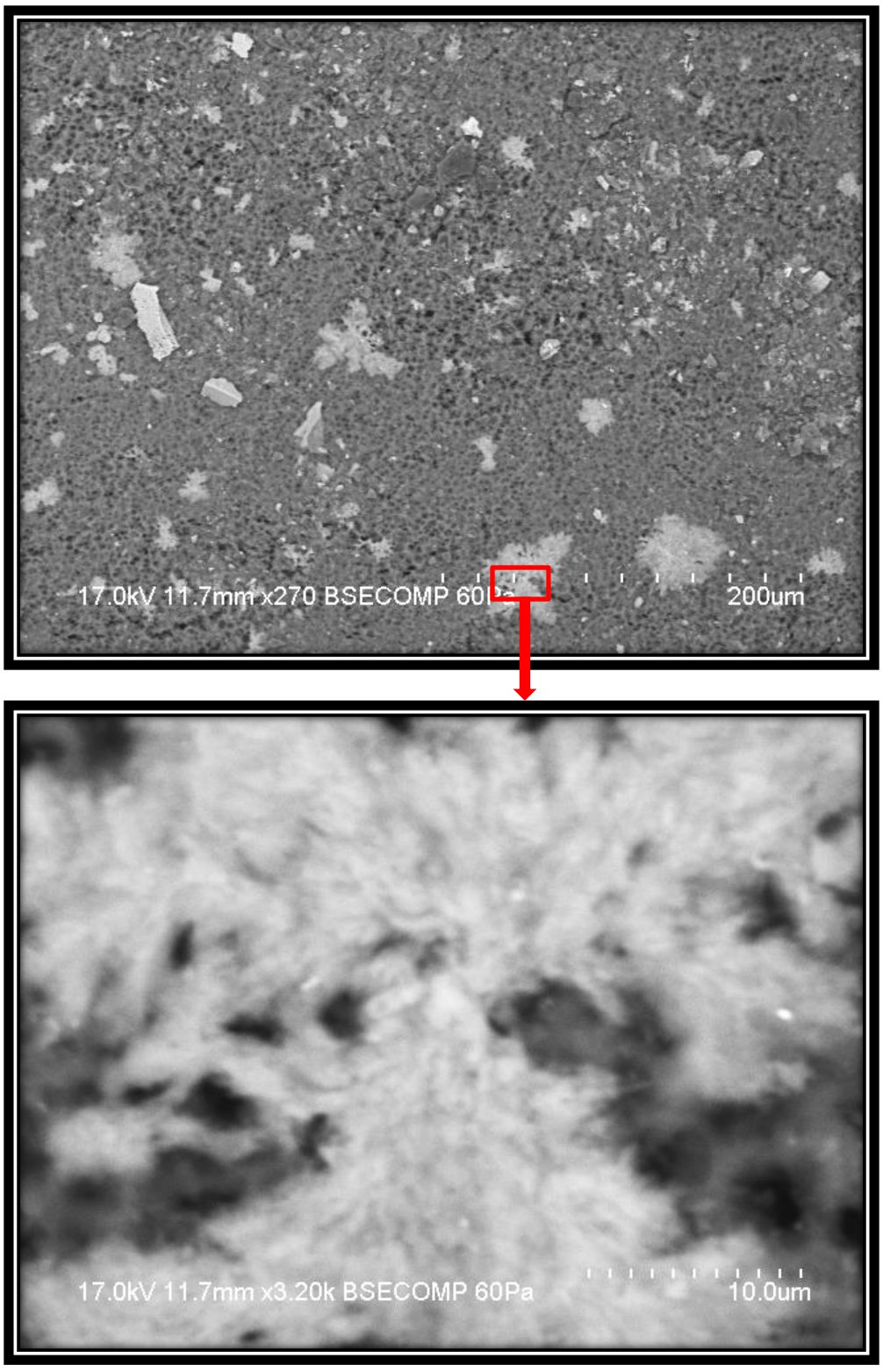


Figure 37: Superimposed Elemental Imaging (SEI®) of calcium sulfate, silts/clays and organic based matter.


17.0kV 11.7mm x270 BSECOMP 60Pa
200um
17.0kV 11.7mm x3.20k BSECOMP 60Pa
10.0um

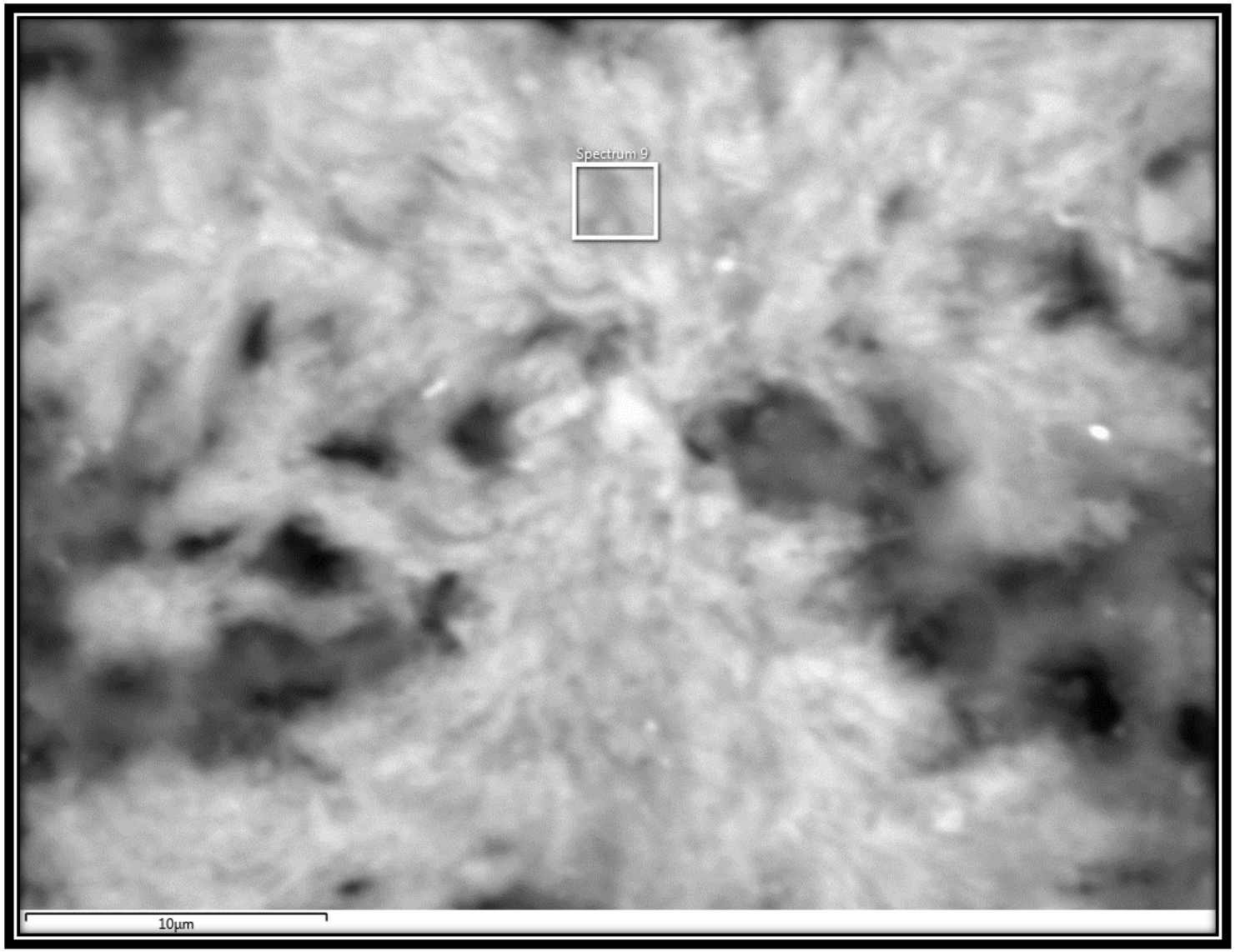


Figure 38: Electron micrograph of the membrane surface at 3200X magnification (Spectrum 9).

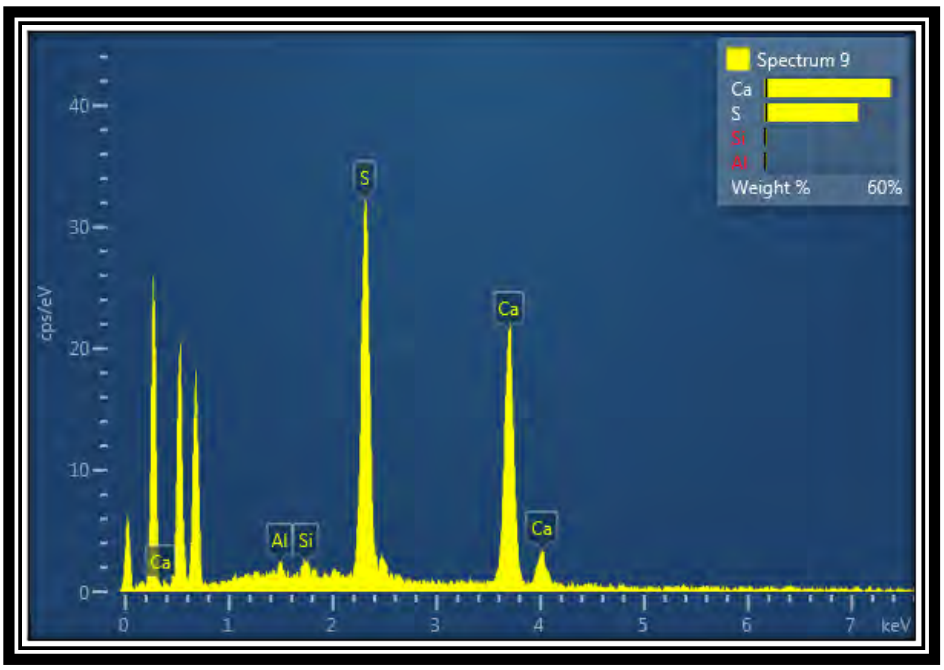


Figure 39: EDS and composition bar graph analysis of the membrane deposit from Spectrum 9.

Spectrum 9	Atomic %
C	49.41
N	2.34
O	22.86
F	14.98
Al	0.15
Si	0.16
S	5.07
Ca	5.03
Total	100.00

Spectrum 9	Atomic %
Carbon, Nitrogen, Oxygen and Fluorine Ignored	
Al	1.39
Si	1.43
S	46.81
Ca	50.37
Total	100.00

Table 10: Composition table from the EDS spectrum of localized deposit from Spectrum 9.

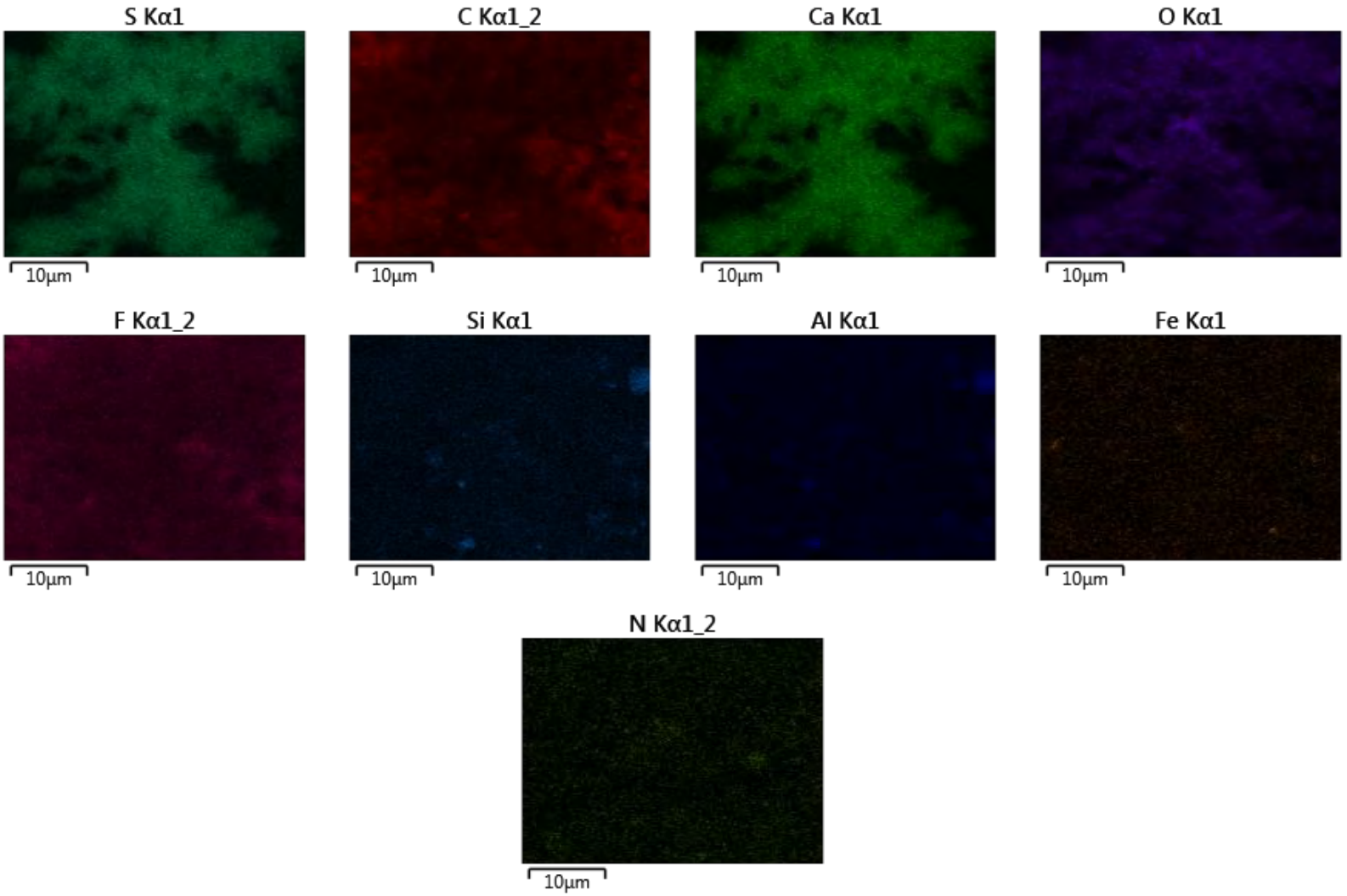


Figure 40: Prismatic Elemental Delineation (PED®) of membrane surface at 3200X magnification. Deposits found: Calcium sulfate, iron hydroxide and silts/clays.

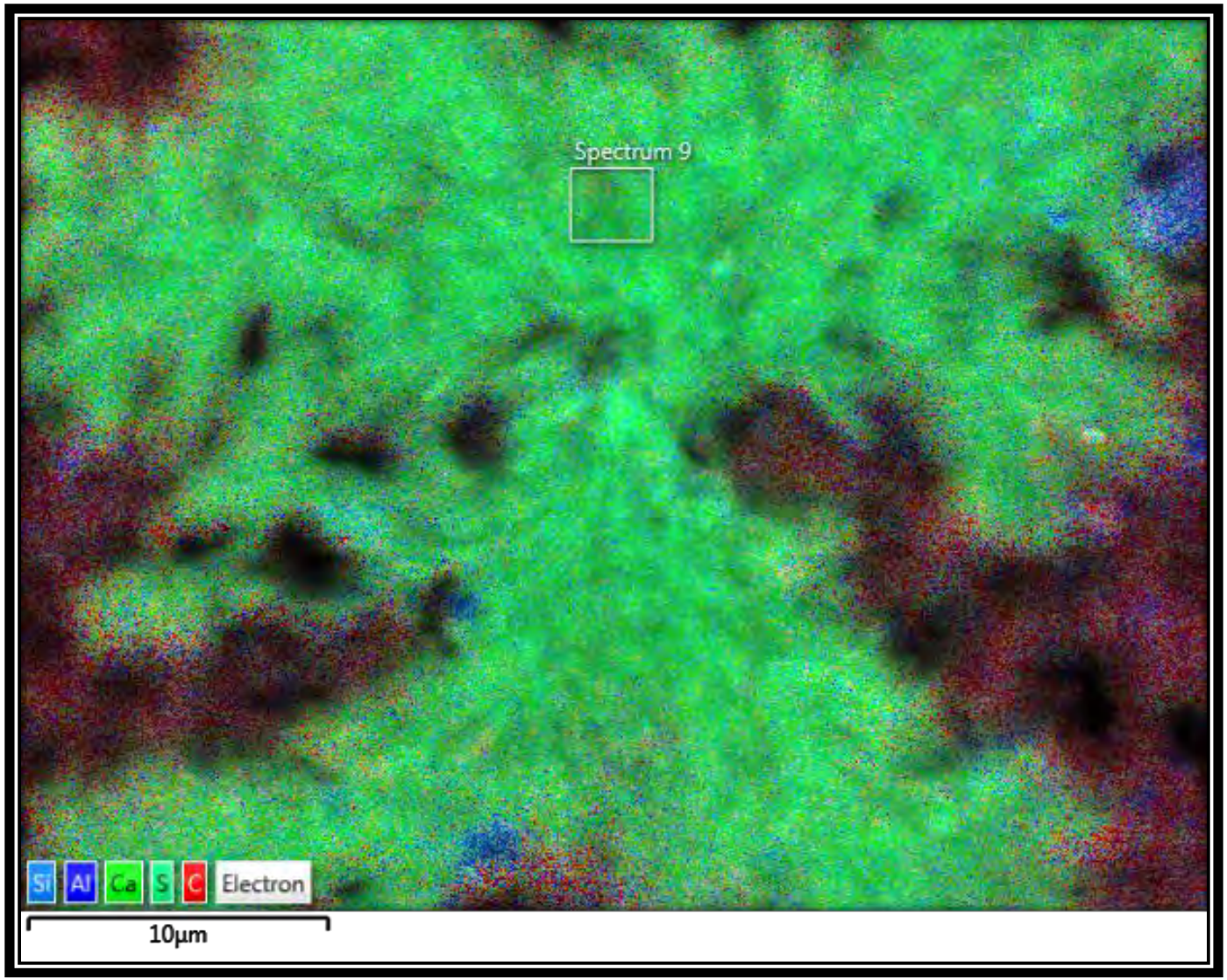


Figure 41: Superimposed Elemental Imaging (SEI®) of calcium sulfate, iron hydroxide and silts/clays.

Bottom

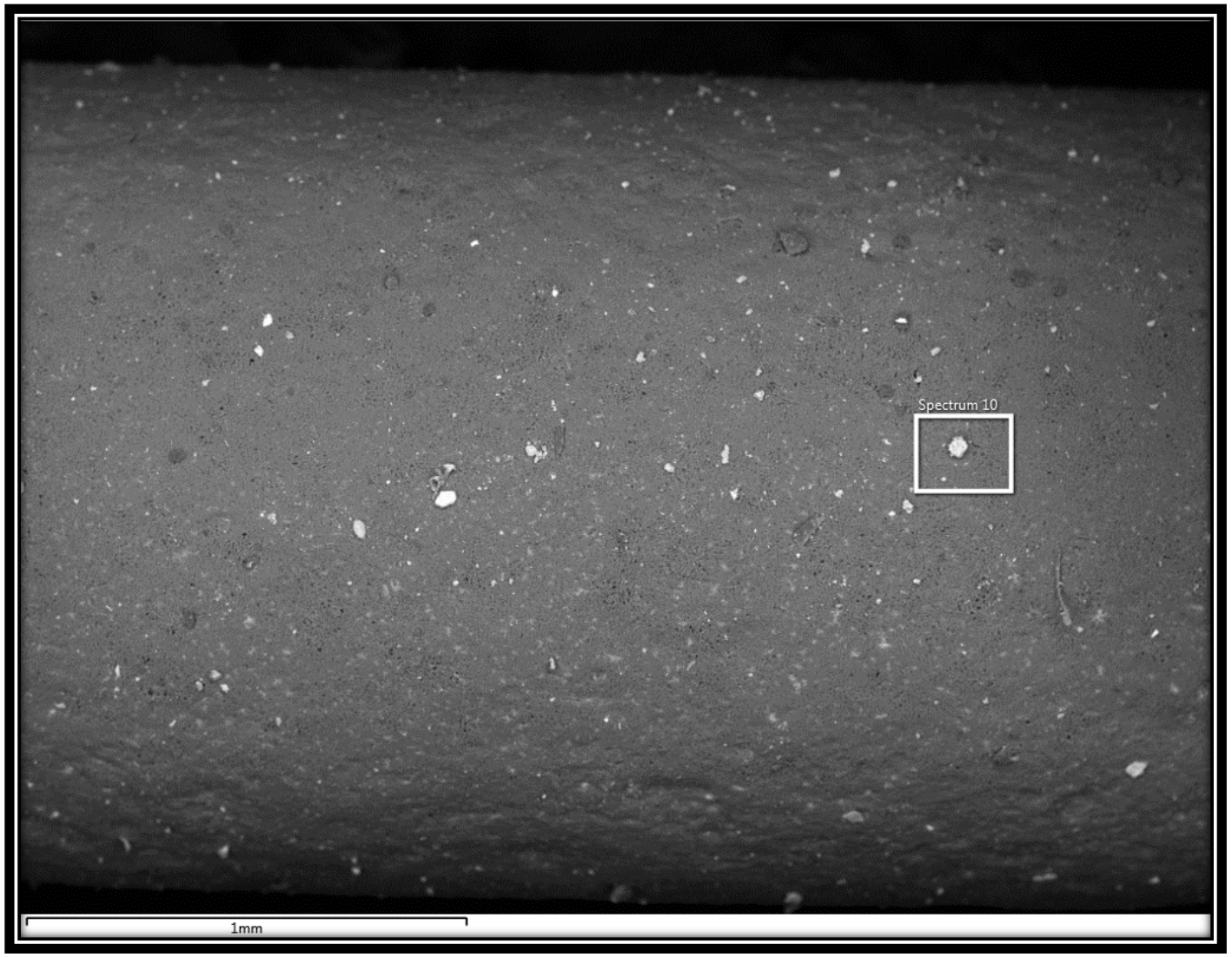


Figure 42: Electron micrograph of the membrane surface at 47X magnification (Spectrum 10).

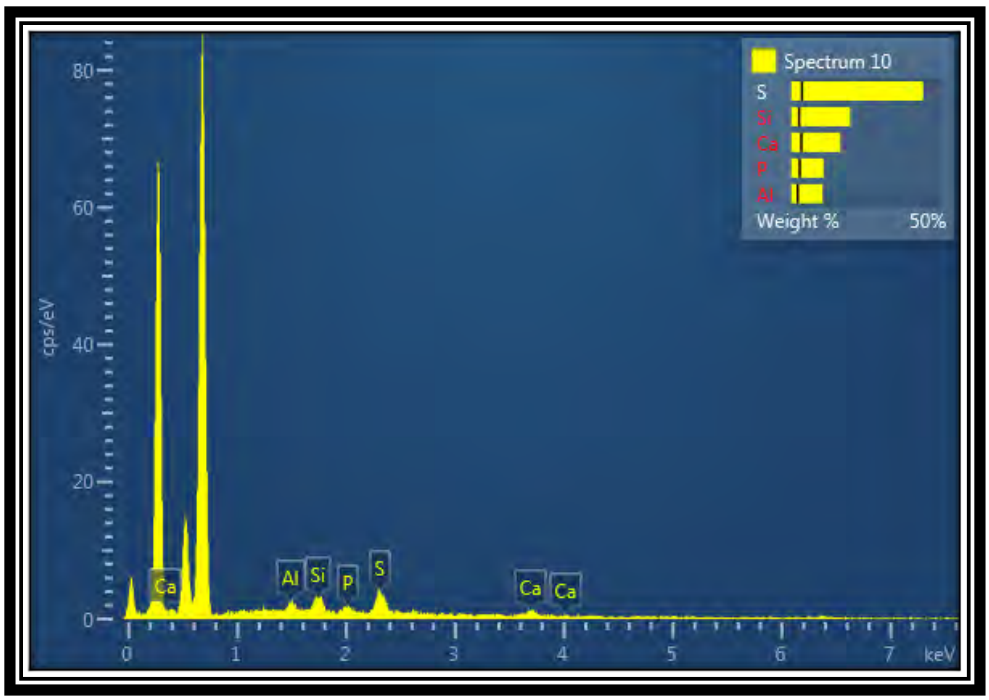


Figure 43: EDS and composition bar graph analysis of the membrane deposit from Spectrum 10.

Spectrum 10	Atomic %
C	57.11
O	8.97
F	32.87
Al	0.17
Si	0.26
P	0.11
S	0.40
Ca	0.12
Total	100.00

Spectrum 10	Atomic %
Carbon, Oxygen and Fluorine Ignored	
Al	11.99
Si	21.78
P	10.85
S	42.68
Ca	12.69
Total	100.00

Table 11: Composition table from the EDS spectrum of localized deposit from Spectrum 10.

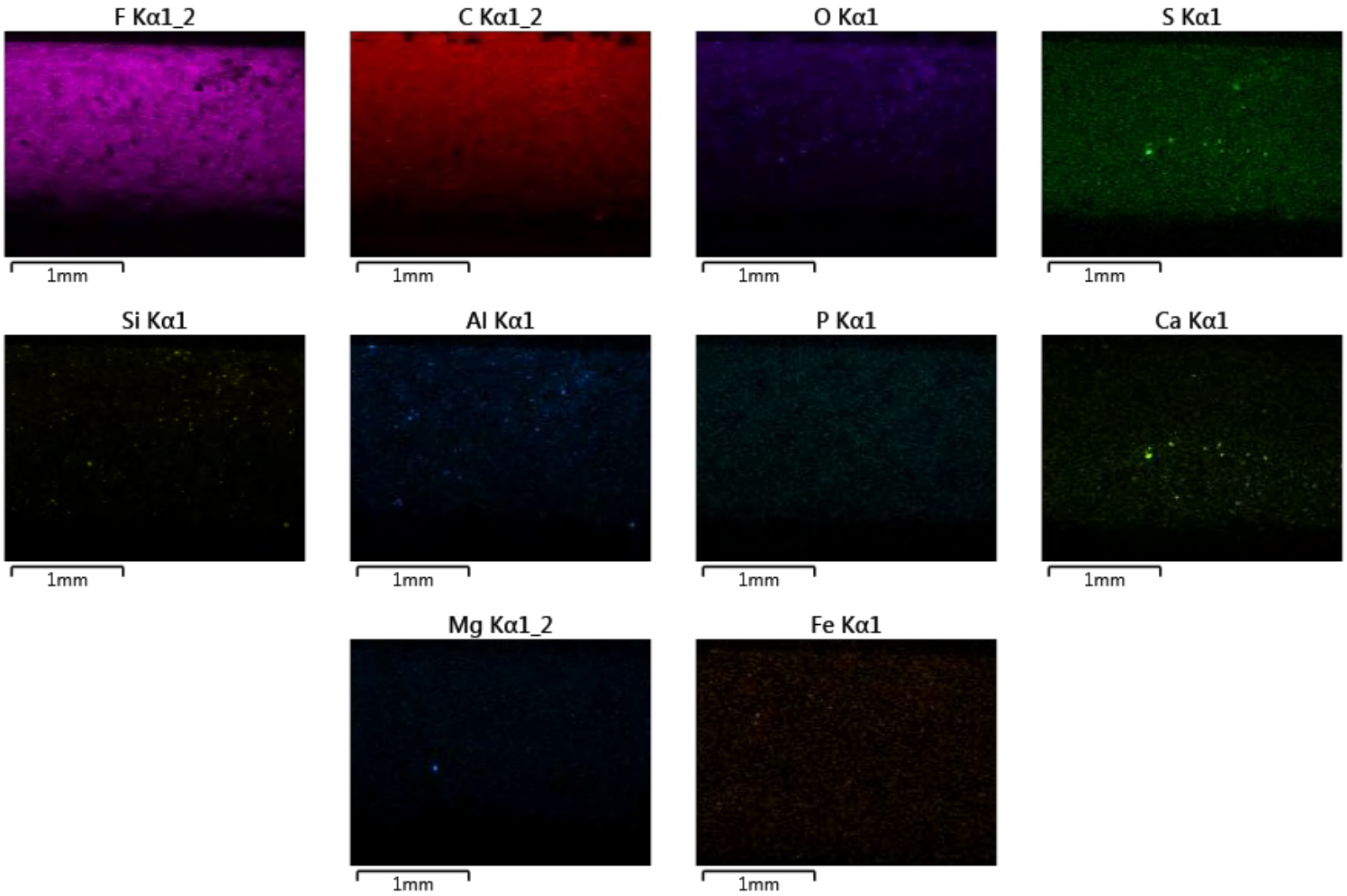


Figure 44: Prismatic Elemental Delineation (PED®) of membrane surface at 47X magnification. Deposits found: Calcium sulfate, iron hydroxide and silts/clays.

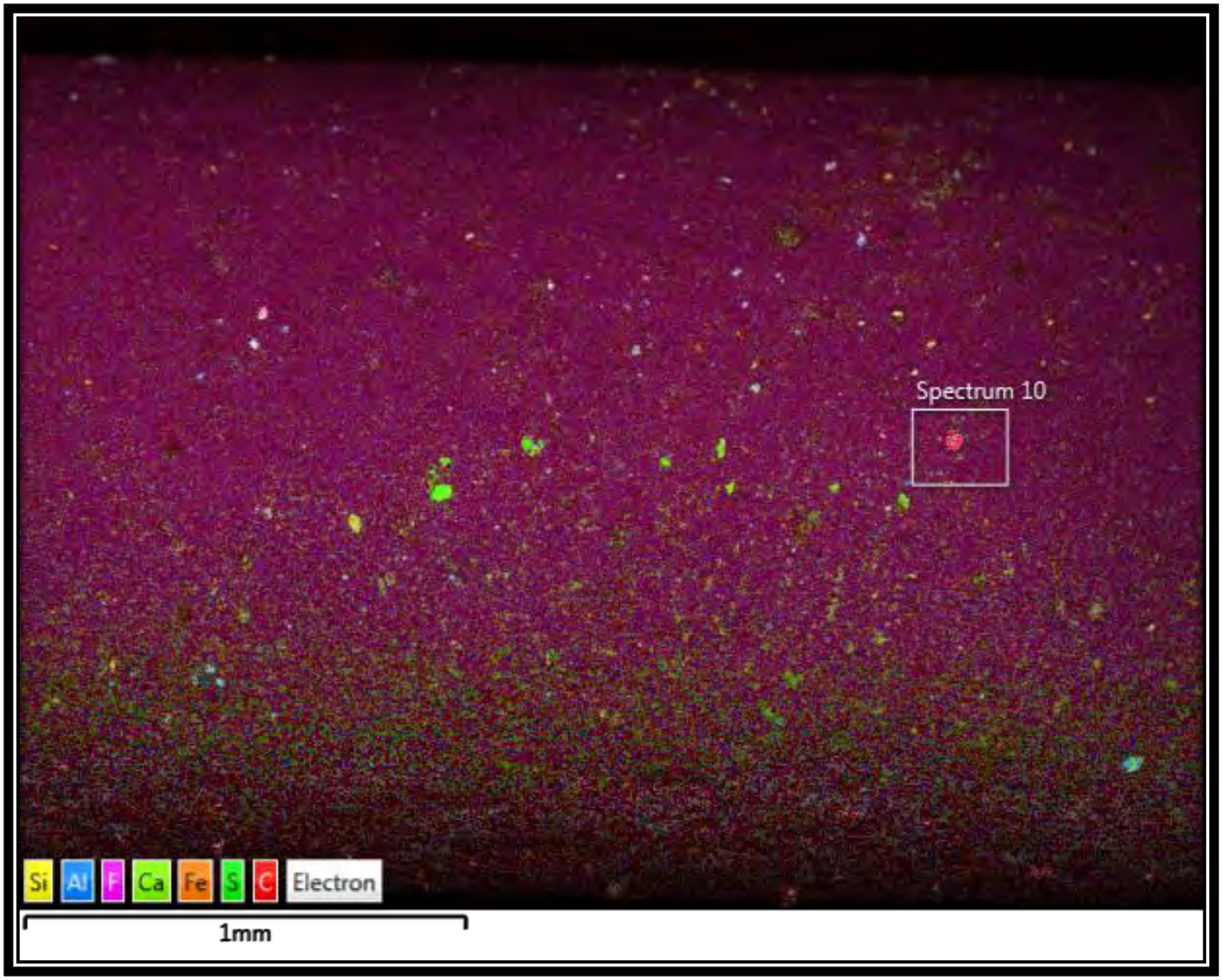
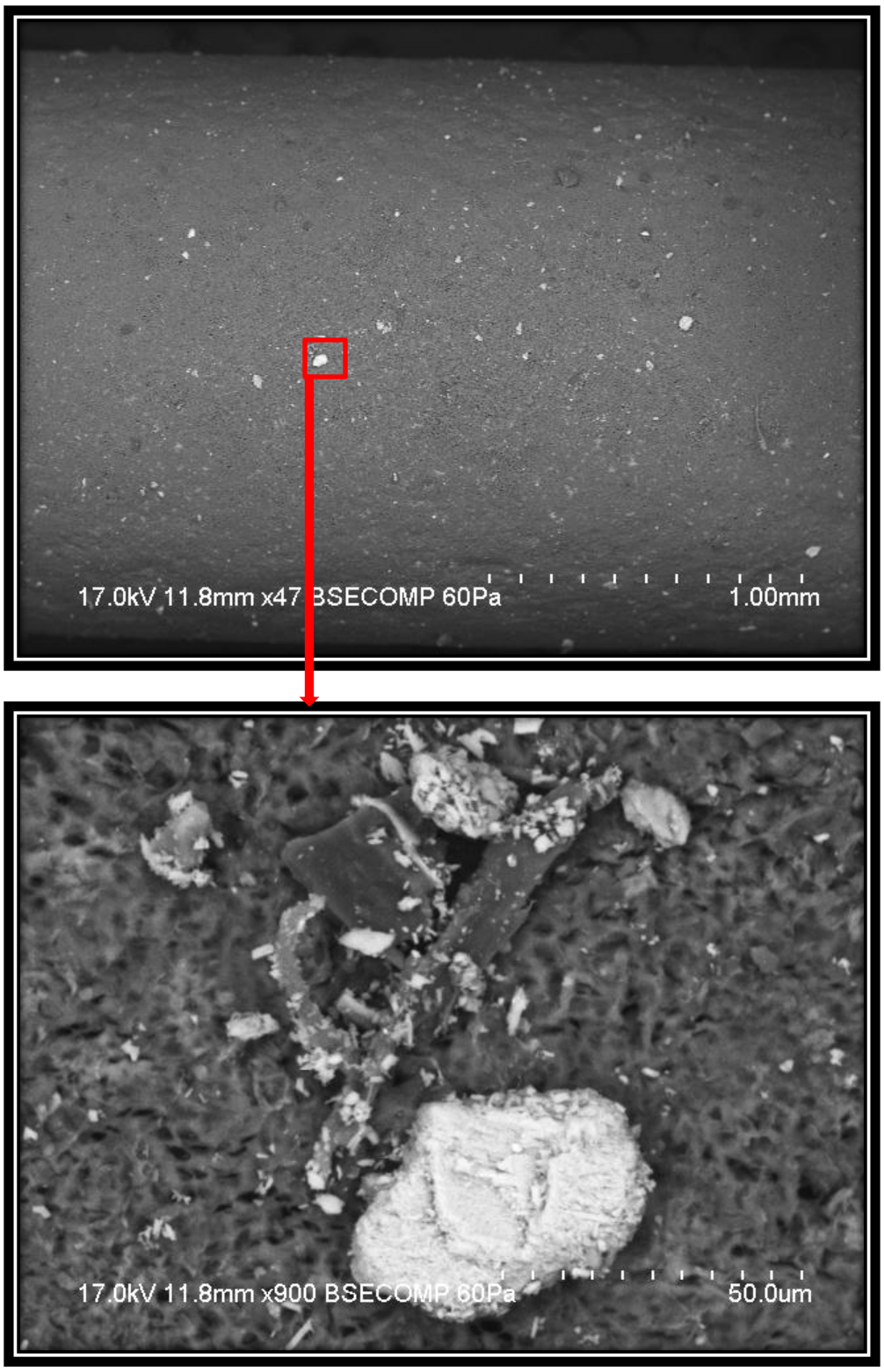


Figure 45: Superimposed Elemental Imaging (SEI®) of calcium sulfate, iron hydroxide and silts/clays.


17.0kV 11.8mm x47 BSECOMP 60Pa
1.00mm
17.0kV 11.8mm x900 BSECOMP 60Pa
50.0um

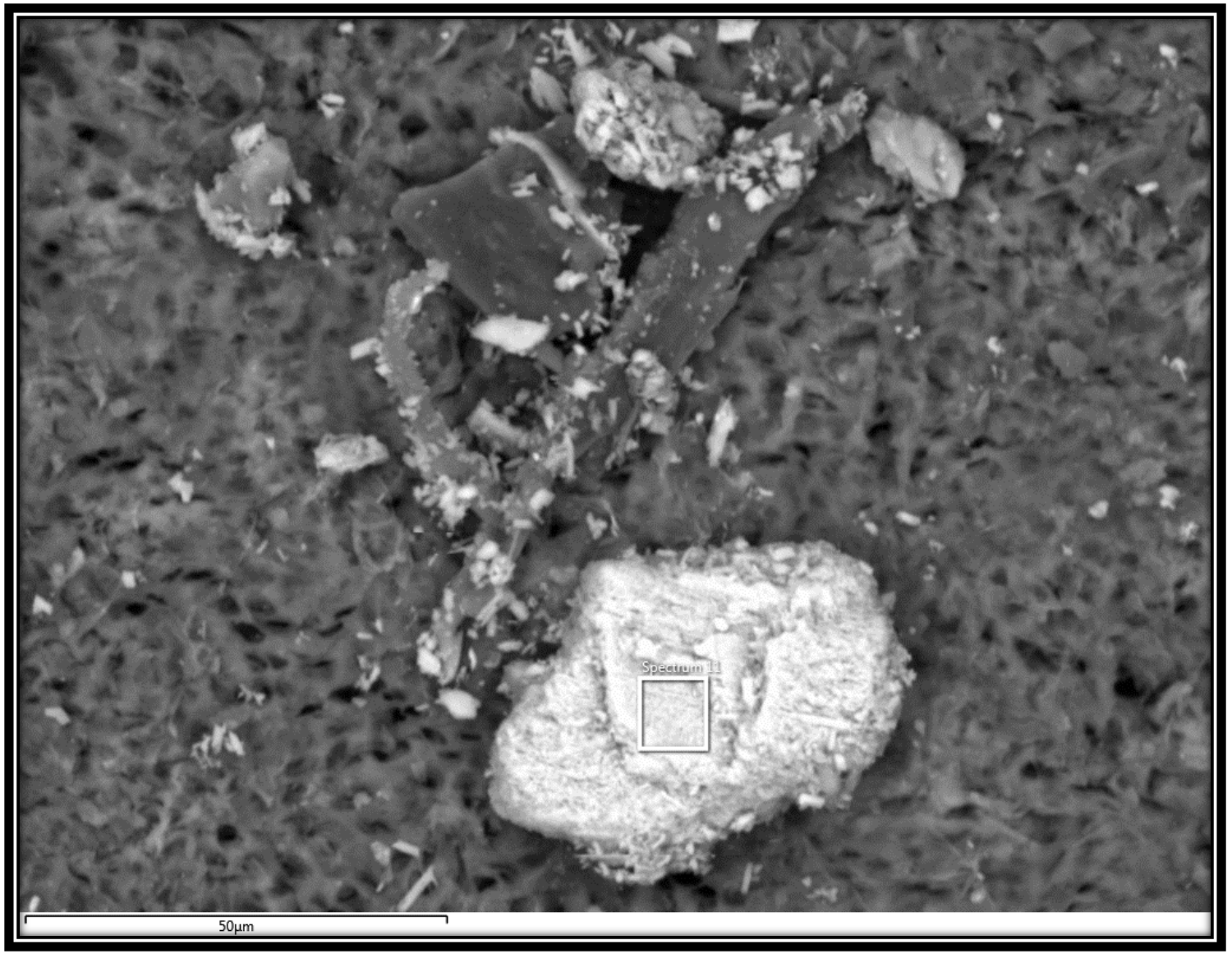


Figure 46: Electron micrograph of the membrane surface at 900X magnification (Spectrum 11).

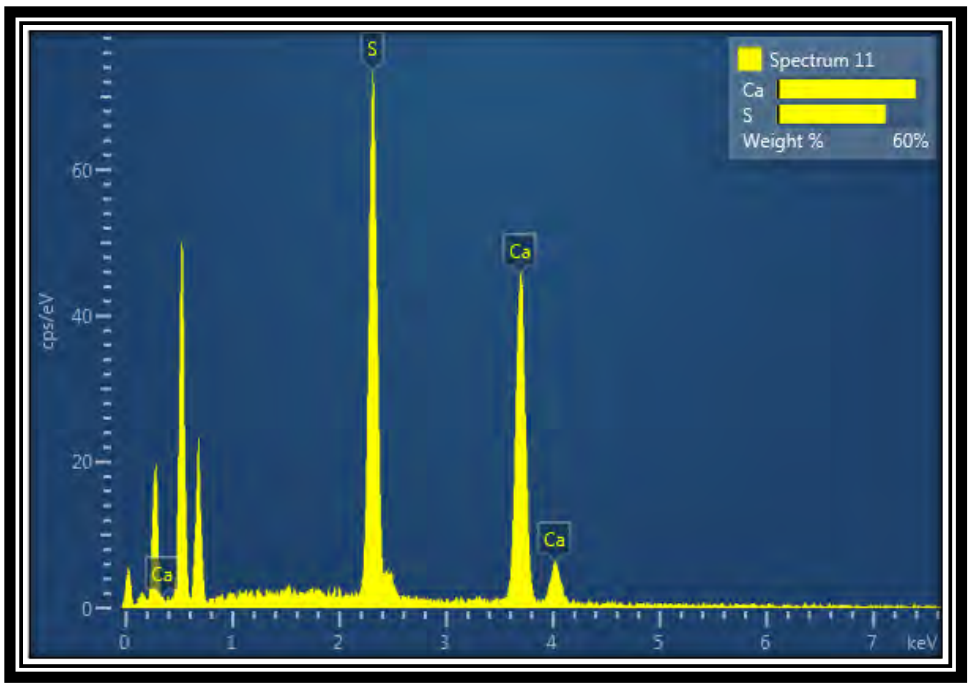


Figure 47: EDS and composition bar graph analysis of the membrane deposit from Spectrum 11.

Spectrum 11	Atomic %
C	33.62
O	36.52
F	14.15
S	8.12
Ca	7.59
Total	100.00

Spectrum 11	Atomic %
Carbon, Oxygen and Fluorine Ignored	
S	49.46
Ca	50.54
Total	100.00

Table 12: Composition table from the EDS spectrum of localized deposit from Spectrum 11.

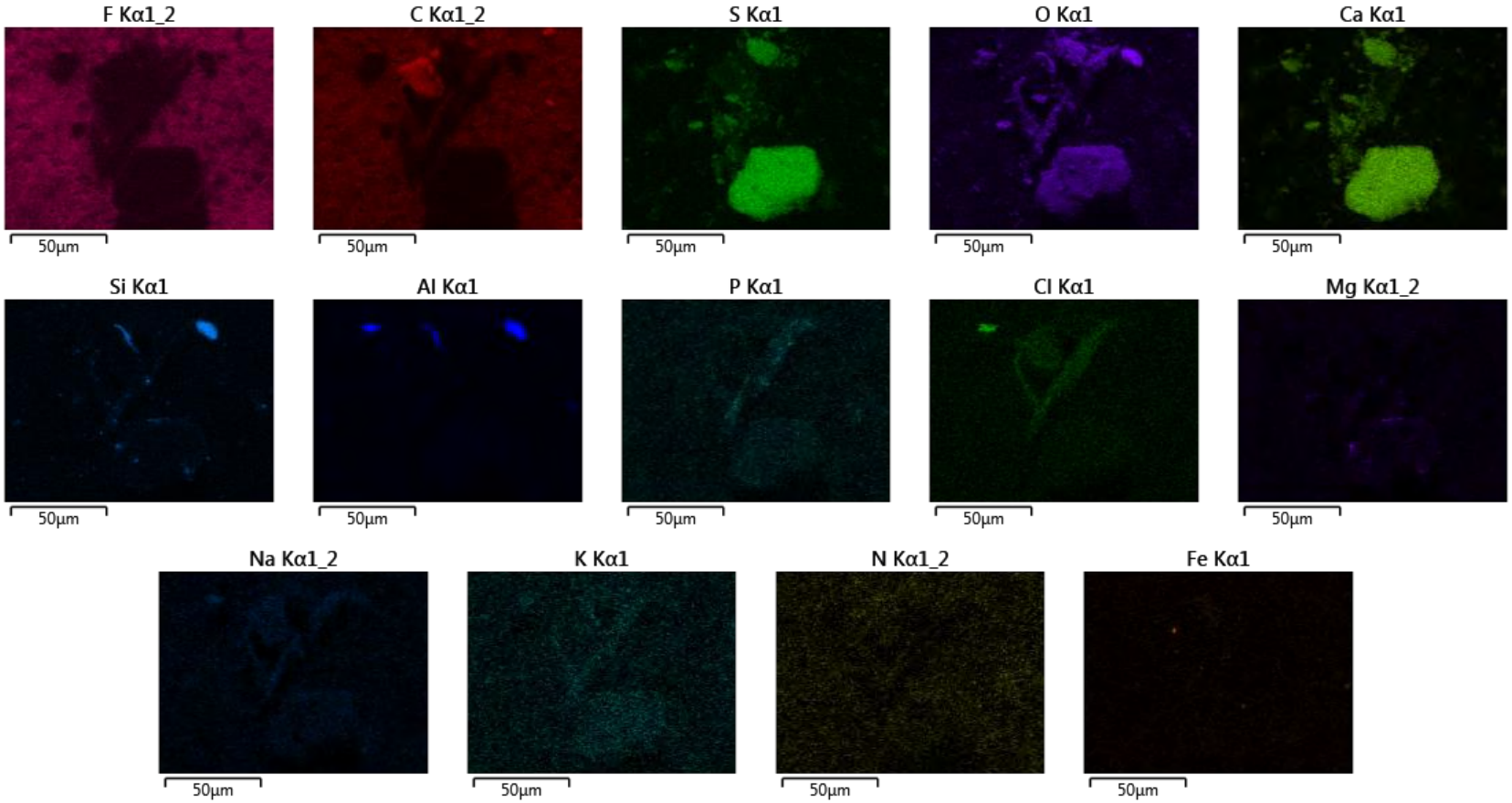


Figure 48: Prismatic Elemental Delineation (PED®) of membrane surface at 900X magnification. Deposits found: Calcium sulfate, silts/clays, iron hydroxide and organic based matter.

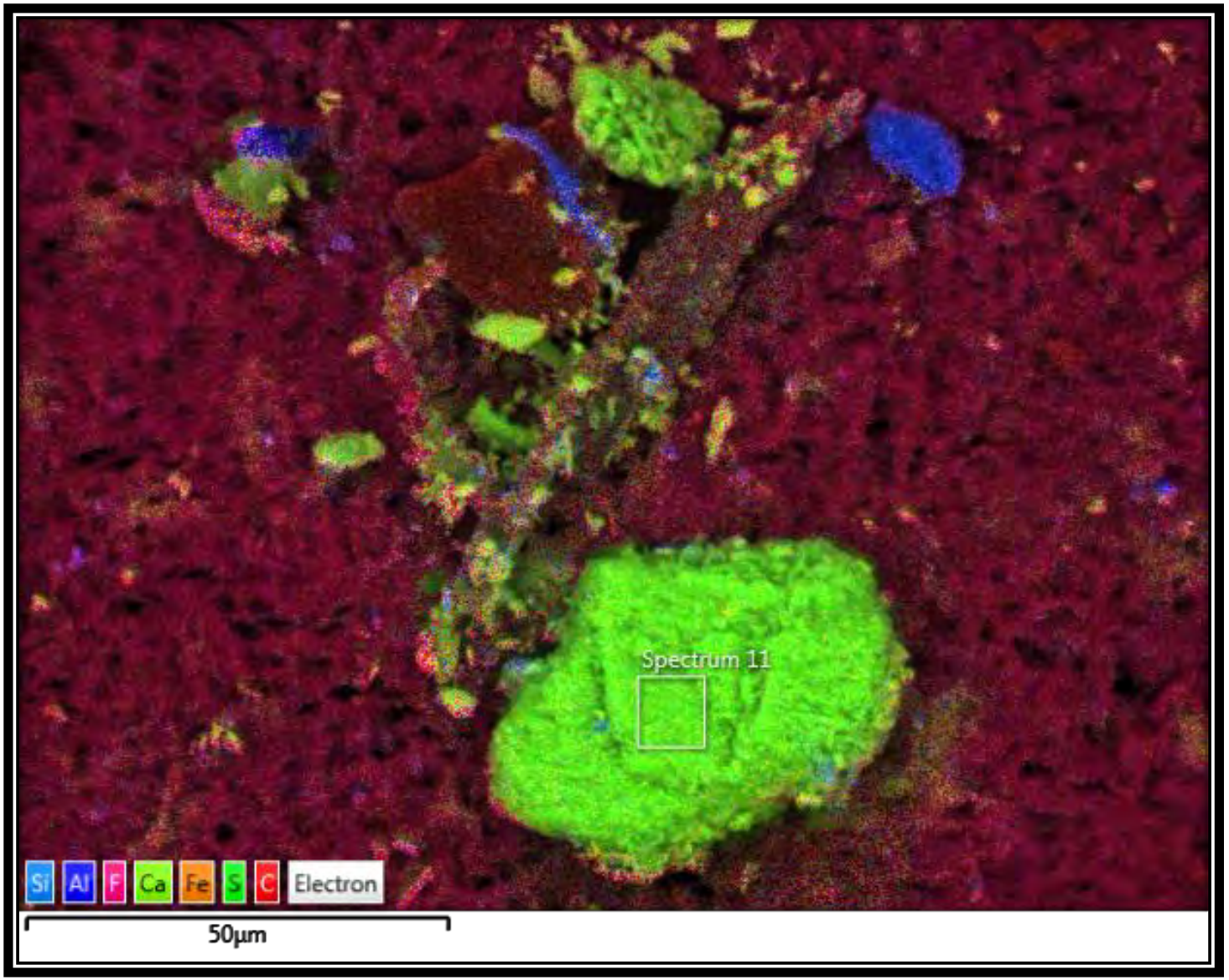


Figure 49: Superimposed Elemental Imaging (SEI®) of calcium sulfate, silts/clays, iron hydroxide and organic based matter.

Post Cleaning

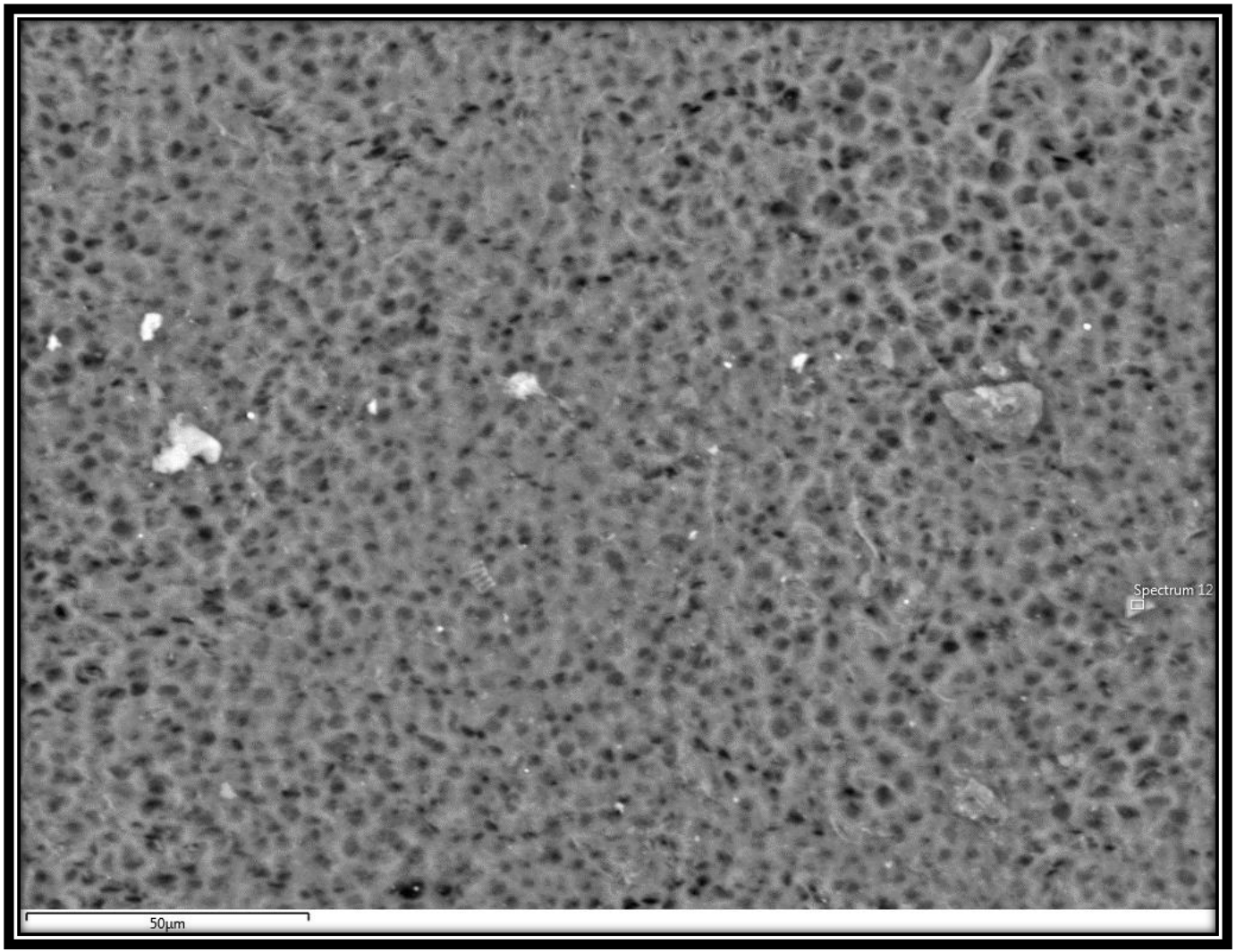


Figure 50: Electron micrograph of the cleaned membrane surface at 1200X magnification.

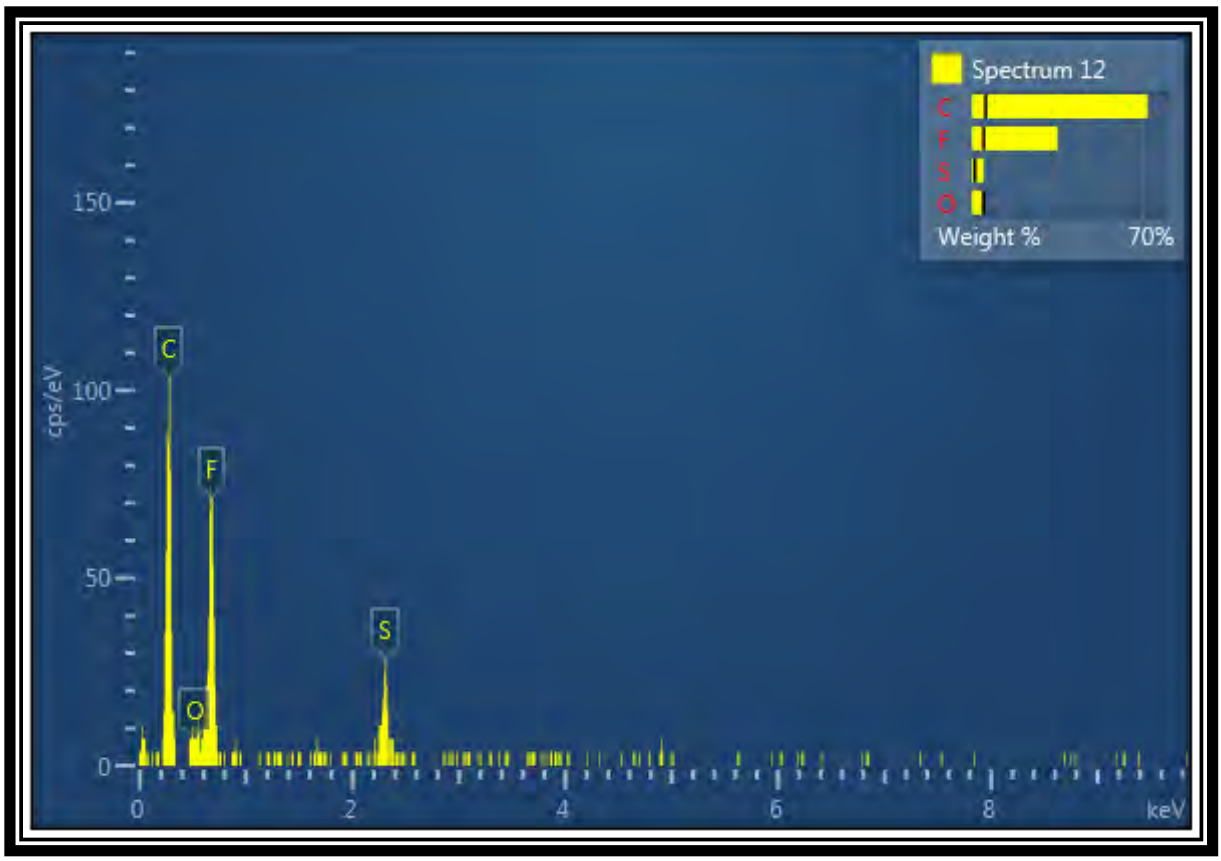


Figure 51: EDS and composition bar graph analysis of the membrane surface from Spectrum 12.

Spectrum 12	Atomic %
C	72.64
O	3.17
F	22.36
S	1.83
Total	100.00

Table 13: Composition table from the EDS spectrum of localized deposit from Spectrum 12.

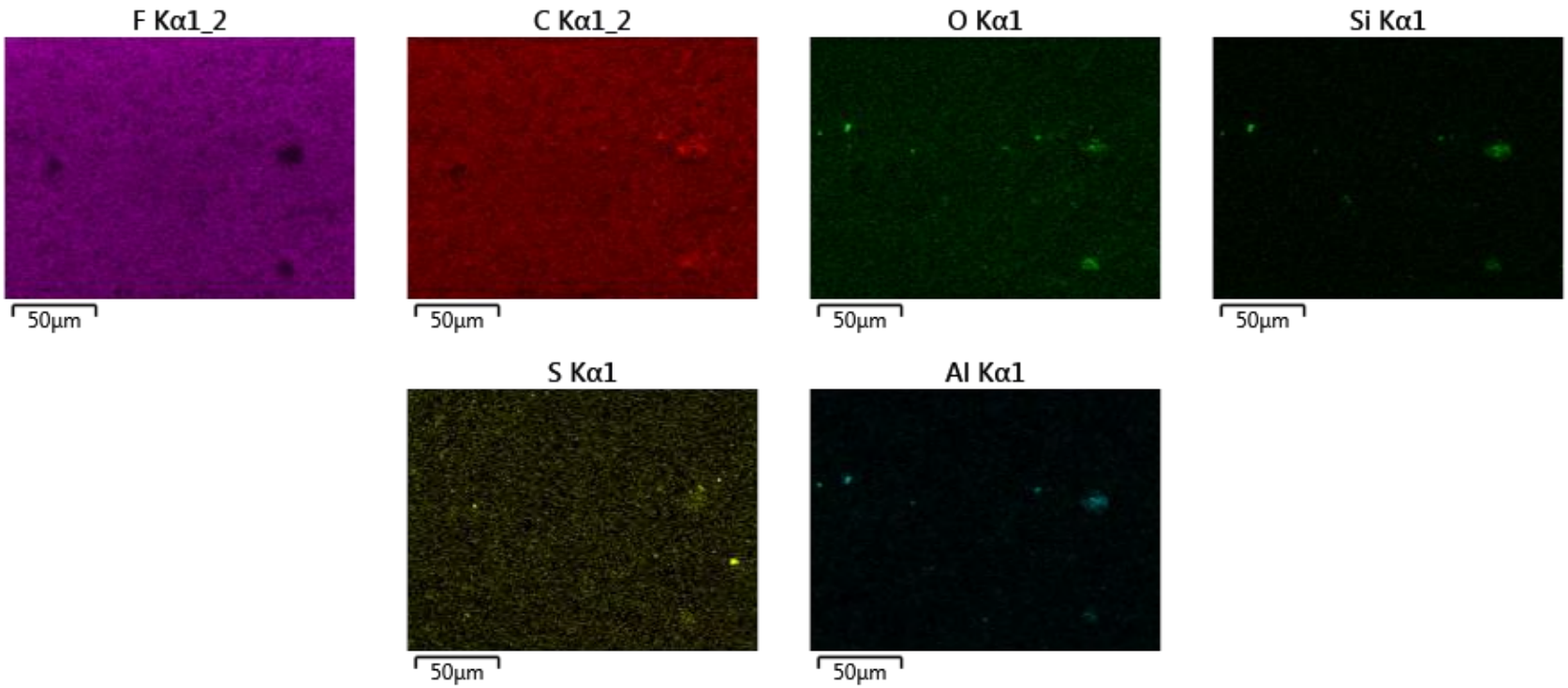


Figure 52: Prismatic Elemental Delineation (PED®) of the cleaned membrane surface at 1600X magnification. Deposits found: Silts/clays and elemental sulfur.

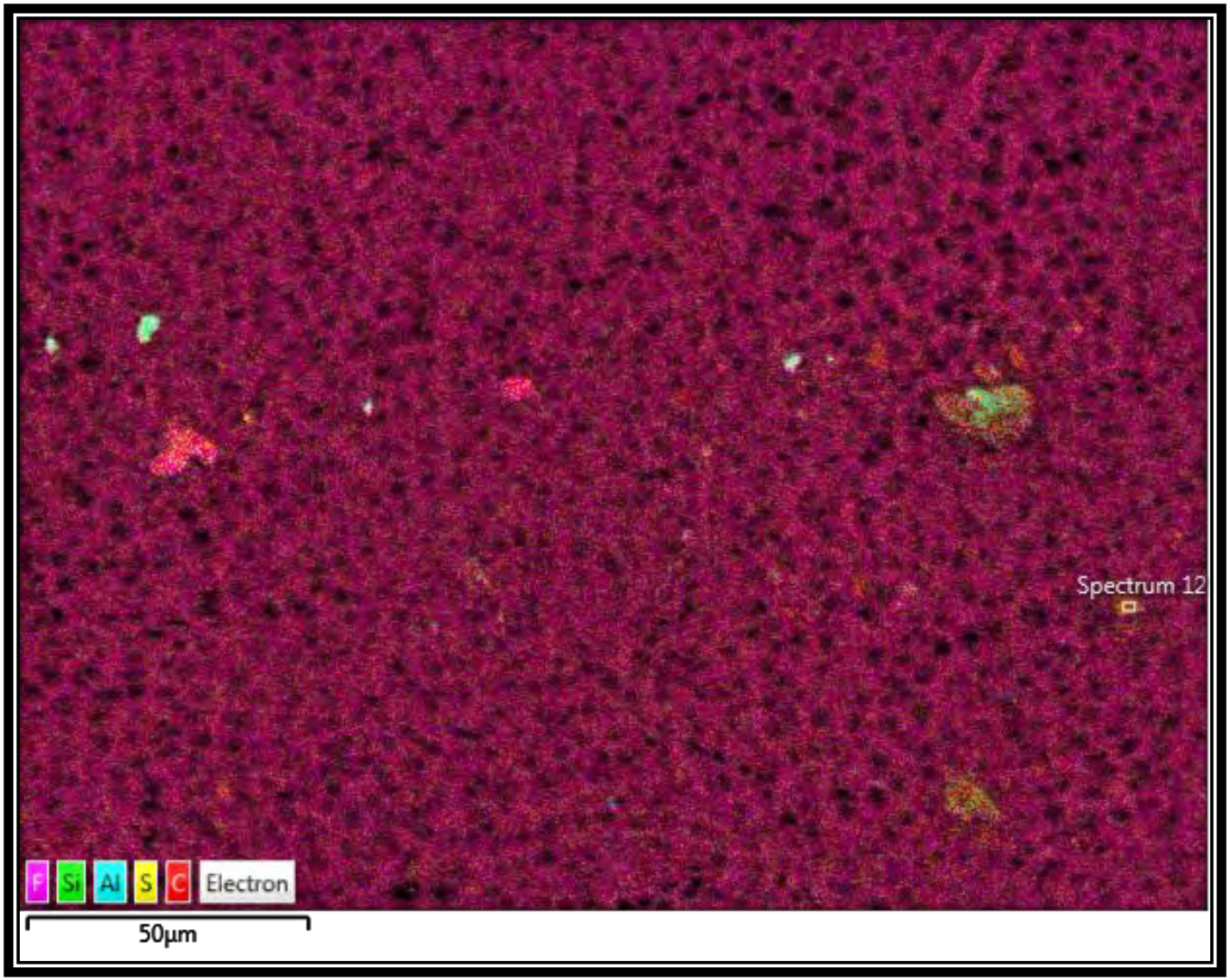


Figure 53: Superimposed Elemental Imaging (SEI®) of the cleaned membrane.

Membrane Surface Analysis

Low Voltage Secondary Electron Imaging can be used to determine the condition of the membrane surface. The samples are sputtered with a thin layer of gold to decrease “charging” and allow observation at higher resolutions. Membrane artifacts and surface tears on a cleaned membrane are measured and characterized.

Results

The size of the pores ranged from <0.7µm to ~5 µm.

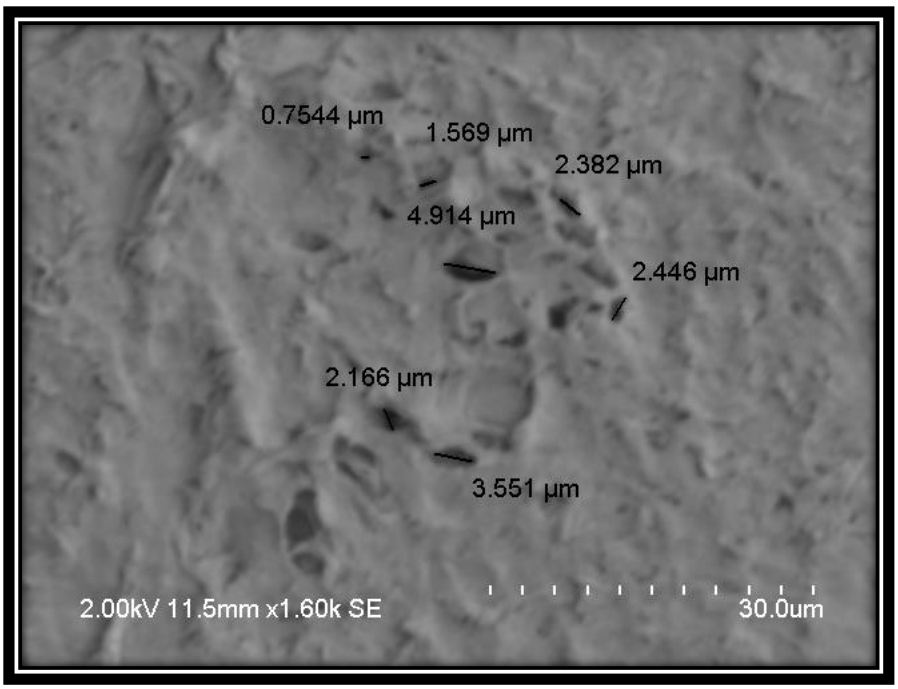


Figure 54: Electron micrograph of the membrane surface at 1600X magnification. The size of the pores ranged from <0.7µm to ~5 µm.

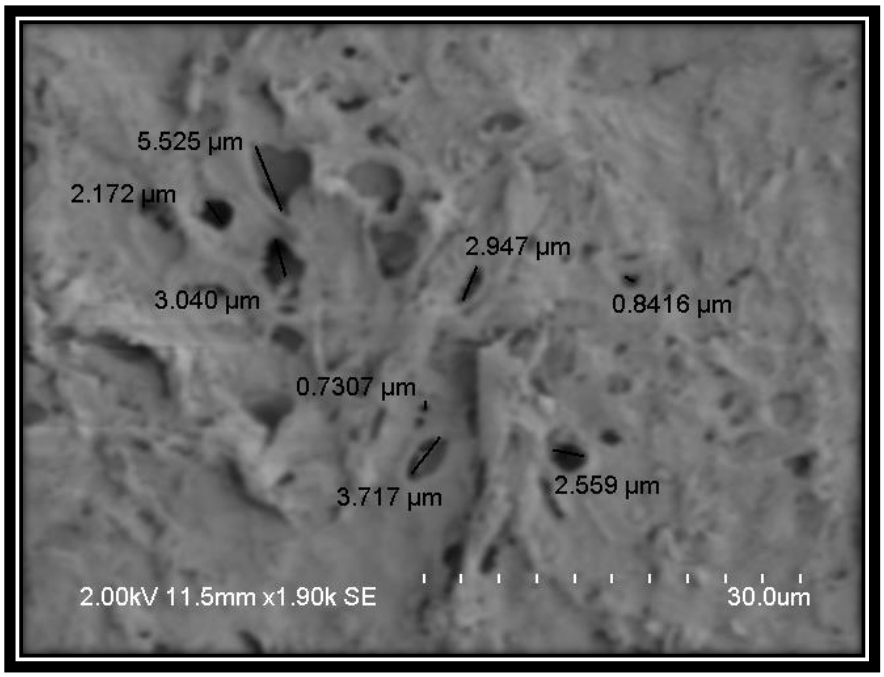


Figure 55: Electron micrograph of the membrane surface at 1900X magnification. The size of the pores ranged from <0.7µm to ~5 µm.

FTIR analysis

Fourier Transform Infrared spectrometer (FTIR) is a powerful tool for identifying types of chemical bonds (functional groups). The wavelength of light absorbed is characteristic to the chemical bond. The tested material can be identified by comparing its spectrum to the spectra of documented compounds in the database.

The following samples were analyzed with FTIR:

- The membrane foulant dehydrated at 105°C for 8 hours (see Figure 56).
- The LOI residue of the foulant collected from the membrane surface (see Figure 61).

Results: Dehydrated Foulant

The spectrum of the dehydrated foulant had peaks that were associated with biofilm. A library search found matches to proteins and yeast. A search in AWC's database found a high correlation to a known biofilm sample.

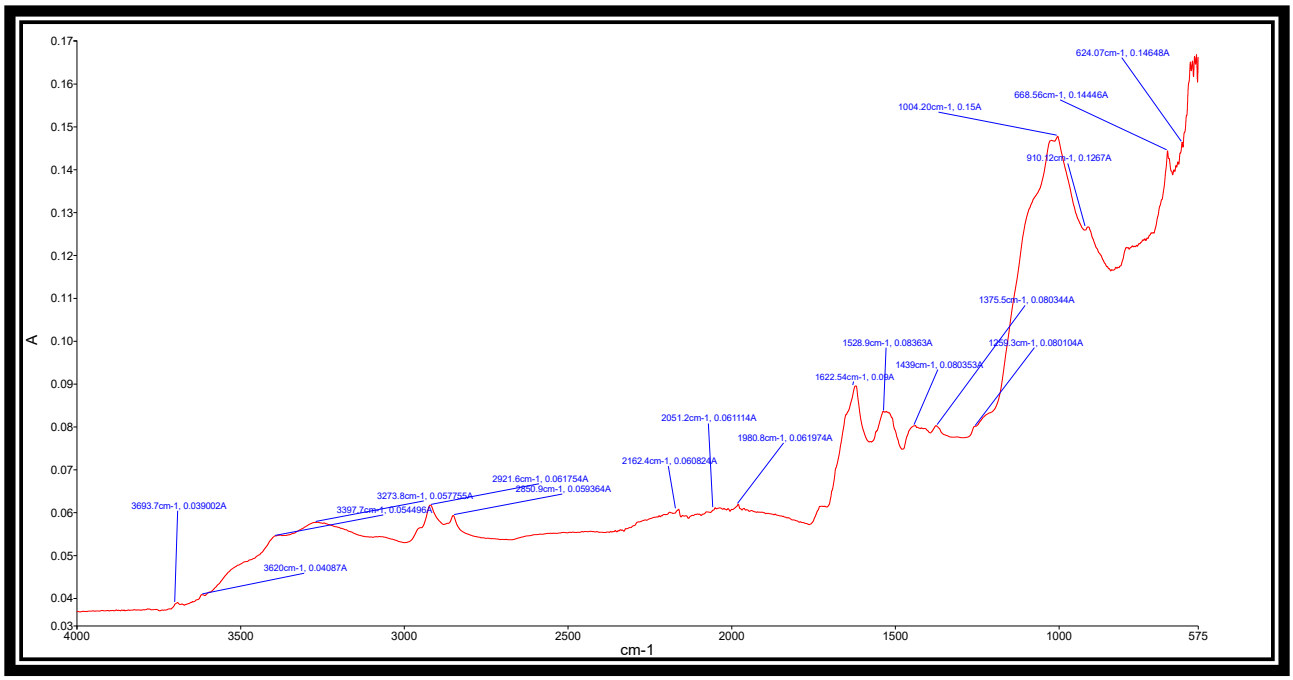


Figure 56: FTIR spectrum of the dehydrated foulant.

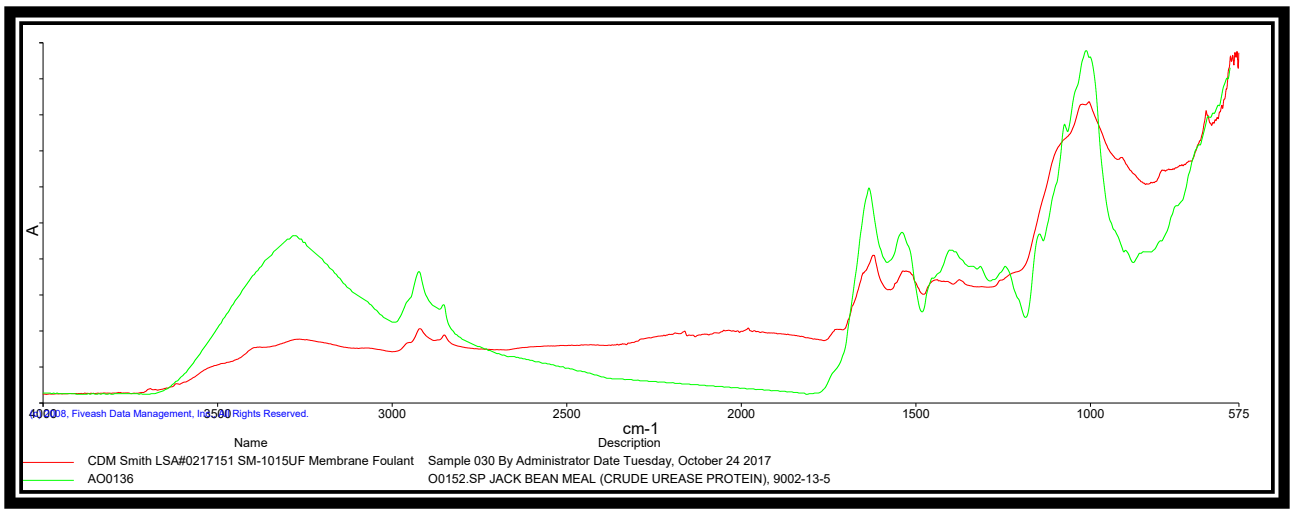


Figure 57: The spectrum of the dehydrated foulant had a ~80% correlation to protein.

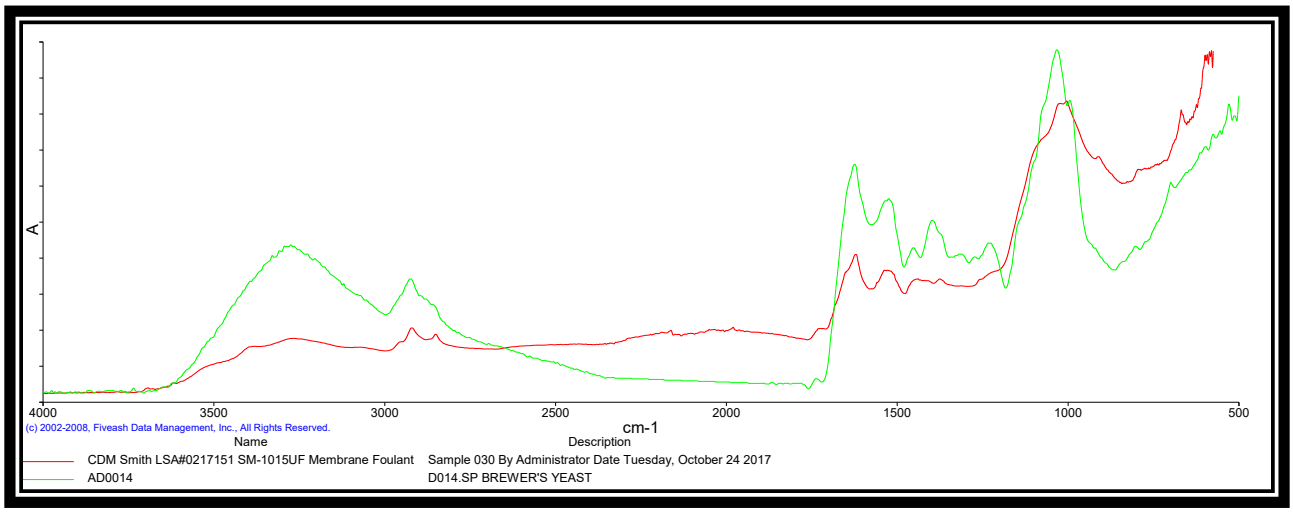


Figure 58: The spectrum of the dehydrated foulant had a ~78% correlation to yeast.

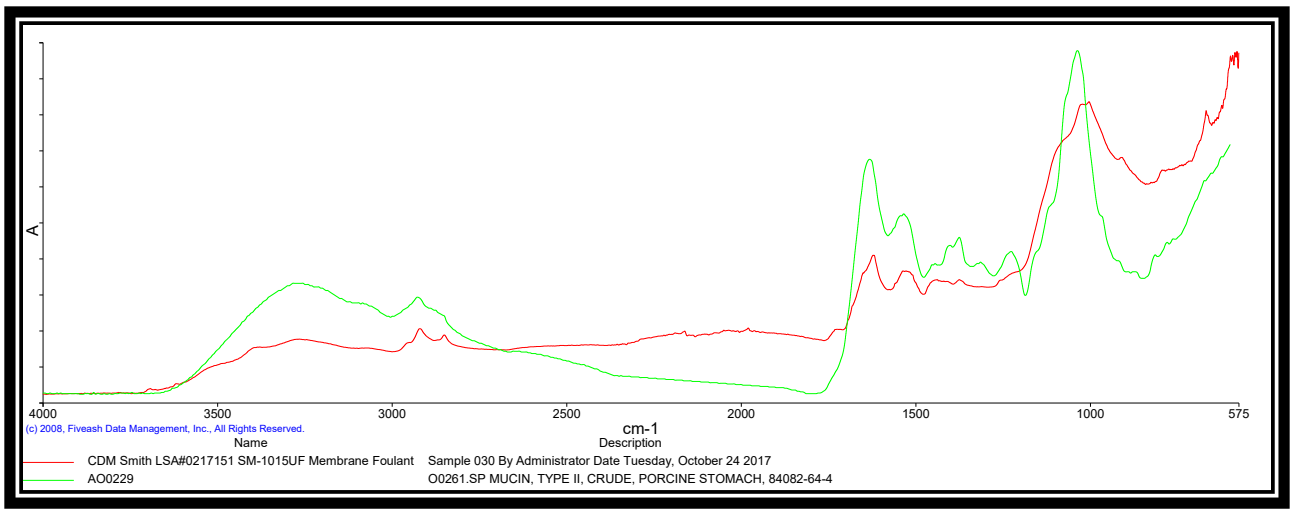


Figure 59: The spectrum of the dehydrated foulant had a ~66% correlation to mucin.

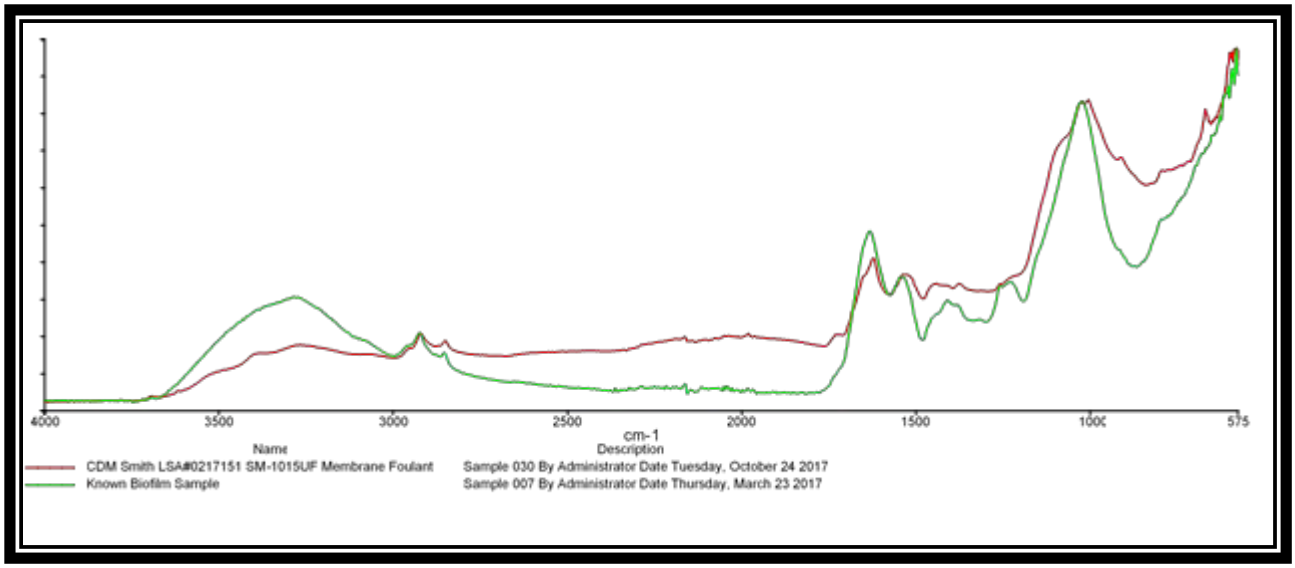


Figure 60: The spectrum of the dehydrated foulant had a ~82% correlation to a known biofilm sample.

Results: LOI residue

The spectrum of the LOI residue had peaks that were associated with crystalline silica. A library search found correlations to aluminosilicate minerals.

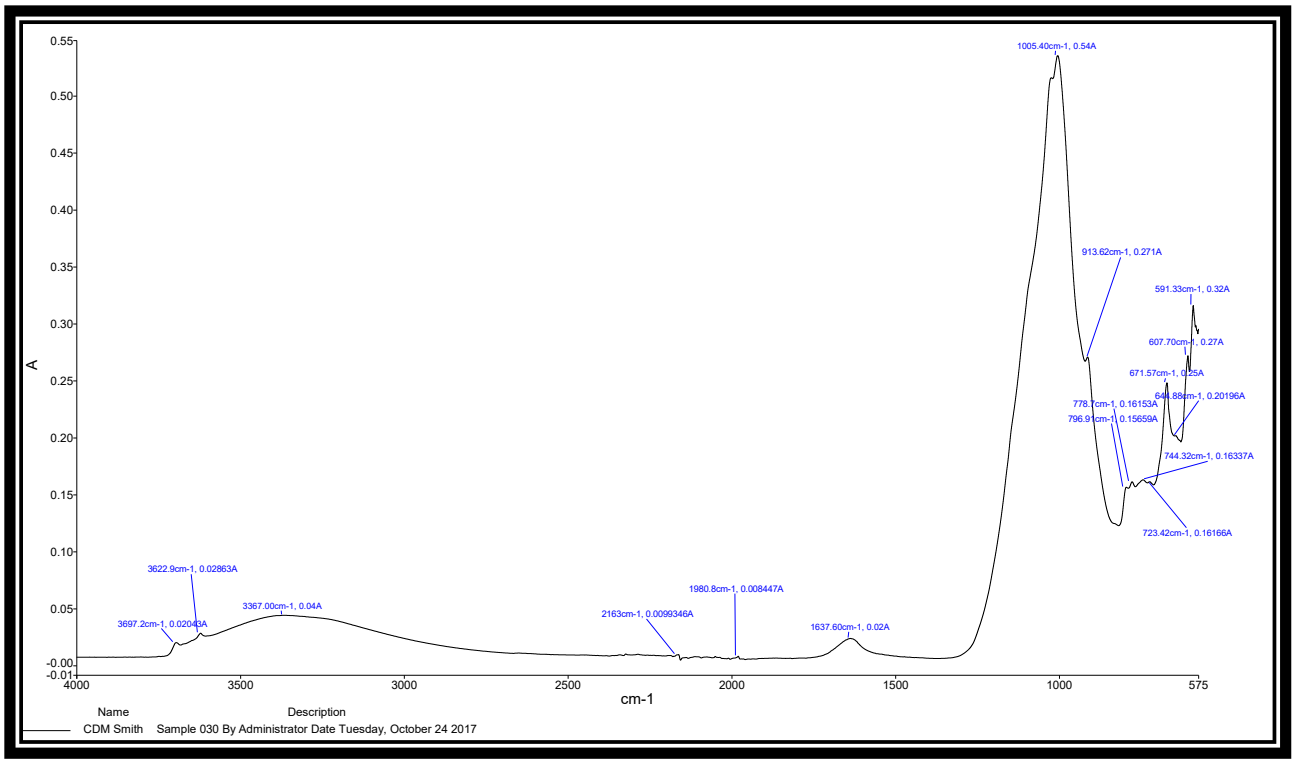


Figure 61: FTIR spectrum of the of the LOI residue.

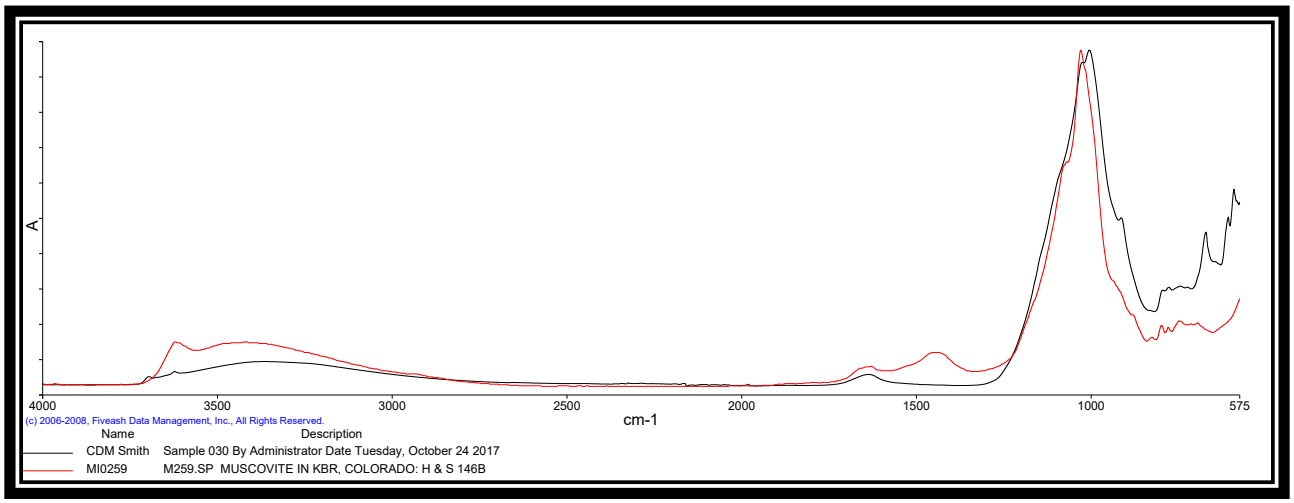


Figure 62: The spectrum of the LOI residue had a 73% correlation to Muscovite (aluminosilicate mineral).

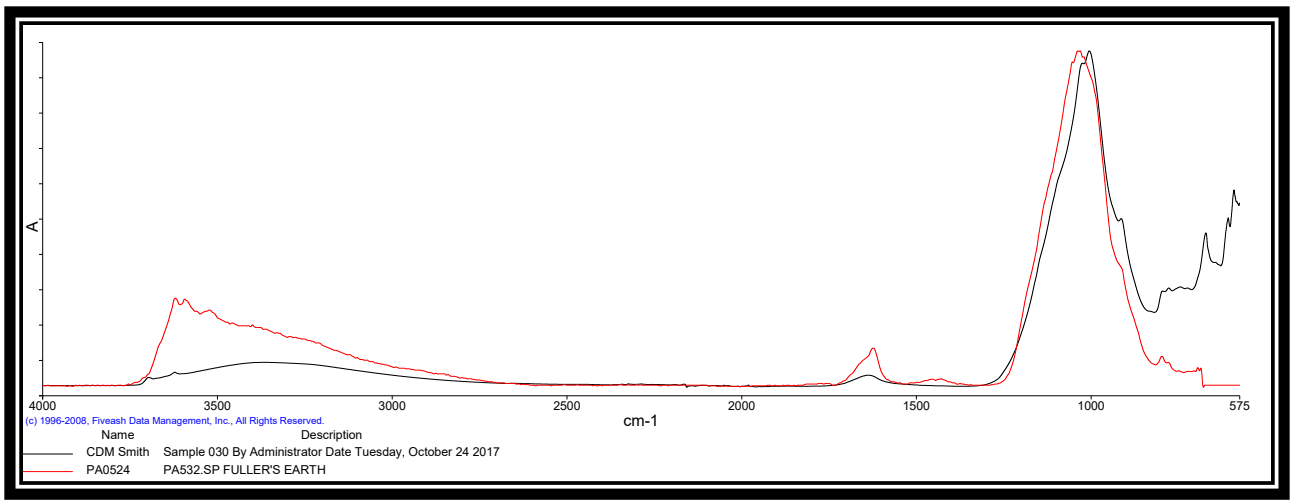


Figure 63: The spectrum of the LOI residue had a ~73% correlation to Fuller's earth (aluminosilicate mineral).

Raman Spectroscopy

Raman spectroscopy is used to identify molecules and study chemical bonding through the inelastic scattering of light caused by the vibrations of molecules. A laser beam is used to irradiate a sample, and the resulting scattered radiation provides information about vibrational frequencies that are specific to a molecule's chemical bonds and symmetry. The unknown material can be identified by comparing its spectrum to the spectra of known compounds in a database.

Results

Raman analysis of the foulant had a ~73% correlation to Jet (aka Lignite, Brown Coal).

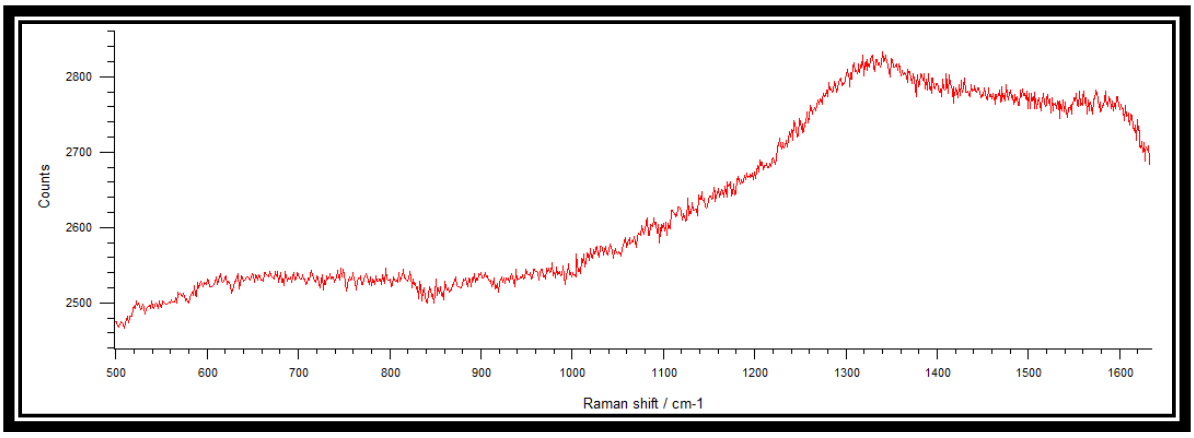


Figure 64: Raman spectrum of the foulant.

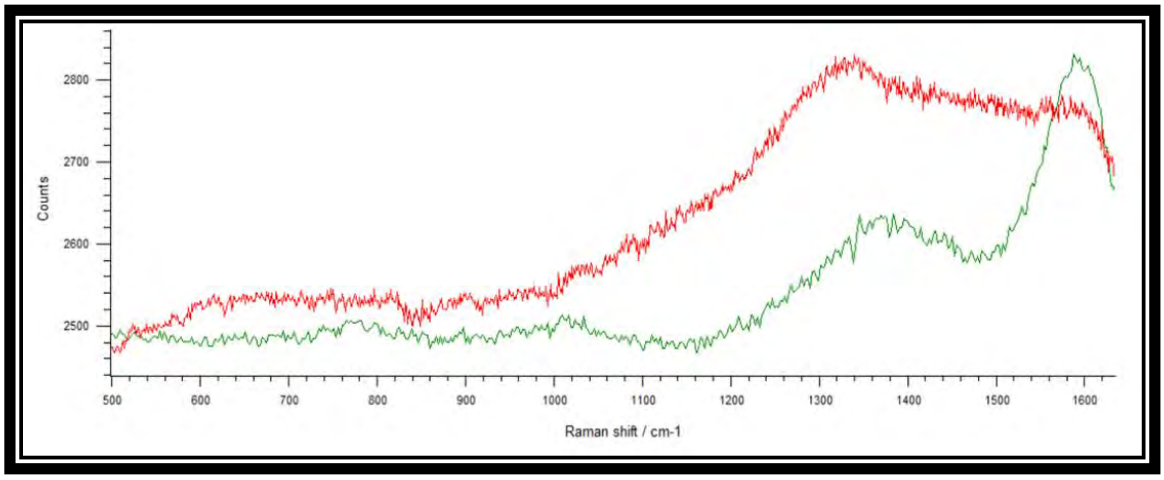


Figure 65: The Raman spectrum of the foulant had a ~73% correlation to the Raman spectrum of Jet (coal).

Results and Discussion

A black foulant was found on the fibers. The LOI test determined the foulant to consist of ~66% organic matter and ~34% inorganic matter.

A small module was constructed so that the hollow fibers could be tested for permeability. The permeability of the fouled fibers was found to be equivalent to that of virgin fibers. Cleaning with a specialty high pH cleaner and a specialty chlorine-based cleaner did not result in significant improvement. This suggested that the 24 hour deionized water soak prior to testing likely removed the foulant that had caused the flux decline reported by the client.

SEM/EDS/SEI/PED analysis of the membrane surface found the foulant to consist of organic based matter, elemental sulfur, iron disulfide (pyrite), calcium phosphate, calcium sulfate, iron hydroxide, titanium oxide, silts and/or clays. Inorganic carbon was identified based on its geometric morphology, but could otherwise not be easily distinguished from organic based matter.

FTIR analysis of the foulant found spectra associated with silts/clays and biofilm. FTIR analysis of the LOI residue found spectra associated with silts/clays.

Raman microscopy analysis found spectra associated with a type of coal.

Release of Liability

The Membrane Autopsy Service (The Service) was performed in accordance with the standards of care, skill, and diligence normally provided by a professional in the performance of similar services. American Water Chemicals, Inc. makes no warranty of any kind with the respect to The Service and will not be liable for any damages resulting from the use or misuse of The Service. In no event shall American Water Chemicals, Inc. have any liability for The Service, including, but not limited to, special, indirect, incidental, consequential, or other direct damages whether such liability arises in contract, negligence, strict liability, or otherwise, and the Client hereby agrees to release and indemnify American Water Chemicals, Inc. against same.

APPENDIX F. DEWATERING TEST REPORT

Evaluation of Dewaterability of the AnMBR

Matthew J. Higgins

Bucknell University

Overview

Two shipments of samples were received. The first shipment was in late April, 2017 and contained a sample from the AnMBR while the second shipment contained two samples, one from the AnMBR and the other from the sedimentation basin. The two samples were dewatered using a method developed at Bucknell University, as described below. The method gives an estimate of the cake solids expected from a typical belt filter press, and also a relative measure of the polymer demand for conditioning.

Method

The dewaterability of the samples were analyzed using a laboratory protocol developed at Bucknell University (Higgins et al., 2014b). A high molecular weight, cation polymer (SNF, 6440) was made to a 0.25% concentration on the day of the dewatering experiment. First, the optimum polymer dose was determined by establishing the polymer dose-response curve using capillary suction time (CST) as the measure of the extent of conditioning and floc formation. A 500 mL sample of digestate was placed in a 2 L, baffled circular container. The polymer was added to the solids and mixed using a single paddle mixer at 563 rpm for 30 s, followed by 54 rpm for 90 s, after which the CST was measured. The dosage with the lowest CST was considered the optimum polymer dose, and this sample was then dewatered.

Dewatering was performed by first gravity draining the solids on belt filter press fabric for a minute. The drained solids were then placed in a specially designed belt filter press centrifuge cup. These cups comprise a piece of belt filter press fabric that was suspended approximately half way up the height of the cup. The samples were then centrifuged at 2075 x g for 10 minutes, and the cake is scraped off the belt filter press fabric for analysis for TS and VS. The cakes are also analyzed for their odorant production potential. Duplicate cake samples were generated and analyzed for each sample.

Results

The TS of the original sample, as well as the cake solids and polymer demand measured during the dewatering test are summarized in Table 1. The cake solids for the AnMBR samples average about 16% for the two different samples (note, each samples was analyzed in duplicate). The polymer demand had an average around 32 kg/metric tonne, which is relatively high. For the sample from the sedimentation basin, the average cake solids was 19.6% and the polymer demand was 9.2 kg/tonne.

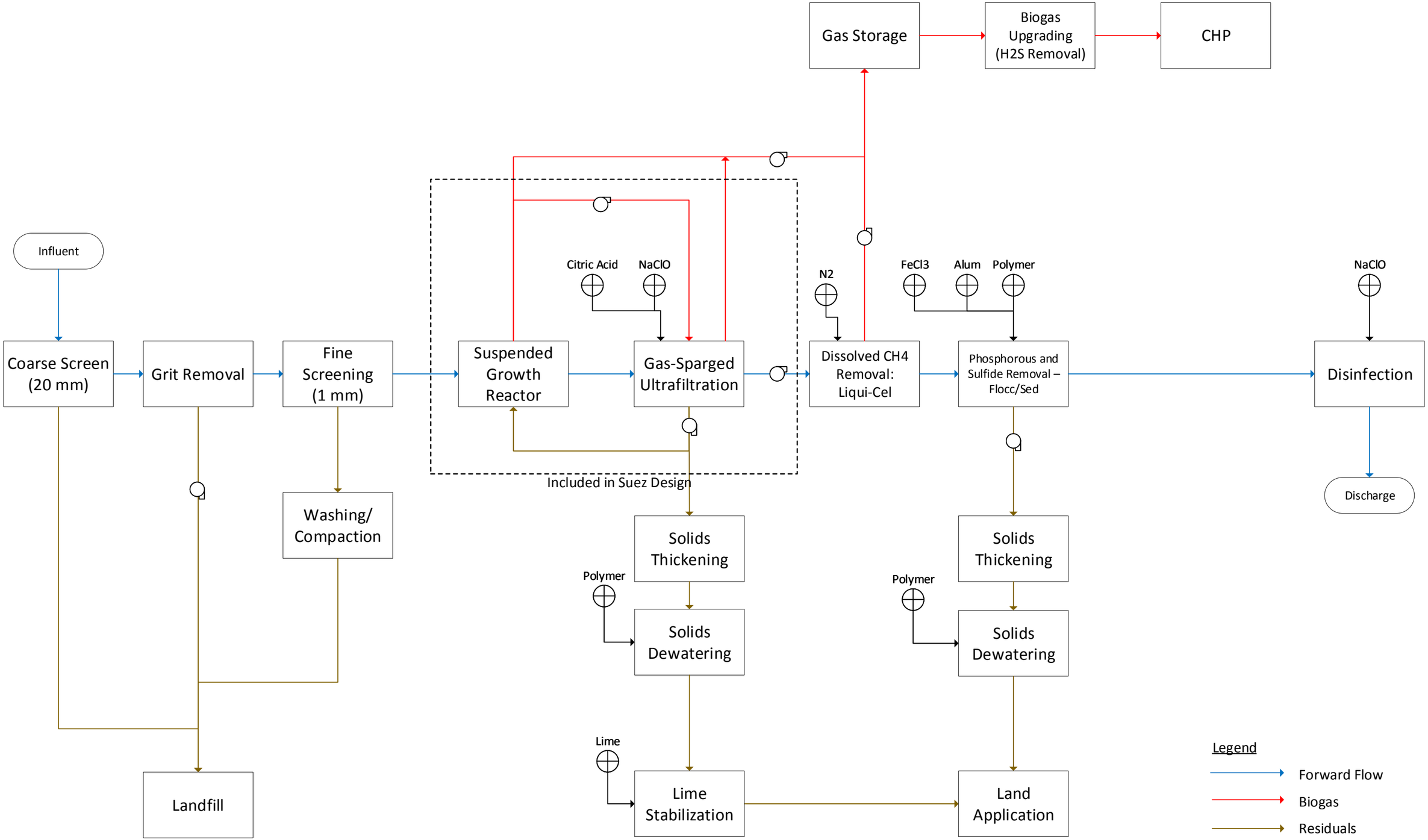
Table 1. Summary of dewaterability parameters for the samples.

Sample	Sample Date	Sample TS (%)	Cake Solids (%)	Polymer Dose (kg/tonne)
AnMBR Bioreactor	4/26/17	1.03	16.2 ± 0.98	29.6
AnMBR Bioreactor	10/19/17	0.22	15.9 ± 0.55	34.4
Sediment Basin	10/19/17	1.24	19.6 ± 0.13	9.2

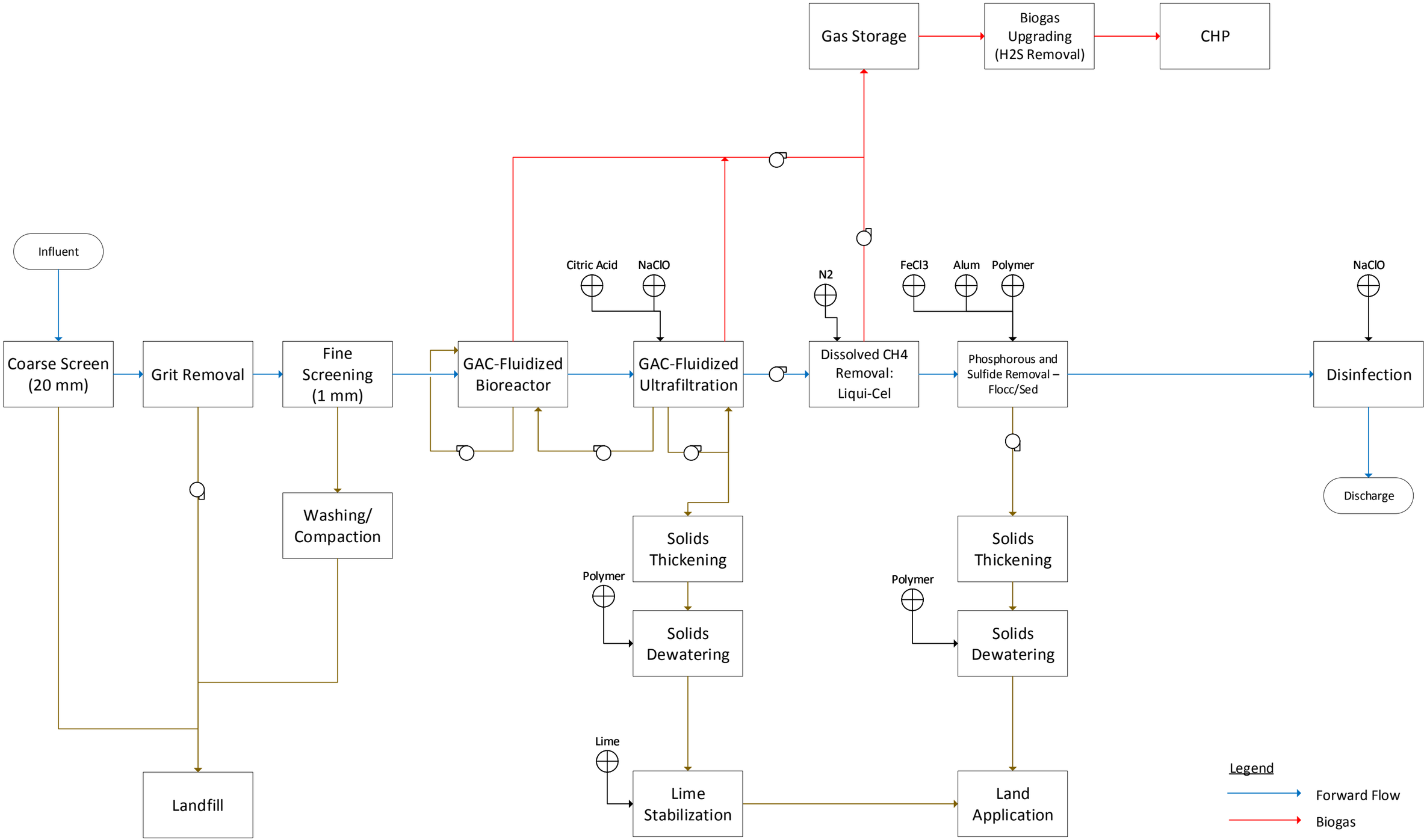
APPENDIX G. COST EVALUATION SUPPORTING DATA

PROCESS CONFIGURATION FLOW DIAGRAMS

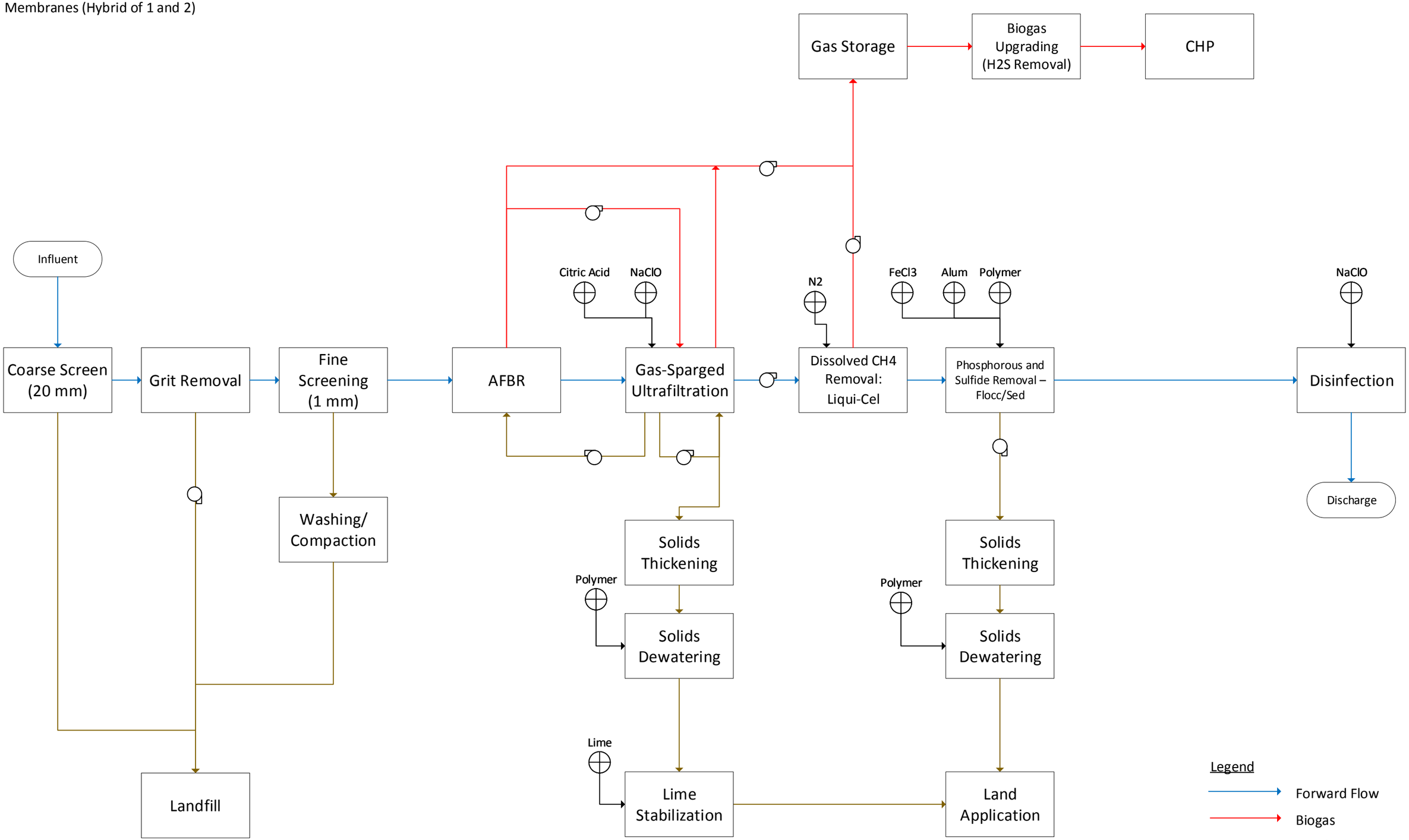
Process Configuration 1
- Gas Sparged AnMBR, Demo Configuration



Process Configuration 2
- GAC-fluidized AnMBR, Demo Configuration

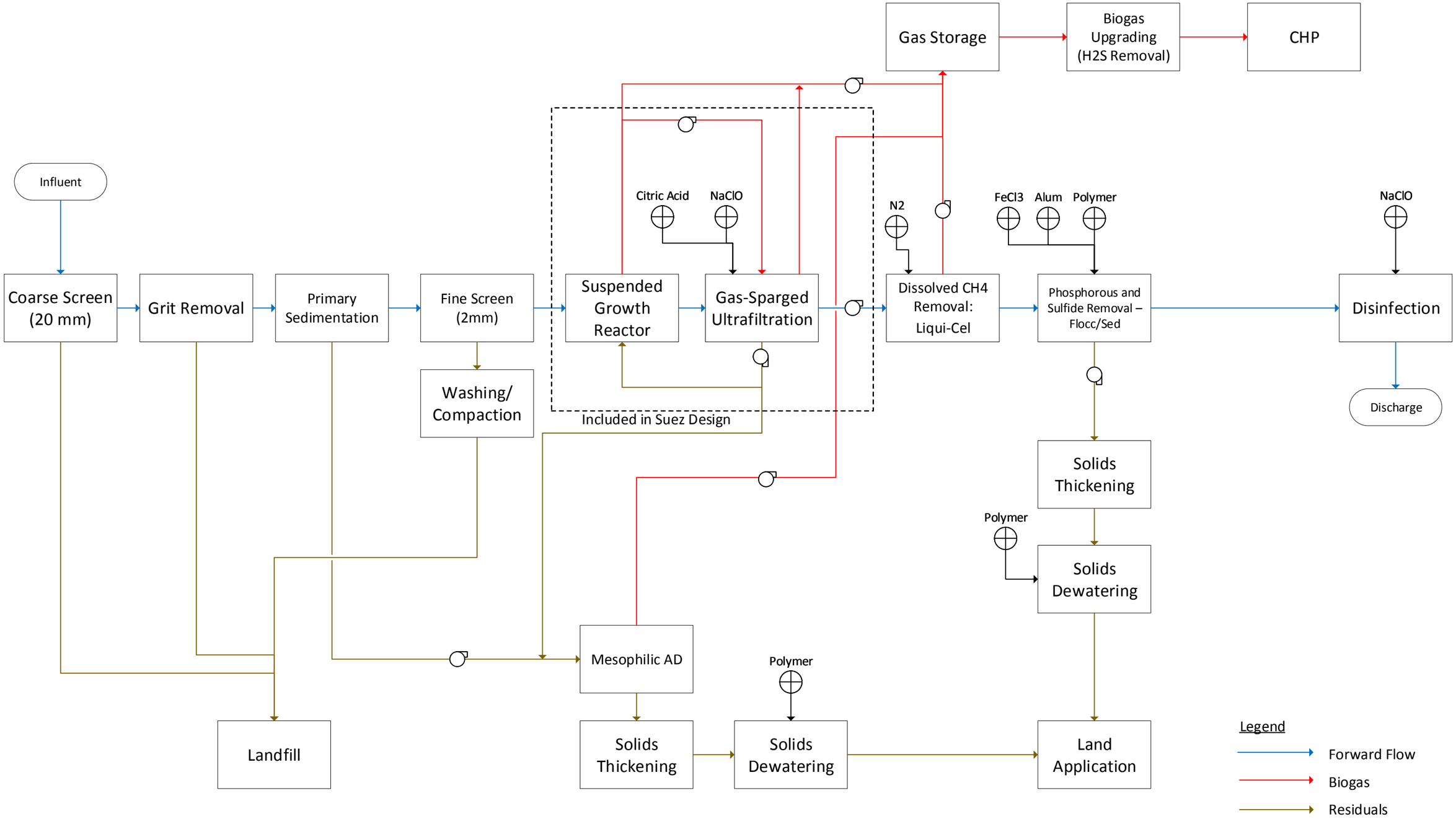


Process Configuration 3
- GAC Fluidized AnMBR with Secondary Membrane UF Membranes (Hybrid of 1 and 2)

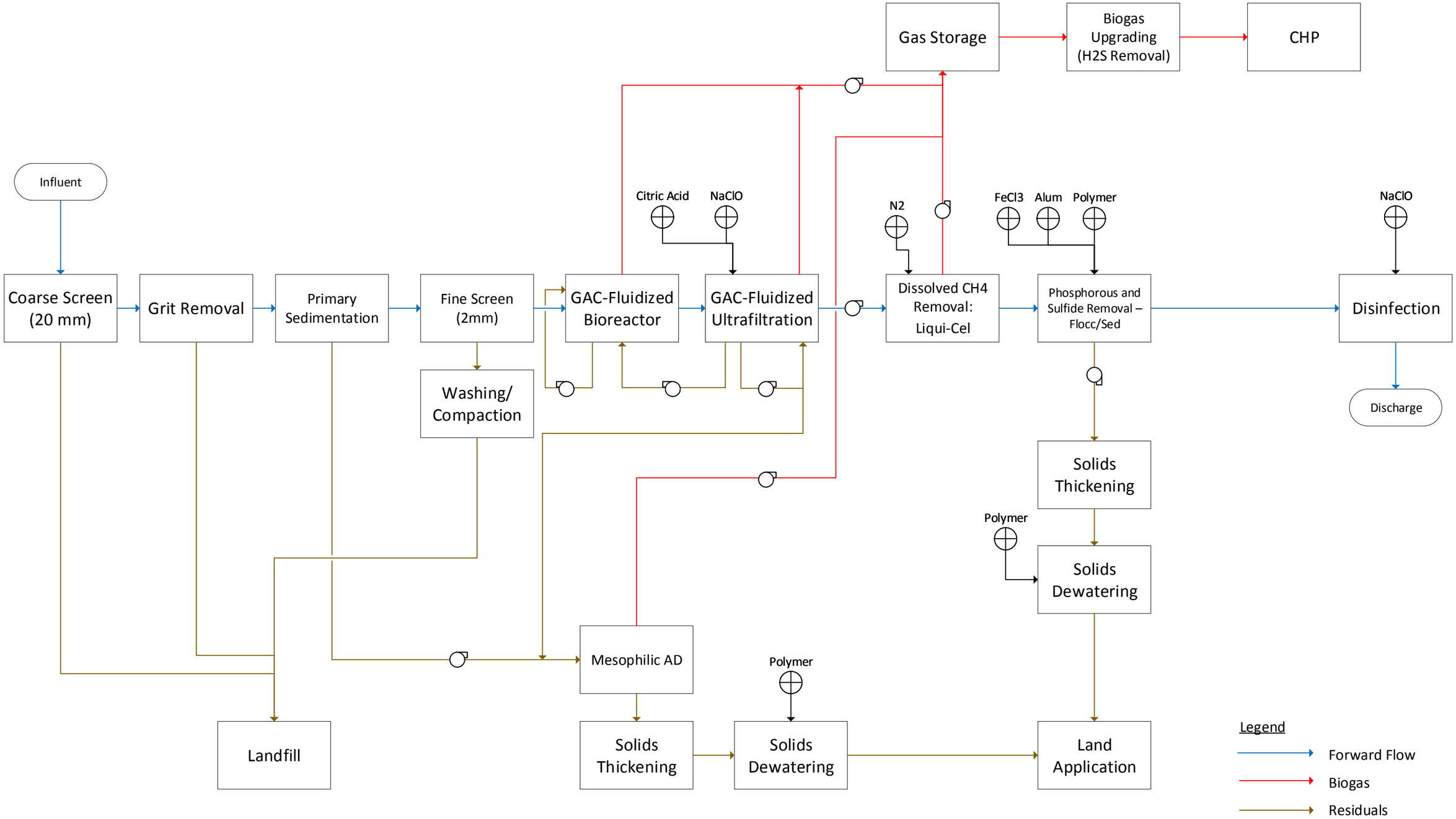


Process Configuration 4

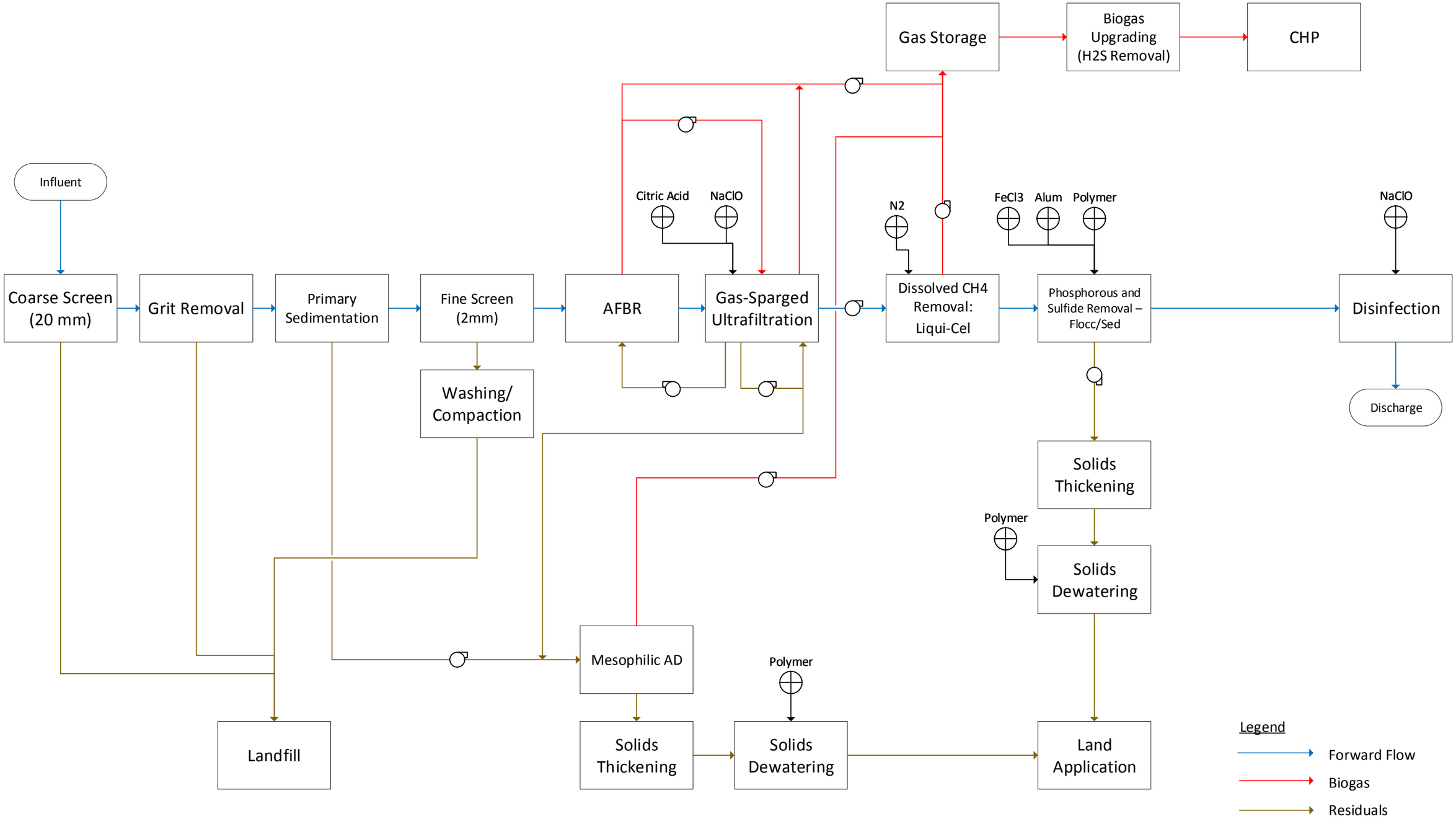
- Gas Sparged AnMBR, Demo Configuration
- with primary sedimentation
- with anaerobic digestion for primary and biological solids



Process Configuration 5
- GAC-Fluidized AnMBR, Demo Configuration
- with primary sedimentation
- with anaerobic digestion for primary and biological solids

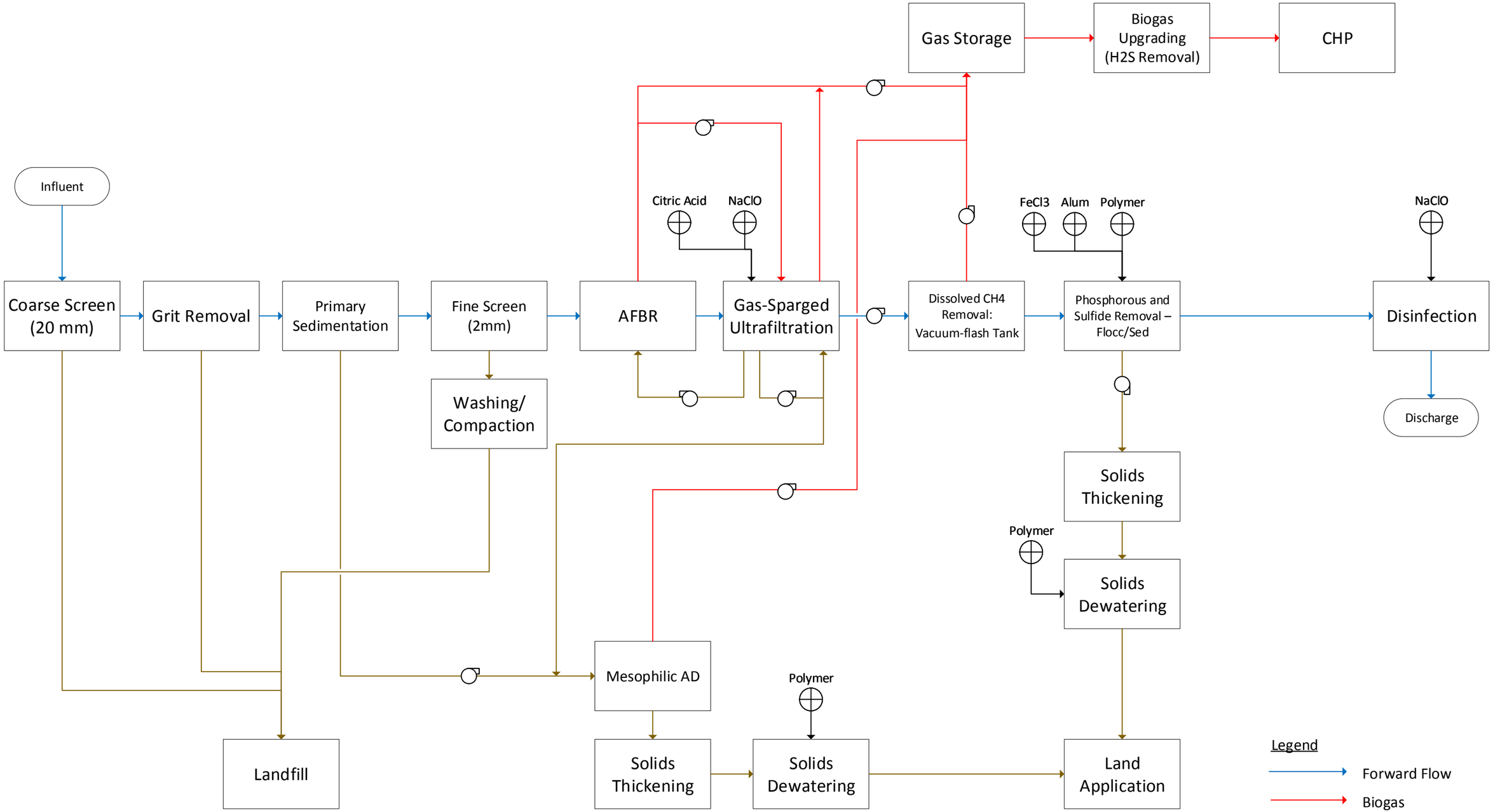


Process Configuration 6
- GAC Fluidized Bed Reactor with Gas Sparged UF Membranes
- with primary sedimentation
- with anaerobic digestion for primary and biological solids

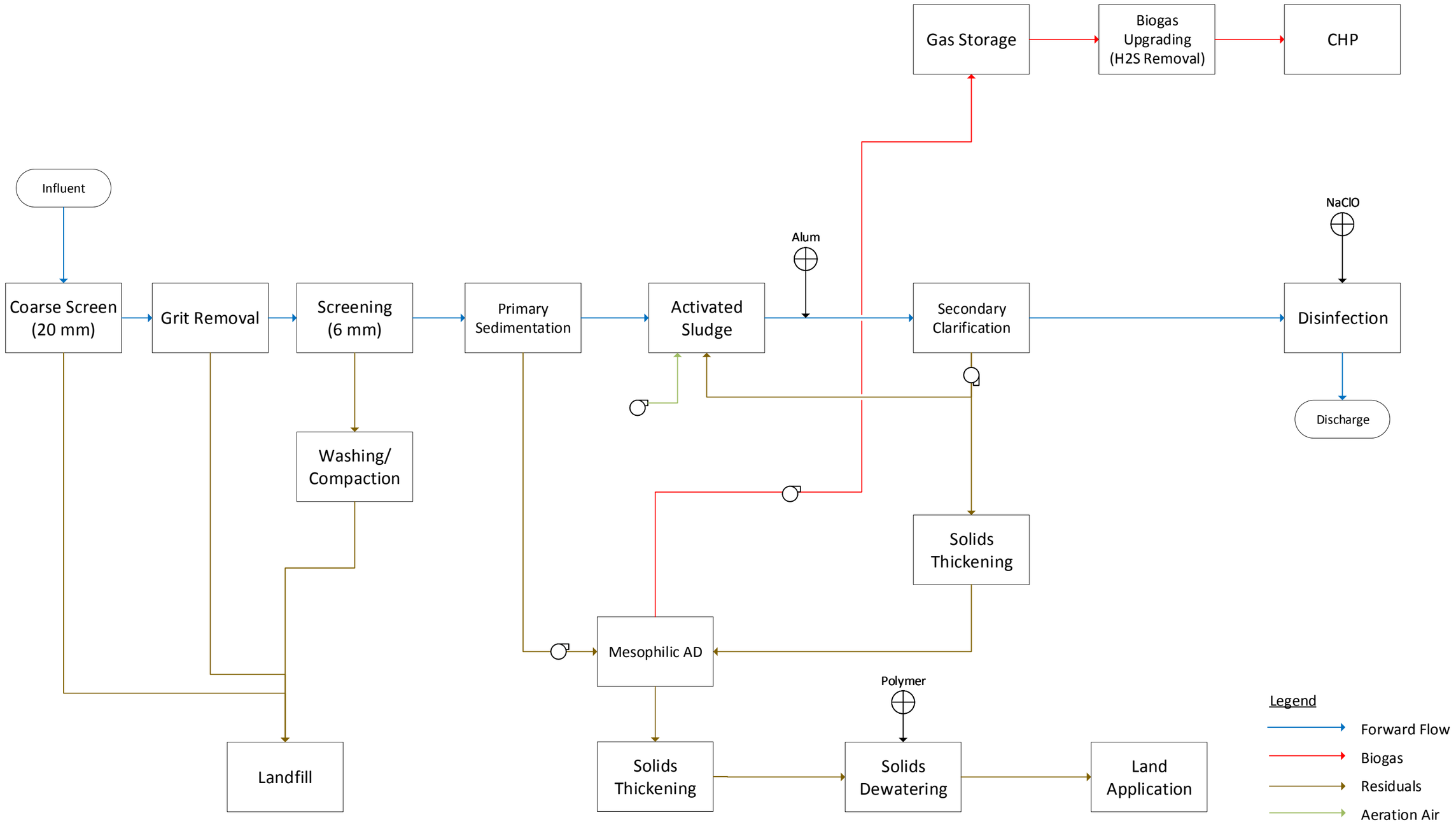


Process Configuration 7

- GAC Fluidized Bed Reactor with Gas Sparged UF Membranes
- with primary sedimentation
- with anaerobic digestion for primary and biological solids
- Alternative dissolved methane removal (Vacuum Flash Tank)



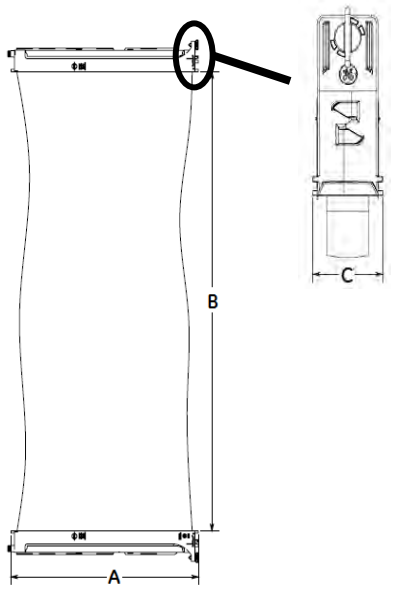
Process Configuration 8
- Conventional activated sludge treatment



BUDGET QUOTATION
FROM SUEZ FOR
MEMBRANE BIOREACTOR
TANKS AND EQUIPMENT

Water Technologies & Solutions
fact sheet

ZeeWeed* 500D module



Module Dimensions			
Product	**Width (A) mm (in)**	**Height (B) mm (in)**	**Depth (C) mm (in)**
370, 340	844 (33.2)	2,198 (86.5)	49 (1.9)
440			52 (2.05)
300s		1,835 (72.25)	49 (1.9)
350s			52 (2.05)

Module Properties									
Application	**Product**	**Nominal Membrane Surface Area m^2 (ft^2)**	**Max. Shipping Weight [1] kg (lb)**	**Lifting Weight [2] kg (lb)**	**Material**	**Nominal Pore Size (µm)**	**Surface Properties**	**Fiber Diameter (mm)**	**Flow Path**
MBR	370	34.4 (370)	28 (61)	28 – 75 (61 – 164)	PVDF	0.04	Non-ionic & Hydrophilic	OD: 1.9 ID: 0.8	Outside-In
	300s	27.9 (300)	24 (53)	24 - 58 (53 - 128)					
Non-MBR	440	40.9 (440)	32 (70)	30 – 74 (66 – 163)					
	350s	32.5 (350)	26 (57)	26 - 72 (57 – 159)					
All	340	31.6 (340)	26 (61)	26 - 60 (57 - 132)					

[1] Packaged
[2] Varies with solids accumulation

Operating & Cleaning Specifications							
Application	**Product**	**TMP Range kPa (psig)**	**Max. Operating pH Range**	**Operating pH Range**	**Max. Cleaning Temp. °C (°F)**	**Cleaning pH Range**	**Max. Cl_2 Conc'n (ppm)**
MBR	370, 340, 300s	-55 to 55 (-8 to 8)	40 (104)	5.0-9.5	40 (104)	2.0 – 10.5 (<30°C) 2.0 -10.0 (30-40°C)	1,000
Non-MBR	440, 340, 350s	-90 to 90 (-13 to 13)					

Find a contact near you by visiting www.suezwatertechnologies.com and clicking on "Contact Us."

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CDM AnMBR Budgetary Estimate for design conditions

No.	Scenario for consideration: Case	Flow	Flow m3/hr	Flow GPD	CDM Design Flux lmh (@20C)	SUEZ ZW500d Membrane System Design: # of Modules	# of Cassettes	# of Trains	Cassettes/ Train	SUEZ Total Membrane Surface Area m2	SUEZ Single Train Tank Dimensions (ft): Membrane Tank Dimensions L (ft)	W (ft)	H (ft)	SUEZ LEAP Gas Flow SCFM	SUEZ Total Power kwh/yr	Budget System Cost USD	Maintenance Clean (per event): NaOCl (kg @100%)	Citric Acid (kg @100%)	Recovery Clean (per event): NaOCl (kg @100%)	Citric Acid (kg @100%)
1	7.5 lmh	Normal	789	5000000	7.5	3060	75	8	10	105264	83.4	11.8	14.3	5076	2,271,530	$11,914,409	121	486	2,760	4,048
2	15 lmh	Normal	789	5000000	15	1530	40	4	10	52632	83.4	11.8	14.3	2538	1,608,780	$7,010,919	61	243	1,380	2,024
3	30 lmh	Normal	789	5000000	30	770	20	2	10	26488	83.4	11.8	14.3	1278	1,280,230	$3,866,491	31	122	690	1,012

Included Scope:

1. Membrane System
   a) Anaerobic Membrane Tank
   b) Membranes & Cassettes
   c) Process Skids
   d) RAS Pumps
   e) Membrane Biogas Blowers
   f) Foam Control
   g) Chemical Skids
   h) Valves and Instrumentation
   i) Remote I/O Skid
2. Electrical
   a) Main Control Panel
   b) Remote I/O Panels
   c) Panelveiw HMI
3. Engineering & Commissioing
   a) Mechanical, Electrical, Process and Project Managment
   b) 24/7, Insight & Service Visit
   e) Drawings and Submittals

Notes:

1. Total power is for the filtration system scope only inlcuding biogas sparging, permeate and recirculation pumps
2. Cleaning recommendation: Maintenance cleaning 2 times per week. Recovery Cleaning 2 times per year

BUDGET QUOTATION FROM 3M FOR DISSOLVED METHANE MEMBRANE CONTACTOR AND VACUUM PUMP

Quotation

Date: August 8, 2018 **Quotation Number:** NA-08082018-USRV
Quotation is valid for 90 days. **3M Customer ID:**

To: Patrick Evans
CDM Smith
14432 SE Eastgate Way, Suite 100
Bellevue, WA 98007

Phone 206 351 0228
E-Mail evanspj@cdmsmith.com

From: Rob Vogel
3M SPSD Liqui-Cel
13840 South Lakes Drive
Charlotte, NC 28273

Phone: 512-784-4588
E-mail: rvogel@mmm.com

Re: Liqui-Cel® Membrane Contactor Quotation **Number of pages:**

Thank you for your interest in Liqui-Cel Membrane Contactors. You will find pricing and a product description for your application below.

Quantity	Membrana Part Number	3M ID Number	Product Description	Unit Price (USD)	Sub Total (USD)
18	G531	70-2013-5093-4	X40 fiber, Epoxy potting, PVC vessel with engineered thermoplastic end caps, 2" ANSI gas side connections, 4" ANSI liquid side connections. Gas ports In line	$14,069.70	$253,254.60
18	K172	70-2013-5303-7	14" Liqui-Cel Contactor Mounting Kit	$315.00	$5,670.00
2	3AV-330-35-S110	70-2013-5492-8	Liquid ring vacuum pump, 15hp, cast iron body, SS portplate and impeller	$11,643.56	$22,287.12
				Estimated Freight	PrePay & Add
				Total	$281,211.72

CURRENT LEAD TIME FOR IS 46 WEEKS, SUBJECT TO CHANGE.

Availability:
For orders with net 30 terms: 46 weeks from receipt of PO.
For orders with Cash-in-advance terms: 46 weeks from payment confirmation.

- Actual ship date will be confirmed upon receipt and acceptance of a valid order by 3M.
- Quantities may be limited. Actual quantity available will be confirmed upon acceptance of a valid order by 3M.
- This offer is non-binding. An effective purchase agreement is subject to a written confirmation

Pricing:	All prices above apply to PO/single shipment quantities.
Shipping Terms:	FOB Charlotte
Payment Terms:	Cash-in-Advance or Net 30 pending credit approval. 3M Standard Terms & Conditions of Sale apply to any resulting sale.

Quotation

If you have any questions please contact me.

When placing an order, please reference the quote number listed on this quote.

Please send orders to 3MMembranesCS@mmm.com.

3M Customer Service
Building 225-5S-14
St. Paul MN 55144
www.3M.com/Liqui-Cel

If using ePOP Please send your PO to: USCustomerOrders@mmm.com

3M STANDARD TERMS AND CONDITIONS OF SALE

These Terms and Conditions shall govern each product sales transaction between 3M Company and its affiliates ("3M") and Buyer. Any inconsistent terms of Buyer, wherever set forth and whether oral or written, shall not be binding upon 3M unless agreed to by 3M in writing. No waiver of these Terms and Conditions or any special terms relating to this order shall be binding upon 3M unless agreed to in writing by 3M.

1. QUOTATIONS. Quotations submitted by 3M are good for acceptance only within ninety (90) days from date of quotation unless otherwise specified. Prices quoted do not include any sales, use, excise, value added, or other similar tax. Delivery lead times contained within quotations shall be effective from the date of receipt by 3M of all necessary engineering and manufacturing information including approved drawings if requested by Buyer and receipt of full payment for Cash in Advance customers.

2. ACCEPTANCE. All orders are subject to 3M's approval and acceptance. A written acknowledgment sent to Buyer of orders so approved shall constitute 3M's acceptance. 3M may at any time alter or suspend credit, refuse shipment, or cancel unfulfilled orders when, in 3M's opinion, the financial conditions of Buyer or the status of Buyer's account warrants it, or when delivery is delayed by fault of Buyer or Buyer's delinquency in payment. No order accepted by 3M will be subject to cancellation, termination, suspension, change, reduction, cutback or any modifications by Buyer except with 3M's prior written consent, which may be subject to fees as 3M determines.

3. CANCELLATION. Orders may be canceled or deliveries deferred by Buyer only upon the condition that the Buyer assumes immediate liability for and makes prompt payment to 3M of all expenses incurred, charges for commitments made by 3M, profit on work in process, and contract value of items completed and ready for shipment.

4. DELIVERY. 3M's delivery terms for products that will remain in the United States are FOB Charlotte, NC. If written approval is granted by 3M in accordance with Section 17 (a) below, international orders shall be delivered DAT [Named Terminal outside the United States], (Incoterms 2010) with freight prepaid and charged back to the Buyer. Shipment schedules are estimated only and are as accurate as present conditions permit. 3M assumes no responsibility or liability for failure or delay in making delivery or otherwise performing hereunder when such failure or delay is due to any cause beyond its control and without its fault or negligence. If for any reason 3M's supply of items

ordered hereunder is caused to be limited, 3M shall have the right to prorate the supply in such manner as 3M in its discretion shall determine. 3M may make partial deliveries which Buyer shall accept and pay for at the prices quoted by 3M in writing. If any part of the order is not delivered by 3M or is not in accordance with the order, the remainder of the order and Buyer's obligation thereunder shall not be affected.

5. PACKAGING. All items sold hereunder shall be packed or crated and shipped in accordance with 3M's best judgment. Any special packing, crating, or shipping instructions of Buyer must be noted on Buyer's original order and acknowledged and approved by 3M.

6. INSPECTION. Buyer shall inspect all items upon arrival and give written notice to 3M within thirty (30) days of arrival of any claim for shortage or nonconformance with these terms. Failure to give such notice, Buyer waives all claims for such shortage or nonconformance, and Buyer shall be bound to accept and pay for all items in accordance with these terms. Claims against a 3M approved carrier must be reported within 14 days.

7. RETURNS. No product may be returned without 3M's prior written approval. Transportation charges are to be prepaid by Buyer. When expressly authorized by 3M in writing, unused non-defective products in unopened packaging may be returned to 3M subject to a service handling and restocking charge.

8. PAYMENT TERMS. Payment terms shall be net thirty (30) days from date of invoice, unless otherwise expressly agreed in writing by 3M. Late charges of the lesser of one and one-half percent (1½%) per month or the maximum amount allowed by law will be assessed on invoices after the due date.

9. CREDITS. If any credit amount is not used, 3M reserves the right to offset it against the oldest outstanding items on the account. Credits are subject to unclaimed property laws. After 3M applies the credit to your oldest outstanding items, if a credit balance remains on your account, the credit will be reported and paid to your state, as required by the laws of your state, and will no longer be available for use on your 3M account.

10. TAXES. Buyer shall pay all sales, use, excise, value added or other similar taxes that may levied, assessed or otherwise become due on account of items to be delivered hereunder, unless proof of exemption is furnished to 3M.

11. REPAIRS, ALTERATIONS AND MODIFICATIONS. If Buyer requests that 3M repair any 3M product not covered by the warranty provided in Section 12, such repair charges shall be at the Buyer’s expense unless specifically authorized in writing by 3M. Any alterations or modifications to the 3M product by Buyer or Buyer’s agents are not permitted without specific authorization in writing by 3M and will void the warranty and render the products non-returnable by Buyer.

12. WARRANTY. 3M warrants that 3M products will conform to those written specifications set forth in 3M’s product literature and/or on 3M packaging and labeling

materials for such products for the time period specified in such literature and materials; provided, however, that products are used in accordance with written instructions

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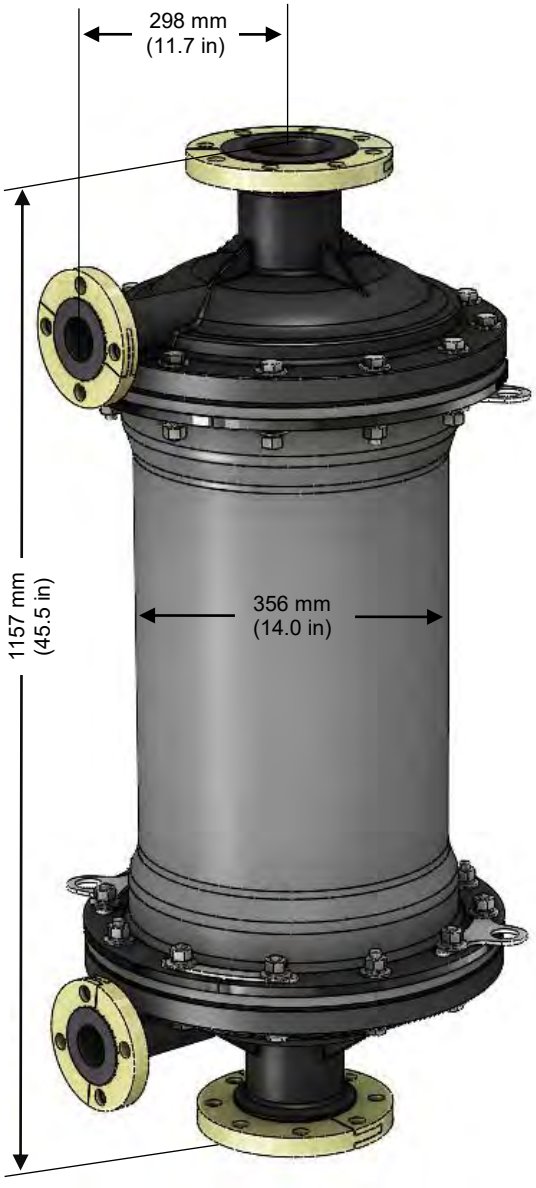
16. INDEMNIFICATION. Buyer indemnifies 3M, its affiliates, and their employees and agents (the "Indemnified Parties") for, and will defend them against, any claim, personal injury, sickness, death, liability, loss, damage, lien, judgment, and cost, including reasonable attorneys' fees and other litigation expenses (collectively referred to as "Loss") in any way related to (a) any alleged express or implied warranty by Buyer or

any party to whom Buyer sells, gives or otherwise transfers Products or a product of Buyer's into which Products are incorporated that differs from 3M's published warranties and (b) any claim related to the use, packaging, labeling, handling, testing, marketing or sale of Products or a product of Buyer's into which Products are incorporated, except where Products are shown not to meet the then-current published specification.

17. GENERAL. (a) Buyer will not sell, or knowingly allow a customer to transfer, any items furnished hereunder outside the 48 contiguous United States unless (i) Buyer first notifies 3M in writing of the intention to so export, (ii) Buyer receives prior written approval from the authorized representative of 3M's Global Channel Services, and (iii) all applicable export regulations are complied with by Buyer and its customer and all applicable licenses are obtained. Buyer will offer nothing of value to any government official on behalf of 3M. (b) 3M is not responsible for typographical errors made in any of its publications or for clerical errors made in preparation of quotations, sales orders, or acknowledgments. All such errors are subject to correction by 3M. (c) These Terms and Conditions shall be governed by the laws of the State of Minnesota, USA without regard to Minnesota's conflicts of law provisions. Buyer submits to the exclusive personal and subject matter jurisdiction of the Minnesota courts to resolve any disputes arising hereunder. (d) The parties expressly agree that the U.N. Convention for the International Sale of Goods does not apply to this or any subsequent transactions between the parties, including these Terms and Conditions. (e) These Terms and Conditions, along with 3M's quotation or proposal, contain the parties' entire understanding on this subject, superseding any prior written or oral agreements, statements, communications or understandings between the parties relating to this subject matter, except that any confidential nondisclosure agreement that has been executed by and between the parties shall remain in effect in accordance with its terms.

January 2016

14 x 28 EXTRA-FLOW PRODUCT DATA SHEET



NOTE: *All dimensions are nominal*

Membrane Characteristics

Cartridge Configuration	Extra-Flow with Center Baffle	
Liquid Flow Guidelines	16- 91 m^3/hr (70 – 400 gpm)	
Membrane Type	**X50 Fiber**	**X40 Fiber**
	Recommended for CO_2 removal from liquid and other gas transfer applications	Recommended for O_2 removal from liquid and other gas transfer applications
Membrane/Potting Material	Polypropylene / Epoxy	
Typical Membrane Surface Area	220 m^2 (2370 ft^2)	
Priming Volume (approximate)	**X50 Fiber**	**X40 Fiber**
Shellside	35.4 L (9.3 gal)	37.3 L (9.9 gal)
Lumenside	23.8 L (6.3 gal)	23.0 L (6.1 gal)

Pressure Guidelines*

	X50 or X40 Fiber
Maximum Shellside LIQUID Working Temperature/Pressure	5-25° C, 7.2 barg (41-77° F, 105 psig) 50° C, 2.1 barg (122° F, 30 psig)
If no vacuum is used, 1.0 barg (15 psig) can be added to pressures above.	
Maximum Applied Gas Pressure	4.1 barg at 25° C (60 psig at 77° F)
Max applied gas pressure is for integrity testing at ambient temperatures. Normal operating pressures are typically lower.	
*Pressures are based on non-dangerous liquids and gasses per the European Union Pressure Equipment Directive 97/23/EC. See Operating Guide for pressure limits in the European Union with dangerous liquids and gasses. See Operating Guide for complete listing of temp/pressure limits for housings and membrane. Note: Liquid pressure should always exceed gas pressure.	

Housing Options and Characteristics

Material	PVC Vessel with Engineered Thermoplastic End Caps
Flange Backing Rings	SMC (Sheet Molded Compound)
Flange Connections	
Shellside (Liquid Inlet/Outlet)	• 4 inch class 150 raised face flange per ANSI B16.5 • 100A 10K raised face flange per JIS B2238
Lumenside	• 2 inch class 150 raised face flange per ANSI B16.5 • 50A 10K flat face flange per JIS B2238
Mounting Kit	
A Mounting Kit with 2 cradles and 2 straps is available and sold separately. It will hold the contactor horizontally or vertically.	

Seal Options

Material	**Applications**
EPDM	General Purpose

Weight (approximate)

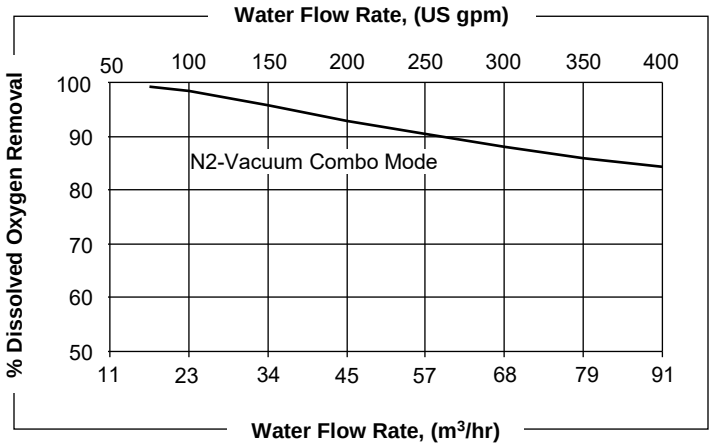
Dry	54 kg (118 lbs)
Liquid full (shellside)	89 kg (196 lbs)
Shipping Weight w/o Mounting kit	65 kg (144 lbs)
Shipping Weight with Mounting kit	74 kg (164 lbs)

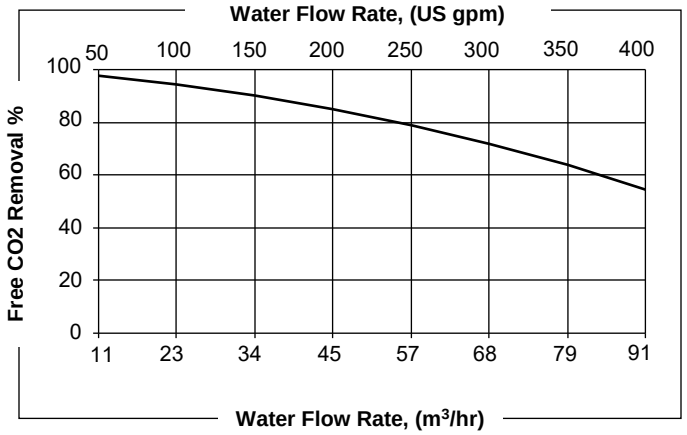
Regulatory

Complies with the limits as set by RoHS Directive 2011/65/EU Annex II; recasting 2002/95/EC.

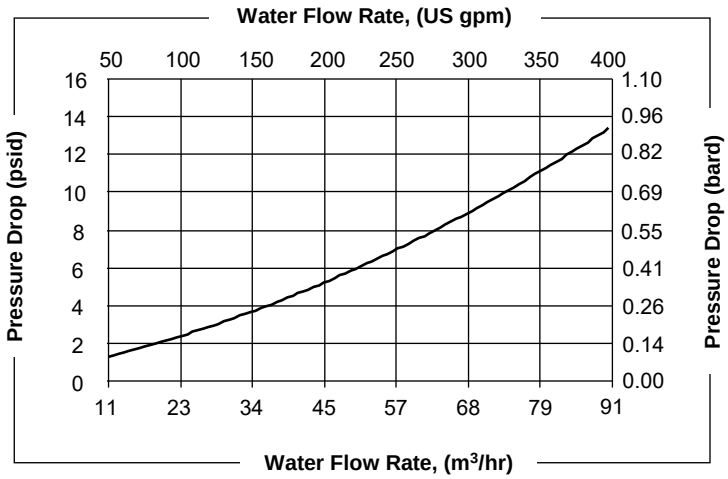
Liqui-Cel®
MEMBRANE CONTACTORS

14 x 28 EXTRA-FLOW PRODUCT DATA SHEET





Note: Performance can be improved by adjusting the sweep rate.



Curves represent nominal values, generated using water at 20°C. Characteristics may change under different operating conditions.

Test condition O_2 Removal: X40 membrane, N_2-vacuum combo mode, vacuum: 75 mm Hg, N_2 Sweep 0.25 scfm.

Test condition CO_2 Removal: X50 membrane, Air vacuum combo mode, vacuum: 150 mm Hg, air sweep 8 scfm.

Technical Information: The technical information, recommendations and other statements contained in this document are based upon tests or experience that 3M believes are reliable, but the accuracy or completeness of such information is not guaranteed.

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Liqui-Cel® Membrane Contactors are tested and certified by WQA against NSF/ANSI 61.

ISO 9001

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MEMBRANA
Now proudly part of 3M

www.liqui-cel.com

AIRTECH® VACUUM

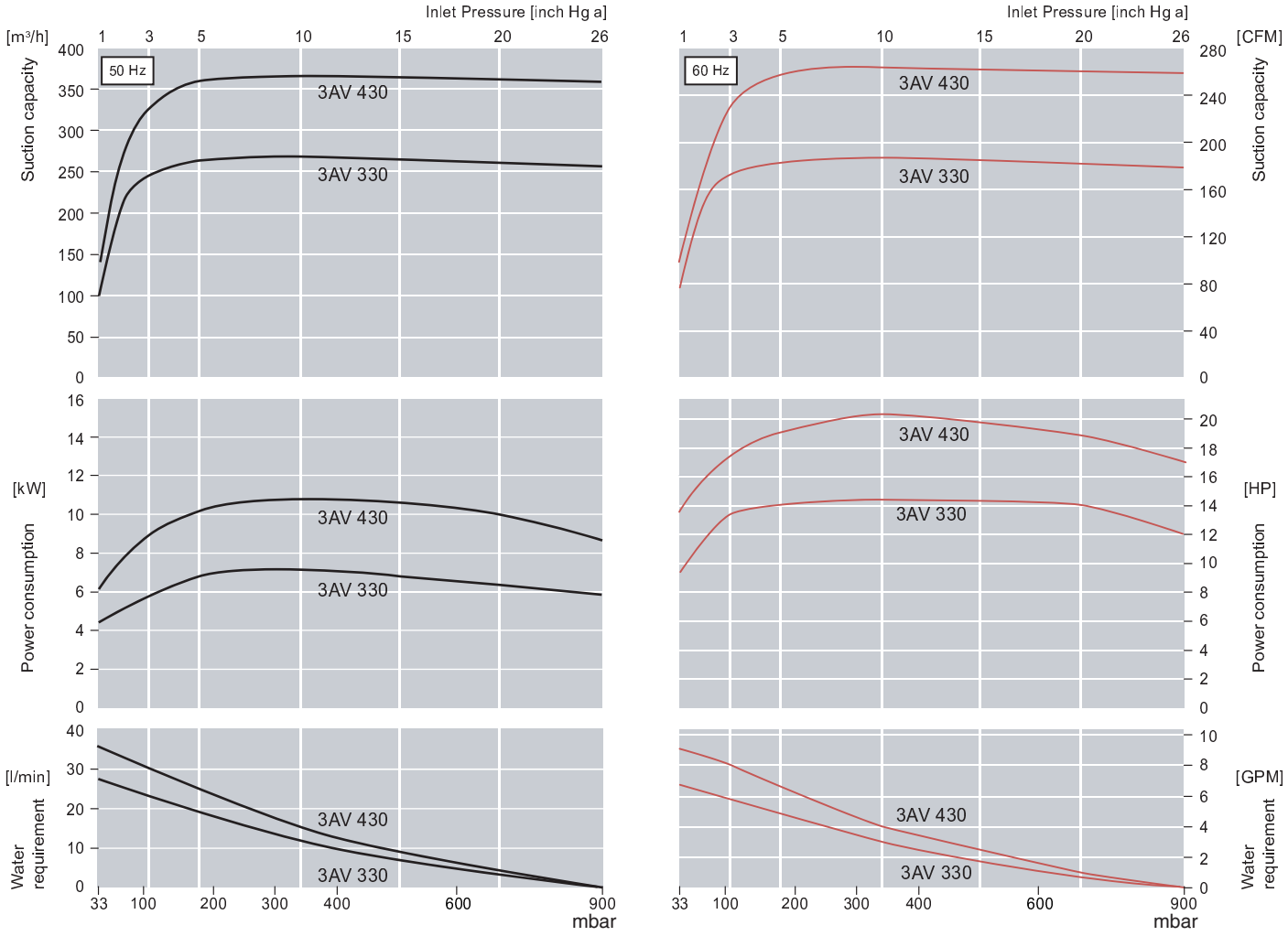
3AV 330/430

Liquid Ring Close-Coupled Vacuum Pumps

The Airtech 3AV Series closed-coupled Liquid RingVacuum Pumps are ideal for various applications that require continuous & quiet operation, a compact design and reduced power consumption.

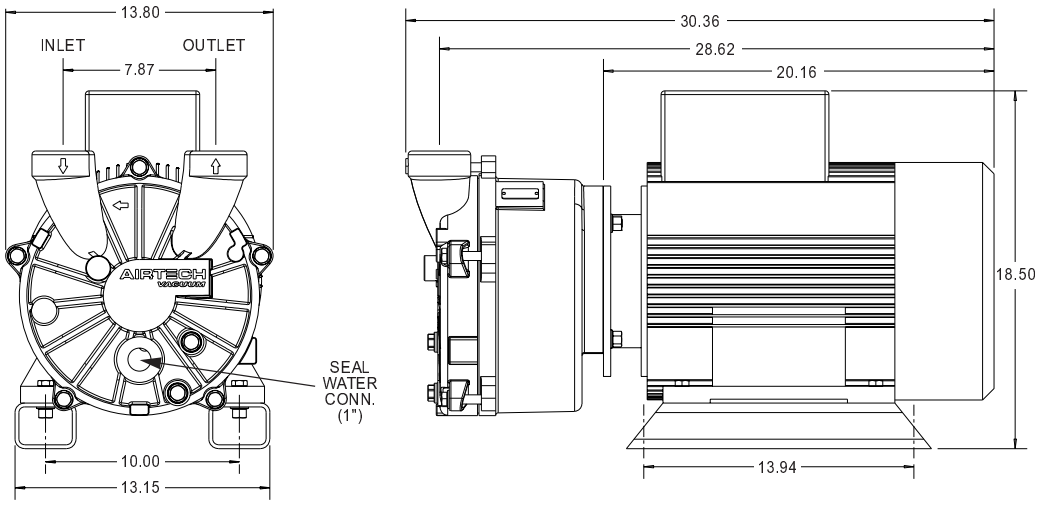
The single stage, variable discharge port design provides efficient operation from 1 through 262 cfm for vacuum levels up to 29"Hg. The impeller's unique design of slower spinning curved blades reduces tip speed enhancing the life expectancy of the pump.

- **More compact than conventional liquid ring pumps**
- **No belts, no couplings - alleviating problems with wear, alignment and belts**
- **Standard pumps have cast iron housing, Stainless Steel impeller & PFTE flap valve.**
- **Other materials of construction are available**
- **Designed for heavy duty applications**
- **Manufactured to ISO 9001 standards**
- **Single face mechanical seal arrangement is standard**

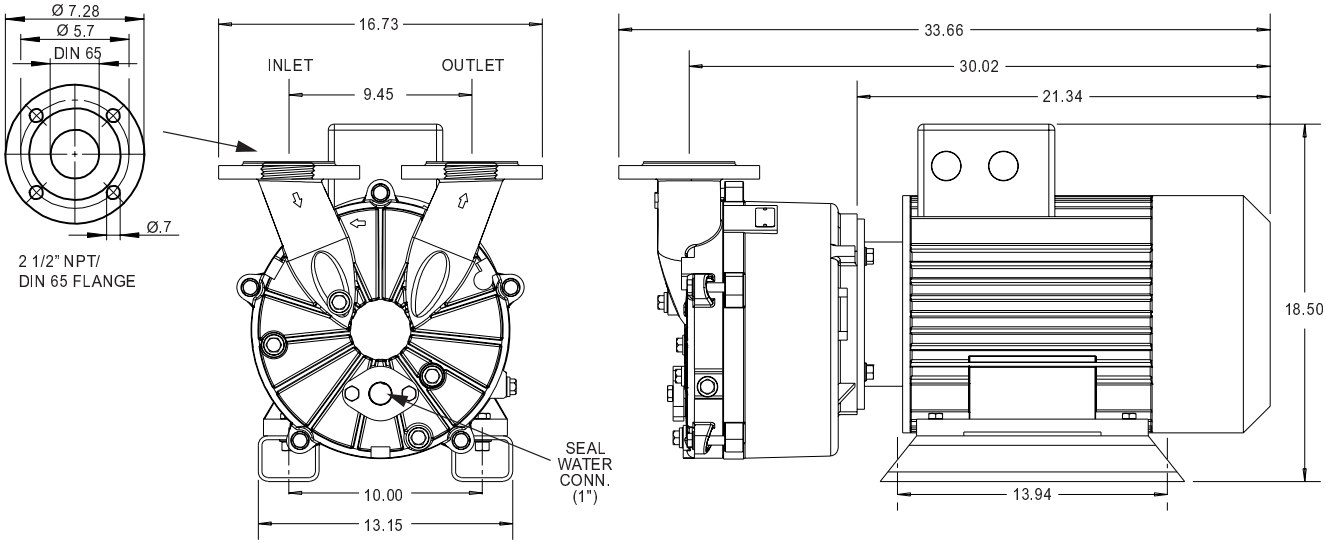


Dimensions: (inches)

3AV 330



3AV 430



Performance Data - Vacuum (60 Hz)

Model	Rated H.P.	CFM	RPM	Voltage Range	Max Amps	Seal Water (GPM)	Sound Level dB(A)	Weight (lbs.)	Inlet/ Outlet
3AV 330	15	187	1750	208–230/460	46.5/25	7.2	72	359	2.0"
3AV 430	20	262	1750	208–230/460	68/39	8.5	72	392	2.5"

The characteristics are applicable for compression of 20° C (68° F) dry air from inlet pressure to atmospheric pressure (1013 mbar / 30 inch Hg a) for nominal speed and drive with three phase motors. Ring liquid is water at 15° C (59° F). The tolerance of the suction capacity is -10% and of the power consumption is +10%. With different operating conditions characteristic curves change (e.g. differing gas operating liquid conditions, conveying of additional liquids and/or pumping of gas-steam mixtures).

BUDGET QUOTATION
FROM CGT, INC. FOR NITROGEN SWEEP GAS GENERATOR

CGT

COMPRESSED GAS TECHNOLOGIES INC.

The Gas Generation Specialists

CGT Ultra-high Purity Nitrogen Generators

CGT Ultra-high Purity Nitrogen Generators

Compressed Gas Technologies Inc. has been an industry leader of on-site nitrogen generators throughout North America since 2001. We can help you save money on your nitrogen gas costs.

Our line of generators allows you to produce nitrogen gas on-site, simply and cost effectively from a supply of compressed air. Eliminate rental charges, transportation expenses, labor costs, and evaporation losses of bulk systems.

High Purity Nitrogen

Nitrogen is used in many commercial and industrial applications to improve the quality of a product or process, or as a safety measure to prevent combustion. Liquid or bottled Nitrogen delivery and storage can be expensive, unreliable, and a safety concern. Nitrogen generators allow users to produce Nitrogen in-house simply and inexpensively using an existing compressed air system.

CGT recognizes the importance of having a safe, reliable and cost effective supply of high-purity Nitrogen. We bring you this Nitrogen generator to meet the increasing demand for high quality complete packaged solutions which save energy and time, while fulfilling the needs of their intended application.

Design

Our experienced team of design engineers are always looking for new and unique technologies and products to bring you the highest level of performance and lowest overall operating cost.

Research & Development

Our team endeavors to provide solutions that go beyond developing an existing product. They are continually researching new technologies which can provide unique advantages over competitive offerings.

Manufacture

These advanced, reliable and energy saving Nitrogen generators are manufactured in a state of the art facility to the highest standards of build quality to ensure reliability and high levels of performance.

Nitrogen generators

Nitrogen is a dry, inert gas which is used in a wide range of applications where Oxygen may be harmful to the product or processes. Nitrogen generators use regular compressed air to deliver a continuous supply of high purity Nitrogen - offering a cost effective and reliable alternative to the use of cylinder or liquid Nitrogen across a wide range of applications.

Our advanced range of Nitrogen generators use integrated Adsorbent Media Tube (AMT) dryer cartridges to provide dehydration of the compressed air prior to separation. This innovative feature (patent pending) eliminates the need for a separate desiccant dryer - saving up to 20% purge loss, significantly reducing capital and installation costs and reducing overall pressure drop by 10 psig or more over traditional Nitrogen generation systems.

A few of the many industries making the switch to our Nitrogen generators include:

- Food (MAP)
- Beverage (bottling)
- Plastics (PET)
- Pharmaceutical (product transfer)
- Chemicals (blanketing)
- Laser Metal Cutting (burring reduction)
- Fire Prevention (eliminating combustion)
- Electronics (wave soldering)

Adsorbent Media Tubes (AMT)

Reliability is built in... and backed by a 2 year warranty.

Benefits - Get more for your money

Guaranteed Performance

- Reliable performance based on decades of experience with pressure swing adsorption technology
- 100% function and performance tested at the factory
- 2 year warranty

Rapid Return on Investment

- Significant cost savings over cylinder or liquid supply provides a typical return on investment of less than 24 months

Environmentally Friendly

- Lower air consumption and refined controls provide greater energy efficiency
- Reduces carbon footprint by eliminating gas delivery to your facility

Safe & Reliable

- Eliminates the safety hazards of transporting and storing pressurized gas cylinders or liquid Nitrogen

Easy to Install

- The compact design allows installation in spaces too small for twin tower generator systems

Easy to Maintain

- Integrated Adsorbent Media Tube (AMT) dryer cartridges eliminate the need for an external dryer of any type
- Integrated exhaust silencers require no maintenance or replacement and ensure proper performance
- Advanced controls simplify operation and require minimal training
- Innovative valves significantly reduce maintenance schedules and minimize downtime

Fits Any Application

- Available in a wide range of flow rates and purities (Oxygen contents from 5% to less than 10 ppm)
- Can handle any power supply from 120 to 240 VAC in 50 or 60 Hz, or 24VDC - with just the flick of a switch

Features and benefits

Integrated AMT dryer cartridge

Traditional Nitrogen generators often require installing and operating an external desiccant dryer. Our innovative Nitrogen generators feature an integrated Adsorbent Media Tube (AMT) dryer cartridge which eliminates the need for a pre-treatment dryer of any type. The integrated drying system reduces purge loss by approximately 20% and reduces pressure drop by 10 psi or more, providing significant energy savings over a traditional generator system.

Ecomode energy saving control

This unique control feature utilizes an outlet pressure monitor to reduce energy consumption during periods of low demand to ensure a continuous uninterrupted Nitrogen supply while minimizing power consumption.

PLC controlled operation

Each CGT Nitrogen generator is operated by a reliable PLC control system with digital and analog outputs for remote monitoring and alarm capabilities. Includes an easy-to-operate touch screen graphical interface which offers valuable features including 'power on', 'hours run', 'Oxygen purity', 'pressure', 'online column' and 'service required' indicators. In addition, four pressure gauges provide the operator with continuous indication of column A, column B, air inlet and Nitrogen outlet pressures.

Multi-bank design

The unique multi-bank design (GEN2 2110 to GEN2 12130) enables additional generators to be added in the future as demand increases. Your CGT Nitrogen generator can grow with your company.

Reliable high performance valves

Inlet, outlet and exhaust are managed through coaxial flow valves integrated into the upper and lower manifolds. These low maintenance valves provide unrestricted flow capacity. They are designed for durability, ease of maintenance and long service life and are backed by a comprehensive two year warranty.

Maximum corrosion protection

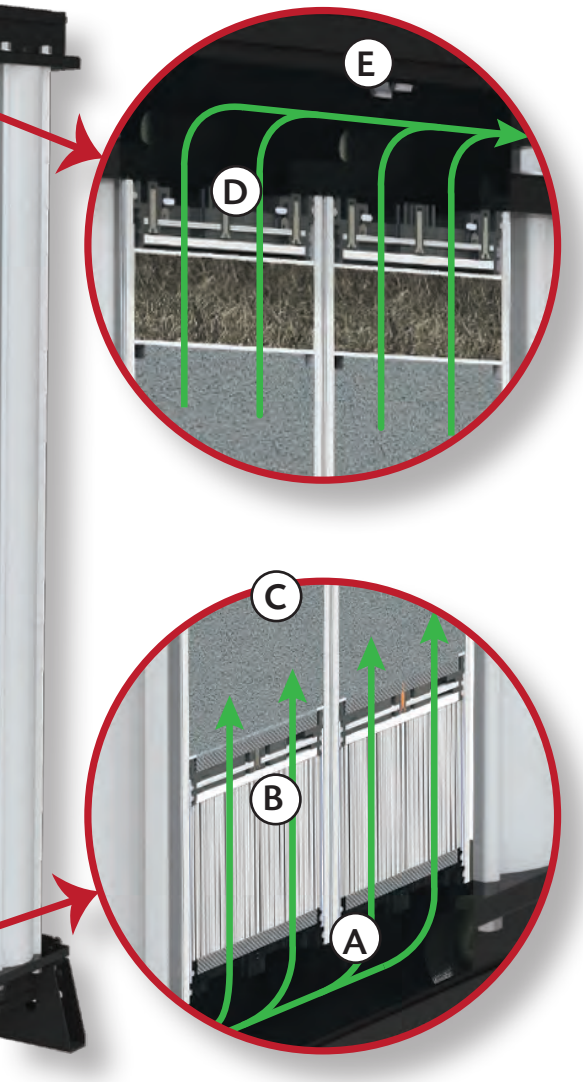
High tensile aluminum columns are first alocromed and then powder coated to provide maximum protection for corrosive environments.

Optional Oxygen analyzer

A built in Oxygen Analyzer continuously monitors the Oxygen concentration in the Nitrogen stream. The analyzer is incorporated into the PLC controls to guarantee downstream purity levels are consistently achieved and maintained.

A	Inlet Manifold
B	Adsorbent Media Tube (AMT) Dryer Cartridges
C	Carbon Molecular Sieve (CMS)
D	Integrated Bed Support Layer
E	Outlet Manifold

System performance



Our technologically advanced Nitrogen generator operates on the Pressure Swing Adsorption (PSA) principle to produce a continuous uninterrupted stream of Nitrogen gas from clean dry compressed air.

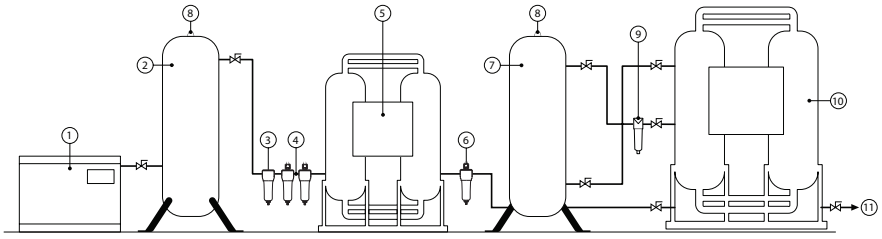
Pairs of dual chamber extruded aluminum columns are fitted with Adsorbent Media Tube (AMT) dryer cartridges and filled with Carbon Molecular Sieve (CMS). Joined via an upper and lower manifold, the high density filled columns produce a two bed system.

Compressed air enters through the Inlet Manifold (A) to the bottom of the 'online' bed and flows up through the AMT stage (B) drying the compressed air. The clean and dry air then flows up through the CMS stage (C) where Oxygen and other trace gases are preferentially adsorbed allowing the Nitrogen to pass through. The Nitrogen then passes through the supporting bed layer (D) and outlet manifold (E) to the buffer vessel and a nano F-Series[1] buffer vessel filter before re-entering the N2 generator for purity monitoring.

After a pre-set time the control system automatically switches the beds. One bed is always online generating Nitrogen while the other is being regenerated.

During regeneration the Oxygen that has been collected in the CMS stage and the moisture that has been collected in the AMT stage are exhausted to atmosphere. A small portion of the outlet Nitrogen gas is expanded into the bed to accelerate the regeneration process.

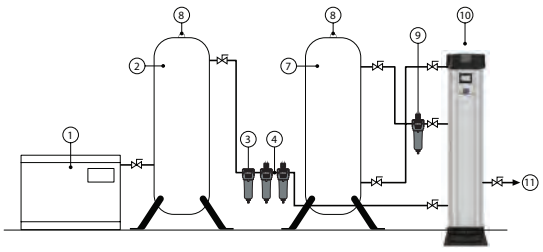
Typical Nitrogen generator installation



1	Compressor
2	Wet Air Receiver
3	Water Separator
4	Pre Filters
5	Dryer *
6	Dust Filter *
7	Buffer Vessel
8	Pressure Relief Valves
9	Buffer Vessel Filter
10	Nitrogen Generator
11	Nitrogen Outlet

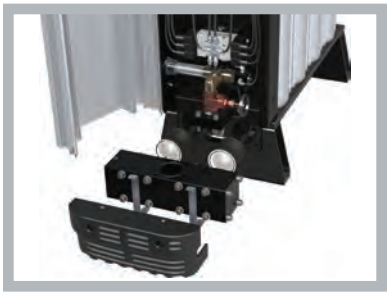
** Not required with CGT generator*

CGT Nitrogen generator installation



Adsorbent Media Tubes (AMT)

PLC controls with touch screen interface



Reliable & durable coaxial flow valves

Technical data

Model	Outlet Flow (1)	Nitrogen Purity at the Outlet (Maximum Oxygen Content)												Dimensions in (mm)			Weight lbs (kg)
		99.999% (10 ppm)	99.995% (50 ppm)	99.99% (100 ppm)	99.75% (250 ppm)	99.95% (500 ppm)	99.9% (0.10%)	99.5% (0.50%)	99% (1%)	98% (2%)	97% (3%)	96% (4%)	95% (5%)	A	B	C	
GEN2 1110	scfh	49	71	81	95	110	127	184	205	258	293	336	364	48 (1220)	16 (400)	23 (580)	176 (50)
	m^3/hr	1.4	2.0	2.3	2.7	3.1	3.6	5.2	5.8	7.3	8.3	9.5	10.3				
GEN2 2110	scfh	99	141	162	191	219	254	367	410	516	586	671	728	48 (1220)	16 (400)	30 (760)	242 (110)
	m^3/hr	2.8	4.0	4.6	5.4	6.2	7.2	10.4	11.6	14.6	16.6	19.0	20.6				
GEN2 3110	scfh	148	212	244	286	328	381	551	615	773	879	1007	1091	48 (1220)	16 (400)	36 (910)	374 (170)
	m^3/hr	4.2	6.0	6.9	8.1	9.3	10.8	15.6	17.4	21.9	24.9	28.5	30.9				
GEN2 2130	scfh	180	254	297	353	403	466	667	742	932	1070	1218	1324	71 (1800)	16 (400)	30 (760)	365 (166)
	m^3/hr	5.1	7.2	8.4	10.0	11.4	13.2	18.9	21.0	26.4	30.3	34.5	37.5				
GEN2 3130	scfh	270	381	445	529	604	699	1001	1112	1398	1605	1828	1986	71 (1800)	16 (400)	36 (910)	490 (222)
	m^3/hr	7.6	10.8	12.6	15.0	17.1	19.8	28.3	31.5	39.6	45.4	51.8	56.2				
GEN2 4130	scfh	360	509	593	706	805	932	1335	1483	1865	2140	2437	2649	71 (1800)	16 (400)	43 (1090)	610 (277)
	m^3/hr	10.2	14.4	16.8	20.0	22.8	26.4	37.8	42.0	52.8	60.6	69.0	75.0				
GEN2 6130	scfh	540	763	890	1058	1208	1398	2002	2225	2797	3210	3655	3973	71 (1800)	16 (400)	56 (1420)	852 (387)
	m^3/hr	15.3	21.6	25.2	30.0	34.2	39.6	56.7	63.0	79.2	90.9	103.5	112.5				
GEN2 8130	scfh	720	1017	1187	1411	1610	1865	2670	2966	3729	4280	4873	5297	71 (1800)	16 (400)	69 (1750)	1100 (550)
	m^3/hr	20.4	28.8	33.6	40.0	45.6	52.8	75.6	84.0	105.6	121.2	138.0	150.0				
GEN2 10130	scfh	828	1170	1365	1623	1852	2144	3070	3411	4289	4922	5604	6092	71 (1800)	16 (400)	83 (2110)	1350 (610)
	m^3/hr	23.4	33.1	38.7	46.0	52.4	60.7	86.9	96.6	121.4	139.4	158.7	172.5				
GEN2 12130	scfh	962	1358	1584	1884	2150	2489	3564	3960	4979	5714	6506	7072	71 (1800)	16 (400)	96 (2440)	1600 (722)
	m^3/hr	27.2	38.5	44.9	53.3	60.9	70.5	100.9	112.1	141.0	161.8	184.2	200.3				

Inlet Air Purity Requirements			Inlet Temperature		Working Pressure		Outlet Gas Dewpoint	Supply Voltage
Particulate	Dewpoint	Oil Content	Minimum	Maximum	Minimum	Maximum		
< 0.1 micron	< 80°F (27°C) PDP	< 0.01 ppm (2)	50°F (10°C)	104°F (40°C)	87 psig (6 barg)	232 psig (16 barg)	< -40° F (-40°C) PDP (3)	120-240 VAC 50 or 60 Hz or 24 VDC

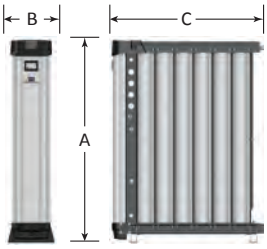
Correction Factors		To calculate the outlet flow for any model at operating conditions other than those above: Outlet Flow (from table above) x K1 x K2 (from tables below) = Outlet Flow at new conditions (4)						
Inlet Temperature - °F (°C)		50 - 75°F (10 - 24°C)		85°F (30°C)		95°F (35°C)		105°F (41°C)
K1	10 ppm	1		0.90		0.81		0.66
	50 to 500 ppm	1		0.98		0.86		0.75
	0.1 to 5.0%	1		0.98		0.95		0.90
Inlet Pressure - psig (barg)		90 (6)	100 (7)	115 (8)	130 (9)	145 (10)	160 (11)	174 - 232 (12 - 16)
K2		0.90	1.00	1.10	1.20	1.25	1.30	1.35

(1) At 100 psig inlet pressure and 68 - 77°F inlet temperature. For outlet flow at all other conditions, refer to the correction factors above or contact us.

(2) Including oil vapor.

(3) Outlet gas dewpoint is < -76°F (-60°C) in high purity applications.

(4) To be used as a rough guide only. All applications should be confirmed by CGT. Contact us for sizing assistance.



GEN2 1110 to 12130

U.S. Mailing address:

Compressed Gas Technologies
P.O. Box 1953 - Troy, Michigan, USA - 48099-1953

email: sales@nitrogen-generators.com
Website: www.nitrogen-generators.com

Canadian Mailing address:

Compressed Gas Technologies
P.O. Box 61, Station "A" - Windsor, Ontario, Canada - N9A 6J5

Toll Free: 1-877-737-7760
Phone: 1-519-737-7760 - Fax: 1-519-737-6944

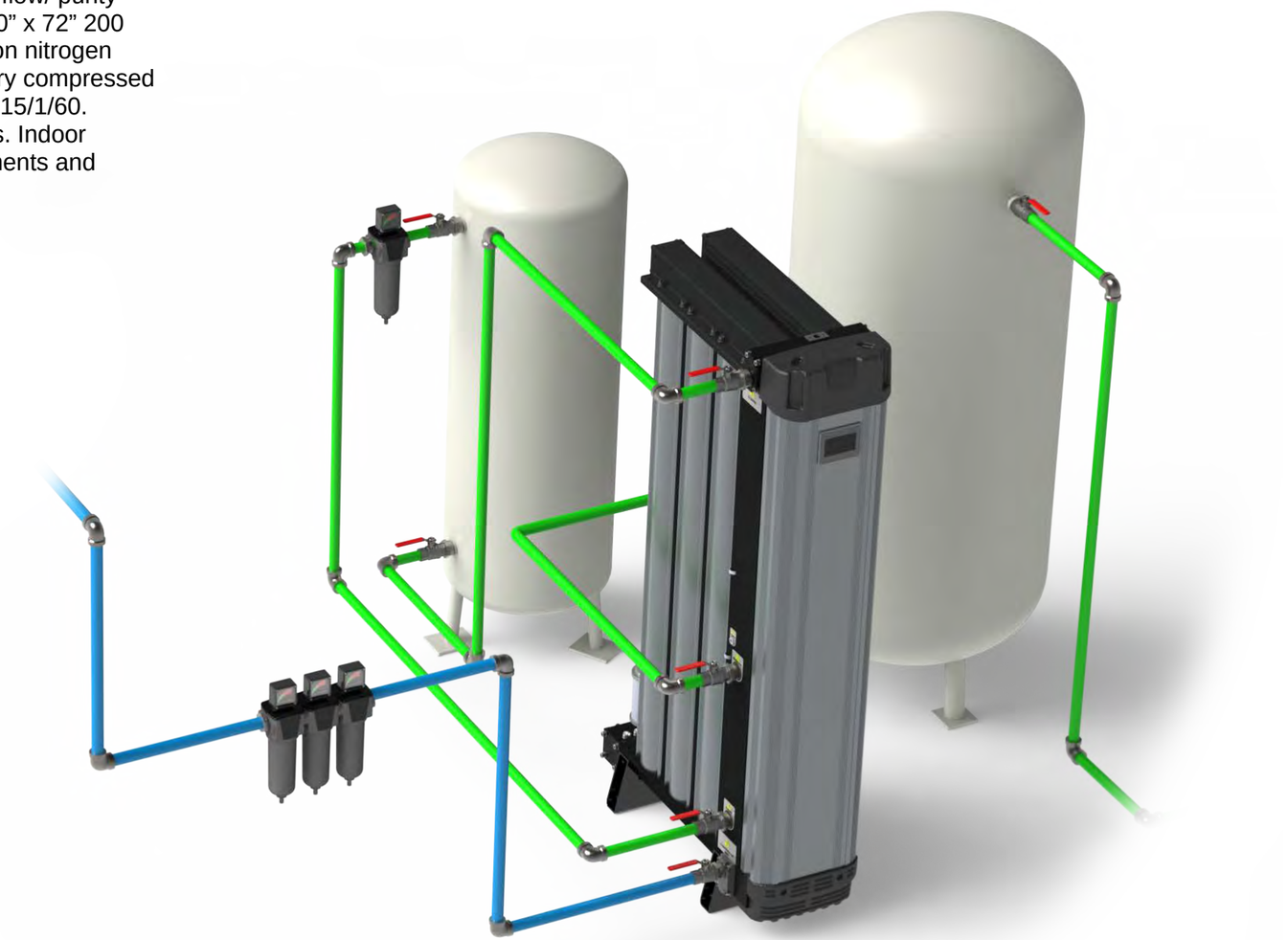
Budget Quotation:

One only CGT PSA nitrogen generator model GEN2-4130 rated for > 1260 scfh @ 99% purity. Nitrogen pressure: 90 psig.

The unit will come complete with filtration package; flow/ purity control; PLC; O2 analyzer. We will also provide a 30” x 72” 200 gallon nitrogen buffer tank and a 30” x 72” 200 gallon nitrogen surge tank. The unit will require 70 scfm of clean, dry compressed air with a minimum pressure of 110 psig. Voltage: 115/1/60. Dimensions: 16” W x 43” D x 71” H. Weight: 610 lbs. Indoor installation. Non-hazardous area. Standard components and documentation apply.

Price: $35,000.00

FOB: Charlotte, NC
Delivery: 10-12 weeks
Terms: TBD.
Start-up & training is included.



CGT GEN2 LAYOUT - NO COMPRESSOR OR DRYER

REFERENCE NUMBER	DATE	REVISION
	11 OCT 17	

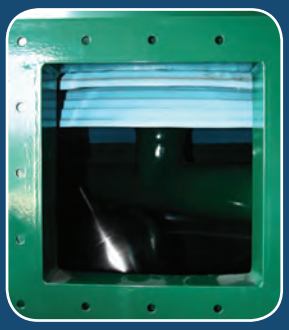
CGT
COMPRESSED GAS TECHNOLOGIES INC.
Nitrogen Generation Specialists

sales@nitrogen-generators.com
www.nitrogen-generators.com
1-877-737-7760

BUDGET QUOTATION FROM ELGIN SEPARATION SOLUTIONS FOR DISSOLVED METHANE VACUUM DEGASSER TANK

ELGIN SEPARATION SOLUTIONS

Vacuum Degasser



The vacuum degasser, also known as a mud/gas separator is one of the first units of solids control equipment arranged to treat drilling mud. As such, they process all of the drilling mud from the flow line before the mud reaches the primary shale shakers. The units have no moving parts and rely on the density difference between the gas and the mud for removal. The process is simple, yet very effective for well drilling fluids processing system.

The vacuum degasser is used to remove the small entrained gas bubbles left in the mud by the mud/gas separator. These units are positioned downstream from mud/gas separators, gumbo removal equipments (if utilized), shale shakers, and mud conditioners (if utilized) while hydrocyclone desanders and decanting centrifuges follow in the arrangement.

Conference Call Report: use 3 of the ESS-DG-1200 Units at an equipment cost per unit of $23,500

Model Number:	ESS-DG-600	ESS-DG-1200
Flow Rate:	600 gpm (38 lps)	1,200 gpm (75 lps)
Vacuum Pump Type & RPM:	I.R & 1500 rpm	I.R & 1500 rpm
Motor:	5 hp	5 hp
Jet Nozzel Type	Eductor Type	Eductor Type
Skid Length:	100" (2,540 mm)	100" (2,540 mm)
Skid Width:	65" (1,651 mm)	68" (1,727 mm)
Height:	70" (1,778 mm)	77" (1,955 mm)
Weight:	3,250 lbs (1,474 kg)	3,579 lbs (1,623 kg)
Skid Type:	Oilfield	Oilfield

Features Include:

- Weir around the plates for equal distribution of liquid on each plate.
- Multiple leaf plates surface area spreads gas-cut mud so that entrained gas bubbles are brought to the surface where deep corrugation provides turbulance giving maximum separation efficiency of gases from mud.
- Vent on each plate for direct vertical exiting of the separated gases.

CERTIFIED ISO 9001

Gas-Sparged AnMBR Design Basis

Pilot results	**7.5 LMH**	**15 LMH**	**30 LMH**
Total HRT (h)	11	Table 3.1	
Membrane area (m2)	12.9		
Membrane tank active volume (gal)	31		
Membrane tank active volume (m3)	0.12	Suez spec sheet says 0.090	
Membrane area/membrane tank volume (m2/m3)	109.94162		
Flux (LMH)	**7.6**	Table 3.1	

Full scale design	**7.5 LMH**	**15 LMH**	**30 LMH**
Flow rate (MGD)	5		
Flow rate (m3/d)	18,925		
HRT (h)	11		
Total active volume (m3)	8,674		
Total active volume (gal)	2,291,667		
Total volume/active volume (includes freeboard)	125%		
Area per module (m2)	34.4		
Flux (LMH)	**7.5**	**15**	**30**
Membrane area (m2)	105,139	52,569	26,285
modules	3,056	1,528	764
Membrane tank active volume (m3)	956	478	239
Membrane tank active volume (gal)	252,659	126,330	63,165
HRT (h)	1.2	0.6	0.3
Primary Bioreactor active volume (m3)	7,718	8,196	8,435
Primary Bioreactor active volume (gal)	2,039,007	2,165,337	2,228,502
HRT (h)	9.8	10.4	10.7
Membrane tank total volume (m3)	1195	598	299
Membrane tank total volume (gal)	315,824	157,912	78,956
Primary Bioreactor total volume (m3)	9,647	10,245	10,544
Primary Bioreactor total volume (gal)	2,548,759	2,706,671	2,785,627

Membrane Recovery Cleaning	**7.5 LMH**	**15 LMH**	**30 LMH**
NaOCl soak solution concentration (mg/L) [a]	1000	1000	1000
Volume of 1000 mg/L NaOCl per Cleaning (m3)	956	478	239
Mass of 100% NaOCl Required per Cleaning (kg)	956	478	239
Citric Acid soak solution concentration (mg/L) [a]	2000	2000	2000
Volume of 2000 mg/L Citric Acid per Cleaning	956	478	239
Mass of 100% Citric Acid Required per Cleaning (kg)	1913	956	478

Full-Scale GAC-Fluidized AnMBR Design Basis

Pilot results			
Total HRT (h)	3.87	Table 3.1	
AFBR GAC (kg)	139		
AMFBR GAC (kg)	264		
Total GAC (kg)	403		
Membrane area (m2)	60		
Membrane tank active volume (m3)	0.77		
Membrane area/membrane tank volume (m2/m3)	78		
Flux (LMH)	**7.1**	Table 3.1	
Bioreactor active volume (m3)	0.99		
Total active volume (m3)	1.76		
GAC mass/total volume (kg/m3)	229		
GAC mass/membrane tank volume (kg/m3)	343		

Full-scale design	**7.5 LMH**	**15 LMH**	**30 LMH**
Flow rate (MGD)	5		
Flow rate (m3/d)	18925		
HRT (h)	3.87		
Total active reactor volume (m3)	3050		
Total active reactor volume (gal)	805,804		
Total GAC mass (kg)	698,374		
Total GAC mass (lb)	1,536,422		
Total volume/active volume (includes freeboard)	125%		
Flux (LMH)	**7.5**	**15**	**30**
Membrane area (m2)	105,139	52,569	26,285
Membrane tank (AFMBR) active volume (m3)	1,349	675	337
Membrane tank (AFMBR) active volume (gal)	356,481	178,241	89,120
HRT (h)	0.27	0.13	0.07
Bioreactor (AFBR) active volume (m3)	1,701	2,375	2,713
Bioreactor (AFBR) active volume (gal)	449,323	627,564	716,684
Membrane tank (AFMBR) total volume (m3)	1,687	843	422
Membrane tank (AFMBR) total volume (gal)	445,602	222,801	111,400
Bioreactor (AFBR) total volume (m3)	2126	2969	3391
Bioreactor (AFBR) total volume (gal)	561,653	784,454	895,855
HRT (h)	2.7	3.8	4.3
GAC mass in membrane tank (kg)	462,611	231,306	115,653
GAC mass in membrane tank (lb)	1,017,744	508,872	254,436
GAC mass in bioreactor (AFBR) (kg)	235,762	467,068	582,721
GAC mass in bioreactor (AFBR) (lb)	518,677	1,027,550	1,281,986
GAC mass in membrane tank/active volume (kg/m3)	343	343	343
GAC mass in bioreactor/active volume (kg/m3)	139	197	215

Membrane Recovery Cleaning	**7.5 LMH**	**15 LMH**	**30 LMH**
NaOCl soak solution concentration (mg/L) [a]	1000	1000	1000
Volume of 1000 mg/L NaOCl per Cleaning (m3)	1349	675	337
Mass of 100% NaOCl Required per Cleaning (kg)	1349	675	337
Citric Acid soak solution concentration (mg/L) [a]	2000	2000	2000
Volume of 2000 mg/L Citric Acid per Cleaning	1349	675	337
Mass of 100% Citric Acid Required per Cleaning (kg)	2699	1349	675

Notes: a. Concentrations provided by Jeff Cumin from Suez

Revised Hybrid AnMBR Design Basis

Full scale design	7.5 LMH	15 LMH	30 LMH	Reactor Type
Flow rate (MGD)	5			
Flow rate (m3/d)	18925			
HRT (h)	3.87			GAC AnMBR
Total active reactor volume (m3)	3050			GAC AnMBR
Total GAC mass (kg)	698373.604			GAC AnMBR
Total GAC mass (lb)	1,536,422			GAC AnMBR
Total volume/active volume (includes freeboard)	125%			
Flux (LMH)	**7.5**	**15**	**30**	
Membrane area (m2)	105139	52569	26285	
Membrane tank active volume (m3)	956	478	239	Gas AnMBR
Bioreactor (AFBR) active volume (m3)	2094	2572	2811	GAC AnMBR
Membrane tank total volume (m3)	1195	598	299	Gas AnMBR
Membrane tank total volume (gal)	315,824	157,912	78,956	Gas AnMBR
Bioreactor (AFBR) active total (m3)	2617	3215	3514	GAC AnMBR
Bioreactor (AFBR) total volume (gal)	691,431	849,343	928,299	GAC AnMBR
GAC mass in bioreactor (AFBR) (kg)	698,374	698,374	698,374	GAC AnMBR
GAC mass in bioreactor (AFBR) (lb)	1,536,422	1,536,422	1,536,422	GAC AnMBR
GAC mass in bioreactor/active volume (kg/m3)	334	272	248	GAC AnMBR
Membrane Recovery Cleaning				
NaOCl soak solution concentration (mg/L) [a]	1000	1000	1000	OU
Volume of 1000 mg/L NaOCl per Cleaning (m3)	956	478	239	
Mass of 100% NaOCl Required per Cleaning (kg)	956	478	239	
Citric Acid soak solution concentration (mg/L) [a]	2000	2000	2000	
Volume of 2000 mg/L Citric Acid per Cleaning	956	478	239	
Mass of 100% Citric Acid Required per Cleaning (kg)	1913	956	478	

Notes: a. Concentrations provided by Jeff Cumin from Suez

Comparison of Suez Pilot Modules and Full-scale Modules

Module data	Pilot	Full-Scale	
Model	NA	ZW500d-370	
Footprint area (m2)	0.0112	0.0448	
Fiber length (mm)	1099	2198	
membrane area (m2)	4.3	34.4	
number of fibers	720	2880	
membrane area/footprint area (m2/m2)	384	768	
Nominal volume based on exposed membrane length and footprint (m3)	0.0123088	0.0984704	
Membrane area/nominal volume (m2/m3)	349	349	**-> Scaling based on m2/m3 is valid**
Fibers/footprint area (#/m2)	64286	64286	

Adjustment of Suez costs from Steel Tanks to Concrete Tanks

Cost per module (Euros)	1015	Assumed wall height:	16 ft
Conversion ($/Euro)	1.16	Assumed wall thickness	1.5 ft

Concrete Wall, Suspended Slab, and Guardrail Costs for Common Wall Concrete Construction

Design Flux (LMH)	# Suez Trains	Wall perimeter total length	Wall concrete volume, CY	5' wide Elevated slab concrete volume, CY	Concrete Wall Costs at $1100/CY	Alum Handrail length	Alum Handrail costs @ $100/LF
7.5	8	980	871	62	$ 1,026,080	257	$ 25,720
15	4	534	475	31	$ 556,013	212	$ 21,200
30	2	311	276	15	$ 320,980	189	$ 18,940

Adjusted Costs

Design Flux (LMH)	# Suez Modules	Module cost ($)	Total Suez cost ($)	Estimated Ancillary Eqmt costs (see below)	Steel Tank Cost (not including Ancillary Equipment, Modules, or Slab) ($)	Concrete Tank Cost (not including Ancillary Equipment, Modules, or Slab)	**Total Cost with Concrete ($)**
7.5	3060	$ 3,611,512	$ 11,914,409	$ 3,350,000	$ 4,952,897	$ 1,051,800	**$ 8,013,312**
15	1530	$ 1,805,756	$ 7,010,919	$ 1,850,000	$ 3,355,163	$ 577,213	**$ 4,232,969**
30	770	$ 908,779	$ 3,866,491	$ 1,325,000	$ 1,632,712	$ 339,920	**$ 2,573,699**

Estimated MBR Ancillary Equipment Costs

	7.5 LMH	**15 LMH**	**30 LMH**		
Recirc pumps	$ 600,000	$ 150,000	$ 150,000		
Biogas blowers	$ 600,000	$ 300,000	$ 150,000	or MAX MONTH CONDITIONS	
Tank covers	$ 1,500,000	$ 750,000	$ 375,000		
Foam control	$ 50,000	$ 50,000	$ 50,000		#VALUE!
Chemical Skids	$ 100,000	$ 100,000	$ 100,000	Solids produced	$ 577,213
Remote I/O skid	$ 100,000	$ 100,000	$ 100,000		#VALUE!
MCP	$ 100,000	$ 100,000	$ 100,000		#VALUE!
Remote I/O panels	$ 100,000	$ 100,000	$ 100,000		
Panelview HMI	$ 100,000	$ 100,000	$ 100,000		
Engineering and commissioning	$ 100,000	$ 100,000	$ 100,000		
Total Ancillary Equipment Costs	**$ 3,350,000**	**$ 1,850,000**	**$ 1,325,000**		

7.5 LMH Gas-Sparged AnMBR Costs

Membrane Tanks		Cost for all Tanks	Installation Factor		Total Cost	Source	# Tanks	Concrete Quantities	
Suez Cost for AnMBR System, adjusted for concrete tanks	$	8,013,312	1.05	$	8,413,977	Suez quote, adjusted for concrete	8	7873	sf
Above grade piping allowance	$	300,000	1.0	$	300,000	Professional judgment			
Small diameter CH4 gas piping	$	50,000	1.0	$	50,000	Professional judgment			
Pre-engineered metal canopy (blowers, pumps, chem skids)	$	250,000	1.0	$	250,000	$50/SF		5000	sf
24" Concrete slab		476776.2963	1		476776.2963	$500/CY, 24" slab		25745.9	cf
		Direct Costs, rounded		**$**	**9,490,000**				

Primary Bioreactors		Cost for All Tanks	Installation Factor		Total Cost	Source	# Tanks	Dimensions, each tank	
24" Concrete slab	$	652,000	1.0	$	652,000	Scaled from 66' diameter AnAD OPCC	2	1,274,380	gal
24" Thick walls	$	1,274,000	1.0	$	1,274,000	Scaled from 66' diameter AnAD OPCC		4867	sf
Gas tight mast	$	116,000	1.0	$	116,000	Scaled from 66' diameter AnAD OPCC		79	dia
Cover	$	714,000	1.0	$	714,000	Scaled from 66' diameter AnAD OPCC		247	lf
Mixer	$	104,000	1.3	$	135,200	Scaled from 66' diameter AnAD OPCC			
Above grade piping allowance	$	160,000	1.0	$	160,000	Professional judgment			
		Direct Costs, rounded		**$**	**3,050,000**				

7.5 LMH GAC-Fluidized AnMBR Costs

Comparison of Gas-Sparged to GAC-Fluidized Membrane Tank Design				OUTPUT for MAX MONTH CONDITIONS	
Gas-sparged membrane tank volume	315,824	gallons	See GAS worksheet		
GAC-fluidized membrane tank volume	445,602	gallons	See GAC worksheet	#VALUE!	
Volume Ratio of GAC to GAS Membrane Tank	1.41		Calculated	Solids proc	0
GAC Mass in Membrane Tank	1,017,744	lbs	See GAC worksheet	#VALUE!	
GAC Mass in Primary Bioreactor	518,677	lbs	See GAC worksheet	#VALUE!	

Membrane Tanks	Cost for All Tanks	Installation Factor	Total Cost	Source
Volume-Adjusted Suez Cost for AnMBR System	$ 11,306,121	1.05	$ 11,871,427	Gas-sparged * GAC:GAS volume ratio
Deduction from Suez Cost for Eliminating Blowers	$ (600,000)	1.1	$ (660,000)	See MBR concrete vs. steel worksheet
Above grade piping allowance	-	1.0	$ 300,000	Same as gas-sparged
Small diameter CH4 gas piping	-	1.0	$ 50,000	Same as gas-sparged
Pre-engineered metal canopy (pumps, chem skids)	-	1.0	$ 250,000	Same as gas-sparged
24" Concrete slab	-	1.0	$ 672,692	Gas-sparged * GAC:GAS volume ratio
GAC purchase and install	$ 1,476,000	1.05	$ 1,549,800	$1.45/lb GAC
	Direct Costs, rounded		**$ 14,030,000**	

Primary Bioreactors	Cost for All Tanks	Installation Factor	Total Cost	Source	# Tanks	Dimensions, each tank	
24" Concrete slab	$ 144,000	1.0	$ 144,000	Scaled from 66' diameter AnAD OPCC	2	280,827	gal
24" Thick walls	$ 598,000	1.0	$ 598,000	Scaled from 66' diameter AnAD OPCC		1073	sf
Gas tight mast	$ 116,000	1.0	$ 116,000	Scaled from 66' diameter AnAD OPCC		37	dia
Cover	$ 158,000	1.0	$ 158,000	Scaled from 66' diameter AnAD OPCC		116	lf
Recirculation pumps and nozzles purchase and install	$ 200,000	1.3	$ 260,000	Professional judgment			
Above grade piping allowance	$ 75,000	1.0	$ 75,000	Professional judgment			
GAC purchase and install	$ 752,000	1.05	$ 789,600	$1.45/lb GAC			
	Direct Costs, rounded		**$ 1,350,000**				

AnMBR Estimated Construction Costs

15 LMH Gas-Sparged AnMBR Costs

Membrane Tanks		Cost for All Tanks	Installation Factor		Total Cost	Source	# Tanks	Concrete Quantities	
Suez Cost for Gas-Sparged AnMBR System, adjusted for concrete tanks	$	4,232,969	1.05	$	4,444,617.60	Suez quote, adjusted for concrete	4	3936	sf
Above grade piping allowance	$	150,000	1	$	150,000	Professional judgment			
Small diameter CH4 gas piping	$	50,000	1	$	50,000	Professional judgment			
Pre-engineered metal canopy (blowers, pumps, chem skids)	$	250,000	1	$	250,000	$50/SF		5000	sf
24" Concrete slab	$	330,981	1	$	330,981	$500/CY, 24" slab		17873	cf
		Direct Costs, rounded		**$**	**5,230,000**				

Primary Bioreactors		Cost for All Tanks	Installation Factor		Total Cost	Source	# Tanks	Dimensions, each tank	
24" Concrete slab	$	694,000	1.0	$	694,000	Scaled from 66' diameter AnAD OPCC	2	1,353,336	gal
24" Thick walls	$	1,314,000	1.0	$	1,314,000	Scaled from 66' diameter AnAD OPCC		5169	sf
Gas tight mast	$	116,000	1.0	$	116,000	Scaled from 66' diameter AnAD OPCC		81	dia
Cover	$	758,000	1.0	$	758,000	Scaled from 66' diameter AnAD OPCC		255	lf
Mixer	$	112,000	1.3	$	145,600	Scaled from 66' diameter AnAD OPCC			
Above grade piping allowance	$	163,215	1.0	$	163,215	Professional judgment			
		Direct Costs, rounded		**$**	**3,190,000**				

AnMBR Estimated Construction Costs

15 LMH GAC-Fluidized AnMBR Costs

Comparison of Gas-Sparged to GAC-Fluidized Membrane Tank Design

Gas-sparged membrane tank volume	157,912	gallons	See GAS worksheet
GAC-fluidized membrane tank volume	222,801	gallons	See GAC worksheet
Volume Ratio of GAC to GAS Membrane Tank	1.41		Calculated
GAC Mass in Membrane Tank	508,872	lbs	See GAC worksheet
GAC Mass in Primary Bioreactor	1,027,550	lbs	See GAC worksheet

Membrane Tanks	**Cost for All Tanks**	**Installation Factor**	**Total Cost**	**Source**
Volume-Adjusted Suez Cost for AnMBR System	$ 5,972,370	1.05	$ 6,270,988.58	Gas-sparged * GAC:GAS volume ratio
Deduction from Suez Cost for Eliminating Blowers	$ (300,000)	1.1	$ (330,000)	See MBR concrete vs. steel worksheet
Above grade piping allowance	-	1.0	$ 150,000	Same as gas-sparged
Small diameter CH4 gas piping	-	1.0	$ 50,000	Same as gas-sparged
Pre-engineered metal canopy (pumps, chem skids)	-	1.0	$ 250,000	Same as gas-sparged
24" Concrete slab	-	1.0	$ 466,987	Gas-sparged * GAC:GAS volume ratio
GAC purchase and install	$ 738,000	1.05	$ 774,900	$1.45/lb GAC
	Direct Costs, rounded		**$ 7,630,000**	

Primary Bioreactors	**Cost for All Tanks**	**Installation Factor**	**Total Cost**	**Source**	**# Tanks**	**Dimensions, each tank**
24" Concrete slab	$ 200,000	1.0	$ 200,000	Scaled from 66' diameter AnAD OPCC	2	392,227 gal
24" Thick walls	$ 708,000	1.0	$ 708,000	Scaled from 66' diameter AnAD OPCC		1498 sf
Gas tight mast	$ 116,000	1.0	$ 116,000	Scaled from 66' diameter AnAD OPCC		44 dia
Cover	$ 220,000	1.0	$ 220,000	Scaled from 66' diameter AnAD OPCC		137 lf
Recirculation pumps and nozzles purchase and install	$ 250,000	1.3	$ 325,000	Professional judgment		
Above grade piping allowance	$ 100,000	1.0	$ 100,000	Professional judgment		
GAC purchase and install	$ 1,490,000	1.05	$ 1,564,500	$1.45/lb GAC		
	Direct Costs, rounded		**$ 1,670,000**			

AnMBR Estimated Construction Costs

30 LMH Gas-Sparged AnMBR Costs

Membrane Tanks	Cost for All Tanks	Installation Factor	Total Cost	Source	# Tanks	Concrete Quantities
Suez Cost for Gas-Sparged AnMBR System, adjusted for concrete tanks	$ 2,573,699	1.05	$ 2,702,384	Suez quote, adjusted for concrete	2	1968 sf
Above grade piping allowance	$ 75,000	1.0	$ 75,000	Professional judgment		
Small diameter CH4 gas piping	$ 50,000	1.0	$ 50,000	Professional judgment		
Pre-engineered metal canopy (blowers, pumps, chem skids)	$ 250,000	1.0	$ 250,000	$50/SF		5000 sf
24" Concrete slab	$ 258,083	1.0	$ 258,083	$500/CY, 24" slab		13936 cf
	Direct Costs, rounded		**$ 3,340,000**		**GAC lbs**	

Primary Bioreactors	Cost for All Tanks	Installation Factor	Total Cost	Source	# Tanks	Dimensions, each tank
24" Concrete slab	$ 714,000	1.0	$ 714,000	Scaled from 66' diameter AnAD OPCC	2	1,392,814 gal
24" Thick walls	$ 1,332,000	1.0	$ 1,332,000	Scaled from 66' diameter AnAD OPCC		5319 sf
Gas tight mast	$ 116,000	1.0	$ 116,000	Scaled from 66' diameter AnAD OPCC		82 dia
Cover	$ 780,000	1.0	$ 780,000	Scaled from 66' diameter AnAD OPCC		259 lf
Mixer	$ 114,000	1.3	$ 148,200	Scaled from 66' diameter AnAD OPCC		
Above grade piping allowance	$ 167,976	1.0	$ 167,976	Professional judgment		
	Direct Costs, rounded		**$ 3,260,000**			

AnMBR Estimated Construction Costs

30 LMH GAC-Fluidized AnMBR Costs

Comparison of Gas-Sparged to GAC-Fluidized Membrane Tank Design

Gas-sparged membrane tank volume	78,956	gallons	See GAS worksheet
GAC-fluidized membrane tank volume	111,400	gallons	See GAC worksheet
Volume Ratio of GAC to GAS Membrane Tank	1.41		Calculated
GAC Mass in Membrane Tank	254,436	lbs	See GAC worksheet
GAC Mass in Primary Bioreactor	1,281,986	lbs	See GAC worksheet

Membrane Tanks	**Cost for All Tanks**	**Installation Factor**	**Total Cost**	**Source**
Volume-Adjusted Suez Cost for AnMBR System	$ 3,631,277	1.05	$ 3,812,841	Gas-sparged * GAC:GAS volume ratio
Deduction from Suez Cost for Eliminating Blowers	$ (150,000)	1.1	$ (165,000)	See MBR concrete vs. steel worksheet
Above grade piping allowance	-	1.0	$ 75,000	Same as gas-sparged
Small diameter CH4 gas piping	-	1.0	$ 50,000	Same as gas-sparged
Pre-engineered metal canopy (pumps, chem skids)	-	1.0	$ 250,000	Same as gas-sparged
24" Concrete slab	-	1.0	$ 364,134	Gas-sparged * GAC:GAS volume ratio
GAC purchase and install	$ 369,000	1.05	$ 387,450	$1.45/lb GAC
	Direct Costs, rounded		**$ 4,770,000**	

Primary Bioreactors	**Cost for All Tanks**	**Installation Factor**	**Total Cost**	**Source**	**# Tanks**	**Dimensions, each tank**
24" Concrete slab	$ 230,000	1.0	$ 230,000	Scaled from 66' diameter AnAD OPCC	2	447,927 gal
24" Thick walls	$ 756,000	1.0	$ 756,000	Scaled from 66' diameter AnAD OPCC		1711 sf
Gas tight mast	$ 116,000	1.0	$ 116,000	Scaled from 66' diameter AnAD OPCC		47 dia
Cover	$ 250,000	1.0	$ 250,000	Scaled from 66' diameter AnAD OPCC		147 lf
Recirculation pumps and nozzles purchase and install	$ 275,000	1.3	$ 357,500	Professional judgment		
Above grade piping allowance	$ 125,000	1.0	$ 125,000	Professional judgment		
GAC purchase and install	$ 1,859,000	1.05	$ 1,951,950	$1.45/lb GAC		
	Direct Costs, rounded		**$ 1,830,000**			

Anaerobic Digestion Estimated Construction Costs

Anaerobic Digester for AnMBR Alternatives

Digester Tank	Cost for All Tanks	Installation Factor	Total Cost	Source	# Tanks	Dimensions, each tank
24" Concrete slab	$ 88,000	1.0	$ 88,000	Scaled from 66' diameter AnAD OPCC	1	295,209 gal
24" Thick walls	$ 331,000	1.0	$ 331,000	Scaled from 66' diameter AnAD OPCC		1315 sf
Gas tight mast	$ 58,000	1.0	$ 58,000	Scaled from 66' diameter AnAD OPCC		41 dia
Cover	96000	1	96000	Scaled from 66' diameter AnAD OPCC		128.6 lf
Mixer	$ 14,000	1.3	$ 18,200	Scaled from 66' diameter AnAD OPCC		
Above grade piping allowance	$ 50,000	1.0	$ 50,000	Professional judgment		
	Direct Costs, rounded		**$ 640,000**			

Anaerobic Digester for Conventional Activated Sludge

Digester Tank	Cost for All Tanks	Installation Factor	Total Cost	Source	# Tanks	Dimensions, each tank
24" Concrete slab	$ 123,000	1.0	$ 123,000	Scaled from 66' diameter AnAD OPCC	1	411,630 gal
24" Thick walls	$ 391,000	1.0	$ 391,000	Scaled from 66' diameter AnAD OPCC		1834 sf
Gas tight mast	$ 58,000	1.0	$ 58,000	Scaled from 66' diameter AnAD OPCC		48 dia
Cover	$ 135,000	1.0	$ 135,000	Scaled from 66' diameter AnAD OPCC		152 lf
Mixer	$ 20,000	1.3	$ 26,000	Scaled from 66' diameter AnAD OPCC		
Above grade piping allowance	$ 50,000	1.0	$ 50,000	Professional judgment		
	Direct Costs, rounded		**$ 780,000**			

AX MONTH CONDITIONS

#VALUE!

Solids proc 0

#VALUE!

#VALUE!

Dissolved Methane Removal Estimated Construction Costs

Vacuum Degasser Costs

Item		Cost	Installation Factor		Cost	Source	Footprint Required	
3 model ESS-DG-1200 skid-mounted units	$	70,500	1.3	$	91,650	Elgin budget quote	800	sf
12" DIP above grade piping allowance	$	24,000	1.0	$	24,000	100 LF at $20/LF-in		
Isolation valves allowance	$	50,000	1.0	$	50,000	Professional judgment		
Small diameter CH4 gas piping	$	50,000	1.0	$	50,000	Professional judgment		
12" concrete slab		14814.81481	1		14814.81481	$500/CY, 12" slab	800	cf
Pre-engineered metal canopy	$	40,000	1.0	$	40,000	$50/SF		
		Direct Costs, rounded		**$**	**270,000**			

Skid Length:	100" (2,540 mm)	100" (2,540 mm)
Skid Width:	65" (1,651 mm)	68" (1,727 mm)

OUTPUT for MAX MONTH CO

Dissolved Methane Removal Estimated Construction Costs

Hollow Fiber Membrane Contactor Costs

##

Solids prod 0

Item		Cost	Installation Factor		Cost	Source	Footprint Required	
								##
Contactor Feed Pumps								
75 HP Feed Pumps	$	90,000	1.2	$	108,000	Prior projects	875	sf
Process/Mech Piping Allowance	$	90,000	1.0	$	90,000			
12" Concrete slab	$	16,204	1.0	$	16,204	$500/CY	875	cf
	Feed Pump Direct Costs, rounded			**$**	**210,000**			
Vacuum-Assisted Contactors								
18 Liquicel contactors in series	$	281,212	1.2	$	337,454	3M budget quote	2625	sf
Two liquid ring pumps	$	-	1.0	$	-	included in above	50	sf
4" DIP above grade piping allowance	$	32,000	1.0	$	32,000	400 LF at $20/LF-in	0	sf
Isolation valves allowance	$	60,000	1.0	$	60,000	Professional judgment		
CH4 gas and liquid ring pump piping	$	50,000	1.0	$	50,000	Professional judgment	0	sf
PSA N2 Generation System								
One PSA system for N2 generation, including filtration package, analyzers, nitrogen buffer tank and surge tank	$	35,000	1.1	$	38,500	Compressed Gas Technologies budget quote	150	sf
One air compressor system for N2 generation	$	10,000	1.1	$	11,000	Professional judgment	36	sf
Process/Mech Piping Allowance	$	10,000	1.0	$	10,000	Professional judgment	0	sf
Electrical Room	$	-		$	-		200	sf
12" Concrete slab	$	56,685	1.0	$	56,685	$500/CY, 12" slab	3061	cf
Pre-Engineered Metal Building	$	382,625	1.0	$	382,625	$125/SF	3061	sf
	Membrane Contactor Facility Direct Costs, rounded			**$**	**980,000**			

Primary Clarifiers and Primary Sludge Design Basis

Primary clarifiers - sizing per TCEQ 217 requirements

Design Average Overflow Rate	1,000	gpd/sf
Maximum Peak Overflow Rate	1,800	gpd/sf

	gpd	sf
Required Surface Area at Average Flow	5,000,000	5000
Required Surface Area at Peak Flow (after EQ)	10,000,000	5556

Selected Surface Area for Design	5,565	sf
Surface Area per tank	2,783	sf
Diameter	60	ft
SWD	14	ft

Primary effluent characteristics

	Average Day Raw Inf Loading	Max Month Raw Inf Loading	% Removal in Primaries	Average Day Primary Effluent Loads	Maximum Month Primary Effluent Loads	Average Day Primary Effluent Concentration
	(lb/d)	(lb/d)		(lb/d)	(lb/d)	mg/L
COD	17,925	23,130	35%	11,651	15,035	279
BOD5	7,920	10,220	35%	5,148	6,643	for MAX MONTH CON
TSS	8,760	11,480	60%	3,504	4,592	84
TKN *	1,670	1,890	0%	1,670	1,890	40
NH_3-N	1,042	1,280	0%	1,042	1,280	Solids produced
TP	290	330	40%	174	198	4.2
Sulfate	1,251	1,251	0%	1,251	1,251	30

* Assume no removal because will get recycled back in centrate since no sidestream tratment

	Average Day	Max Month	
Sludge quantity	5,256	6,888	lb/day
Concentration	4%	4%	
Cludge volume	1,753	2,298	gal/d

Conventional Activated Sludge Design Basis

Bioreactor Design Based on McKinney Yield Equations

PRIMARY EFFLUENT MAX MONTH DATA:

FLOW	**BOD in**	**TSS in**	**TKN in**	**Abasin V**	Abasin T	Sludge age	**Sludge age**	Ts/T	Effluent TSS
MGD	**mg/l**	**mg/l**	**mg/l**	**MG**	Hrs	Hrs	**days**	-	mg/L
5.00	**123.00**	**84.00**	**40.00**	**1.50**	7.20	240	**10.0**	33.3	10

ORGANICS METABOLISM:

F, mg/l	Ma, mg/l	Me, mg/l	Mi, mg/l	Mii, mg/l	MLSSc, mg/l	WAS, lbs/d
1.6	594	570	896	676	2,736	3,423

NITROGEN METABOLISM:

						Max Month	Net Yield
F,mg/l	Ma,mg/l	Me,mg/l	Mi,mg/l	Mt,mg/l	**MLSSt mg/l**	**WAS lbs/d**	Lb WAS/lb BOD
0.038	124.4	119.4	24.4	268.1	**3,004**	**3,341**	0.65
					% Volatile	80%	
					Volatile WAS	2,660	lb/d

Abasin V per tank	
2	# tanks
0.75	MG
100254	cubic feet
18	SWD
40	Width
139	Length

OUTPUT for MAX MONTH CONDITIONS

TSS:BOD	0.68	-
Solids produced	3,341	lb/d
BOD removed	5,129	lb/d
Net solids yield	**0.65**	lb/lb

Secondary clarifiers - Sizing per 10 states for clarifiers with chemical addition for P removal

Maximum Peak Overflow Rate	900	gpd/sf
Design Peak Flow	15,000,000	gpd
Minimum Required Surface Area	16667	sf

Total Surface Area	16667	sf
Number of Tanks	2	
Surface Area per tank	8333	sf
Diameter	103	ft
SWD	14	ft

Cost of one 135' dia	$	1,215,000
Cost of two 105' dia	$	1,890,000
Cost of three 85' dia	$	2,295,000
Cost of four 75' dia	$	2,700,000

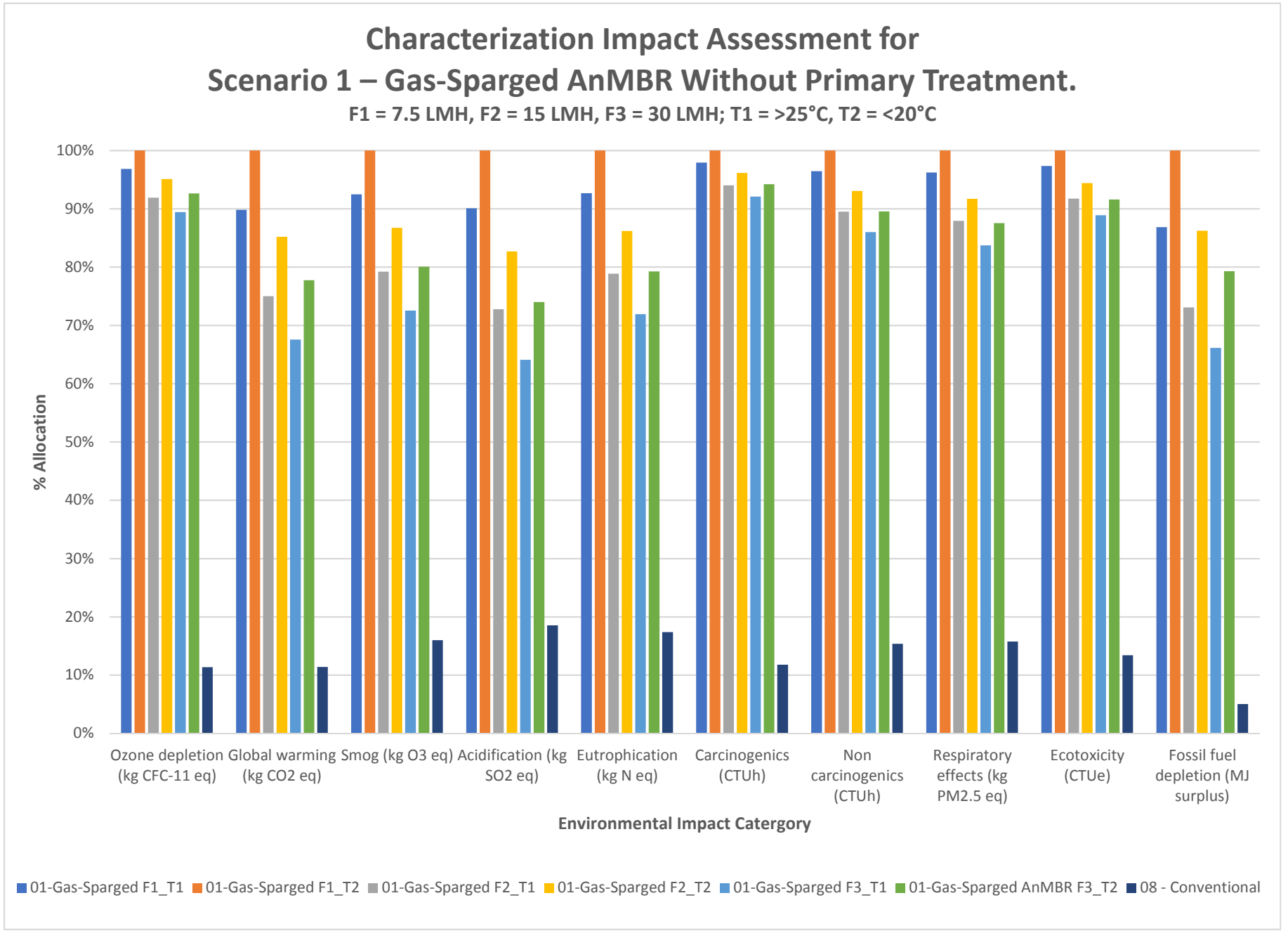
Primary and Secondary Sludge Calculations

Parameter	Unit	Anaerobic MBR Alternatives without Primary Sedimentation	Anaerobic MBR Alternatives with Primary Sedimentation	Conventional Activated Sludge Alternative
Sludge Production				
Primary Sludge	dry lb/d	0	5,256	5,256
Secondary Sludge - Biological	dry lb/d	2,330	1,515	2,660
Secondary Sludge - Inert	dry lb/d	-	-	1524.948022
Total Solids	dry lb/d	2,330	6,771	9,441
Total Volatile Solids	dry lb/d	2,330	6,771	7,916
Sludge Thickening - Secondary Solids Only				
Sludge to thickening	lb/day	2,330	1,515	4,185
Polymer dose	lb/dry ton	8	8	8
Polymer required	lb active/d	9.3	6.1	16.7
Sludge Stabilization - Blended Primary + Thickened Secondary Solids				
Type		Lime stabilization of dewatered	Mesophilic Digestion of thickened	Mesophilic Digestion of thickened
Total sludge feed	dry lb/d	2,330	6,771	9,441
Total volatile feed	dry lb/d	2,330	6,771	7,916
Total sludge feed, blended primary and thickened secondary sludge	gal/d	5,080	14,760	20,582
Sludge Feed Content	%	5.5%	5.5%	5.5%
Lime Dose required	tons/d	0.35	-	-
Lime Conveyors and Mixing Power	HP	30.0	-	-
SRT	days	-	20	20
Total Digester Volume	gallons	-	295,209	411,630
Organic Loading Rate	lb VS /cu ft	-	0.17	0.14
Number Digesters		-	1	1
Digester Depth	ft		35	35
Digester Dimensions		-	41-ft diameter	48-ft diameter
Digester Mixing HP, each	HP		10	10
VSR	%	-	55%	55%
VSR	dry lb/d	-	3,724	4,354
Stabilized Sludge	dry lb/d	3,029	3,047	5,087
Sludge Dewatering - Stabilized Secondary and Primary Solids				
Polymer dose	lb/dry ton	18	18	18
Polymer required (before lime)	lb active/d	21.0	27.4	45.8
Sludge Content	%	20%	20%	20%
Dewatered Cake	wet tons/d	7.6	7.6	12.7

GBT Sizing Check				
Width of GBT	m	2	2	2
Allowable GBT Loading to 2m GBT	gpm	400	400	400
Secondary Biologial Sludge Solids	pct	0.91%	0.91%	0.60%
Secondary Biological Sludge Flow	gal/day	30703	19957	83628
Hours of Operation	hr/day	7	7	7
Flow during Operation	gpm	73	48	199
Sizing Factor	-	1.3	1.3	1.3
Number of 2m GBTs reqd	-	0.24	0.15	0.65

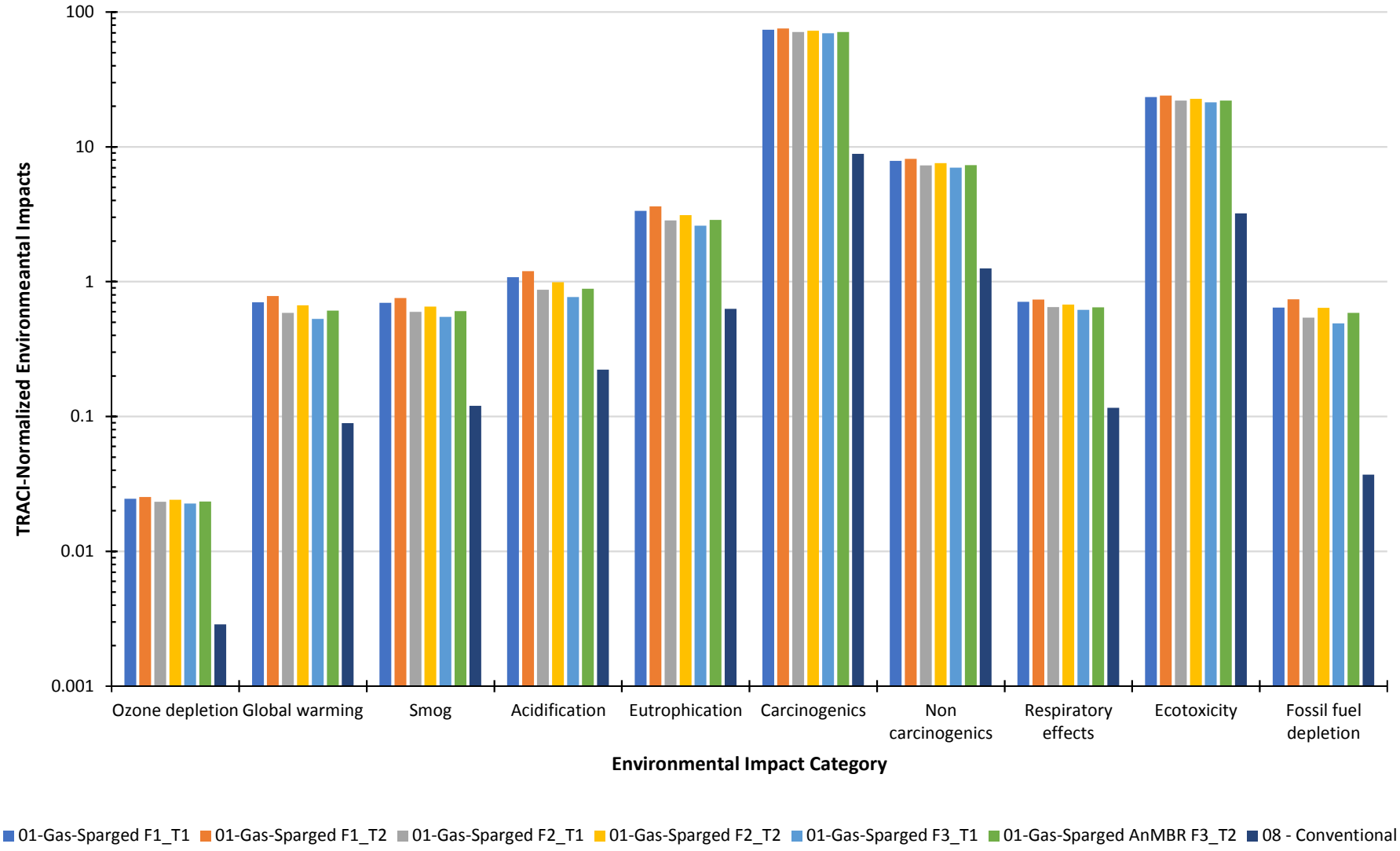
BFP Sizing Check				
Width of BFP	m	2	2	2
Thickened Sludge Solids	pct	5.5%	4.0%	4.0%
Thickened Sludge Flow	gal/day	6604	9133	15249
Hours of Operation	hr/day	5	5	5
Flow during Operation	gpm	22	30	51
Flow during Operation	l/s	1.39	1.92	3.21
Sizing Factor	-	1.3	1.3	1.3
Hydraulic Loading to BFP	l/s per m	0.90	1.25	2.08
		Per Metcalf & Eddy, target range is 1.3-3.2 L/s per meter belt width		
Solids Loading to BFP	kg/h per m	37.2	37.4	62.5
		Per Metcalf & Eddy, target range is 180-320 kg/h per meter belt width		

APPENDIX H. LIFECYCLE ASSESSMENT SUPPORTING DATA

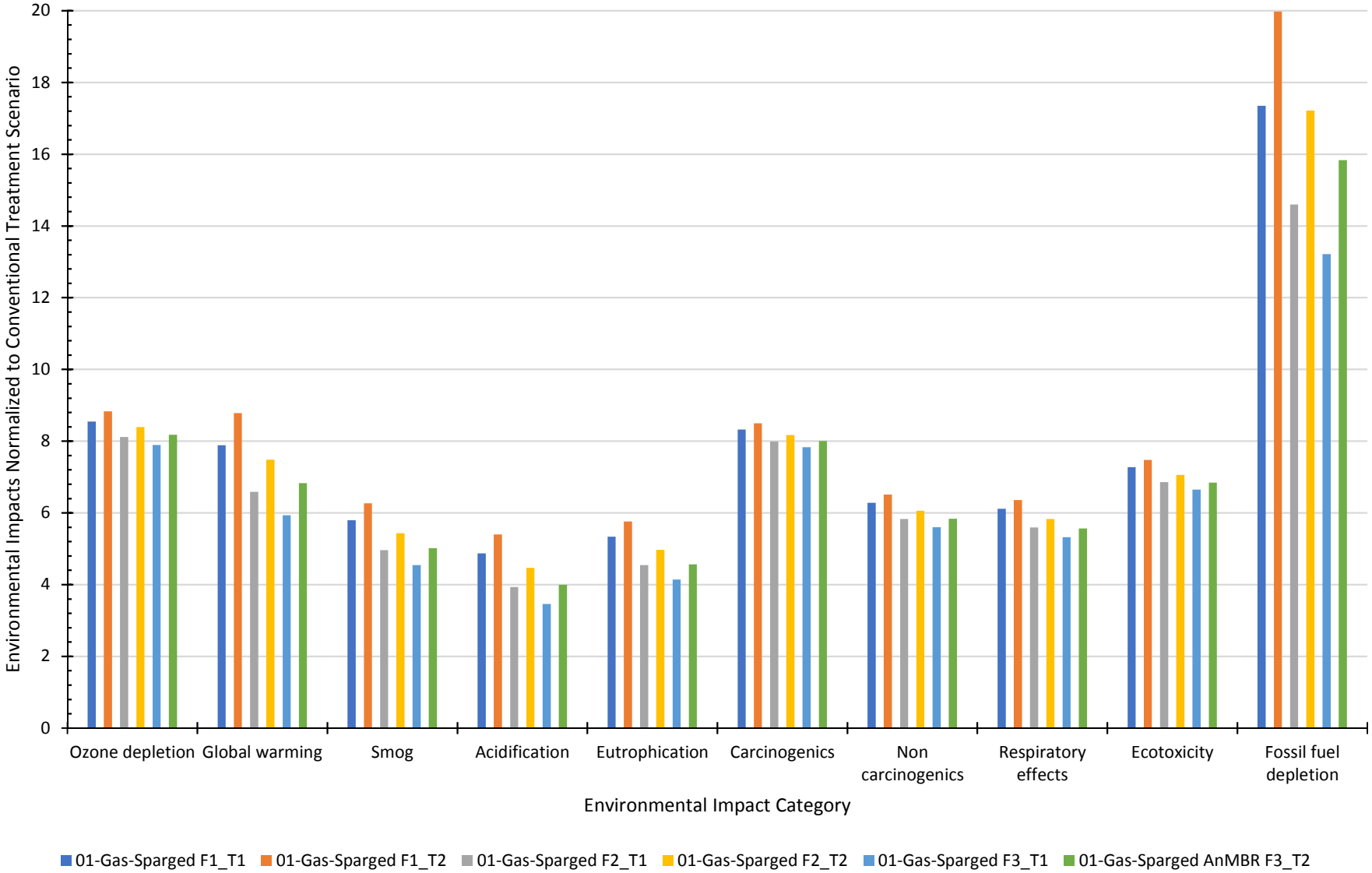

Characterization Impact Assessment for
Scenario 1 – Gas-Sparged AnMBR Without Primary Treatment.
F1 = 7.5 LMH, F2 = 15 LMH, F3 = 30 LMH; T1 = >25°C, T2 = <20°C
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
% Allocation
Ozone depletion (kg CFC-11 eq)
Global warming (kg CO2 eq)
Smog (kg O3 eq)
Acidification (kg SO2 eq)
Eutrophication (kg N eq)
Carcinogenics (CTUh)
Non carcinogenics (CTUh)
Respiratory effects (kg PM2.5 eq)
Ecotoxicity (CTUe)
Fossil fuel depletion (MJ surplus)
Environmental Impact Catergory
01-Gas-Sparged F1_T1
01-Gas-Sparged F1_T2
01-Gas-Sparged F2_T1
01-Gas-Sparged F2_T2
01-Gas-Sparged F3_T1
01-Gas-Sparged AnMBR F3_T2
08 - Conventional

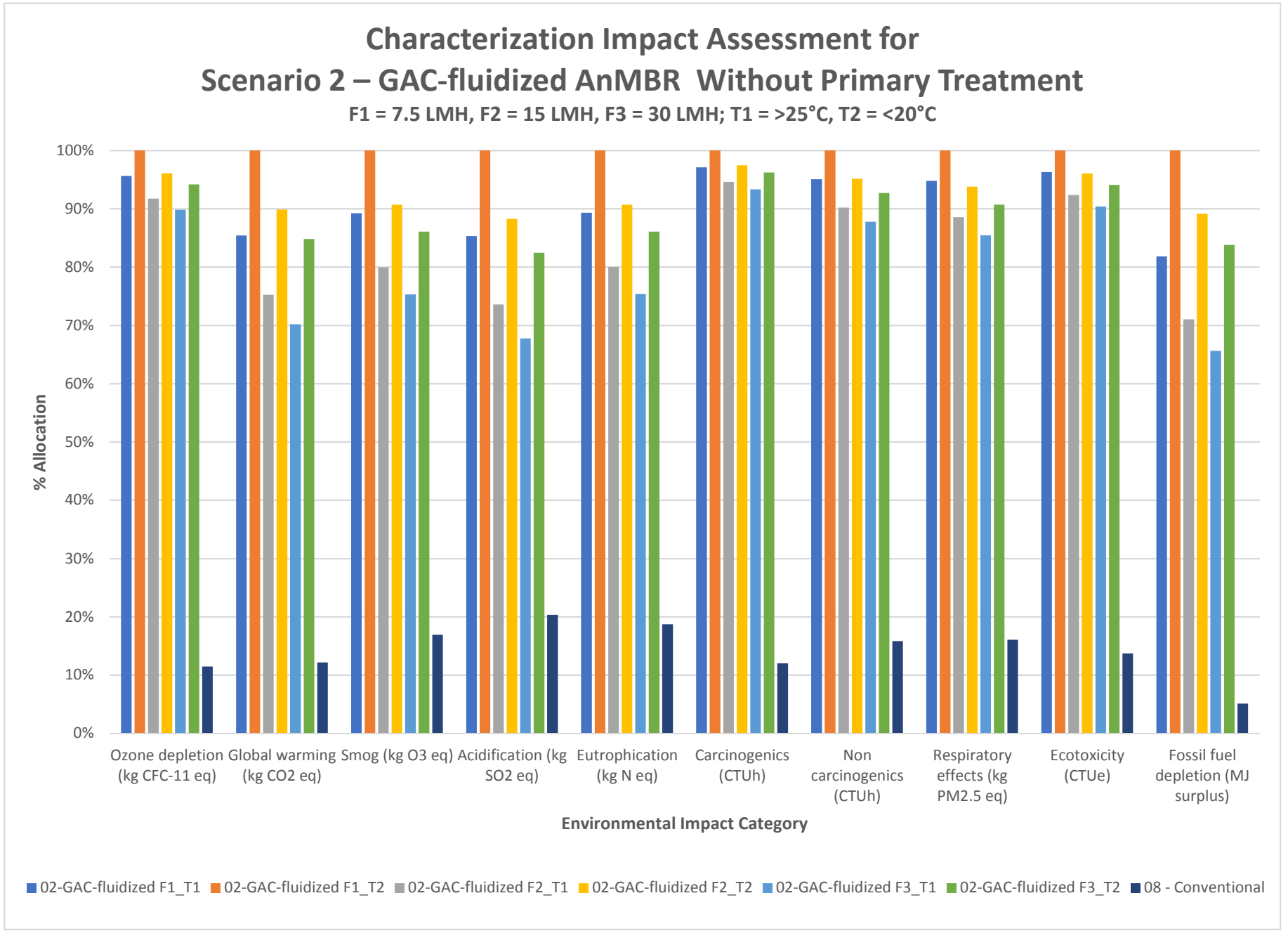
TRACI Normalized Impact Assesment for Scenario 1 – Gas-Sparged AnMBR Without Primary Treatment.

F1 = 7.5 LMH, F2 = 15 LMH, F3 = 30 LMH; TI = >25°C, T2 = <20°C



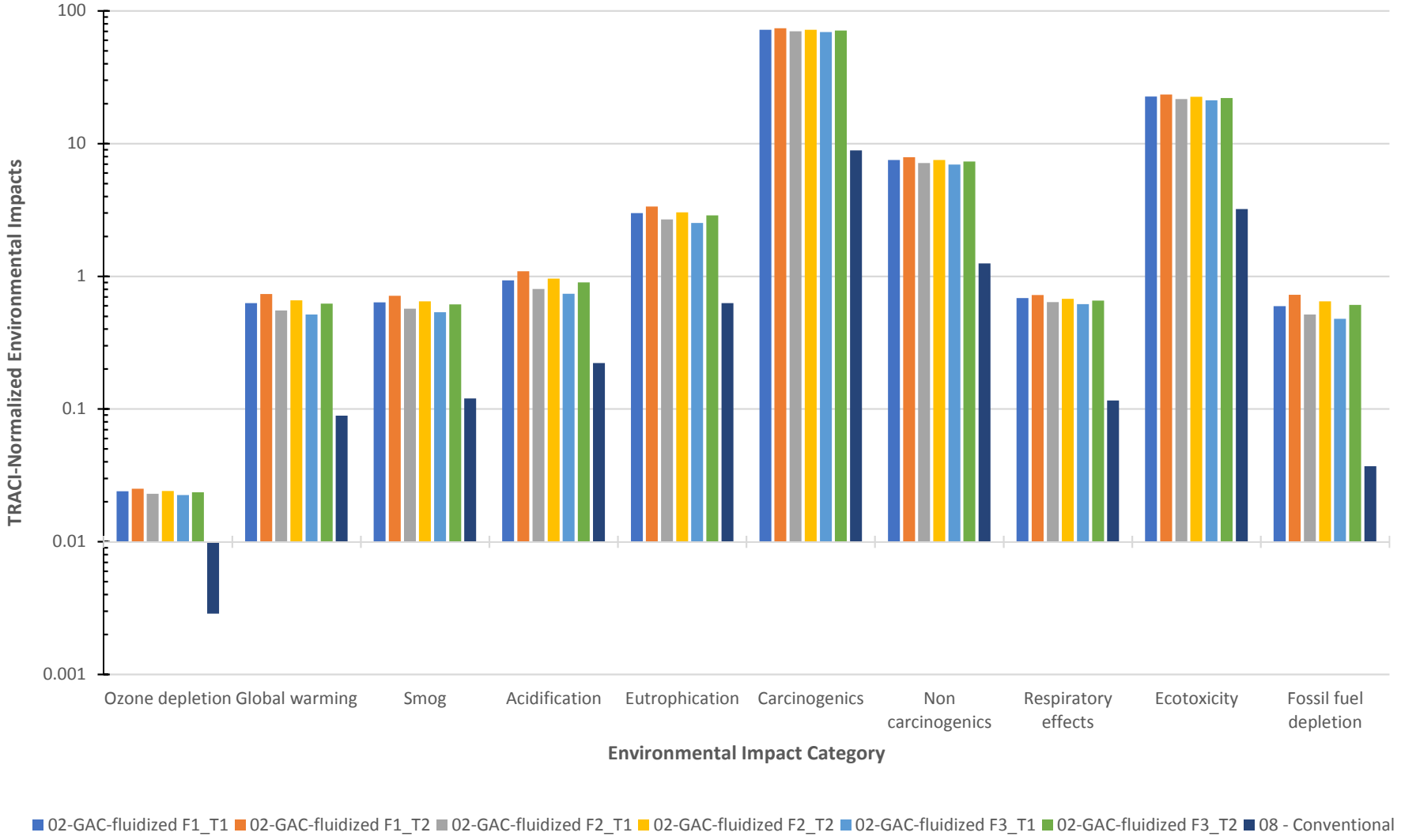
Impact Assesment Normalized to Conventional Treatment Method for Scenario 1 – Gas-Sparged AnMBR Without Primary Treatment.
F1 = 7.5 LMH, F2 = 15 LMH, F3 = 30 LMH; TI = >25°C, T2 = <20°C

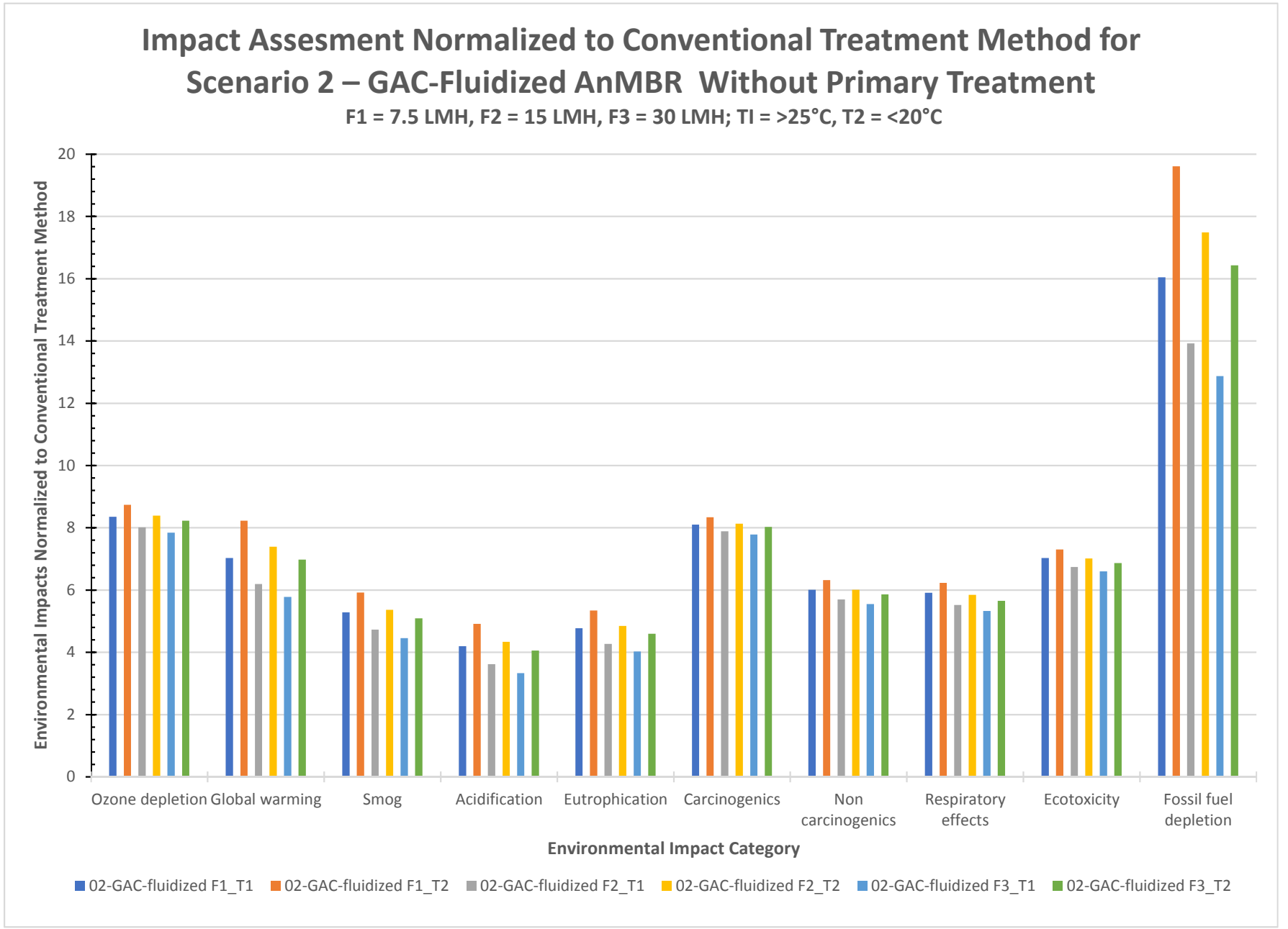


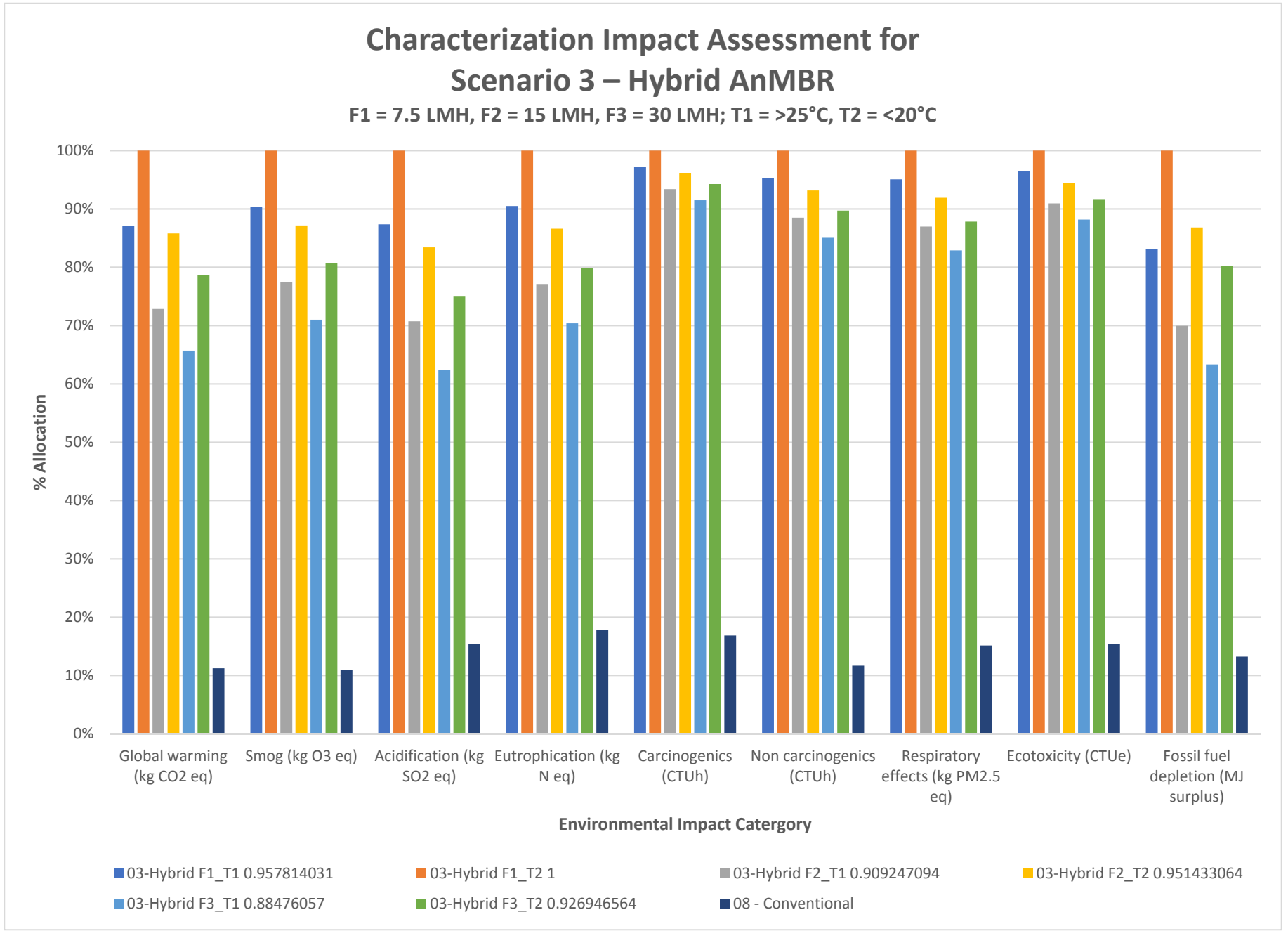

Characterization Impact Assessment for
Scenario 2 – GAC-fluidized AnMBR Without Primary Treatment
F1 = 7.5 LMH, F2 = 15 LMH, F3 = 30 LMH; T1 = >25°C, T2 = <20°C
% Allocation
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Ozone depletion (kg CFC-11 eq)
Global warming (kg CO2 eq)
Smog (kg O3 eq)
Acidification (kg SO2 eq)
Eutrophication (kg N eq)
Carcinogenics (CTUh)
Non carcinogenics (CTUh)
Respiratory effects (kg PM2.5 eq)
Ecotoxicity (CTUe)
Fossil fuel depletion (MJ surplus)
Environmental Impact Category
02-GAC-fluidized F1_T1
02-GAC-fluidized F1_T2
02-GAC-fluidized F2_T1
02-GAC-fluidized F2_T2
02-GAC-fluidized F3_T1
02-GAC-fluidized F3_T2
08 - Conventional

TRACI Normalized Impact Assesment for Scenario 2 – GAC-Fluidized AnMBR Without Primary Treatment

F1 = 7.5 LMH, F2 = 15 LMH, F3 = 30 LMH; TI = >25°C, T2 = <20°C

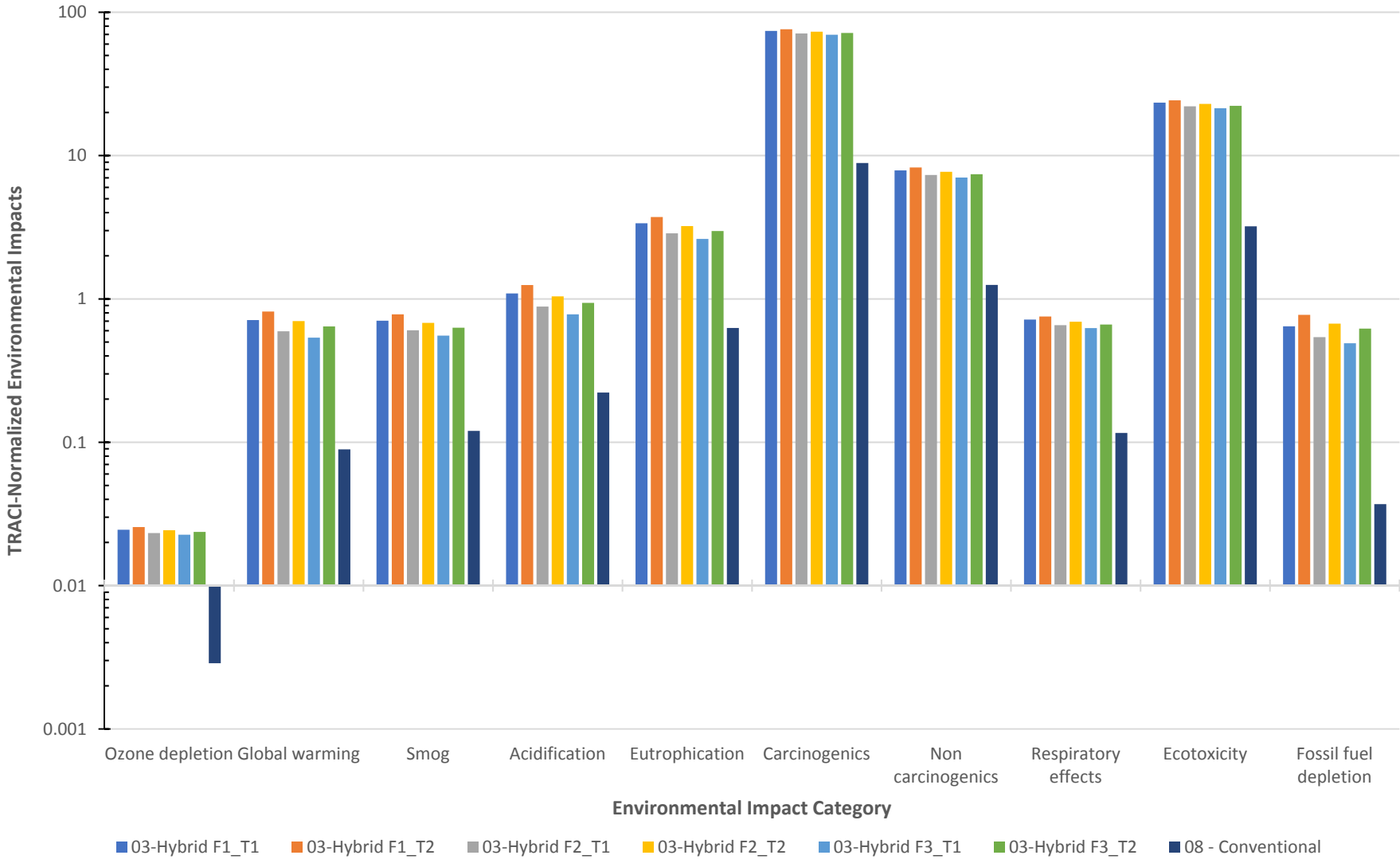



Impact Assesment Normalized to Conventional Treatment Method for Scenario 2 – GAC-Fluidized AnMBR Without Primary Treatment
F1 = 7.5 LMH, F2 = 15 LMH, F3 = 30 LMH; TI = >25°C, T2 = <20°C
Environmental Impacts Normalized to Conventional Treatment Method
0
2
4
6
8
10
12
14
16
18
20
Ozone depletion
Global warming
Smog
Acidification
Eutrophication
Carcinogenics
Non carcinogenics
Respiratory effects
Ecotoxicity
Fossil fuel depletion
Environmental Impact Category
02-GAC-fluidized F1_T1
02-GAC-fluidized F1_T2
02-GAC-fluidized F2_T1
02-GAC-fluidized F2_T2
02-GAC-fluidized F3_T1
02-GAC-fluidized F3_T2


Characterization Impact Assessment for Scenario 3 – Hybrid AnMBR
F1 = 7.5 LMH, F2 = 15 LMH, F3 = 30 LMH; T1 = >25°C, T2 = <20°C
% Allocation
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Global warming (kg CO2 eq)
Smog (kg O3 eq)
Acidification (kg SO2 eq)
Eutrophication (kg N eq)
Carcinogenics (CTUh)
Non carcinogenics (CTUh)
Respiratory effects (kg PM2.5 eq)
Ecotoxicity (CTUe)
Fossil fuel depletion (MJ surplus)
Environmental Impact Catergory
03-Hybrid F1_T1 0.957814031
03-Hybrid F1_T2 1
03-Hybrid F2_T1 0.909247094
03-Hybrid F2_T2 0.951433064
03-Hybrid F3_T1 0.88476057
03-Hybrid F3_T2 0.926946564
08 - Conventional

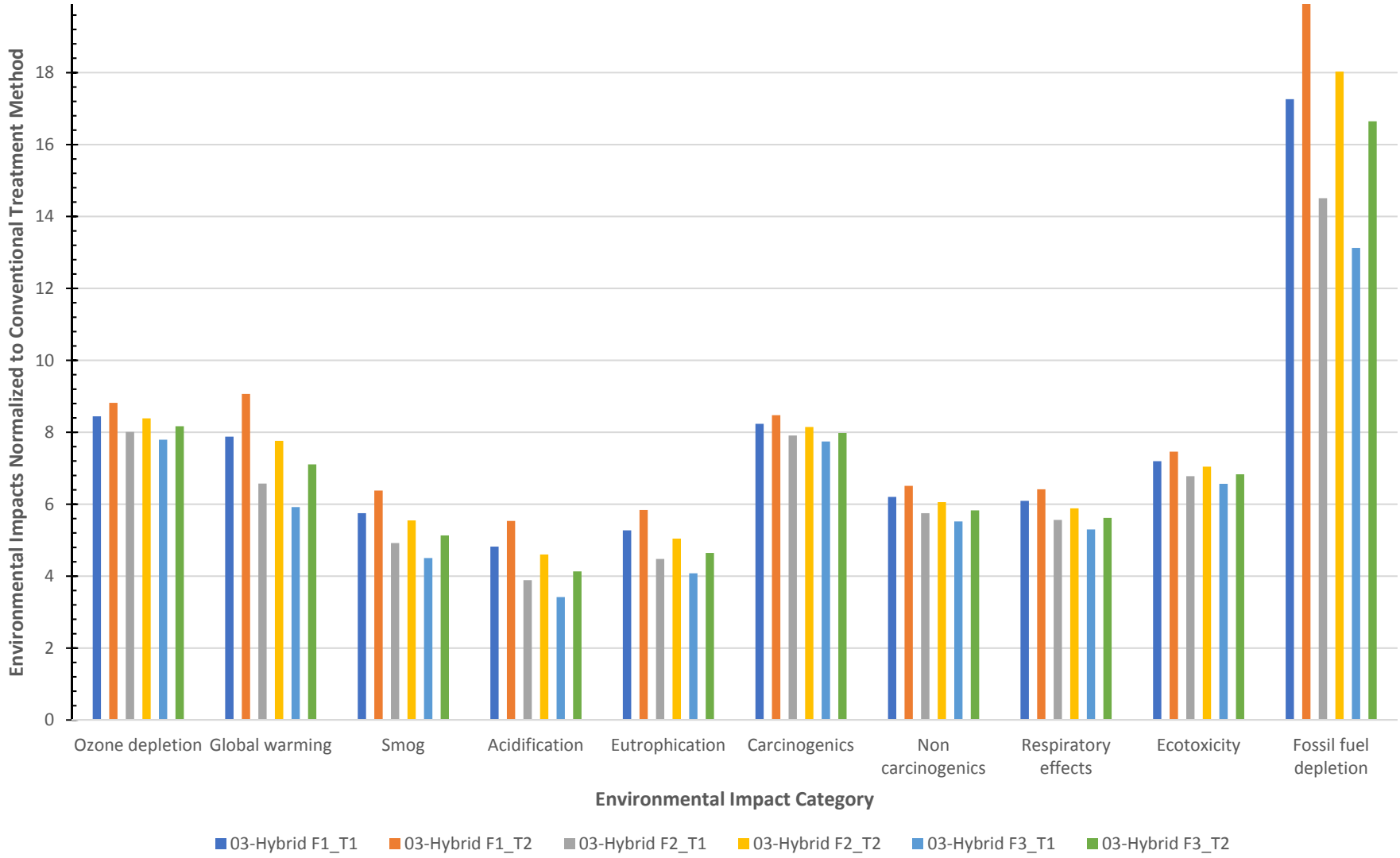
TRACI Normalized Impact Assesment for Scenario 3 – Hybrid AnMBR

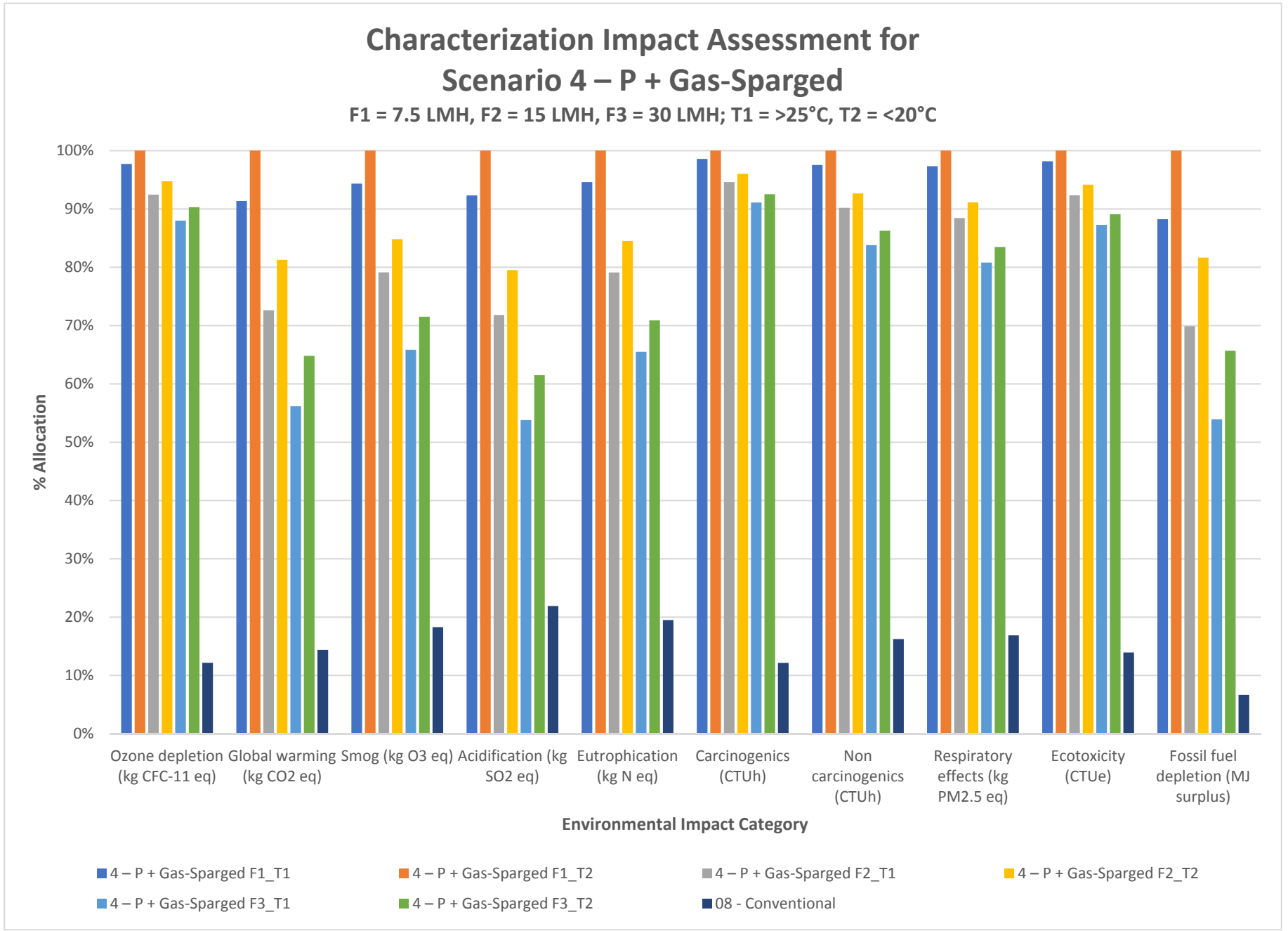
F1 = 7.5 LMH, F2 = 15 LMH, F3 = 30 LMH; TI = >25°C, T2 = <20°C

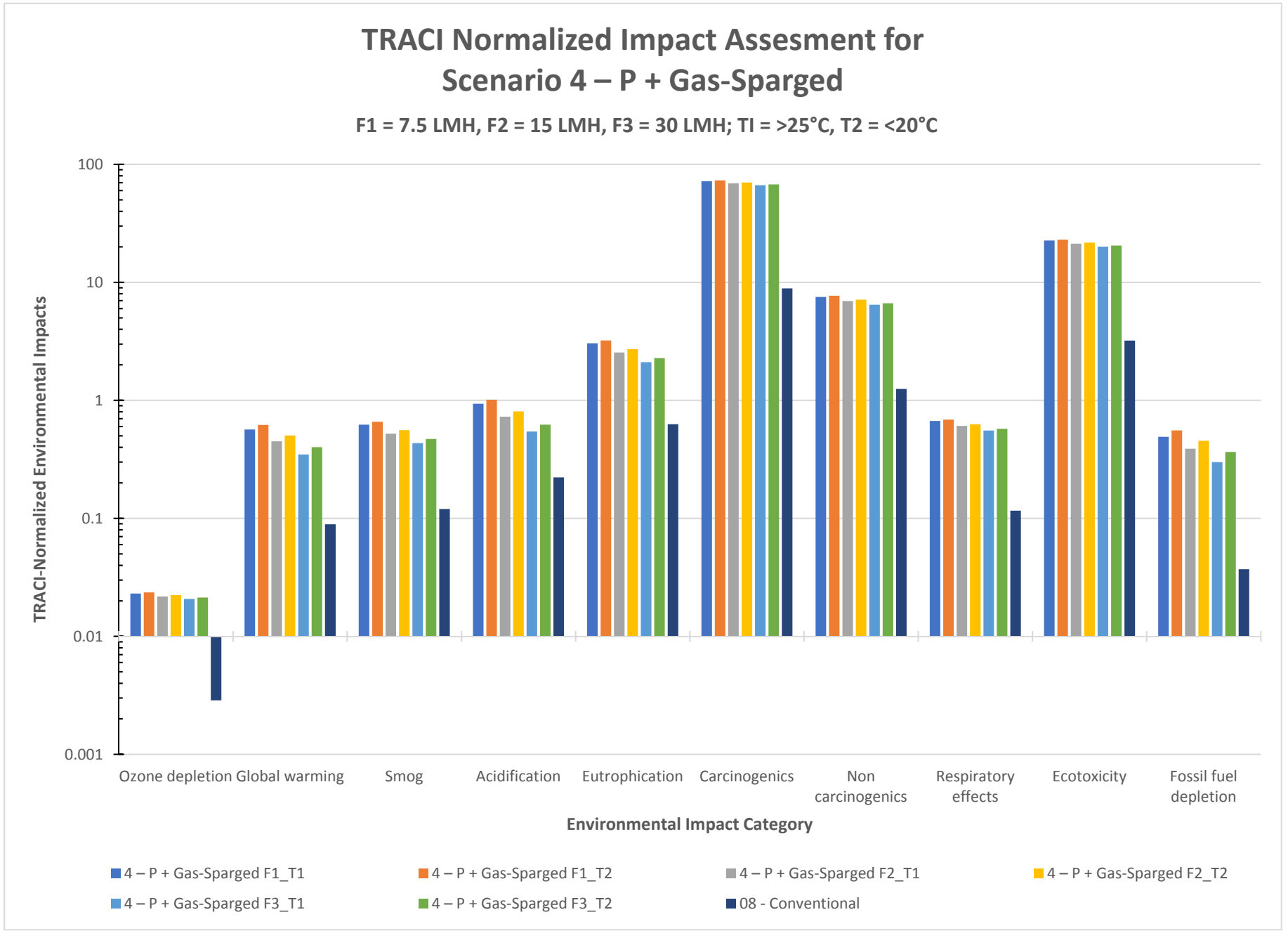


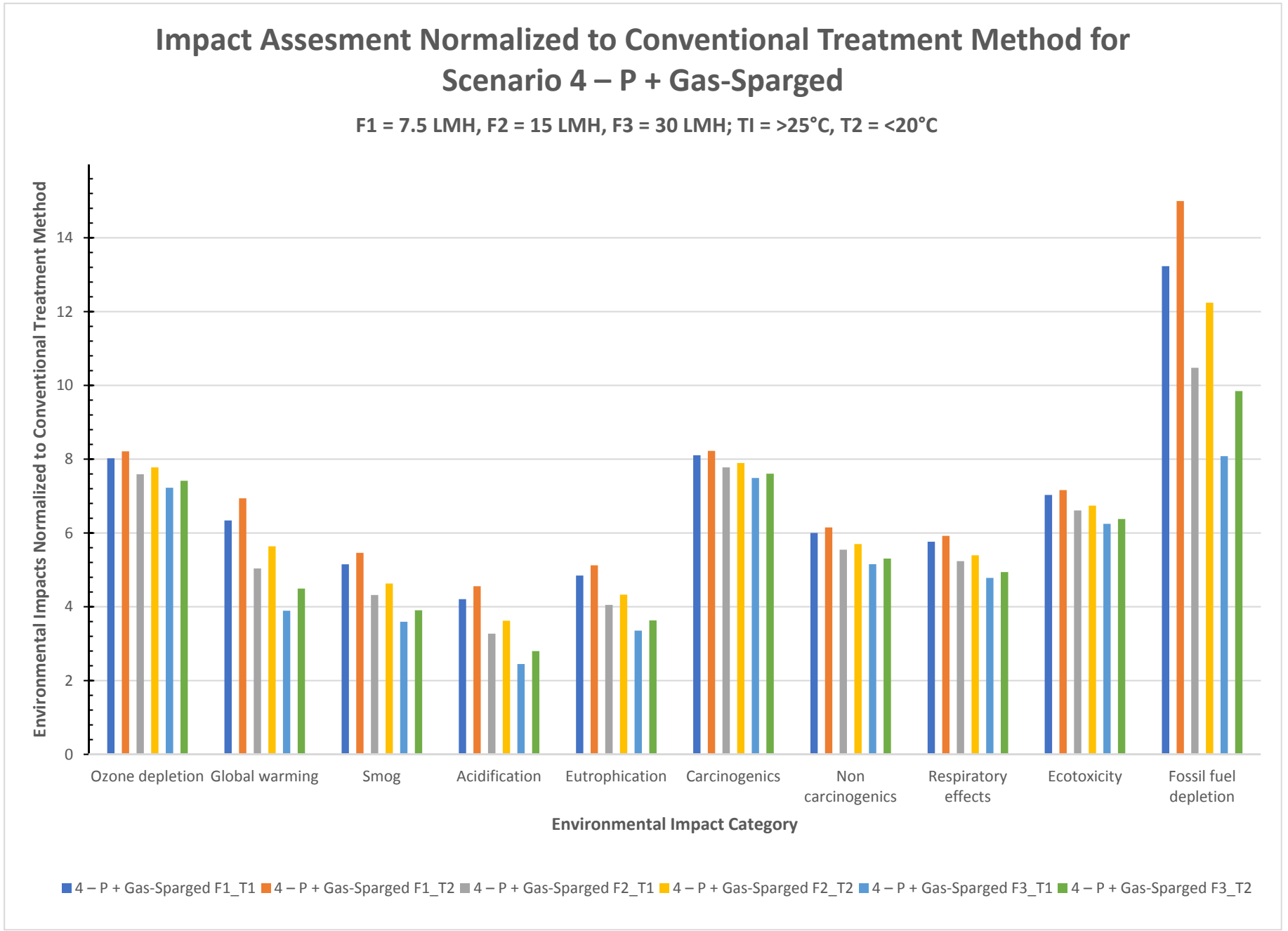
Impact Assesment Normalized to Conventional Treatment Method for Scenario 3 – Hybrid AnMBR

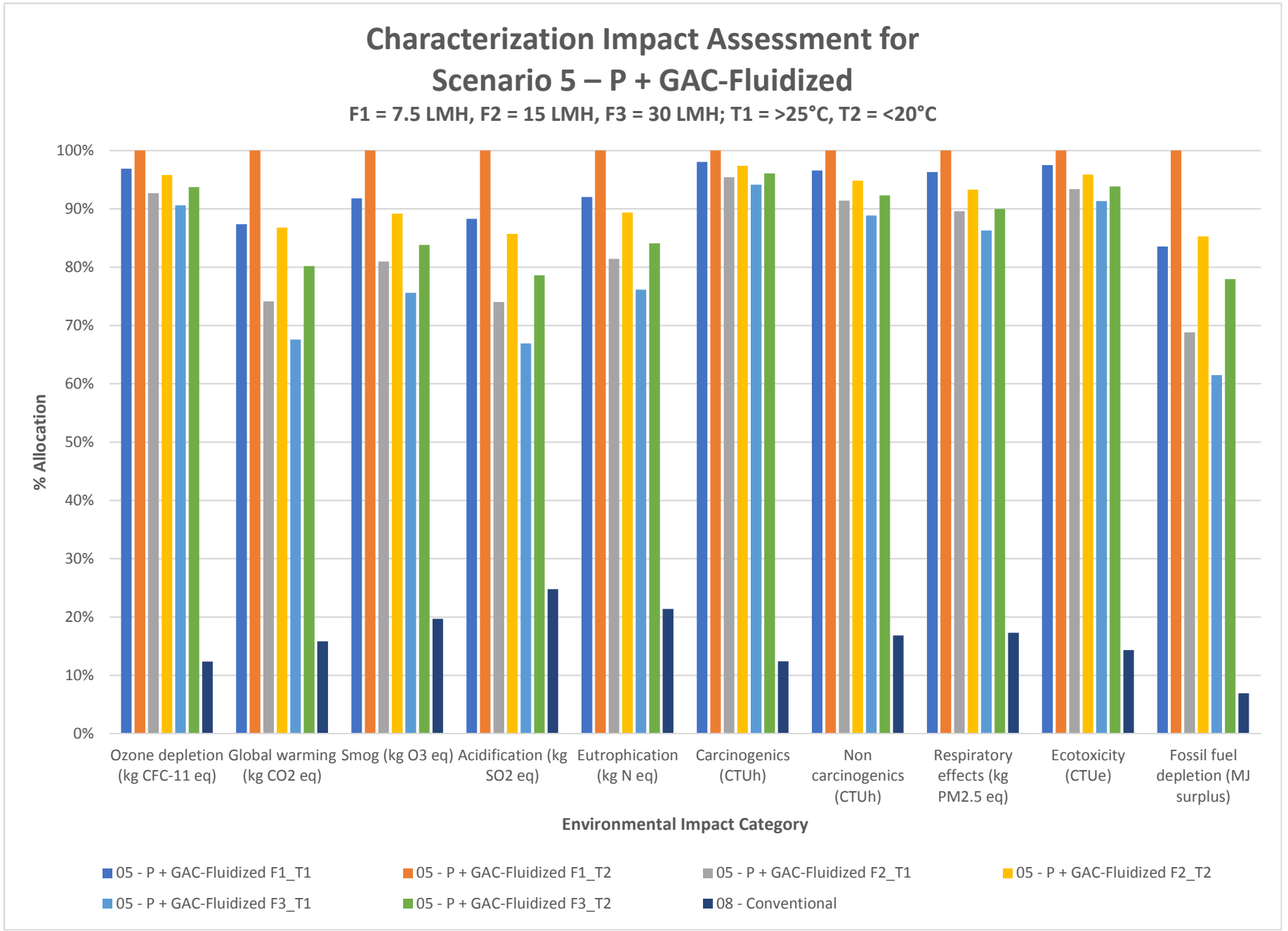
F1 = 7.5 LMH, F2 = 15 LMH, F3 = 30 LMH; TI = >25°C, T2 = <20°C




Characterization Impact Assessment for Scenario 4 – P + Gas-Sparged
F1 = 7.5 LMH, F2 = 15 LMH, F3 = 30 LMH; T1 = >25°C, T2 = <20°C
% Allocation
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Ozone depletion (kg CFC-11 eq)
Global warming (kg CO2 eq)
Smog (kg O3 eq)
Acidification (kg SO2 eq)
Eutrophication (kg N eq)
Carcinogenics (CTUh)
Non carcinogenics (CTUh)
Respiratory effects (kg PM2.5 eq)
Ecotoxicity (CTUe)
Fossil fuel depletion (MJ surplus)
Environmental Impact Category
4 – P + Gas-Sparged F1_T1
4 – P + Gas-Sparged F1_T2
4 – P + Gas-Sparged F2_T1
4 – P + Gas-Sparged F2_T2
4 – P + Gas-Sparged F3_T1
4 – P + Gas-Sparged F3_T2
08 - Conventional

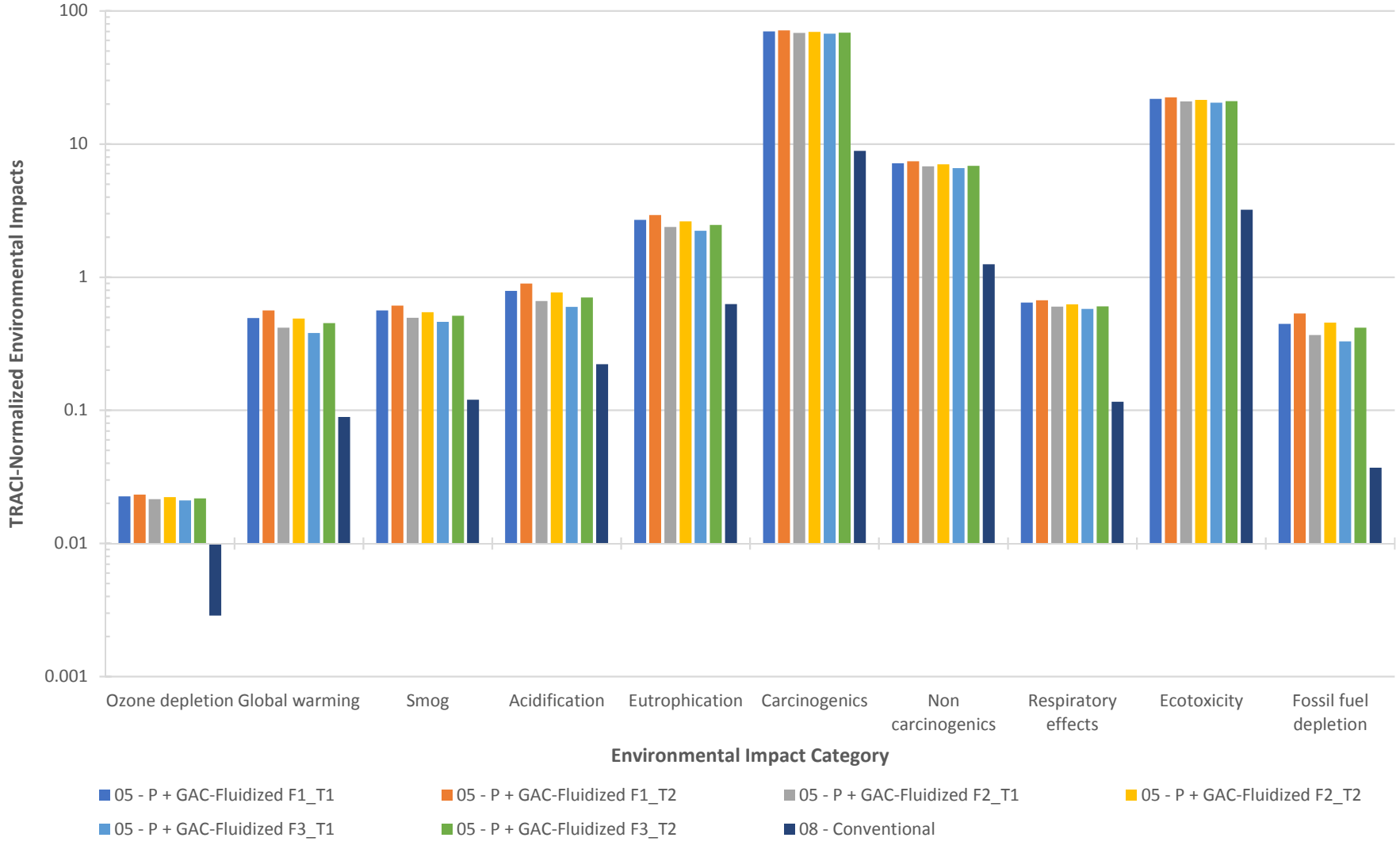

TRACI Normalized Impact Assesment for Scenario 4 – P + Gas-Sparged
F1 = 7.5 LMH, F2 = 15 LMH, F3 = 30 LMH; TI = >25°C, T2 = <20°C
TRACI-Normalized Environmental Impacts
100
10
1
0.1
0.01
0.001
Ozone depletion
Global warming
Smog
Acidification
Eutrophication
Carcinogenics
Non carcinogenics
Respiratory effects
Ecotoxicity
Fossil fuel depletion
Environmental Impact Category
4 – P + Gas-Sparged F1_T1
4 – P + Gas-Sparged F1_T2
4 – P + Gas-Sparged F2_T1
4 – P + Gas-Sparged F2_T2
4 – P + Gas-Sparged F3_T1
4 – P + Gas-Sparged F3_T2
08 - Conventional


Impact Assesment Normalized to Conventional Treatment Method for Scenario 4 – P + Gas-Sparged
F1 = 7.5 LMH, F2 = 15 LMH, F3 = 30 LMH; TI = >25°C, T2 = <20°C
Environmental Impacts Normalized to Conventional Treatment Method
0
2
4
6
8
10
12
14
Ozone depletion
Global warming
Smog
Acidification
Eutrophication
Carcinogenics
Non carcinogenics
Respiratory effects
Ecotoxicity
Fossil fuel depletion
Environmental Impact Category
4 – P + Gas-Sparged F1_T1
4 – P + Gas-Sparged F1_T2
4 – P + Gas-Sparged F2_T1
4 – P + Gas-Sparged F2_T2
4 – P + Gas-Sparged F3_T1
4 – P + Gas-Sparged F3_T2


Characterization Impact Assessment for
Scenario 5 – P + GAC-Fluidized
F1 = 7.5 LMH, F2 = 15 LMH, F3 = 30 LMH; T1 = >25°C, T2 = <20°C
% Allocation
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Ozone depletion (kg CFC-11 eq)
Global warming (kg CO2 eq)
Smog (kg O3 eq)
Acidification (kg SO2 eq)
Eutrophication (kg N eq)
Carcinogenics (CTUh)
Non carcinogenics (CTUh)
Respiratory effects (kg PM2.5 eq)
Ecotoxicity (CTUe)
Fossil fuel depletion (MJ surplus)
Environmental Impact Category
05 - P + GAC-Fluidized F1_T1
05 - P + GAC-Fluidized F1_T2
05 - P + GAC-Fluidized F2_T1
05 - P + GAC-Fluidized F2_T2
05 - P + GAC-Fluidized F3_T1
05 - P + GAC-Fluidized F3_T2
08 - Conventional

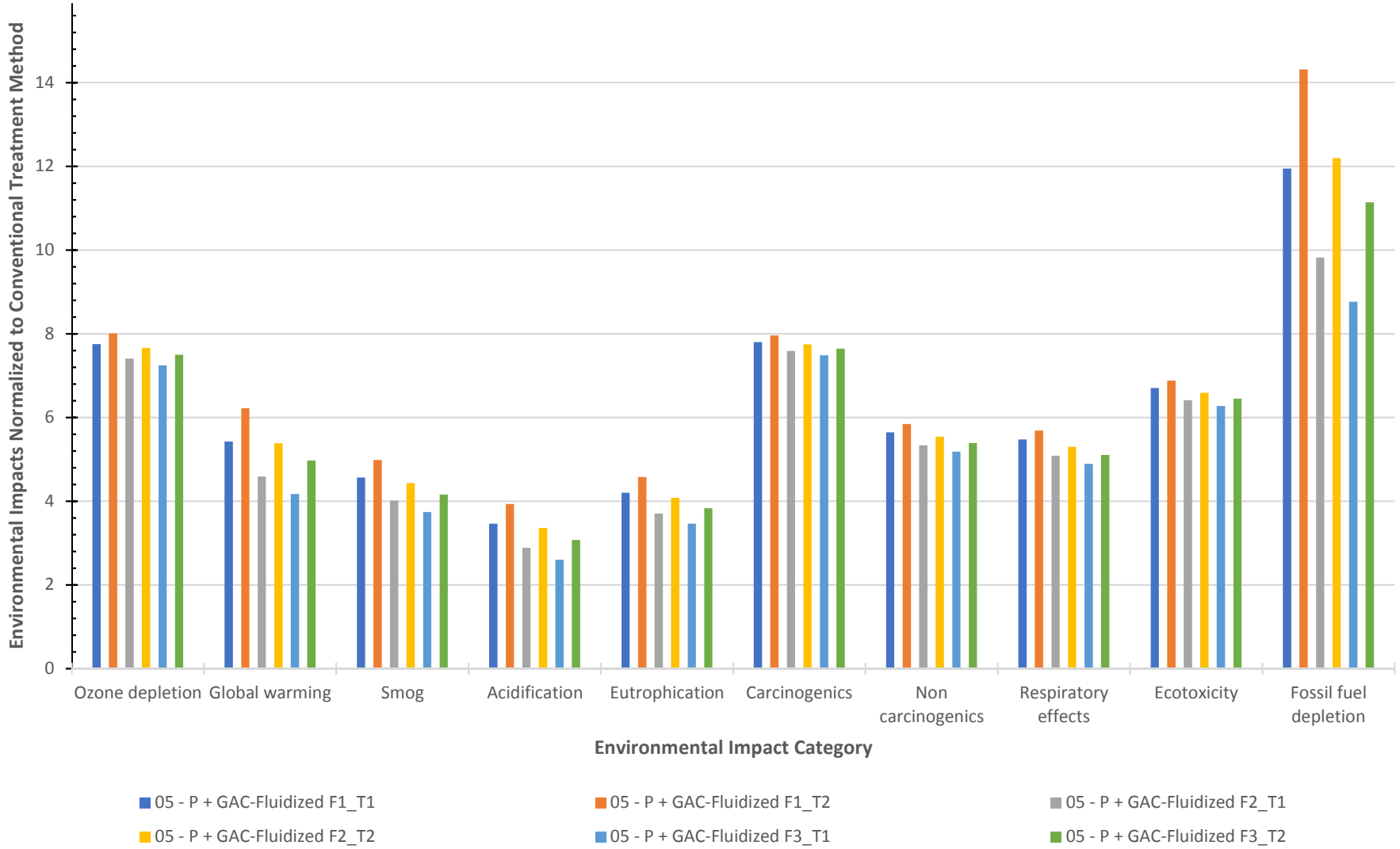
TRACI Normalized Impact Assesment for Scenario 5 – P + GAC-Fluidized

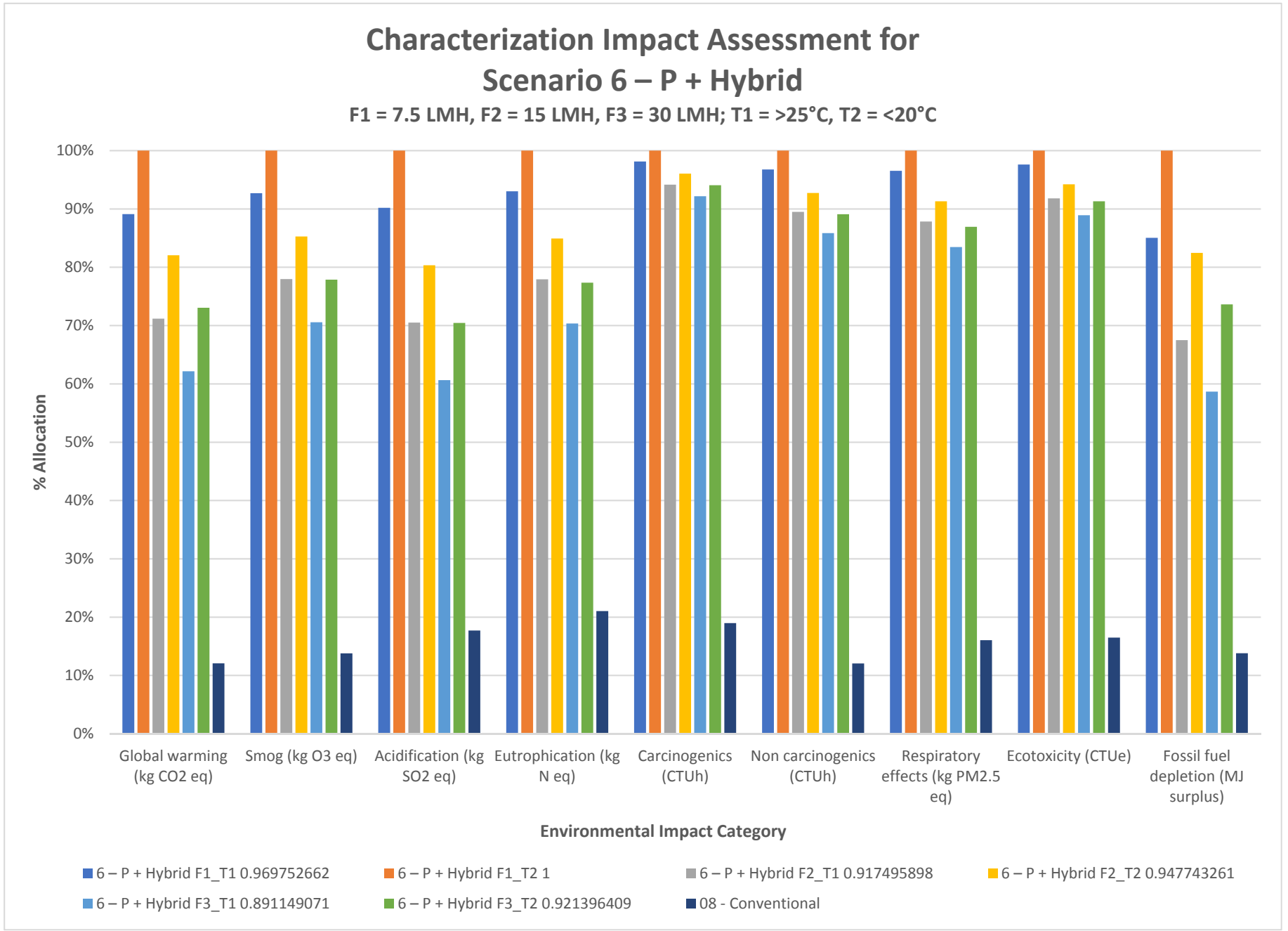
F1 = 7.5 LMH, F2 = 15 LMH, F3 = 30 LMH; TI = >25°C, T2 = <20°C



Impact Assesment Normalized to Conventional Treatment Method for Scenario 5 – P + GAC-Fluidized

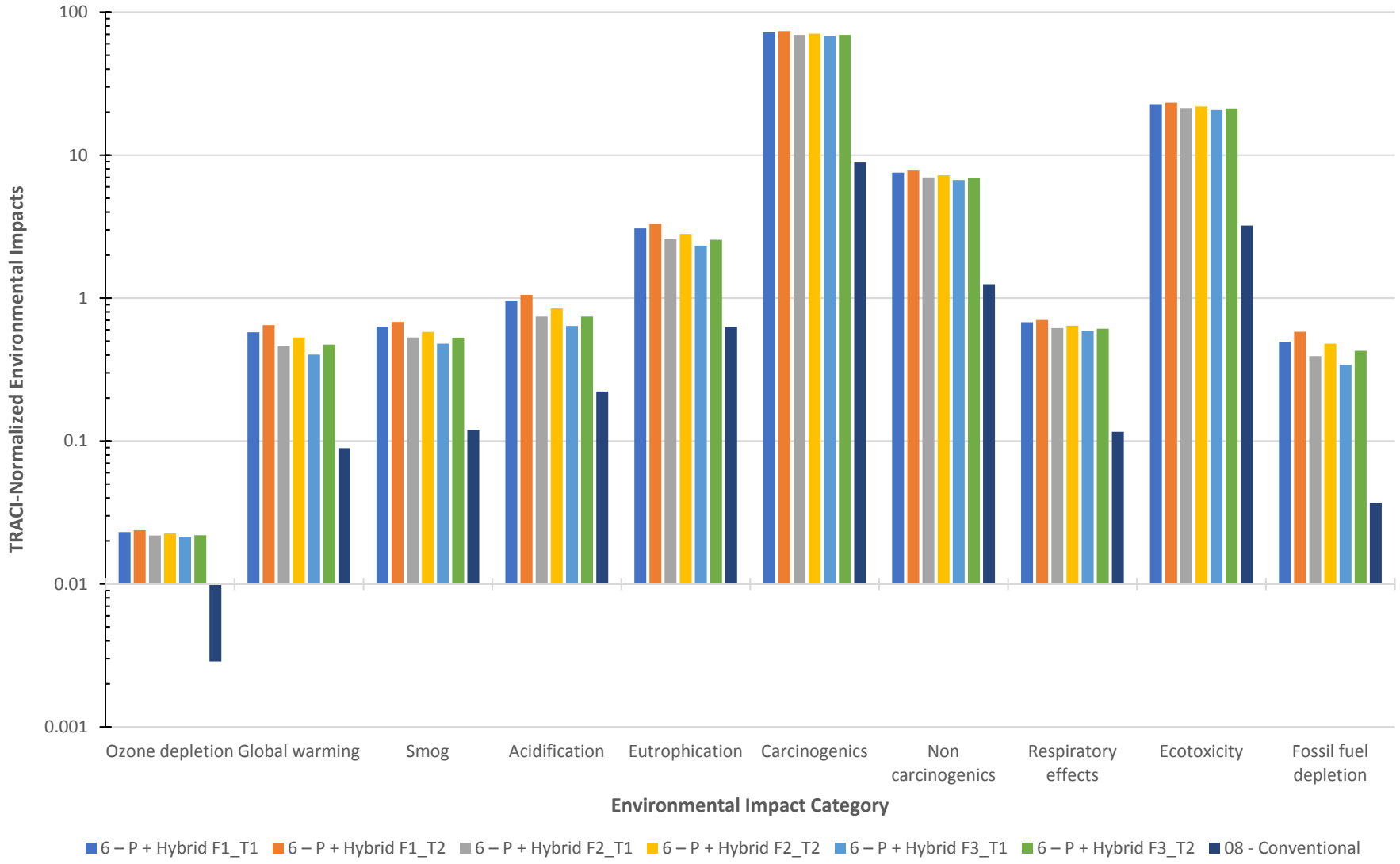
F1 = 7.5 LMH, F2 = 15 LMH, F3 = 30 LMH; TI = >25°C, T2 = <20°C




Characterization Impact Assessment for Scenario 6 – P + Hybrid
F1 = 7.5 LMH, F2 = 15 LMH, F3 = 30 LMH; T1 = >25°C, T2 = <20°C
% Allocation
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Global warming (kg CO2 eq)
Smog (kg O3 eq)
Acidification (kg SO2 eq)
Eutrophication (kg N eq)
Carcinogenics (CTUh)
Non carcinogenics (CTUh)
Respiratory effects (kg PM2.5 eq)
Ecotoxicity (CTUe)
Fossil fuel depletion (MJ surplus)
Environmental Impact Category
6 – P + Hybrid F1_T1 0.969752662
6 – P + Hybrid F1_T2 1
6 – P + Hybrid F2_T1 0.917495898
6 – P + Hybrid F2_T2 0.947743261
6 – P + Hybrid F3_T1 0.891149071
6 – P + Hybrid F3_T2 0.921396409
08 - Conventional

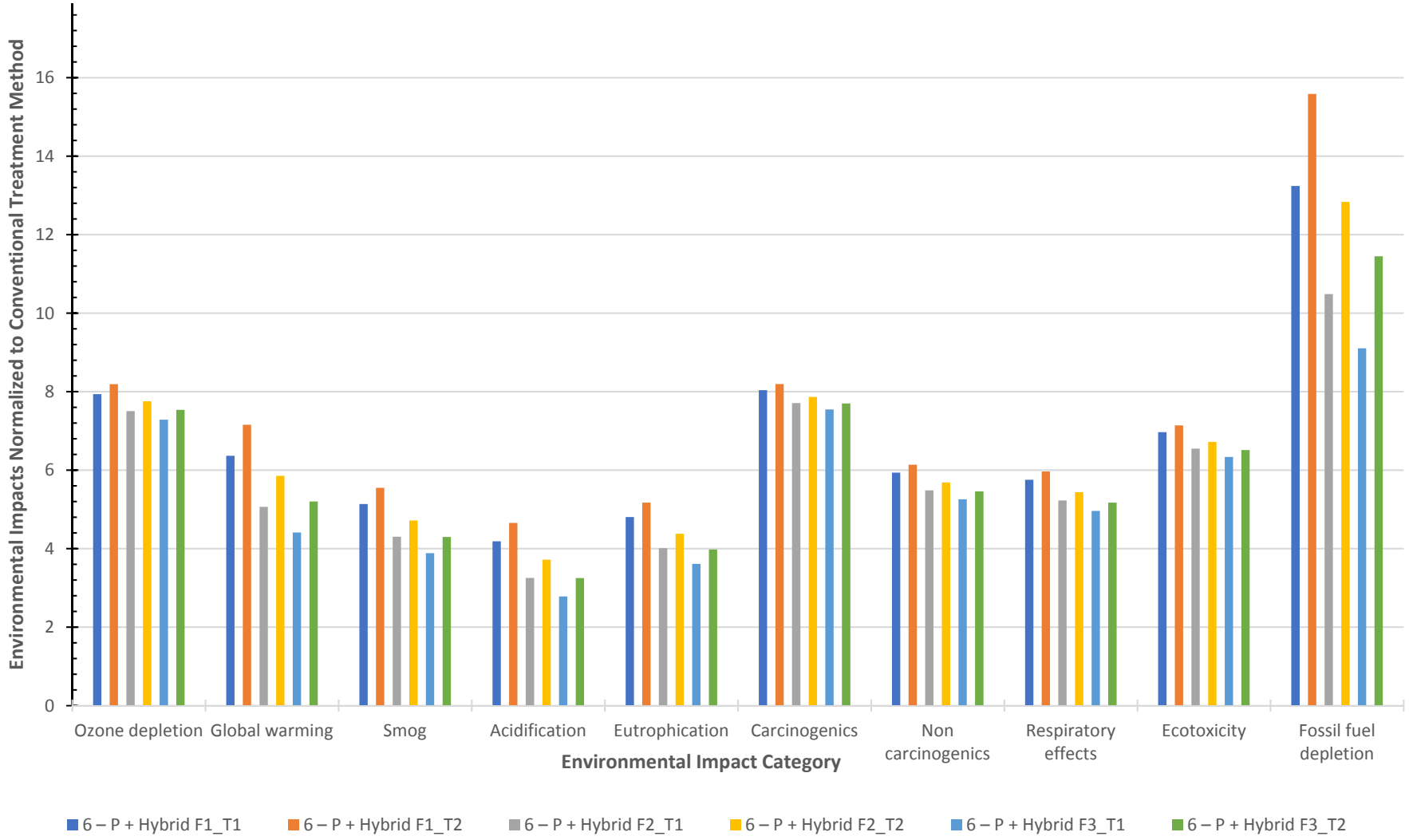
TRACI Normalized Impact Assesment for Scenario 6 – P + Hybrid

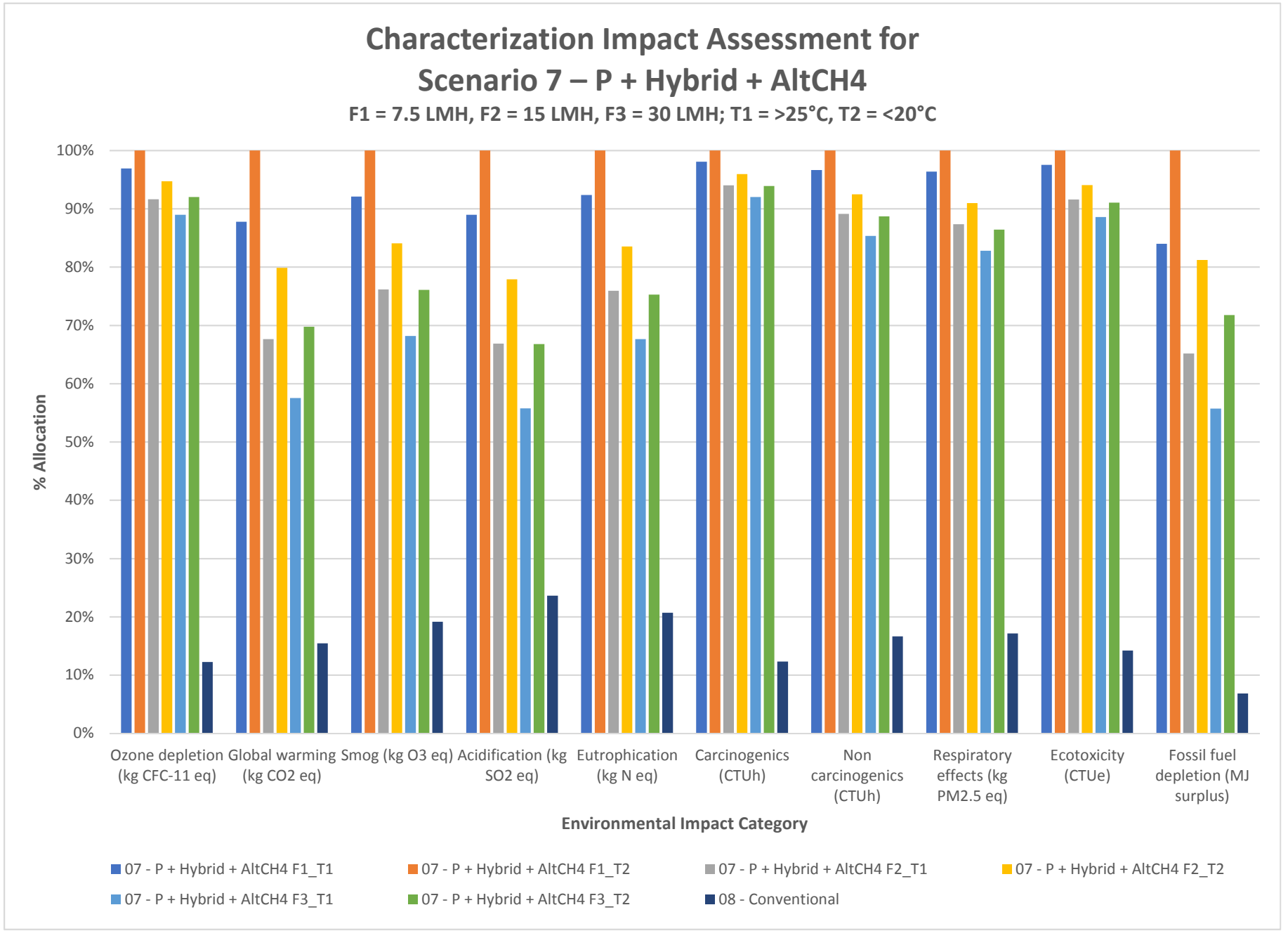
F1 = 7.5 LMH, F2 = 15 LMH, F3 = 30 LMH; TI = >25°C, T2 = <20°C

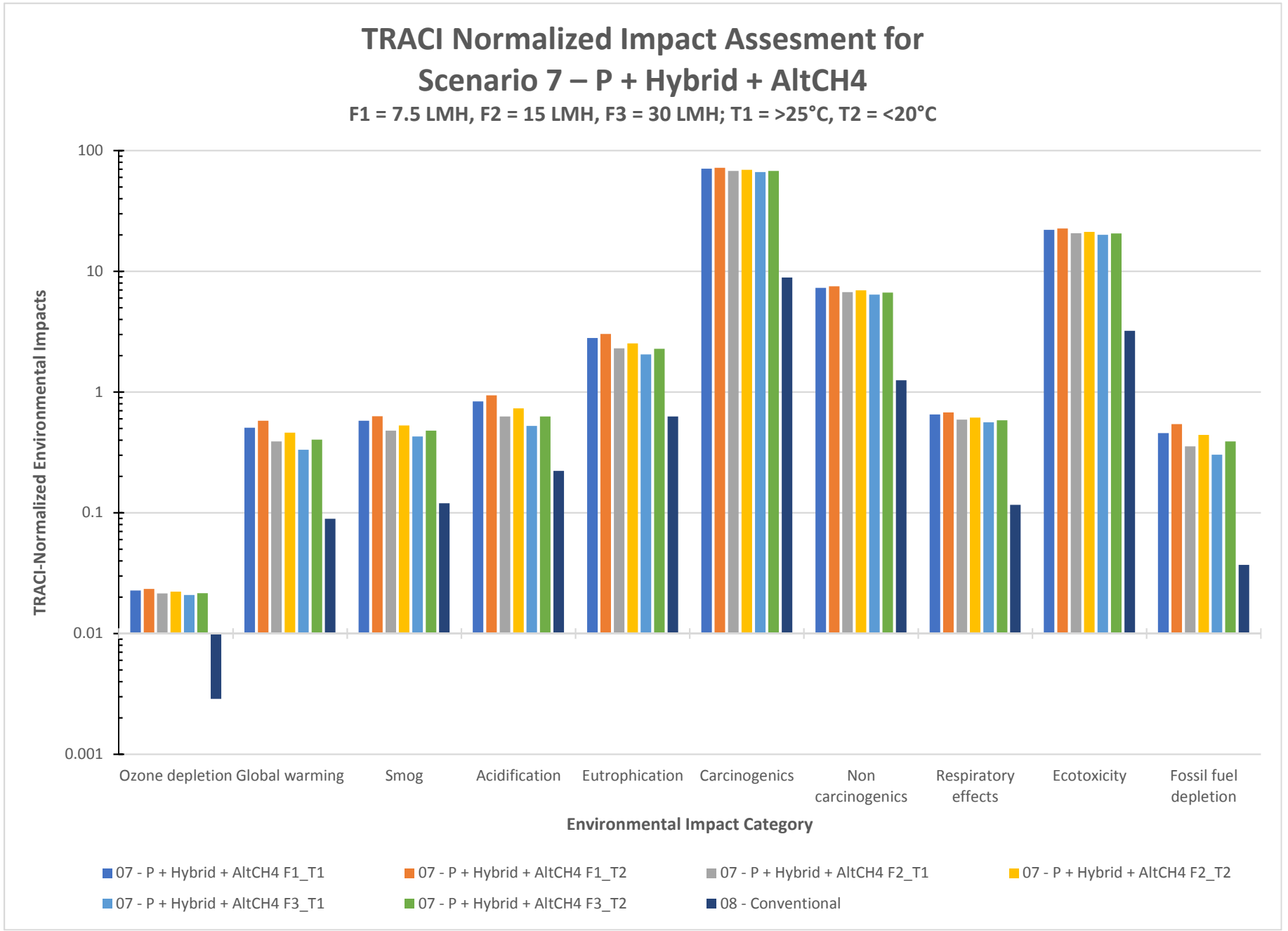


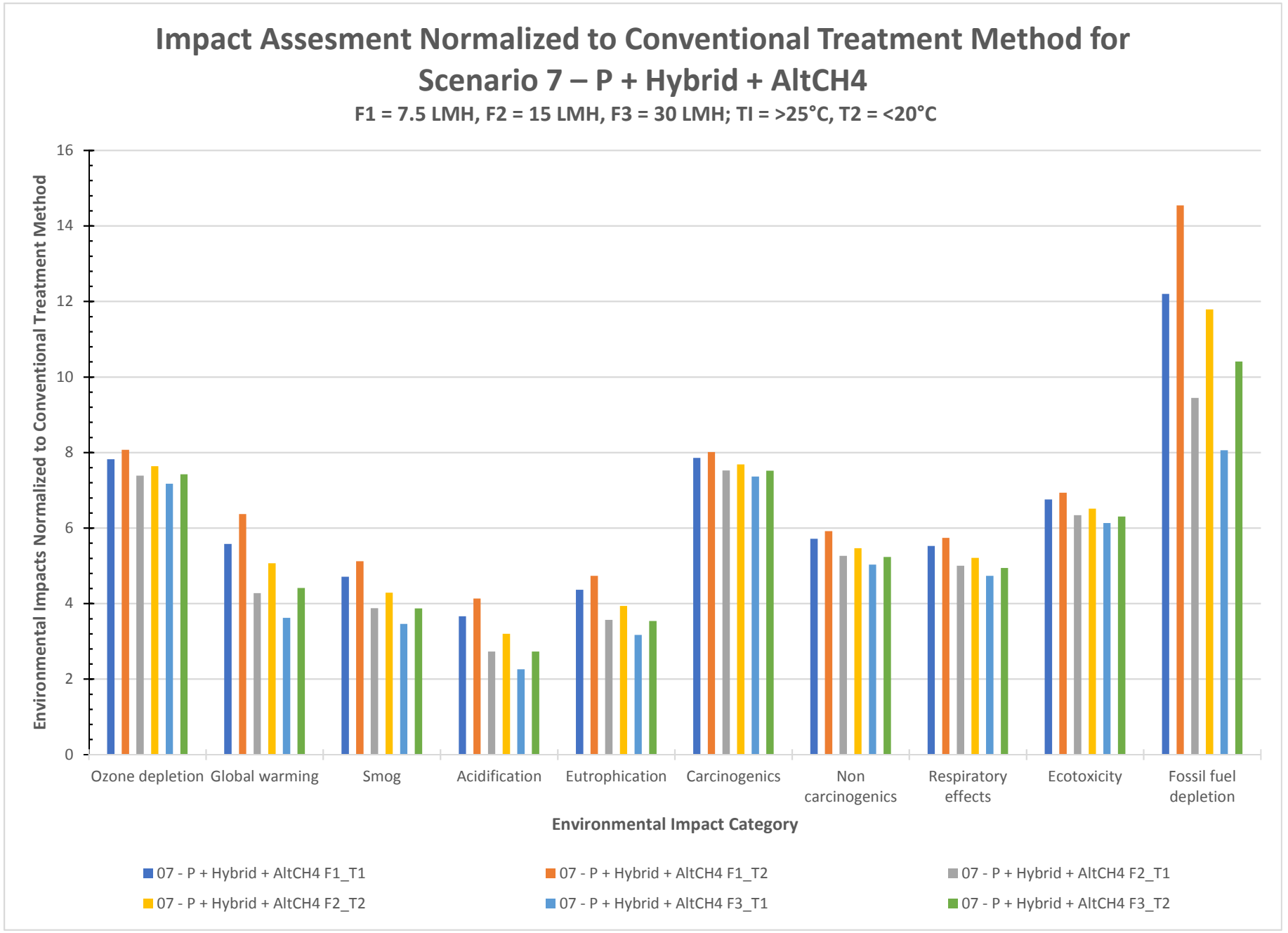
Impact Assesment Normalized to Conventional Treatment Method for Scenario 6 – P + Hybrid

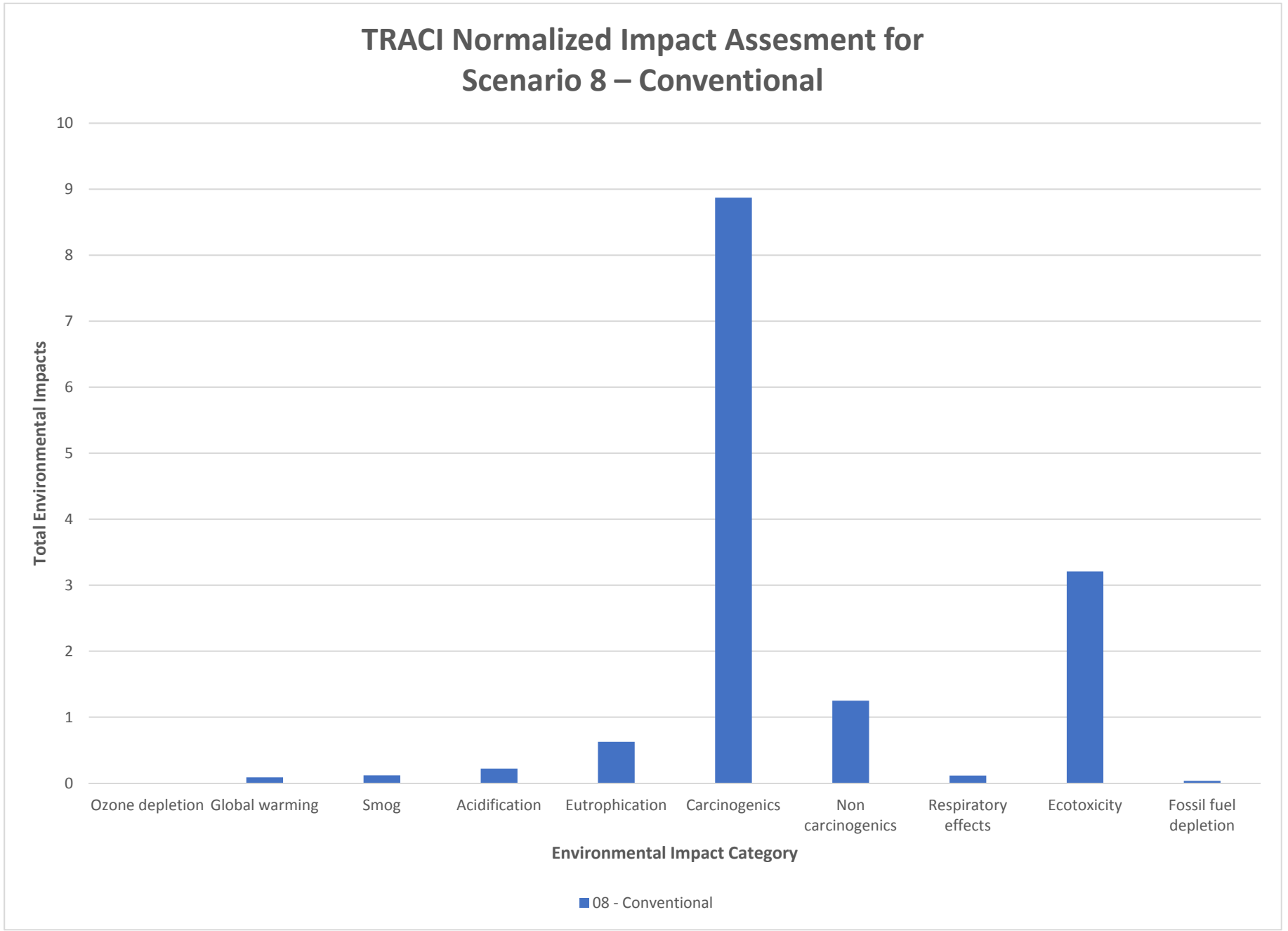
F1 = 7.5 LMH, F2 = 15 LMH, F3 = 30 LMH; TI = >25°C, T2 = <20°C




Characterization Impact Assessment for
Scenario 7 – P + Hybrid + AltCH4
F1 = 7.5 LMH, F2 = 15 LMH, F3 = 30 LMH; T1 = >25°C, T2 = <20°C
% Allocation
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Ozone depletion (kg CFC-11 eq)
Global warming (kg CO2 eq)
Smog (kg O3 eq)
Acidification (kg SO2 eq)
Eutrophication (kg N eq)
Carcinogenics (CTUh)
Non carcinogenics (CTUh)
Respiratory effects (kg PM2.5 eq)
Ecotoxicity (CTUe)
Fossil fuel depletion (MJ surplus)
Environmental Impact Category
07 - P + Hybrid + AltCH4 F1_T1
07 - P + Hybrid + AltCH4 F1_T2
07 - P + Hybrid + AltCH4 F2_T1
07 - P + Hybrid + AltCH4 F2_T2
07 - P + Hybrid + AltCH4 F3_T1
07 - P + Hybrid + AltCH4 F3_T2
08 - Conventional


TRACI Normalized Impact Assesment for
Scenario 7 – P + Hybrid + AltCH4
F1 = 7.5 LMH, F2 = 15 LMH, F3 = 30 LMH; T1 = >25°C, T2 = <20°C
TRACI-Normalized Environmental Impacts
100
10
1
0.1
0.01
0.001
Ozone depletion
Global warming
Smog
Acidification
Eutrophication
Carcinogenics
Non carcinogenics
Respiratory effects
Ecotoxicity
Fossil fuel depletion
Environmental Impact Category
07 - P + Hybrid + AltCH4 F1_T1
07 - P + Hybrid + AltCH4 F1_T2
07 - P + Hybrid + AltCH4 F2_T1
07 - P + Hybrid + AltCH4 F2_T2
07 - P + Hybrid + AltCH4 F3_T1
07 - P + Hybrid + AltCH4 F3_T2
08 - Conventional

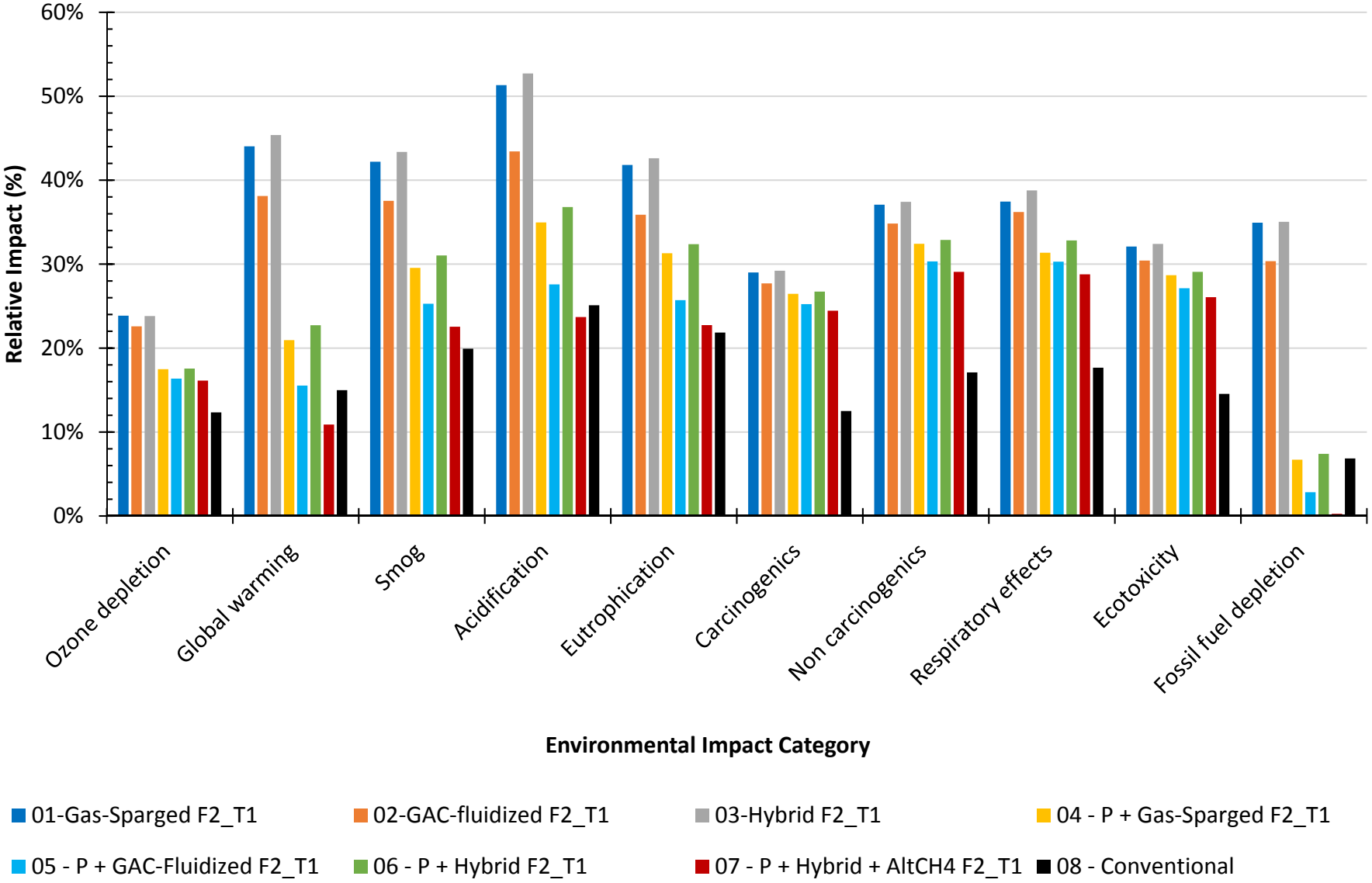

Impact Assesment Normalized to Conventional Treatment Method for Scenario 7 – P + Hybrid + AltCH4
F1 = 7.5 LMH, F2 = 15 LMH, F3 = 30 LMH; TI = >25°C, T2 = <20°C
Environmental Impacts Normalized to Conventional Treatment Method
16
14
12
10
8
6
4
2
0
Ozone depletion
Global warming
Smog
Acidification
Eutrophication
Carcinogenics
Non carcinogenics
Respiratory effects
Ecotoxicity
Fossil fuel depletion
Environmental Impact Category
07 - P + Hybrid + AltCH4 F1_T1
07 - P + Hybrid + AltCH4 F1_T2
07 - P + Hybrid + AltCH4 F2_T1
07 - P + Hybrid + AltCH4 F2_T2
07 - P + Hybrid + AltCH4 F3_T1
07 - P + Hybrid + AltCH4 F3_T2

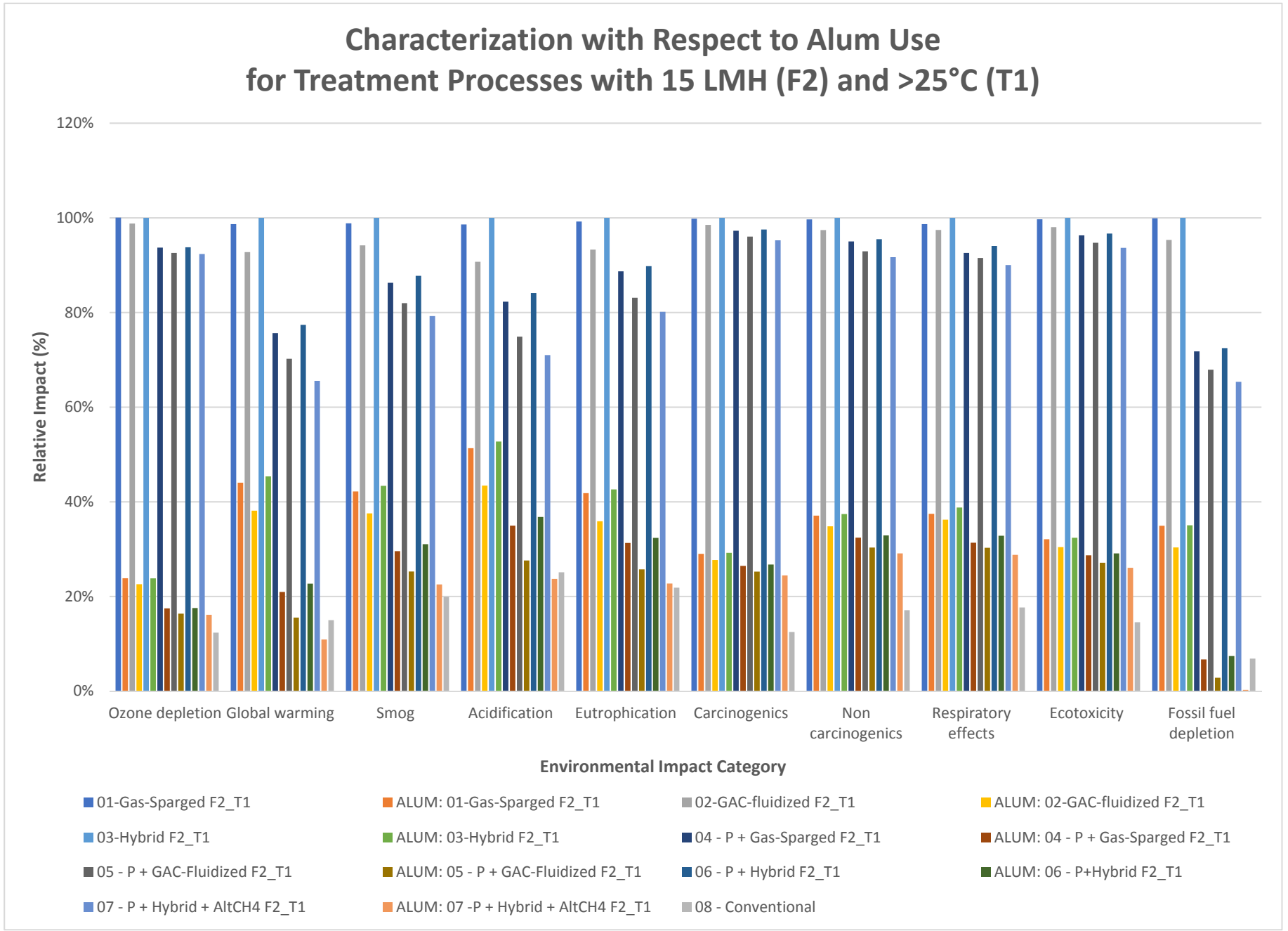

TRACI Normalized Impact Assesment for
Scenario 8 – Conventional
Total Environmental Impacts
10
9
8
7
6
5
4
3
2
1
0
Ozone depletion
Global warming
Smog
Acidification
Eutrophication
Carcinogenics
Non carcinogenics
Respiratory effects
Ecotoxicity
Fossil fuel depletion
Environmental Impact Category
08 - Conventional

Appendix H

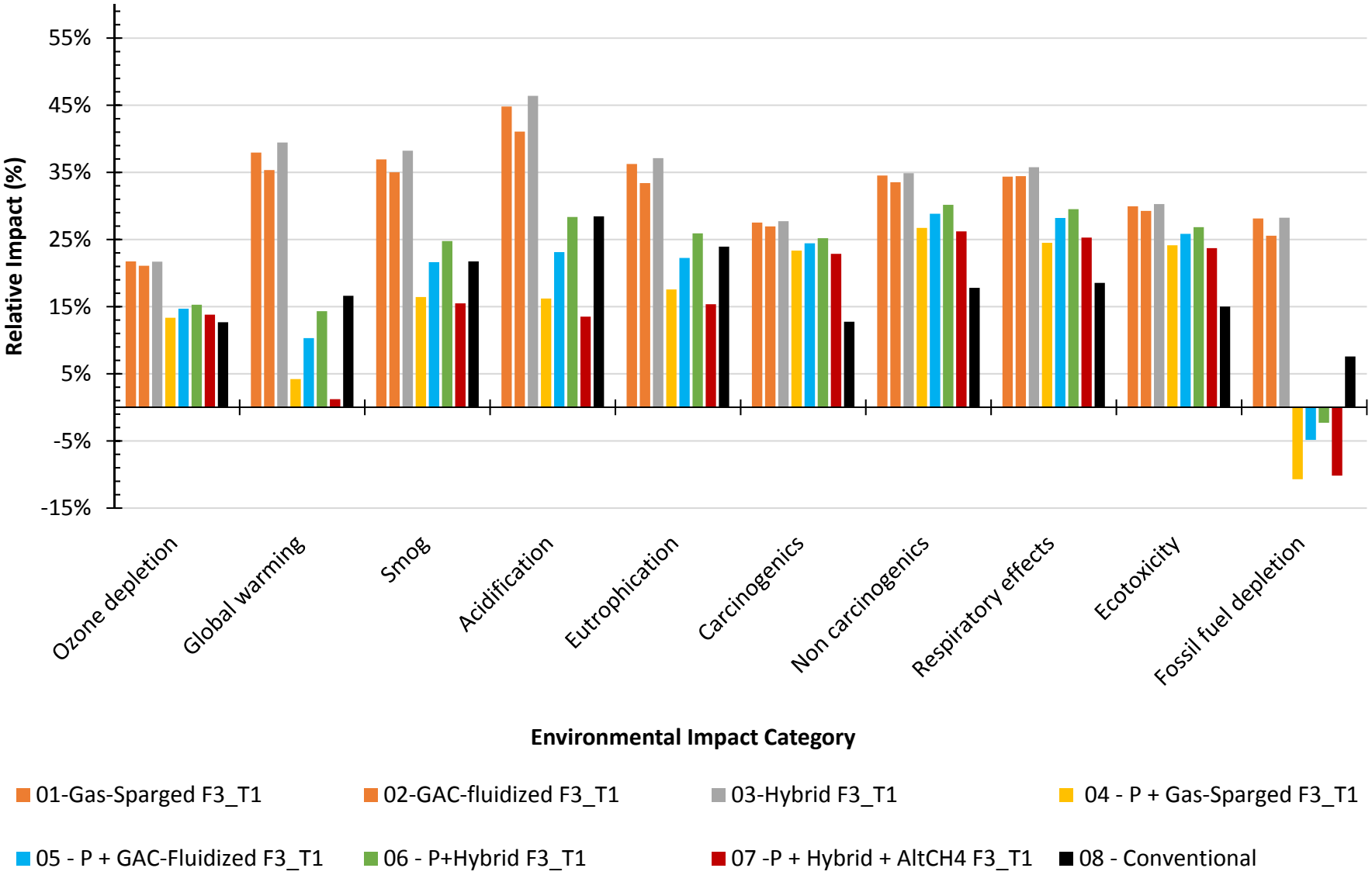
Characterization Environmental Impact Assessment Alum Sensitivity Analysis

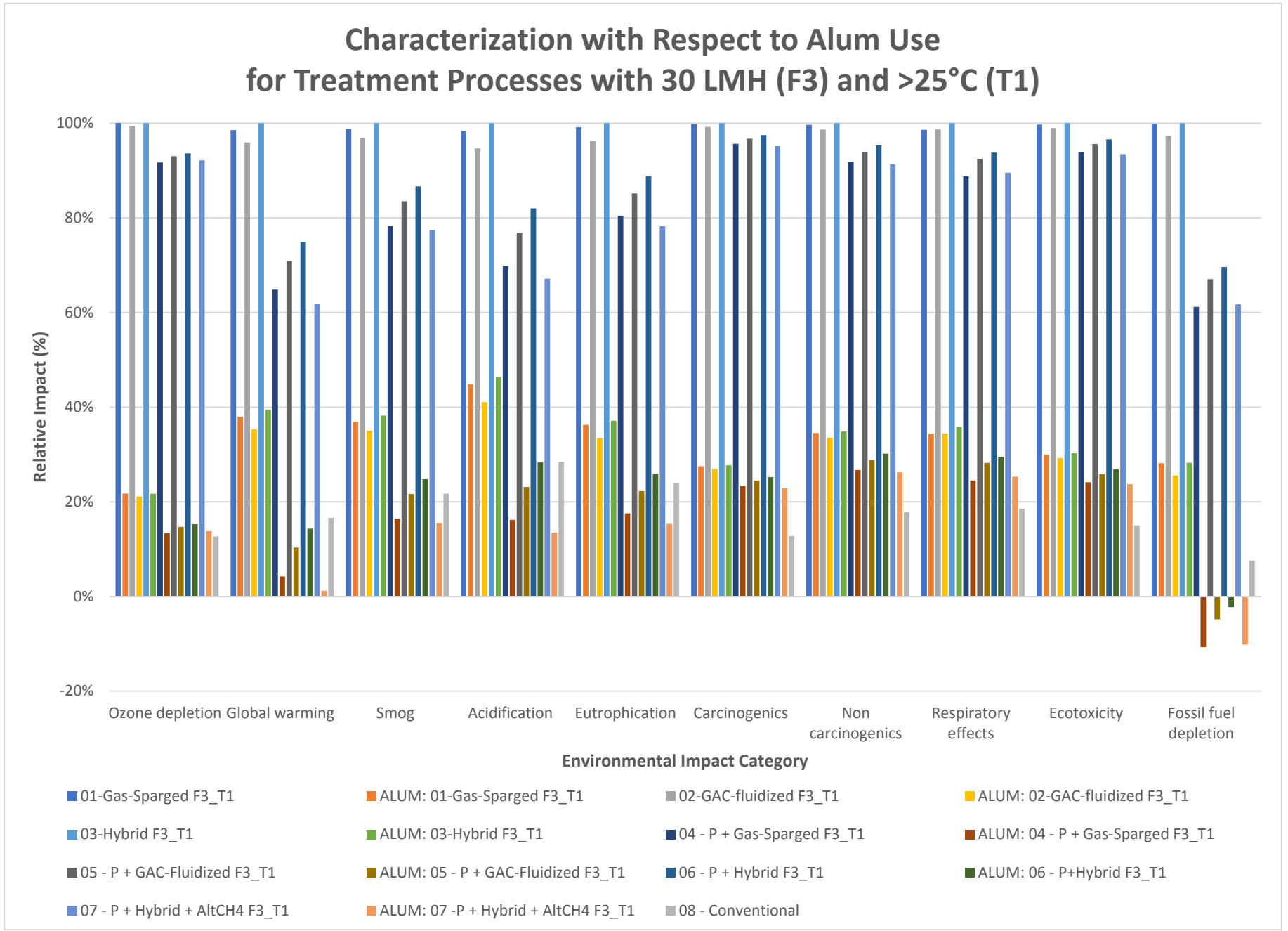
Characterization for Treatment Processes Using Alum for Sulfide and Phosphorus Removal with 15 LMH (F2) and >25°C (T1)




Characterization with Respect to Alum Use
for Treatment Processes with 15 LMH (F2) and >25°C (T1)
120%
100%
80%
60%
40%
20%
0%
Relative Impact (%)
Ozone depletion
Global warming
Smog
Acidification
Eutrophication
Carcinogenics
Non carcinogenics
Respiratory effects
Ecotoxicity
Fossil fuel depletion
Environmental Impact Category
01-Gas-Sparged F2_T1
ALUM: 01-Gas-Sparged F2_T1
02-GAC-fluidized F2_T1
ALUM: 02-GAC-fluidized F2_T1
03-Hybrid F2_T1
ALUM: 03-Hybrid F2_T1
04 - P + Gas-Sparged F2_T1
ALUM: 04 - P + Gas-Sparged F2_T1
05 - P + GAC-Fluidized F2_T1
ALUM: 05 - P + GAC-Fluidized F2_T1
06 - P + Hybrid F2_T1
ALUM: 06 - P+Hybrid F2_T1
07 - P + Hybrid + AltCH4 F2_T1
ALUM: 07 -P + Hybrid + AltCH4 F2_T1
08 - Conventional

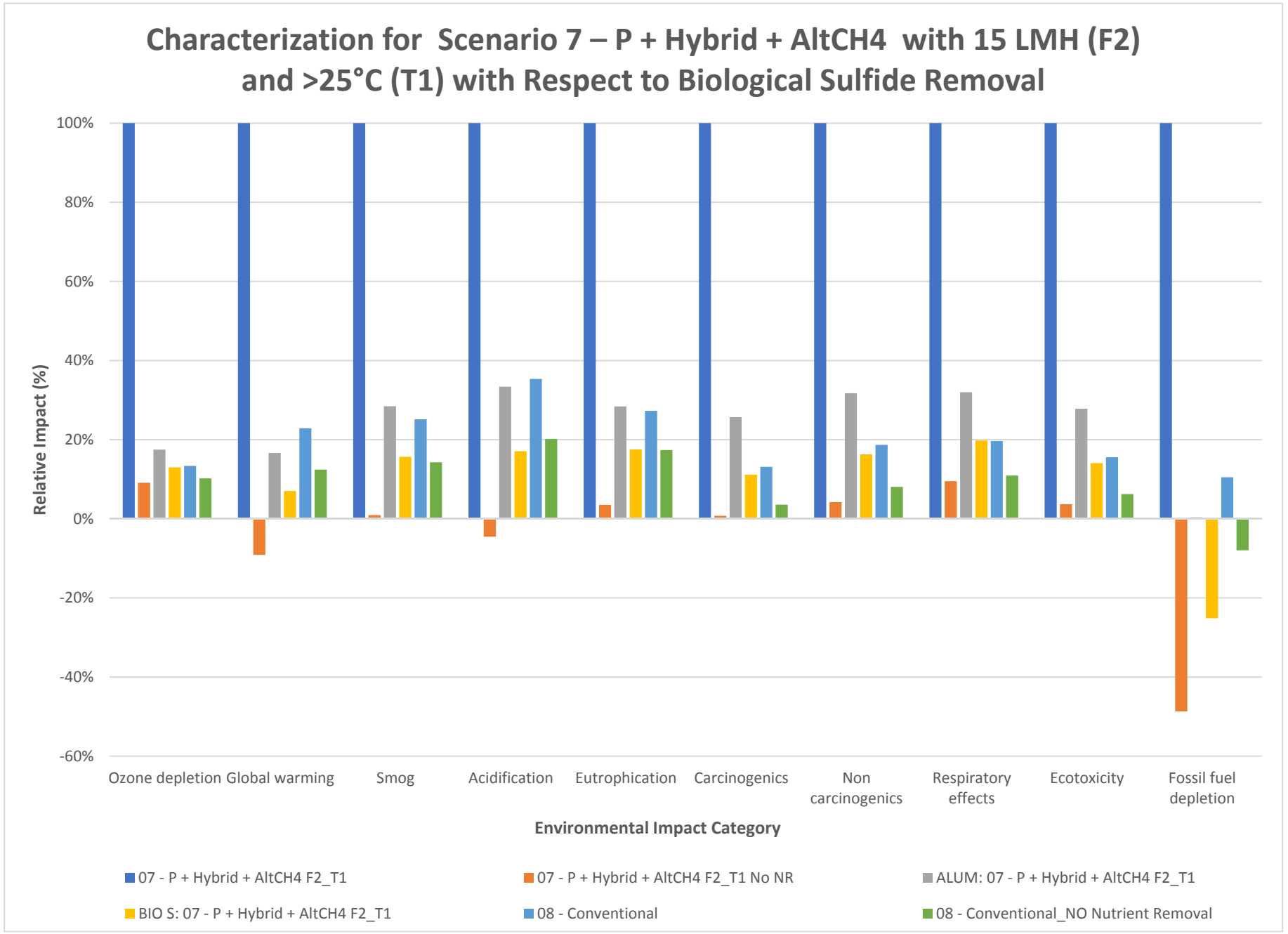
Characterization for Treatment Processes Using Alum for Sulfide and Phosphorus Removal with 30 LMH (F3) and >25°C (T1)




Characterization with Respect to Alum Use
for Treatment Processes with 30 LMH (F3) and >25°C (T1)
Relative Impact (%)
100%
80%
60%
40%
20%
0%
-20%
Ozone depletion
Global warming
Smog
Acidification
Eutrophication
Carcinogenics
Non carcinogenics
Respiratory effects
Ecotoxicity
Fossil fuel depletion
Environmental Impact Category
01-Gas-Sparged F3_T1
ALUM: 01-Gas-Sparged F3_T1
02-GAC-fluidized F3_T1
ALUM: 02-GAC-fluidized F3_T1
03-Hybrid F3_T1
ALUM: 03-Hybrid F3_T1
04 - P + Gas-Sparged F3_T1
ALUM: 04 - P + Gas-Sparged F3_T1
05 - P + GAC-Fluidized F3_T1
ALUM: 05 - P + GAC-Fluidized F3_T1
06 - P + Hybrid F3_T1
ALUM: 06 - P+Hybrid F3_T1
07 - P + Hybrid + AltCH4 F3_T1
ALUM: 07 -P + Hybrid + AltCH4 F3_T1
08 - Conventional

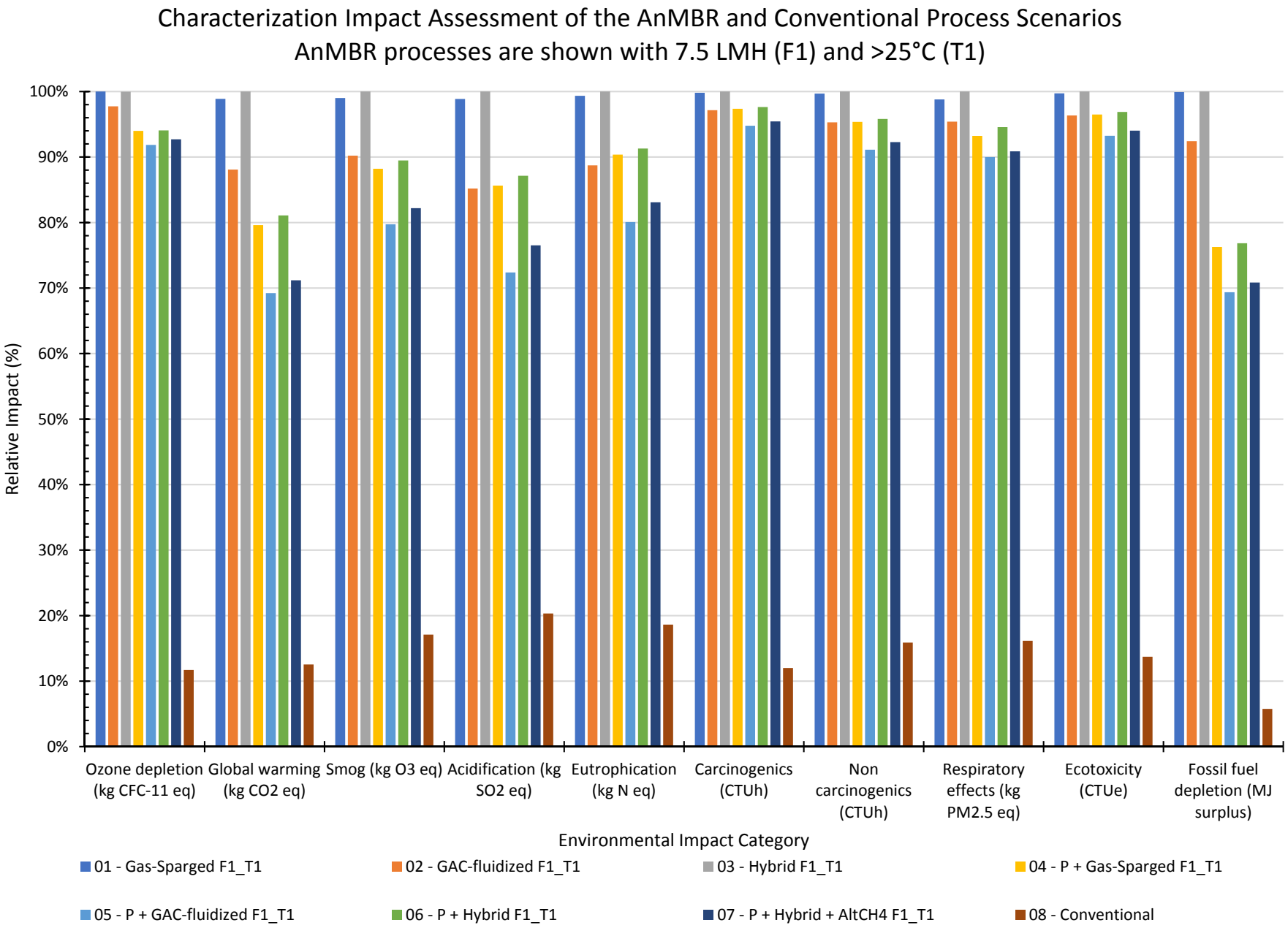
Appendix H

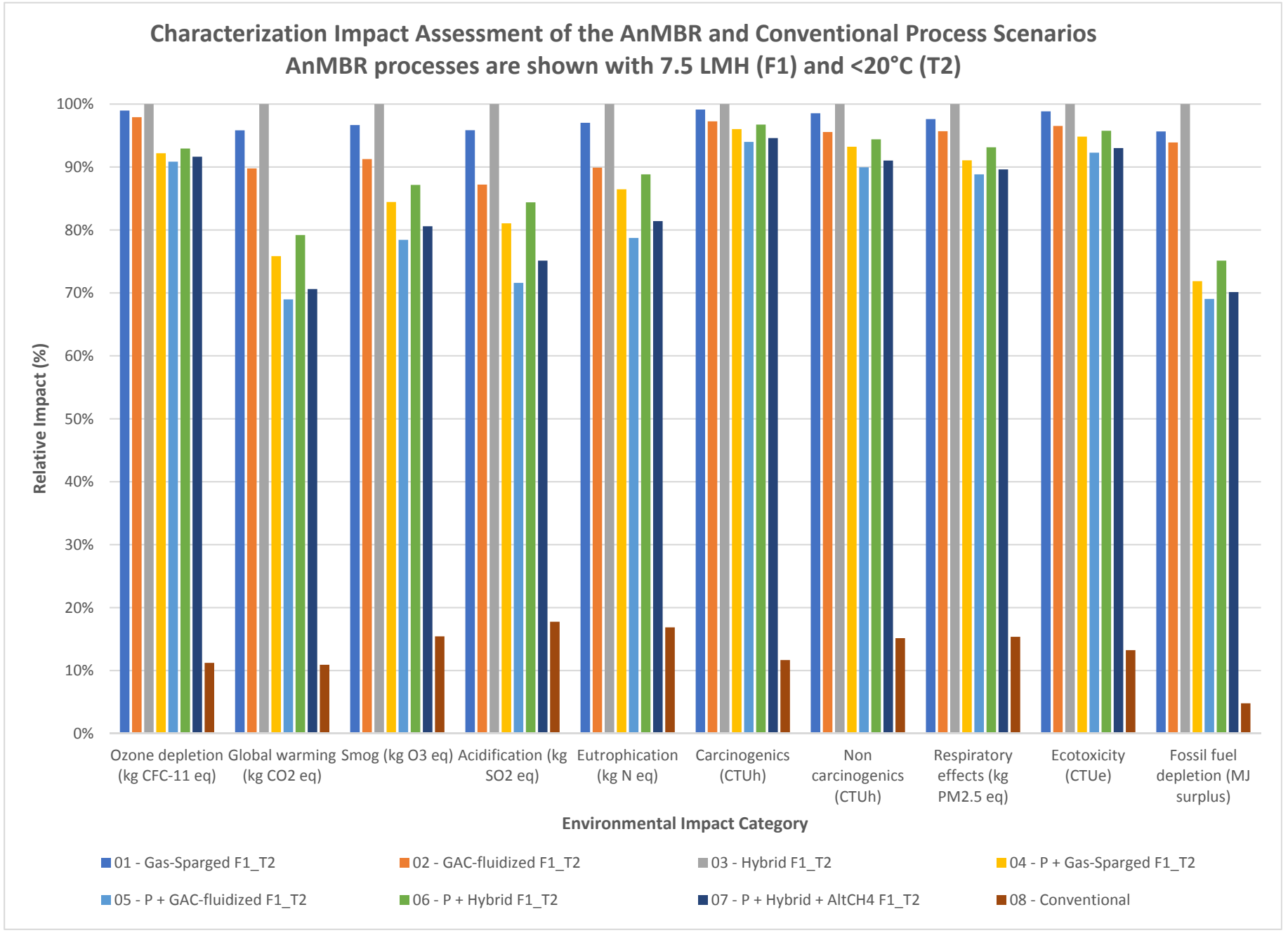
Characterization Environmental Impact Assessment Biological Sulfide Removal Sensitivity Analysis

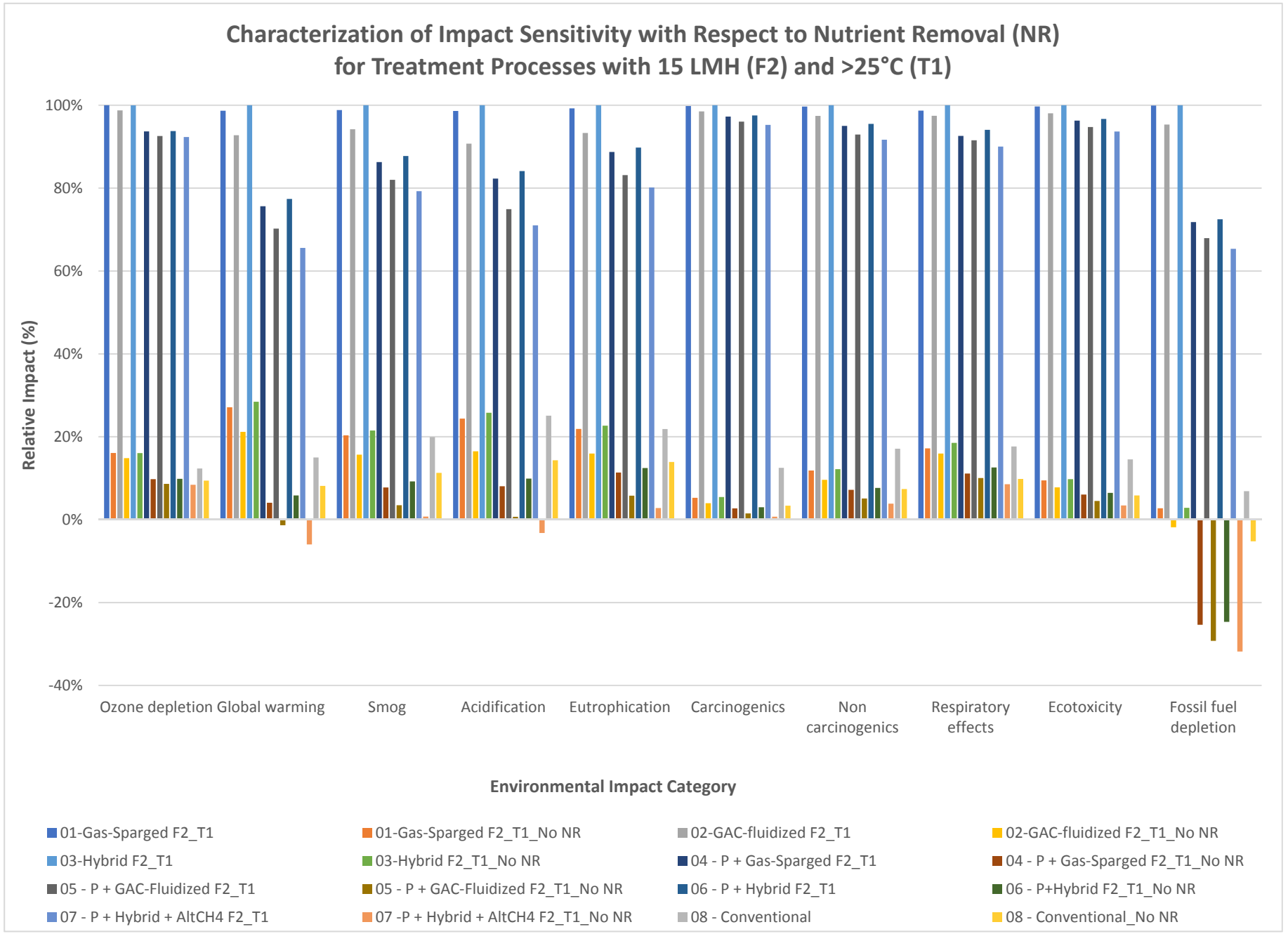

Characterization for Scenario 7 – P + Hybrid + AltCH4 with 15 LMH (F2) and >25°C (T1) with Respect to Biological Sulfide Removal
Relative Impact (%)
100%
80%
60%
40%
20%
0%
-20%
-40%
-60%
Ozone depletion
Global warming
Smog
Acidification
Eutrophication
Carcinogenics
Non carcinogenics
Respiratory effects
Ecotoxicity
Fossil fuel depletion
Environmental Impact Category
07 - P + Hybrid + AltCH4 F2_T1
07 - P + Hybrid + AltCH4 F2_T1 No NR
ALUM: 07 - P + Hybrid + AltCH4 F2_T1
BIO S: 07 - P + Hybrid + AltCH4 F2_T1
08 - Conventional
08 - Conventional_NO Nutrient Removal

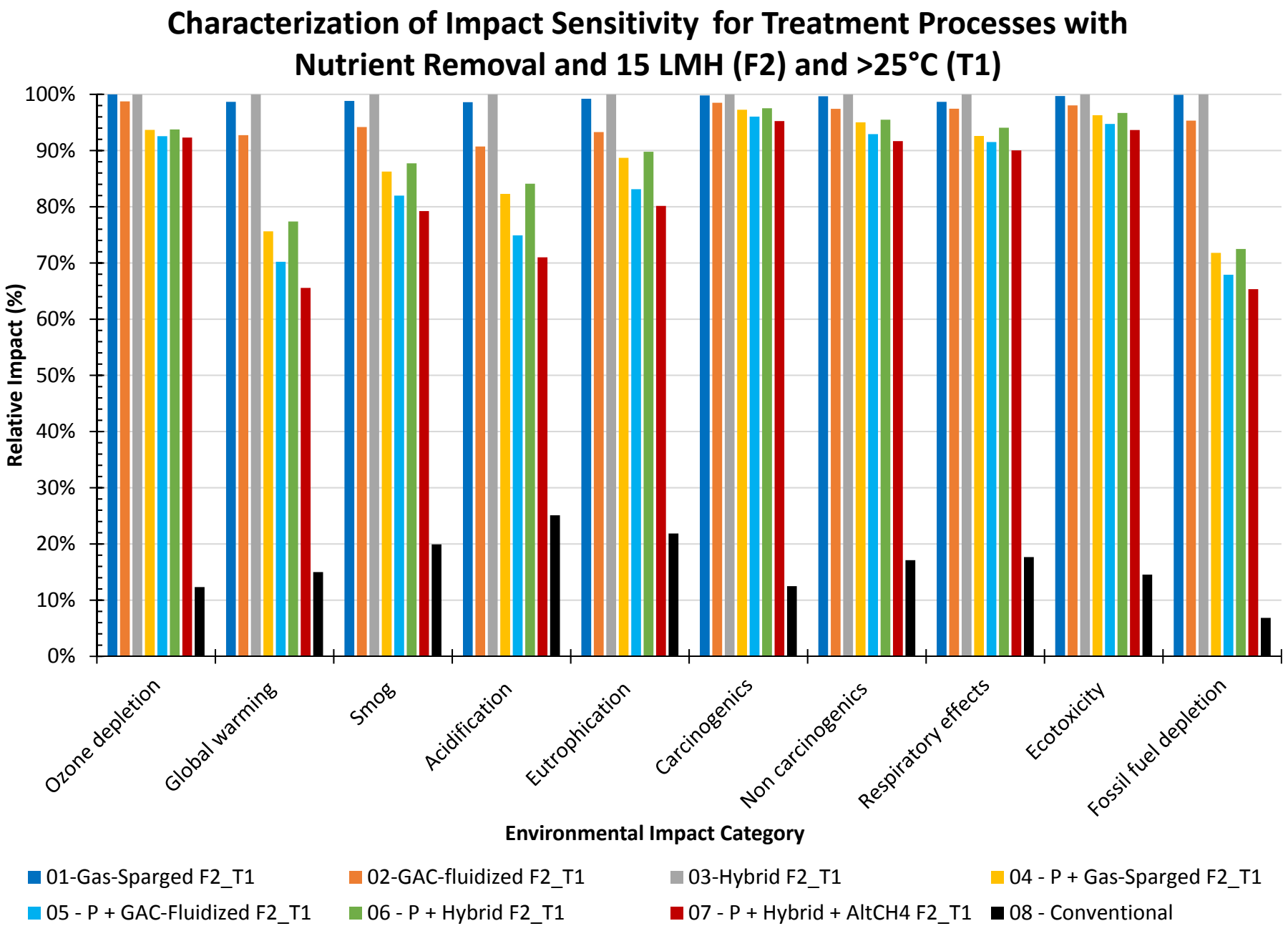
Appendix H

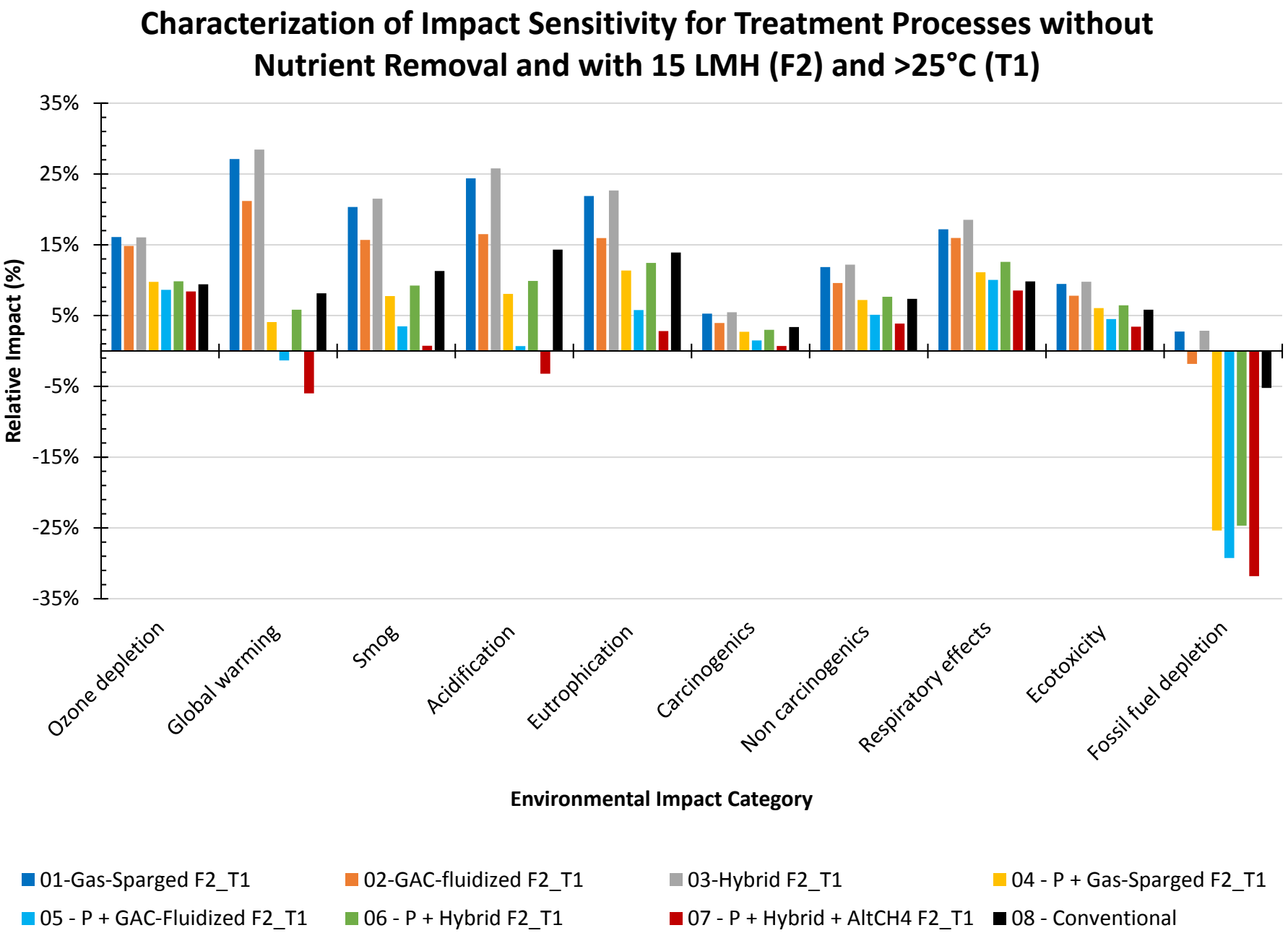
Characterization Environmental Impact Assessment Comparing Treatment Processes for Each Flux and Temperature Scenario, Including Nutrient Removal Sensitivity Analysis

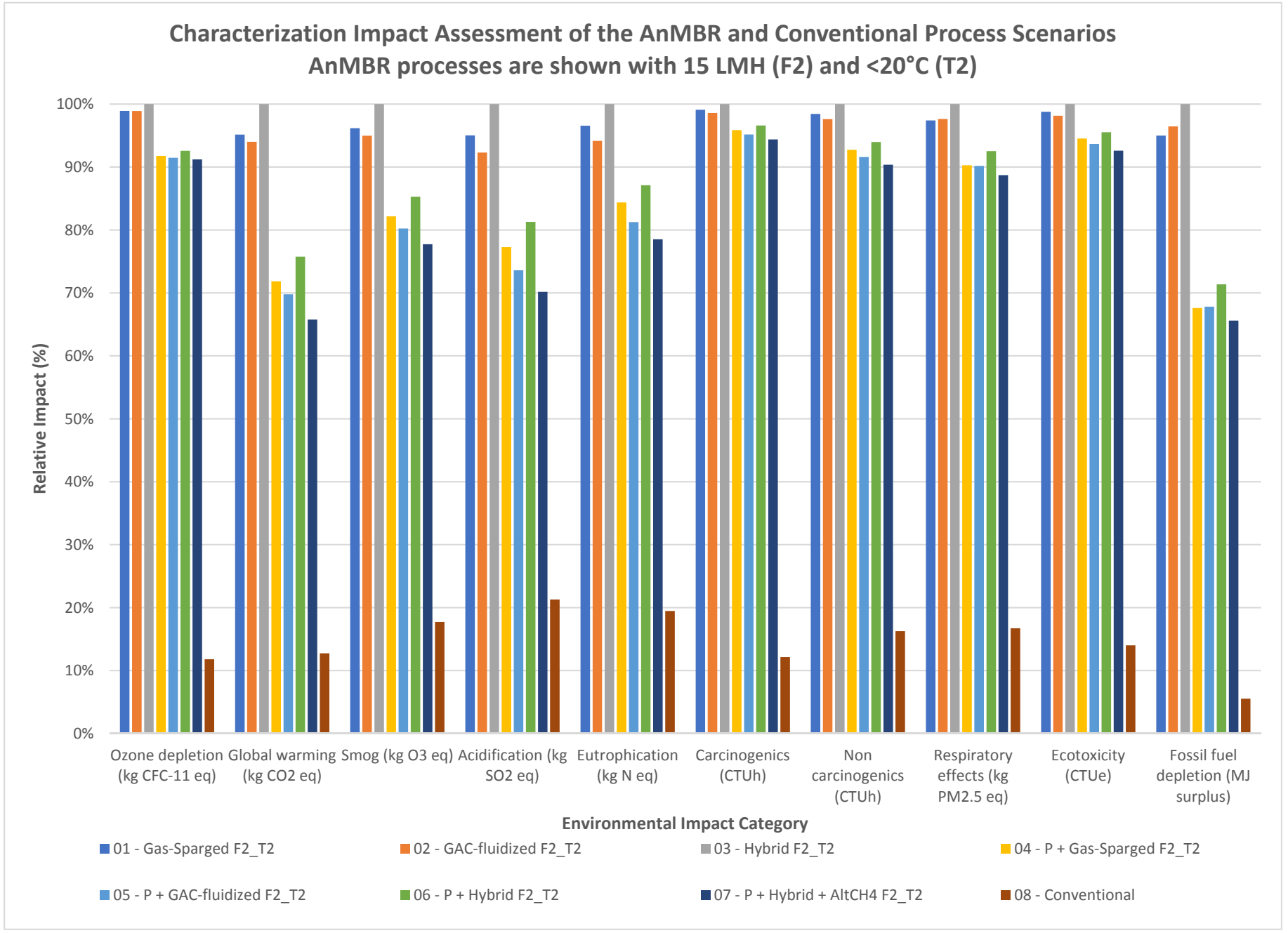

Characterization Impact Assessment of the AnMBR and Conventional Process Scenarios
AnMBR processes are shown with 7.5 LMH (F1) and >25°C (T1)
Relative Impact (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Ozone depletion (kg CFC-11 eq)
Global warming (kg CO2 eq)
Smog (kg O3 eq)
Acidification (kg SO2 eq)
Eutrophication (kg N eq)
Carcinogenics (CTUh)
Non carcinogenics (CTUh)
Respiratory effects (kg PM2.5 eq)
Ecotoxicity (CTUe)
Fossil fuel depletion (MJ surplus)
Environmental Impact Category
01 - Gas-Sparged F1_T1
02 - GAC-fluidized F1_T1
03 - Hybrid F1_T1
04 - P + Gas-Sparged F1_T1
05 - P + GAC-fluidized F1_T1
06 - P + Hybrid F1_T1
07 - P + Hybrid + AltCH4 F1_T1
08 - Conventional

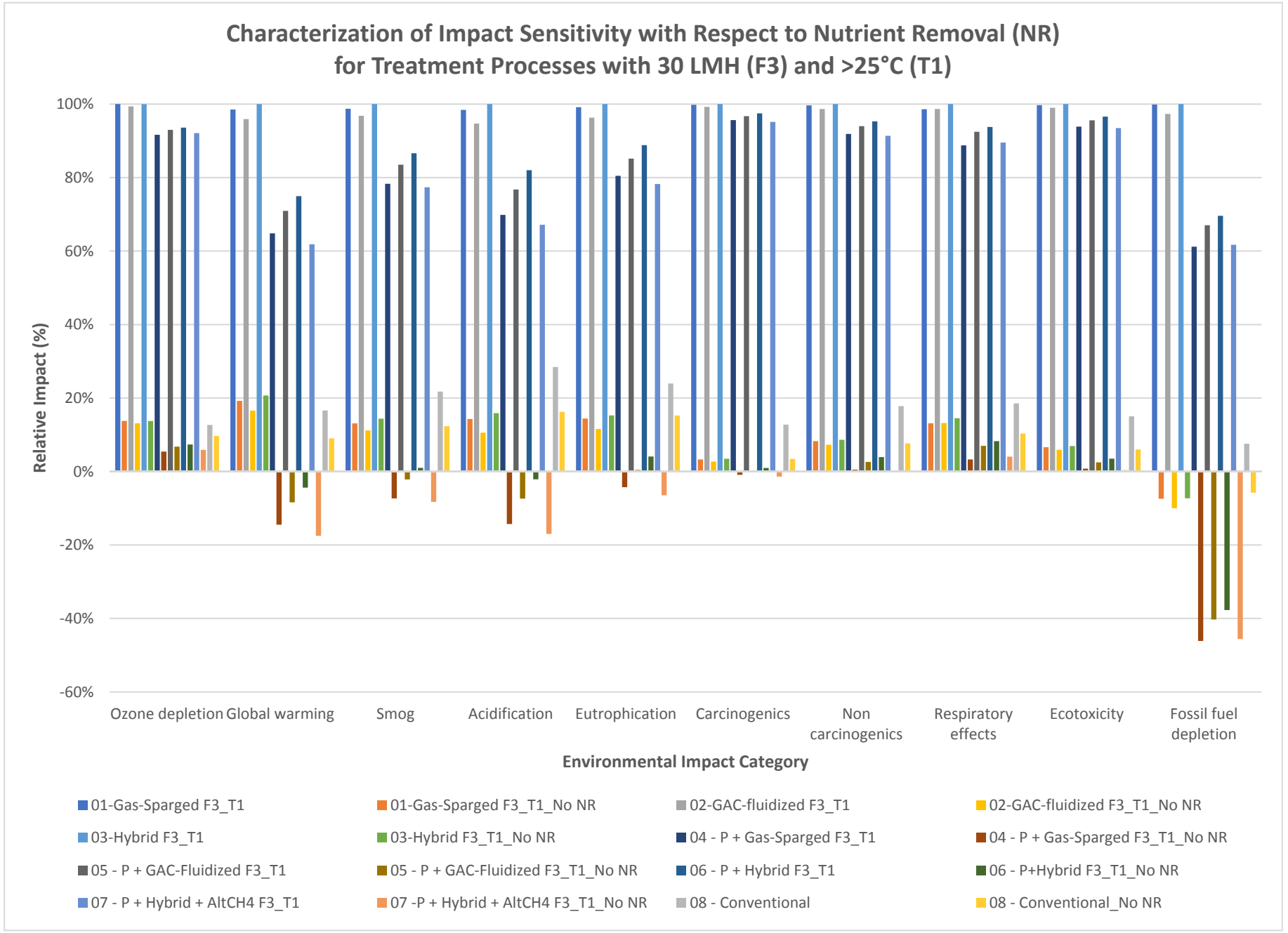

Characterization Impact Assessment of the AnMBR and Conventional Process Scenarios
AnMBR processes are shown with 7.5 LMH (F1) and <20°C (T2)
Relative Impact (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Ozone depletion (kg CFC-11 eq)
Global warming (kg CO2 eq)
Smog (kg O3 eq)
Acidification (kg SO2 eq)
Eutrophication (kg N eq)
Carcinogenics (CTUh)
Non carcinogenics (CTUh)
Respiratory effects (kg PM2.5 eq)
Ecotoxicity (CTUe)
Fossil fuel depletion (MJ surplus)
Environmental Impact Category
01 - Gas-Sparged F1_T2
02 - GAC-fluidized F1_T2
03 - Hybrid F1_T2
04 - P + Gas-Sparged F1_T2
05 - P + GAC-fluidized F1_T2
06 - P + Hybrid F1_T2
07 - P + Hybrid + AltCH4 F1_T2
08 - Conventional

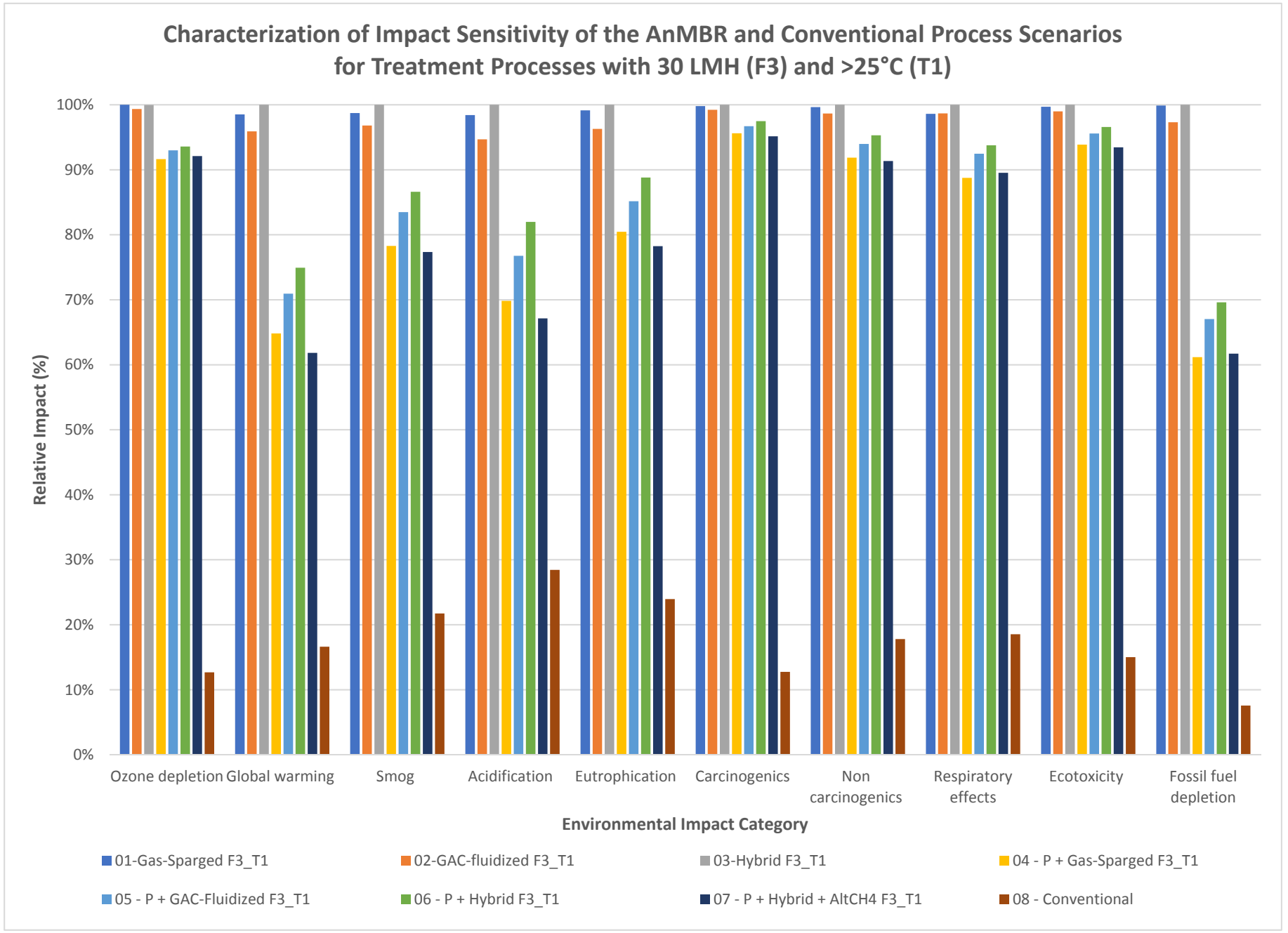

Characterization of Impact Sensitivity with Respect to Nutrient Removal (NR)
for Treatment Processes with 15 LMH (F2) and >25°C (T1)
Relative Impact (%)
100%
80%
60%
40%
20%
0%
-20%
-40%
Ozone depletion
Global warming
Smog
Acidification
Eutrophication
Carcinogenics
Non carcinogenics
Respiratory effects
Ecotoxicity
Fossil fuel depletion
Environmental Impact Category
01-Gas-Sparged F2_T1
01-Gas-Sparged F2_T1_No NR
02-GAC-fluidized F2_T1
02-GAC-fluidized F2_T1_No NR
03-Hybrid F2_T1
03-Hybrid F2_T1_No NR
04 - P + Gas-Sparged F2_T1
04 - P + Gas-Sparged F2_T1_No NR
05 - P + GAC-Fluidized F2_T1
05 - P + GAC-Fluidized F2_T1_No NR
06 - P + Hybrid F2_T1
06 - P+Hybrid F2_T1_No NR
07 - P + Hybrid + AltCH4 F2_T1
07 -P + Hybrid + AltCH4 F2_T1_No NR
08 - Conventional
08 - Conventional_No NR

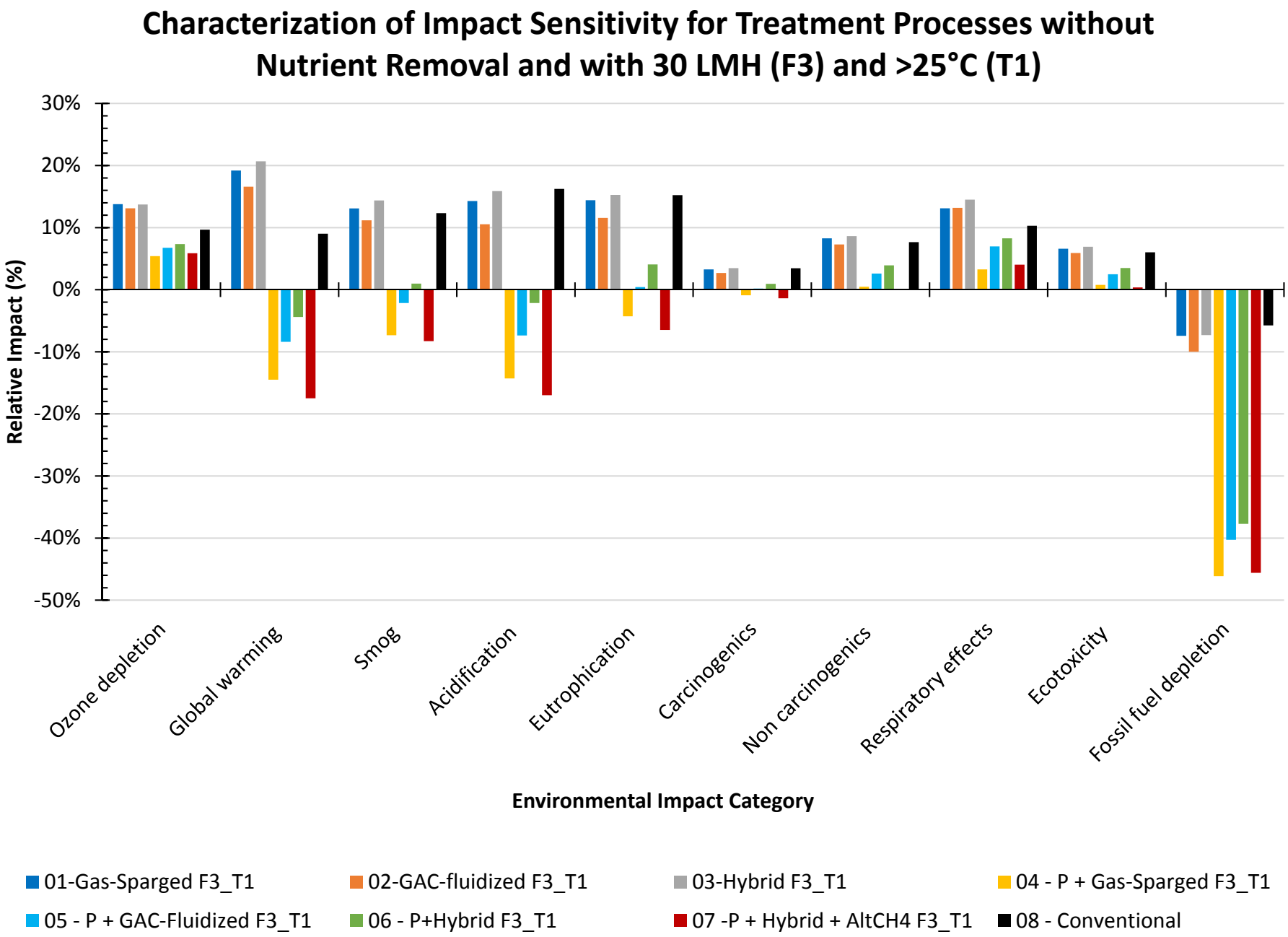

Characterization of Impact Sensitivity for Treatment Processes with Nutrient Removal and 15 LMH (F2) and >25°C (T1)
Relative Impact (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Ozone depletion
Global warming
Smog
Acidification
Eutrophication
Carcinogenics
Non carcinogenics
Respiratory effects
Ecotoxicity
Fossil fuel depletion
Environmental Impact Category
01-Gas-Sparged F2_T1
02-GAC-fluidized F2_T1
03-Hybrid F2_T1
04 - P + Gas-Sparged F2_T1
05 - P + GAC-Fluidized F2_T1
06 - P + Hybrid F2_T1
07 - P + Hybrid + AltCH4 F2_T1
08 - Conventional

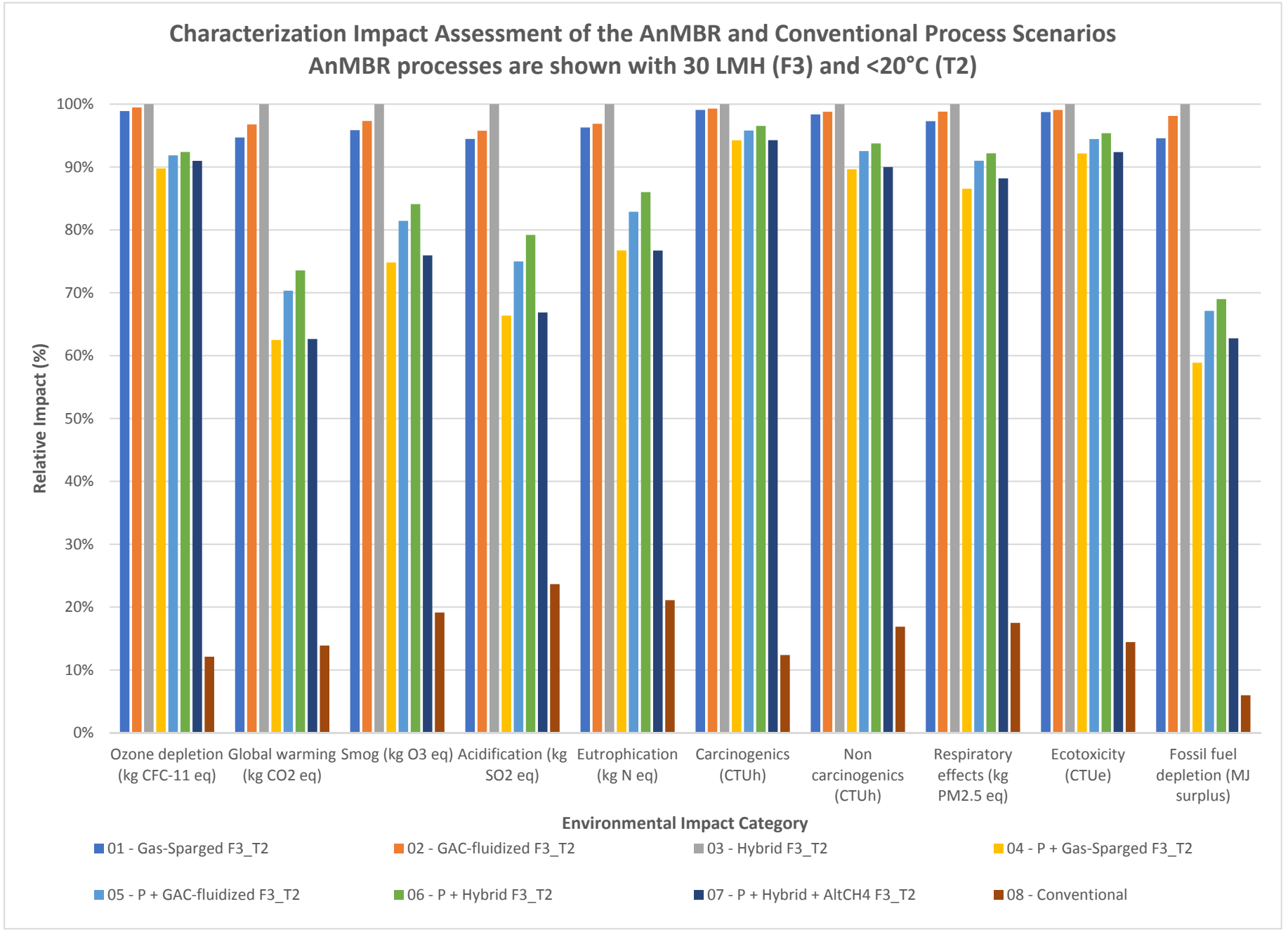

Characterization of Impact Sensitivity for Treatment Processes without Nutrient Removal and with 15 LMH (F2) and >25°C (T1)
Relative Impact (%)
35%
25%
15%
5%
-5%
-15%
-25%
-35%
Ozone depletion
Global warming
Smog
Acidification
Eutrophication
Carcinogenics
Non carcinogenics
Respiratory effects
Ecotoxicity
Fossil fuel depletion
Environmental Impact Category
01-Gas-Sparged F2_T1
02-GAC-fluidized F2_T1
03-Hybrid F2_T1
04 - P + Gas-Sparged F2_T1
05 - P + GAC-Fluidized F2_T1
06 - P + Hybrid F2_T1
07 - P + Hybrid + AltCH4 F2_T1
08 - Conventional


Characterization Impact Assessment of the AnMBR and Conventional Process Scenarios
AnMBR processes are shown with 15 LMH (F2) and <20°C (T2)
Relative Impact (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Ozone depletion (kg CFC-11 eq)
Global warming (kg CO2 eq)
Smog (kg O3 eq)
Acidification (kg SO2 eq)
Eutrophication (kg N eq)
Carcinogenics (CTUh)
Non carcinogenics (CTUh)
Respiratory effects (kg PM2.5 eq)
Ecotoxicity (CTUe)
Fossil fuel depletion (MJ surplus)
Environmental Impact Category
01 - Gas-Sparged F2_T2
02 - GAC-fluidized F2_T2
03 - Hybrid F2_T2
04 - P + Gas-Sparged F2_T2
05 - P + GAC-fluidized F2_T2
06 - P + Hybrid F2_T2
07 - P + Hybrid + AltCH4 F2_T2
08 - Conventional


Characterization of Impact Sensitivity with Respect to Nutrient Removal (NR)
for Treatment Processes with 30 LMH (F3) and >25°C (T1)
Relative Impact (%)
100%
80%
60%
40%
20%
0%
-20%
-40%
-60%
Ozone depletion
Global warming
Smog
Acidification
Eutrophication
Carcinogenics
Non carcinogenics
Respiratory effects
Ecotoxicity
Fossil fuel depletion
Environmental Impact Category
01-Gas-Sparged F3_T1
01-Gas-Sparged F3_T1_No NR
02-GAC-fluidized F3_T1
02-GAC-fluidized F3_T1_No NR
03-Hybrid F3_T1
03-Hybrid F3_T1_No NR
04 - P + Gas-Sparged F3_T1
04 - P + Gas-Sparged F3_T1_No NR
05 - P + GAC-Fluidized F3_T1
05 - P + GAC-Fluidized F3_T1_No NR
06 - P + Hybrid F3_T1
06 - P+Hybrid F3_T1_No NR
07 - P + Hybrid + AltCH4 F3_T1
07 -P + Hybrid + AltCH4 F3_T1_No NR
08 - Conventional
08 - Conventional_No NR


Characterization of Impact Sensitivity of the AnMBR and Conventional Process Scenarios for Treatment Processes with 30 LMH (F3) and >25°C (T1)
Relative Impact (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Ozone depletion
Global warming
Smog
Acidification
Eutrophication
Carcinogenics
Non carcinogenics
Respiratory effects
Ecotoxicity
Fossil fuel depletion
Environmental Impact Category
01-Gas-Sparged F3_T1
02-GAC-fluidized F3_T1
03-Hybrid F3_T1
04 - P + Gas-Sparged F3_T1
05 - P + GAC-Fluidized F3_T1
06 - P + Hybrid F3_T1
07 - P + Hybrid + AltCH4 F3_T1
08 - Conventional

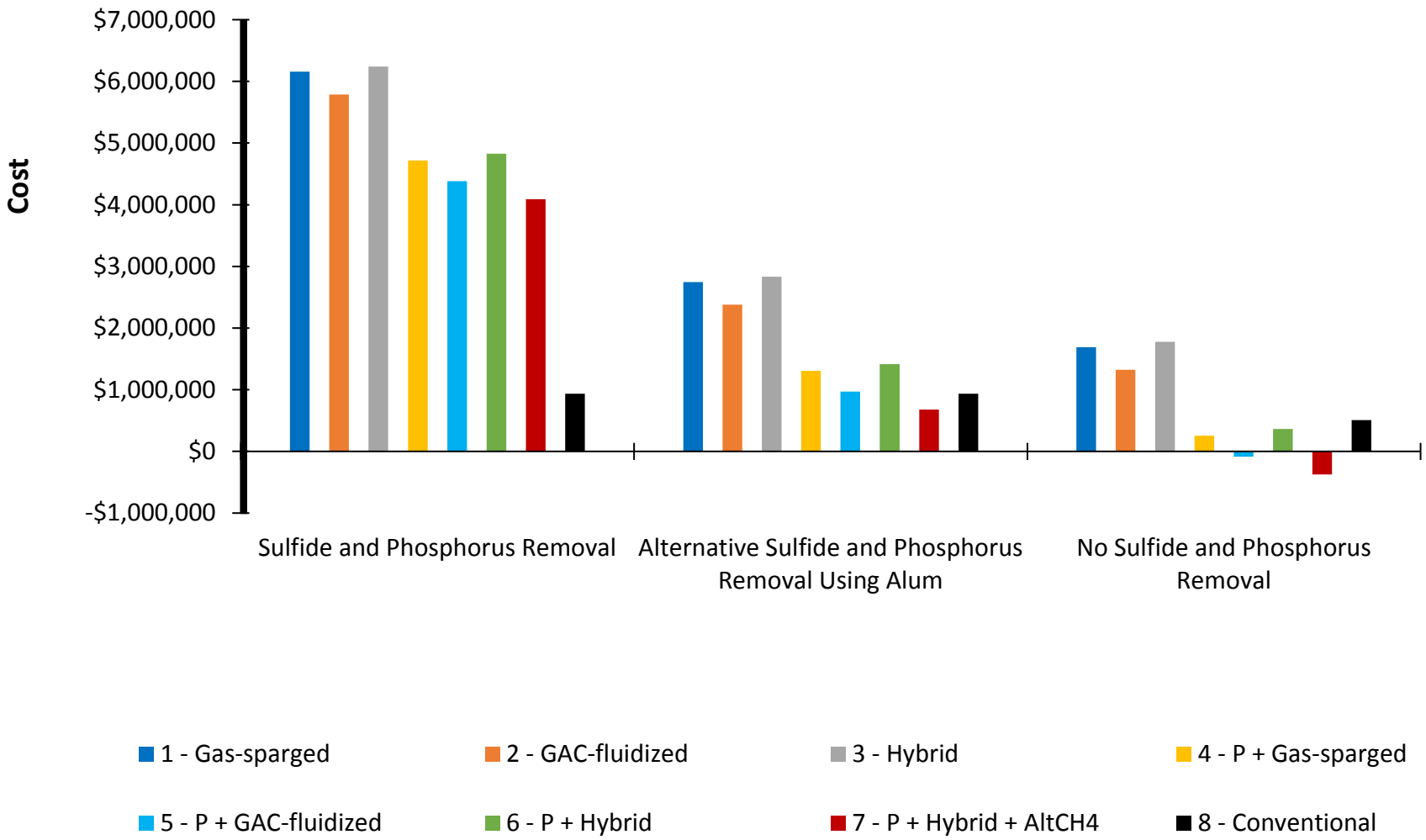

Characterization of Impact Sensitivity for Treatment Processes without Nutrient Removal and with 30 LMH (F3) and >25°C (T1)
Relative Impact (%)
30%
20%
10%
0%
-10%
-20%
-30%
-40%
-50%
Ozone depletion
Global warming
Smog
Acidification
Eutrophication
Carcinogenics
Non carcinogenics
Respiratory effects
Ecotoxicity
Fossil fuel depletion
Environmental Impact Category
01-Gas-Sparged F3_T1
02-GAC-fluidized F3_T1
03-Hybrid F3_T1
04 - P + Gas-Sparged F3_T1
05 - P + GAC-Fluidized F3_T1
06 - P+Hybrid F3_T1
07 -P + Hybrid + AltCH4 F3_T1
08 - Conventional

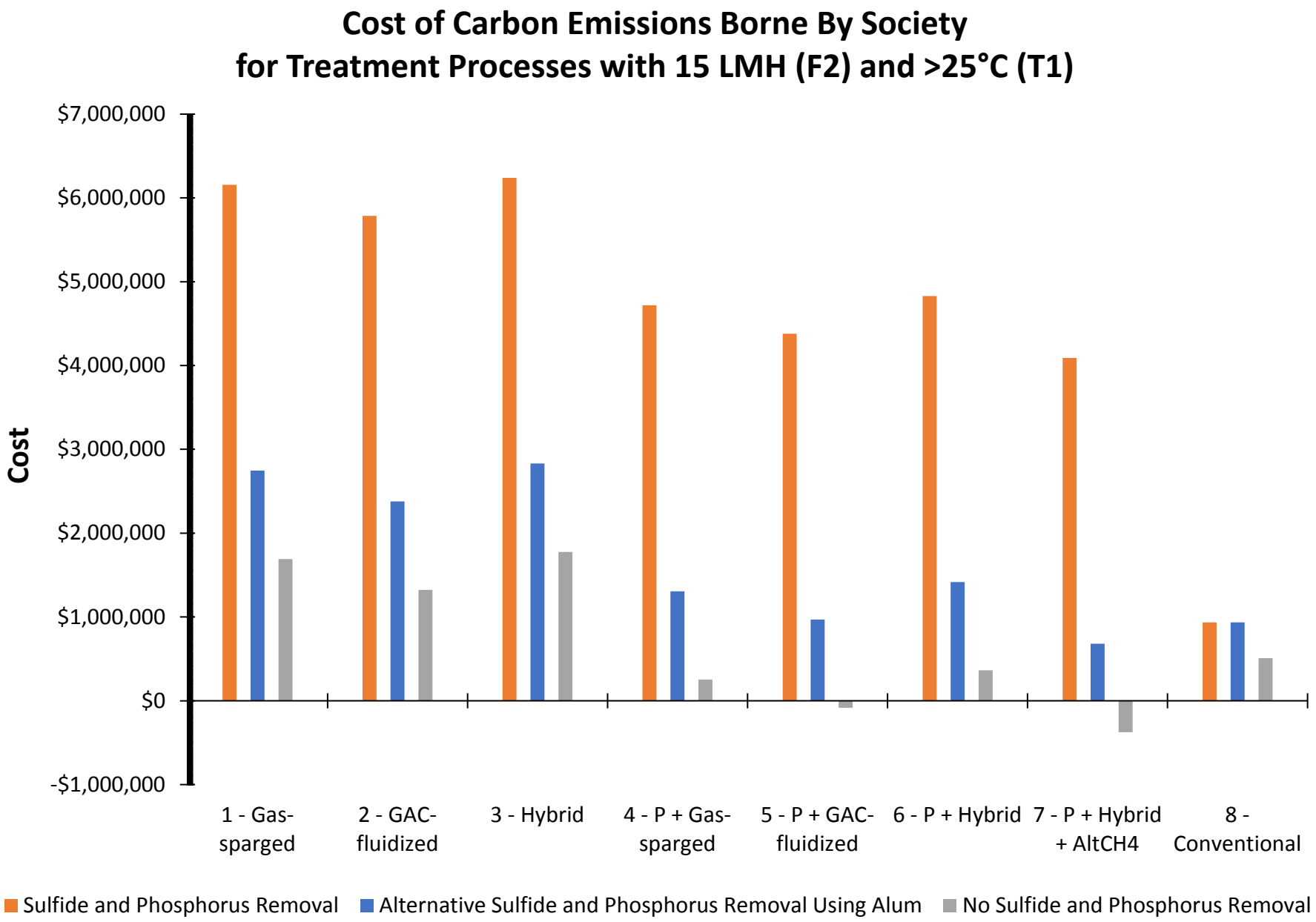

Characterization Impact Assessment of the AnMBR and Conventional Process Scenarios
AnMBR processes are shown with 30 LMH (F3) and <20°C (T2)
Relative Impact (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Ozone depletion (kg CFC-11 eq)
Global warming (kg CO2 eq)
Smog (kg O3 eq)
Acidification (kg SO2 eq)
Eutrophication (kg N eq)
Carcinogenics (CTUh)
Non carcinogenics (CTUh)
Respiratory effects (kg PM2.5 eq)
Ecotoxicity (CTUe)
Fossil fuel depletion (MJ surplus)
Environmental Impact Category
01 - Gas-Sparged F3_T2
02 - GAC-fluidized F3_T2
03 - Hybrid F3_T2
04 - P + Gas-Sparged F3_T2
05 - P + GAC-fluidized F3_T2
06 - P + Hybrid F3_T2
07 - P + Hybrid + AltCH4 F3_T2
08 - Conventional

Appendix H

Social Cost of Carbon

Cost of Carbon Emissions Borne By Society for Treatment Processes with 15 LMH (F2) and >25°C (T1)




Cost of Carbon Emissions Borne By Society
for Treatment Processes with 15 LMH (F2) and >25°C (T1)
Cost
$7,000,000
$6,000,000
$5,000,000
$4,000,000
$3,000,000
$2,000,000
$1,000,000
$0
-$1,000,000
1 - Gas-sparged
2 - GAC-fluidized
3 - Hybrid
4 - P + Gas-sparged
5 - P + GAC-fluidized
6 - P + Hybrid
7 - P + Hybrid + AltCH4
8 - Conventional
Sulfide and Phosphorus Removal
Alternative Sulfide and Phosphorus Removal Using Alum
No Sulfide and Phosphorus Removal

Appendix H

Lifecycle Assessment Material and Energy Inventory

				01 - Primary Treatment				
				Energy Consumed	Energy Consumed	Energy Consumed	Waste Produced	Waste Hauled - by truck
Process	Membrane Flux lmh	Temperature °C	F/T	Screening and Grit Removal kWh/day	Equalization kWh/day	Primary Sedimentation kWh/day	Screenings and Grit kg/day	Screenings and Grit Hauled to Landfill km/day
1	7.5	>25	F1/T1	630	35	0	850	4.459
1	7.5	<20	F1/T2	630	35	0	850	4.459
1	15.0	>25	F2/T1	630	35	0	850	4.459
1	15.0	<20	F2/T2	630	35	0	850	4.459
1	30.0	>25	F3/T1	630	35	0	850	4.459
1	30.0	<20	F3/T2	630	35	0	850	4.459
2	7.5	>25	F1/T1	630	35	0	850	4.459
2	7.5	<20	F1/T2	630	35	0	850	4.459
2	15.0	>25	F2/T1	630	35	0	850	4.459
2	15.0	<20	F2/T2	630	35	0	850	4.459
2	30.0	>25	F3/T1	630	35	0	850	4.459
2	30.0	<20	F3/T2	630	35	0	850	4.459
3	7.5	>25	F1/T1	630	35	0	850	4.459
3	7.5	<20	F1/T2	630	35	0	850	4.459
3	15.0	>25	F2/T1	630	35	0	850	4.459
3	15.0	<20	F2/T2	630	35	0	850	4.459
3	30.0	>25	F3/T1	630	35	0	850	4.459
3	30.0	<20	F3/T2	630	35	0	850	4.459
4	7.5	>25	F1/T1	630	35	100	843	4.424
4	7.5	<20	F1/T2	630	35	100	843	4.424
4	15.0	>25	F2/T1	630	35	100	843	4.424
4	15.0	<20	F2/T2	630	35	100	843	4.424
4	30.0	>25	F3/T1	630	35	100	843	4.424
4	30.0	<20	F3/T2	630	35	100	843	4.424
5	7.5	>25	F1/T1	630	35	100	843	4.424
5	7.5	<20	F1/T2	630	35	100	843	4.424
5	15.0	>25	F2/T1	630	35	100	843	4.424
5	15.0	<20	F2/T2	630	35	100	843	4.424
5	30.0	>25	F3/T1	630	35	100	843	4.424
5	30.0	<20	F3/T2	630	35	100	843	4.424
6	7.5	>25	F1/T1	630	35	100	843	4.424
6	7.5	<20	F1/T2	630	35	100	843	4.424
6	15.0	>25	F2/T1	630	35	100	843	4.424
6	15.0	<20	F2/T2	630	35	100	843	4.424
6	30.0	>25	F3/T1	630	35	100	843	4.424
6	30.0	<20	F3/T2	630	35	100	843	4.424
7	7.5	>25	F1/T1	630	35	100	843	4.424
7	7.5	<20	F1/T2	630	35	100	843	4.424
7	15.0	>25	F2/T1	630	35	100	843	4.424
7	15.0	<20	F2/T2	630	35	100	843	4.424
7	30.0	>25	F3/T1	630	35	100	843	4.424
7	30.0	<20	F3/T2	630	35	100	843	4.424
8	N/A	N/A	--	602	0	100	819	4.299

				02 - Secondary Treatment														
				Energy Consumed	Chem. Consumed - GAC		Chemical Consumed - NaOCl for Membrane Cleaning			Chemical Consumed - Citric Acid for Membrane Cleaning				Membrane Materials Consumed and Disposed				Waste Produced
Process	Membrane Flux	Temperature	F/T	Biological Treatment	GAC	GAC Delivered to Site by Truck	NaOCl 100%	Dilution H2O	NaOCl Hauling by Truck	Citric Acid 100%	Dilution H2O	Product Delivered to Site (50% Solution)	Citric Acid Hauling by Truck	UF Membrane Disposal - PVC	UF Membrane Disposal - Polyester	PVC Hauling to Recycling Facility	PE Solids Hauling to Recycling Facility	CO2 Emissions from Biological Metabolism
	lmh	°C		kWh/day	kg/day	km/day	kg/day	kg/day	km/day	kg/day	kg/day	kg/day	km/day	kg/day	kg/day	km/day	km/day	kg/day
1	7.5	>25	F1/T1	6621	0	0.000	40	226	0.696	149	149	299	0.784	19.9	2.2	0.104	0.012	163
1	7.5	<20	F1/T2	6621	0	0.000	40	226	0.696	149	149	299	0.784	19.9	2.2	0.104	0.012	63
1	15.0	>25	F2/T1	3665	0	0.000	20	114	0.351	75	75	149	0.392	9.9	1.1	0.052	0.006	163
1	15.0	<20	F2/T2	3665	0	0.000	20	114	0.351	75	75	149	0.392	9.9	1.1	0.052	0.006	63
1	30.0	>25	F3/T1	2187	0	0.000	10	58	0.178	37	37	75	0.197	5.0	0.6	0.026	0.003	163
1	30.0	<20	F3/T2	2187	0	0.000	10	58	0.178	37	37	75	0.197	5.0	0.6	0.026	0.003	63
2	7.5	>25	F1/T1	3604	109	0.286	42	238	0.734	154	154	307	0.806	79.4	4.4	0.417	0.023	173
2	7.5	<20	F1/T2	3604	109	0.286	42	238	0.734	154	154	307	0.806	79.4	4.4	0.417	0.023	41
2	15.0	>25	F2/T1	2157	109	0.286	21	120	0.370	77	77	154	0.403	39.7	2.2	0.208	0.012	173
2	15.0	<20	F2/T2	2157	109	0.286	21	120	0.370	77	77	154	0.403	39.7	2.2	0.208	0.012	41
2	30.0	>25	F3/T1	1433	109	0.286	11	61	0.187	39	39	77	0.202	20.0	1.1	0.105	0.006	173
2	30.0	<20	F3/T2	1433	109	0.286	11	61	0.187	39	39	77	0.202	20.0	1.1	0.105	0.006	41
3	7.5	>25	F1/T1	6621	109	0.286	40	226	0.696	149	149	299	0.784	19.9	2.2	0.104	0.012	171
3	7.5	<20	F1/T2	6621	109	0.286	40	226	0.696	149	149	299	0.784	19.9	2.2	0.104	0.012	41
3	15.0	>25	F2/T1	3665	109	0.286	20	114	0.351	75	75	149	0.392	9.9	1.1	0.052	0.006	171
3	15.0	<20	F2/T2	3665	109	0.286	20	114	0.351	75	75	149	0.392	9.9	1.1	0.052	0.006	41
3	30.0	>25	F3/T1	2187	109	0.286	10	58	0.178	37	37	75	0.197	5.0	0.6	0.026	0.003	171
3	30.0	<20	F3/T2	2187	109	0.286	10	58	0.178	37	37	75	0.197	5.0	0.6	0.026	0.003	41
4	7.5	>25	F1/T1	6621	0	0.000	40	226	0.696	149	149	299	0.784	19.9	2.2	0.104	0.012	890
4	7.5	<20	F1/T2	6621	0	0.000	40	226	0.696	149	149	299	0.784	19.9	2.2	0.104	0.012	822
4	15.0	>25	F2/T1	3665	0	0.000	20	114	0.351	75	75	149	0.392	9.9	1.1	0.052	0.006	890
4	15.0	<20	F2/T2	3665	0	0.000	20	114	0.351	75	75	149	0.392	9.9	1.1	0.052	0.006	822
4	30.0	>25	F3/T1	2187	0	0.000	10	58	0.178	37	37	75	0.197	5.0	0.6	0.026	0.003	890
4	30.0	<20	F3/T2	2187	0	0.000	10	58	0.178	37	37	75	0.197	5.0	0.6	0.026	0.003	822
5	7.5	>25	F1/T1	3604	109	0.286	42	238	0.734	154	154	307	0.806	79.4	4.4	0.417	0.023	896
5	7.5	<20	F1/T2	3604	109	0.286	42	238	0.734	154	154	307	0.806	79.4	4.4	0.417	0.023	808
5	15.0	>25	F2/T1	2157	109	0.286	21	120	0.370	77	77	154	0.403	39.7	2.2	0.208	0.012	896
5	15.0	<20	F2/T2	2157	109	0.286	21	120	0.370	77	77	154	0.403	39.7	2.2	0.208	0.012	808
5	30.0	>25	F3/T1	1433	109	0.286	11	61	0.187	39	39	77	0.202	20.0	1.1	0.105	0.006	896
5	30.0	<20	F3/T2	1433	109	0.286	11	61	0.187	39	39	77	0.202	20.0	1.1	0.105	0.006	808
6	7.5	>25	F1/T1	6621	109	0.286	40	226	0.696	149	149	299	0.784	19.9	2.2	0.104	0.012	895
6	7.5	<20	F1/T2	6621	109	0.286	40	226	0.696	149	149	299	0.784	19.9	2.2	0.104	0.012	808
6	15.0	>25	F2/T1	3665	109	0.286	20	114	0.351	75	75	149	0.392	9.9	1.1	0.052	0.006	895
6	15.0	<20	F2/T2	3665	109	0.286	20	114	0.351	75	75	149	0.392	9.9	1.1	0.052	0.006	808
6	30.0	>25	F3/T1	2187	109	0.286	10	58	0.178	37	37	75	0.197	5.0	0.6	0.026	0.003	895
6	30.0	<20	F3/T2	2187	109	0.286	10	58	0.178	37	37	75	0.197	5.0	0.6	0.026	0.003	808
7	7.5	>25	F1/T1	6621	109	0.286	40	226	0.696	149	149	299	0.784	19.9	2.2	0.104	0.012	895
7	7.5	<20	F1/T2	6621	109	0.286	40	226	0.696	149	149	299	0.784	19.9	2.2	0.104	0.012	808
7	15.0	>25	F2/T1	3665	109	0.286	20	114	0.351	75	75	149	0.392	9.9	1.1	0.052	0.006	895
7	15.0	<20	F2/T2	3665	109	0.286	20	114	0.351	75	75	149	0.392	9.9	1.1	0.052	0.006	808
7	30.0	>25	F3/T1	2187	109	0.286	10	58	0.178	37	37	75	0.197	5.0	0.6	0.026	0.003	895
7	30.0	<20	F3/T2	2187	109	0.286	10	58	0.178	37	37	75	0.197	5.0	0.6	0.026	0.003	808
8	N/A	N/A	--	5322	0	0.000	0	0	0.000	0	0	0	0.000	0	0	0.000	0.000	3960

				03 - Nutrient Removal																
				Energy Consumed	Chemical Consumed - FeCl3				Chemical Consumed - PACl		Chemical Consumed - Polymer for P Removal					Chemical Consumed - Alum for P Removal				
Process	Membrane Flux	Temperature	F/T	Phosphorous Removal	FeCl3, 100% solution	Dilution H2O	Product Delivered to Site (40% FeCl3)	FeCl3 Hauling to Site	PACl Solution Delivered to Site	PACl Hauling to Site	Polyacrylamide	Hydrotreated Light Petroleum Distillates	Dilution H2O	Product Delivered to Site	Polymer Hauling to Site	100% Aluminum Sulfate	Dilution H2O	Product Delivered to Site (48% Alum Solution)	Alum Hauling to Site
	lmh	°C		kWh/day	kg/day	kg/day	kg/day	km/day	kg/day	km/day	kg/day	kg/day	kg/day	kg/day	km/day	kg/day	kg/day	kg/day	km/day
1	7.5	>25	F1/T1	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
1	7.5	<20	F1/T2	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
1	15.0	>25	F2/T1	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
1	15.0	<20	F2/T2	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
1	30.0	>25	F3/T1	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
1	30.0	<20	F3/T2	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
2	7.5	>25	F1/T1	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
2	7.5	<20	F1/T2	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
2	15.0	>25	F2/T1	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
2	15.0	<20	F2/T2	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
2	30.0	>25	F3/T1	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
2	30.0	<20	F3/T2	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
3	7.5	>25	F1/T1	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
3	7.5	<20	F1/T2	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
3	15.0	>25	F2/T1	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
3	15.0	<20	F2/T2	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
3	30.0	>25	F3/T1	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
3	30.0	<20	F3/T2	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
4	7.5	>25	F1/T1	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
4	7.5	<20	F1/T2	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
4	15.0	>25	F2/T1	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
4	15.0	<20	F2/T2	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
4	30.0	>25	F3/T1	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
4	30.0	<20	F3/T2	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
5	7.5	>25	F1/T1	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
5	7.5	<20	F1/T2	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
5	15.0	>25	F2/T1	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
5	15.0	<20	F2/T2	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
5	30.0	>25	F3/T1	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
5	30.0	<20	F3/T2	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
6	7.5	>25	F1/T1	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
6	7.5	<20	F1/T2	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
6	15.0	>25	F2/T1	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
6	15.0	<20	F2/T2	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
6	30.0	>25	F3/T1	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
6	30.0	<20	F3/T2	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
7	7.5	>25	F1/T1	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
7	7.5	<20	F1/T2	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
7	15.0	>25	F2/T1	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
7	15.0	<20	F2/T2	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
7	30.0	>25	F3/T1	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
7	30.0	<20	F3/T2	303	3829	5743	9572	25	3306	8.7	4.1	4.1	5.5	14	0.036	0	0	0	0
8	N/A	N/A	--	215	0	0	0	0	0	0.0	0	0	0	0	0.000	1008	1092	2100	5.5

				04 - Sludge Management																		
				Energy Consumed	Energy Consumed	Chemical Consumed - Polymer for Biosolids Thickening+Dewatering					Chemical Consumed - Polymer for Chem Solids Thickening+Dewatering					Chemical Consumed - Quicklime		Waste Produced - Biosolids		Waste Produced - Inorganic Solids		Total Material Hauling
	Membrane Flux	Temperature	F/T	Thickening and Dewatering - Biosolids	Thickening and Dewatering - Chem Sludge	Polyacrylamide	Hydrotreated Light Petroleum Distillates	Dilution H2O	Product Shipped to Site	Polymer Hauling to Site by Truck	Polyacrylamide	Hydrotreated Light Petroleum Distillates	Dilution H2O	Product Shipped to Site	Polymer Hauling to Site by Truck	Quicklime	Quicklime Hauling to Site	Biosolids (wet cake)	Biosolids Hauling to Land Application Site	Inorganic Solids (wet cake)	Inorganic Solids Hauling to Land Application Site	Operation, lorry 16-13t, EURO5/RER S
Process	lmh	°C		kWh/day	kWh/day	kg/day	kg/day	kg/day	kg/day	km/day	kg/day	kg/day	kg/day	kg/day	km/day	kg/day	km/day	kg/day	km/day	kg/day	km/day	km
1	7.5	>25	F1/T1	143	48	4	4	5	14	0.036	11	11	15	37	0.098	1058	2.78	6346	16.7	20199	53.0	2.909
1	7.5	<20	F1/T2	143	48	4	4	5	14	0.036	11	11	15	37	0.098	1058	2.78	6346	16.7	20199	53.0	2.909
1	15.0	>25	F2/T1	143	48	4	4	5	14	0.036	11	11	15	37	0.098	1058	2.78	6346	16.7	20199	53.0	2.909
1	15.0	<20	F2/T2	143	48	4	4	5	14	0.036	11	11	15	37	0.098	1058	2.78	6346	16.7	20199	53.0	2.909
1	30.0	>25	F3/T1	143	48	4	4	5	14	0.036	11	11	15	37	0.098	1058	2.78	6346	16.7	20199	53.0	2.909
1	30.0	<20	F3/T2	143	48	4	4	5	14	0.036	11	11	15	37	0.098	1058	2.78	6346	16.7	20199	53.0	2.909
2	7.5	>25	F1/T1	143	48	4	4	5	14	0.036	11	11	15	37	0.098	1058	2.78	6346	16.7	20199	53.0	2.909
2	7.5	<20	F1/T2	143	48	4	4	5	14	0.036	11	11	15	37	0.098	1058	2.78	6346	16.7	20199	53.0	2.909
2	15.0	>25	F2/T1	143	48	4	4	5	14	0.036	11	11	15	37	0.098	1058	2.78	6346	16.7	20199	53.0	2.909
2	15.0	<20	F2/T2	143	48	4	4	5	14	0.036	11	11	15	37	0.098	1058	2.78	6346	16.7	20199	53.0	2.909
2	30.0	>25	F3/T1	143	48	4	4	5	14	0.036	11	11	15	37	0.098	1058	2.78	6346	16.7	20199	53.0	2.909
2	30.0	<20	F3/T2	143	48	4	4	5	14	0.036	11	11	15	37	0.098	1058	2.78	6346	16.7	20199	53.0	2.909
3	7.5	>25	F1/T1	143	48	4	4	5	14	0.036	11	11	15	37	0.098	1058	2.78	6346	16.7	20199	53.0	2.909
3	7.5	<20	F1/T2	143	48	4	4	5	14	0.036	11	11	15	37	0.098	1058	2.78	6346	16.7	20199	53.0	2.909
3	15.0	>25	F2/T1	143	48	4	4	5	14	0.036	11	11	15	37	0.098	1058	2.78	6346	16.7	20199	53.0	2.909
3	15.0	<20	F2/T2	143	48	4	4	5	14	0.036	11	11	15	37	0.098	1058	2.78	6346	16.7	20199	53.0	2.909
3	30.0	>25	F3/T1	143	48	4	4	5	14	0.036	11	11	15	37	0.098	1058	2.78	6346	16.7	20199	53.0	2.909
3	30.0	<20	F3/T2	143	48	4	4	5	14	0.036	11	11	15	37	0.098	1058	2.78	6346	16.7	20199	53.0	2.909
4	7.5	>25	F1/T1	143	48	7	7	10	25	0.065	11	11	15	37	0.098	0	0.00	6912	18.1	20199	53.0	0.162
4	7.5	<20	F1/T2	143	48	7	7	10	25	0.065	11	11	15	37	0.098	0	0.00	6912	18.1	20199	53.0	0.162
4	15.0	>25	F2/T1	143	48	7	7	10	25	0.065	11	11	15	37	0.098	0	0.00	6912	18.1	20199	53.0	0.162
4	15.0	<20	F2/T2	143	48	7	7	10	25	0.065	11	11	15	37	0.098	0	0.00	6912	18.1	20199	53.0	0.162
4	30.0	>25	F3/T1	143	48	7	7	10	25	0.065	11	11	15	37	0.098	0	0.00	6912	18.1	20199	53.0	0.162
4	30.0	<20	F3/T2	143	48	7	7	10	25	0.065	11	11	15	37	0.098	0	0.00	6912	18.1	20199	53.0	0.162
5	7.5	>25	F1/T1	143	48	7	7	10	25	0.065	11	11	15	37	0.098	0	0.00	6912	18.1	20199	53.0	0.162
5	7.5	<20	F1/T2	143	48	7	7	10	25	0.065	11	11	15	37	0.098	0	0.00	6912	18.1	20199	53.0	0.162
5	15.0	>25	F2/T1	143	48	7	7	10	25	0.065	11	11	15	37	0.098	0	0.00	6912	18.1	20199	53.0	0.162
5	15.0	<20	F2/T2	143	48	7	7	10	25	0.065	11	11	15	37	0.098	0	0.00	6912	18.1	20199	53.0	0.162
5	30.0	>25	F3/T1	143	48	7	7	10	25	0.065	11	11	15	37	0.098	0	0.00	6912	18.1	20199	53.0	0.162
5	30.0	<20	F3/T2	143	48	7	7	10	25	0.065	11	11	15	37	0.098	0	0.00	6912	18.1	20199	53.0	0.162
6	7.5	>25	F1/T1	143	48	7	7	10	25	0.065	11	11	15	37	0.098	0	0.00	6912	18.1	20199	53.0	0.162
6	7.5	<20	F1/T2	143	48	7	7	10	25	0.065	11	11	15	37	0.098	0	0.00	6912	18.1	20199	53.0	0.162
6	15.0	>25	F2/T1	143	48	7	7	10	25	0.065	11	11	15	37	0.098	0	0.00	6912	18.1	20199	53.0	0.162
6	15.0	<20	F2/T2	143	48	7	7	10	25	0.065	11	11	15	37	0.098	0	0.00	6912	18.1	20199	53.0	0.162
6	30.0	>25	F3/T1	143	48	7	7	10	25	0.065	11	11	15	37	0.098	0	0.00	6912	18.1	20199	53.0	0.162
6	30.0	<20	F3/T2	143	48	7	7	10	25	0.065	11	11	15	37	0.098	0	0.00	6912	18.1	20199	53.0	0.162
7	7.5	>25	F1/T1	143	48	7	7	10	25	0.065	11	11	15	37	0.098	0	0.00	6912	18.1	20199	53.0	0.162
7	7.5	<20	F1/T2	143	48	7	7	10	25	0.065	11	11	15	37	0.098	0	0.00	6912	18.1	20199	53.0	0.162
7	15.0	>25	F2/T1	143	48	7	7	10	25	0.065	11	11	15	37	0.098	0	0.00	6912	18.1	20199	53.0	0.162
7	15.0	<20	F2/T2	143	48	7	7	10	25	0.065	11	11	15	37	0.098	0	0.00	6912	18.1	20199	53.0	0.162
7	30.0	>25	F3/T1	143	48	7	7	10	25	0.065	11	11	15	37	0.098	0	0.00	6912	18.1	20199	53.0	0.162
7	30.0	<20	F3/T2	143	48	7	7	10	25	0.065	11	11	15	37	0.098	0	0.00	6912	18.1	20199	53.0	0.162
8	N/A	N/A	--	143	0	9	9	11	28	0.074	0	0	0	0	0.000	0	0.00	11543	30.3	0	0	0.074

				05 - Biogas Handling, Treatment, and Beneficial Use									
				Energy Consumed	Energy Consumed	Energy Consumed	Energy Produced	Energy Produced	Energy Produced	Process Byproduct	Waste Produced		Process Byproduct
Process	Membrane Flux	Temperature	F/T	Anaerobic Digester Mixer	Anaerobic Digester Heating	Biogas Treatment and Storage	Bioreactor Methane - AVOIDED PRODUCT	AD Methane - AVOIDED PRODUCT	Dissolved Methane Recovery - AVOIDED PRODUCT	Elemental Sulfur for disposal or recycle - AVOIDED PRODUCT	CO2 Emissions	Heat Balance on Digesters	Excess Heat - AVOID PRODUCT
	lmh	°C		kWh/day	kWh/day	kWh/day	kWh/day	kWh/day	kWh/day	kg/day	kg/day	kWh/day	MJ/day
1	7.5	>25	F1/T1	0	0	351	3317	0	1506	5.8	2691	4647	16729
1	7.5	<20	F1/T2	0	0	294	1287	0	1614	2.2	1700	3315	11933
1	15.0	>25	F2/T1	0	0	351	3317	0	1506	5.8	2691	4647	16729
1	15.0	<20	F2/T2	0	0	294	1287	0	1614	2.2	1700	3315	11933
1	30.0	>25	F3/T1	0	0	351	3317	0	1506	5.8	2691	4647	16729
1	30.0	<20	F3/T2	0	0	294	1287	0	1614	2.2	1700	3315	11933
2	7.5	>25	F1/T1	0	0	357	3526	0	1506	6.1	2800	4801	17283
2	7.5	<20	F1/T2	0	0	282	831	0	1614	1.5	1463	2980	10729
2	15.0	>25	F2/T1	0	0	357	3526	0	1506	6.1	2800	4801	17283
2	15.0	<20	F2/T2	0	0	282	831	0	1614	1.5	1463	2980	10729
2	30.0	>25	F3/T1	0	0	357	3526	0	1506	6.1	2800	4801	17283
2	30.0	<20	F3/T2	0	0	282	831	0	1614	1.5	1463	2980	10729
3	7.5	>25	F1/T1	0	0	356	3492	0	1506	6.1	2782	4776	17193
3	7.5	<20	F1/T2	0	0	282	827	0	1614	1.4	1460	2977	10716
3	15.0	>25	F2/T1	0	0	356	3492	0	1506	6.1	2782	4776	17193
3	15.0	<20	F2/T2	0	0	282	827	0	1614	1.4	1460	2977	10716
3	30.0	>25	F3/T1	0	0	356	3492	0	1506	6.1	2782	4776	17193
3	30.0	<20	F3/T2	0	0	282	827	0	1614	1.4	1460	2977	10716
4	7.5	>25	F1/T1	48	0	433	2156	3907	979	7.3	3848	6271	22574
4	7.5	<20	F1/T2	48	0	395	783	3907	1097	4.9	3206	5349	19257
4	15.0	>25	F2/T1	48	0	433	2156	3907	979	7.3	3848	6271	22574
4	15.0	<20	F2/T2	48	0	395	783	3907	1097	4.9	3206	5349	19257
4	30.0	>25	F3/T1	48	0	433	2156	3907	979	7.3	3848	6271	22574
4	30.0	<20	F3/T2	48	0	395	783	3907	1097	4.9	3206	5349	19257
5	7.5	>25	F1/T1	48	0	437	2292	3907	979	7.6	3919	6370	22933
5	7.5	<20	F1/T2	48	0	386	487	3907	1097	4.4	3052	5132	18475
5	15.0	>25	F2/T1	48	0	437	2292	3907	979	7.6	3919	6370	22933
5	15.0	<20	F2/T2	48	0	386	487	3907	1097	4.4	3052	5132	18475
5	30.0	>25	F3/T1	48	0	437	2292	3907	979	7.6	3919	6370	22933
5	30.0	<20	F3/T2	48	0	386	487	3907	1097	4.4	3052	5132	18475
6	7.5	>25	F1/T1	48	0	436	2270	3907	979	7.5	3908	6354	22875
6	7.5	<20	F1/T2	48	0	386	484	3907	1097	4.4	3050	5130	18466
6	15.0	>25	F2/T1	48	0	436	2270	3907	979	7.5	3908	6354	22875
6	15.0	<20	F2/T2	48	0	386	484	3907	1097	4.4	3050	5130	18466
6	30.0	>25	F3/T1	48	0	436	2270	3907	979	7.5	3908	6354	22875
6	30.0	<20	F3/T2	48	0	386	484	3907	1097	4.4	3050	5130	18466
7	7.5	>25	F1/T1	48	0	375	2270	3907	979	7.5	3847	5967	21482
7	7.5	<20	F1/T2	48	0	325	484	3907	1097	4.4	2990	4742	17073
7	15.0	>25	F2/T1	48	0	375	2270	3907	979	7.5	3847	5967	21482
7	15.0	<20	F2/T2	48	0	325	484	3907	1097	4.4	2990	4742	17073
7	30.0	>25	F3/T1	48	0	375	2270	3907	979	7.5	3847	5967	21482
7	30.0	<20	F3/T2	48	0	325	484	3907	1097	4.4	2990	4742	17073
8	N/A	N/A	--	48	0	277	0	4568	0	4.2	2383	3348	12052

				06 - Dissolved Methane Removal						07 - Disinfection			
				Energy Consumed	Membrane Materials Consumed and Disposed				Methane Emissions	Chemical Consumed - NaOCl for Disinfection			
Process	Membrane Flux	Temperature	F/T	Dissolved CH4 Removal	CH4 Contactor Disposal - PVC	CH4 Contactor Disposal - Polypropylene	PVC Hauling to Recycling Facility	PP Solids Hauling to Recycling Facility	Dissolved CH4 Emitted to Atmosphere	100% NaOCl - Disinfection	Dilution H2O	Product Delivered to Facility (12.5% Solution)	NaOCl hauling to site
	lmh	°C		kWh/day	kg/day	kg/day	km/day	km/day	kg/day	kg/day	kg/day	kg/day	km/day
1	7.5	>25	F1/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
1	7.5	<20	F1/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
1	15.0	>25	F2/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
1	15.0	<20	F2/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
1	30.0	>25	F3/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
1	30.0	<20	F3/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
2	7.5	>25	F1/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
2	7.5	<20	F1/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
2	15.0	>25	F2/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
2	15.0	<20	F2/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
2	30.0	>25	F3/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
2	30.0	<20	F3/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
3	7.5	>25	F1/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
3	7.5	<20	F1/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
3	15.0	>25	F2/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
3	15.0	<20	F2/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
3	30.0	>25	F3/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
3	30.0	<20	F3/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
4	7.5	>25	F1/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
4	7.5	<20	F1/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
4	15.0	>25	F2/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
4	15.0	<20	F2/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
4	30.0	>25	F3/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
4	30.0	<20	F3/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
5	7.5	>25	F1/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
5	7.5	<20	F1/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
5	15.0	>25	F2/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
5	15.0	<20	F2/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
5	30.0	>25	F3/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
5	30.0	<20	F3/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
6	7.5	>25	F1/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
6	7.5	<20	F1/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
6	15.0	>25	F2/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
6	15.0	<20	F2/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
6	30.0	>25	F3/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
6	30.0	<20	F3/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
7	7.5	>25	F1/T1	413	0	0	0.000	0.000	20.685	341	1932	2273	6.0
7	7.5	<20	F1/T2	413	0	0	0.000	0.000	23.178	341	1932	2273	6.0
7	15.0	>25	F2/T1	413	0	0	0.000	0.000	20.685	341	1932	2273	6.0
7	15.0	<20	F2/T2	413	0	0	0.000	0.000	23.178	341	1932	2273	6.0
7	30.0	>25	F3/T1	413	0	0	0.000	0.000	20.685	341	1932	2273	6.0
7	30.0	<20	F3/T2	413	0	0	0.000	0.000	23.178	341	1932	2273	6.0
8	N/A	N/A	--	0	0	0	0.000	0.000	0.000	273	1546	1818	4.8

				Total Hauling	**Net Energy Calculation**			**Unit energy**	
				Sum of all Hauling	**Energy From the Grid**	Energy Consumed	Energy Produced	Energy Consumed	Energy Produced
Process	Membrane Flux lmh	Temperature °C	F/T	landfill, land application, and chemical delivery km/day	(+) Energy from Grid (-) Energy to Grid kWh/day	Consumed from Grid kWh/day	Sold Back to the Grid kWh/day	Consumed from Grid kWh/m³	Sold Back to the Grid kWh/m³
1	7.5	>25	F1/T1	55	5778	5778	0	0.305	0.000
1	7.5	<20	F1/T2	55	7644	7644	0	0.404	0.000
1	15.0	>25	F2/T1	55	2822	2822	0	0.149	0.000
1	15.0	<20	F2/T2	55	4688	4688	0	0.248	0.000
1	30.0	>25	F3/T1	54	1344	1344	0	0.071	0.000
1	30.0	<20	F3/T2	54	3210	3210	0	0.170	0.000
2	7.5	>25	F1/T1	56	2558	2558	0	0.135	0.000
2	7.5	<20	F1/T2	56	5069	5069	0	0.268	0.000
2	15.0	>25	F2/T1	55	1110	1110	0	0.059	0.000
2	15.0	<20	F2/T2	55	3622	3622	0	0.191	0.000
2	30.0	>25	F3/T1	55	386	386	0	0.020	0.000
2	30.0	<20	F3/T2	55	2898	2898	0	0.153	0.000
3	7.5	>25	F1/T1	56	5608	5608	0	0.296	0.000
3	7.5	<20	F1/T2	56	8091	8091	0	0.428	0.000
3	15.0	>25	F2/T1	55	2652	2652	0	0.140	0.000
3	15.0	<20	F2/T2	55	5135	5135	0	0.271	0.000
3	30.0	>25	F3/T1	55	1174	1174	0	0.062	0.000
3	30.0	<20	F3/T2	55	3657	3657	0	0.193	0.000
4	7.5	>25	F1/T1	54	3789	3789	0	0.200	0.000
4	7.5	<20	F1/T2	54	5006	5006	0	0.265	0.000
4	15.0	>25	F2/T1	53	833	833	0	0.044	0.000
4	15.0	<20	F2/T2	53	2050	2050	0	0.108	0.000
4	30.0	>25	F3/T1	53	-645	0	645	0.000	0.034
4	30.0	<20	F3/T2	53	572	572	0	0.030	0.000
5	7.5	>25	F1/T1	55	640	640	0	0.034	0.000
5	7.5	<20	F1/T2	55	2276	2276	0	0.120	0.000
5	15.0	>25	F2/T1	54	-808	0	808	0.000	0.043
5	15.0	<20	F2/T2	54	829	829	0	0.044	0.000
5	30.0	>25	F3/T1	53	-1531	0	1531	0.000	0.081
5	30.0	<20	F3/T2	53	105	105	0	0.006	0.000
6	7.5	>25	F1/T1	54	3678	3678	0	0.194	0.000
6	7.5	<20	F1/T2	54	5296	5296	0	0.280	0.000
6	15.0	>25	F2/T1	54	722	722	0	0.038	0.000
6	15.0	<20	F2/T2	54	2340	2340	0	0.124	0.000
6	30.0	>25	F3/T1	53	-756	0	756	0.000	0.040
6	30.0	<20	F3/T2	53	862	862	0	0.046	0.000
7	7.5	>25	F1/T1	54	1559	1559	0	0.082	0.000
7	7.5	<20	F1/T2	54	3177	3177	0	0.168	0.000
7	15.0	>25	F2/T1	54	-1397	0	1397	0.000	0.074
7	15.0	<20	F2/T2	54	221	221	0	0.012	0.000
7	30.0	>25	F3/T1	53	-2875	0	2875	0.000	0.152
7	30.0	<20	F3/T2	53	-1257	0	1257	0.000	0.066
8	N/A	N/A	--	45	2139	2139	0	0.113	0.000

Appendix H

Lifecycle Assessment Waste Inventory

				Sludge								Membrane Recycling								Overall Waste (sludge &
	Membrane Flux	Temperature	F/T	Screenings and Grit		Biosolids (wet cake)		Inorganic Solids (wet cake)		Total		UF Membrane Disposal - PVC		UF Membrane Disposal - Polyester		CH4 Contactor Disposal - PVC		CH4 Contactor Disposal - Polypropylene		Total		
Process	lmh	°C		kg/day	%	kg/day	%	kg/day	%	kg/day	% overall waste	kg/day	%	kg/day	%	kg/day	%	kg/day	%	kg/day	% overall waste	kg/day
1	7.5	>25	F1/T1	850	3.10%	6346	23.16%	20199	73.73%	27394	99.92%	19.9	86.74%	2.2	9.64%	0.66	2.90%	0.17	0.72%	22.88	0.08%	27417.26
1	7.5	<20	F1/T2	850	3.10%	6346	23.16%	20199	73.73%	27394	99.92%	19.9	86.74%	2.2	9.64%	0.66	2.90%	0.17	0.72%	22.88	0.08%	27417.26
1	15.0	>25	F2/T1	850	3.10%	6346	23.16%	20199	73.73%	27394	99.96%	9.9	83.71%	1.1	9.30%	0.66	5.59%	0.17	1.40%	11.86	0.04%	27406.23
1	15.0	<20	F2/T2	850	3.10%	6346	23.16%	20199	73.73%	27394	99.96%	9.9	83.71%	1.1	9.30%	0.66	5.59%	0.17	1.40%	11.86	0.04%	27406.23
1	30.0	>25	F3/T1	850	3.10%	6346	23.16%	20199	73.73%	27394	99.98%	5.0	78.31%	0.6	8.70%	0.66	10.39%	0.17	2.60%	6.38	0.02%	27400.76
1	30.0	<20	F3/T2	850	3.10%	6346	23.16%	20199	73.73%	27394	99.98%	5.0	78.31%	0.6	8.70%	0.66	10.39%	0.17	2.60%	6.38	0.02%	27400.76
2	7.5	>25	F1/T1	850	3.10%	6346	23.16%	20199	73.73%	27394	99.69%	79.4	93.81%	4.4	5.21%	0.66	0.78%	0.17	0.20%	84.64	0.31%	27479.02
2	7.5	<20	F1/T2	850	3.10%	6346	23.16%	20199	73.73%	27394	99.69%	79.4	93.81%	4.4	5.21%	0.66	0.78%	0.17	0.20%	84.64	0.31%	27479.02
2	15.0	>25	F2/T1	850	3.10%	6346	23.16%	20199	73.73%	27394	99.84%	39.7	92.90%	2.2	5.16%	0.66	1.55%	0.17	0.39%	42.74	0.16%	27437.11
2	15.0	<20	F2/T2	850	3.10%	6346	23.16%	20199	73.73%	27394	99.84%	39.7	92.90%	2.2	5.16%	0.66	1.55%	0.17	0.39%	42.74	0.16%	27437.11
2	30.0	>25	F3/T1	850	3.10%	6346	23.16%	20199	73.73%	27394	99.92%	20.0	91.16%	1.1	5.06%	0.66	3.02%	0.17	0.76%	21.92	0.08%	27416.30
2	30.0	<20	F3/T2	850	3.10%	6346	23.16%	20199	73.73%	27394	99.92%	20.0	91.16%	1.1	5.06%	0.66	3.02%	0.17	0.76%	21.92	0.08%	27416.30
3	7.5	>25	F1/T1	850	3.10%	6346	23.16%	20199	73.73%	27394	99.92%	19.9	86.74%	2.2	9.64%	0.66	2.90%	0.17	0.72%	22.88	0.08%	27417.26
3	7.5	<20	F1/T2	850	3.10%	6346	23.16%	20199	73.73%	27394	99.92%	19.9	86.74%	2.2	9.64%	0.66	2.90%	0.17	0.72%	22.88	0.08%	27417.26
3	15.0	>25	F2/T1	850	3.10%	6346	23.16%	20199	73.73%	27394	99.96%	9.9	83.71%	1.1	9.30%	0.66	5.59%	0.17	1.40%	11.86	0.04%	27406.23
3	15.0	<20	F2/T2	850	3.10%	6346	23.16%	20199	73.73%	27394	99.96%	9.9	83.71%	1.1	9.30%	0.66	5.59%	0.17	1.40%	11.86	0.04%	27406.23
3	30.0	>25	F3/T1	850	3.10%	6346	23.16%	20199	73.73%	27394	99.98%	5.0	78.31%	0.6	8.70%	0.66	10.39%	0.17	2.60%	6.38	0.02%	27400.76
3	30.0	<20	F3/T2	850	3.10%	6346	23.16%	20199	73.73%	27394	99.98%	5.0	78.31%	0.6	8.70%	0.66	10.39%	0.17	2.60%	6.38	0.02%	27400.76
4	7.5	>25	F1/T1	843	3.02%	6912	24.73%	20199	72.26%	27955	99.92%	19.9	86.74%	2.2	9.64%	0.66	2.90%	0.17	0.72%	22.88	0.08%	27977.40
4	7.5	<20	F1/T2	843	3.02%	6912	24.73%	20199	72.26%	27955	99.92%	19.9	86.74%	2.2	9.64%	0.66	2.90%	0.17	0.72%	22.88	0.08%	27977.40
4	15.0	>25	F2/T1	843	3.02%	6912	24.73%	20199	72.26%	27955	99.96%	9.9	83.71%	1.1	9.30%	0.66	5.59%	0.17	1.40%	11.86	0.04%	27966.38
4	15.0	<20	F2/T2	843	3.02%	6912	24.73%	20199	72.26%	27955	99.96%	9.9	83.71%	1.1	9.30%	0.66	5.59%	0.17	1.40%	11.86	0.04%	27966.38
4	30.0	>25	F3/T1	843	3.02%	6912	24.73%	20199	72.26%	27955	99.98%	5.0	78.31%	0.6	8.70%	0.66	10.39%	0.17	2.60%	6.38	0.02%	27960.90
4	30.0	<20	F3/T2	843	3.02%	6912	24.73%	20199	72.26%	27955	99.98%	5.0	78.31%	0.6	8.70%	0.66	10.39%	0.17	2.60%	6.38	0.02%	27960.90
5	7.5	>25	F1/T1	843	3.02%	6912	24.73%	20199	72.26%	27955	99.70%	79.4	93.81%	4.4	5.21%	0.66	0.78%	0.17	0.20%	84.64	0.30%	28039.16
5	7.5	<20	F1/T2	843	3.02%	6912	24.73%	20199	72.26%	27955	99.70%	79.4	93.81%	4.4	5.21%	0.66	0.78%	0.17	0.20%	84.64	0.30%	28039.16
5	15.0	>25	F2/T1	843	3.02%	6912	24.73%	20199	72.26%	27955	99.85%	39.7	92.90%	2.2	5.16%	0.66	1.55%	0.17	0.39%	42.74	0.15%	27997.25
5	15.0	<20	F2/T2	843	3.02%	6912	24.73%	20199	72.26%	27955	99.85%	39.7	92.90%	2.2	5.16%	0.66	1.55%	0.17	0.39%	42.74	0.15%	27997.25
5	30.0	>25	F3/T1	843	3.02%	6912	24.73%	20199	72.26%	27955	99.92%	20.0	91.16%	1.1	5.06%	0.66	3.02%	0.17	0.76%	21.92	0.08%	27976.44
5	30.0	<20	F3/T2	843	3.02%	6912	24.73%	20199	72.26%	27955	99.92%	20.0	91.16%	1.1	5.06%	0.66	3.02%	0.17	0.76%	21.92	0.08%	27976.44
6	7.5	>25	F1/T1	843	3.02%	6912	24.73%	20199	72.26%	27955	99.92%	19.9	86.74%	2.2	9.64%	0.66	2.90%	0.17	0.72%	22.88	0.08%	27977.40
6	7.5	<20	F1/T2	843	3.02%	6912	24.73%	20199	72.26%	27955	99.92%	19.9	86.74%	2.2	9.64%	0.66	2.90%	0.17	0.72%	22.88	0.08%	27977.40
6	15.0	>25	F2/T1	843	3.02%	6912	24.73%	20199	72.26%	27955	99.96%	9.9	83.71%	1.1	9.30%	0.66	5.59%	0.17	1.40%	11.86	0.04%	27966.38
6	15.0	<20	F2/T2	843	3.02%	6912	24.73%	20199	72.26%	27955	99.96%	9.9	83.71%	1.1	9.30%	0.66	5.59%	0.17	1.40%	11.86	0.04%	27966.38
6	30.0	>25	F3/T1	843	3.02%	6912	24.73%	20199	72.26%	27955	99.98%	5.0	78.31%	0.6	8.70%	0.66	10.39%	0.17	2.60%	6.38	0.02%	27960.90
6	30.0	<20	F3/T2	843	3.02%	6912	24.73%	20199	72.26%	27955	99.98%	5.0	78.31%	0.6	8.70%	0.66	10.39%	0.17	2.60%	6.38	0.02%	27960.90
7	7.5	>25	F1/T1	843	3.02%	6912	24.73%	20199	72.26%	27955	99.92%	19.9	90.00%	2.2	10.00%	0	0.00%	0	0.00%	22.06	0.08%	27976.58
7	7.5	<20	F1/T2	843	3.02%	6912	24.73%	20199	72.26%	27955	99.92%	19.9	90.00%	2.2	10.00%	0	0.00%	0	0.00%	22.06	0.08%	27976.58
7	15.0	>25	F2/T1	843	3.02%	6912	24.73%	20199	72.26%	27955	99.96%	9.9	90.00%	1.1	10.00%	0	0.00%	0	0.00%	11.03	0.04%	27965.55
7	15.0	<20	F2/T2	843	3.02%	6912	24.73%	20199	72.26%	27955	99.96%	9.9	90.00%	1.1	10.00%	0	0.00%	0	0.00%	11.03	0.04%	27965.55
7	30.0	>25	F3/T1	843	3.02%	6912	24.73%	20199	72.26%	27955	99.98%	5.0	90.00%	0.6	10.00%	0	0.00%	0	0.00%	5.55	0.02%	27960.07
7	30.0	<20	F3/T2	843	3.02%	6912	24.73%	20199	72.26%	27955	99.98%	5.0	90.00%	0.6	10.00%	0	0.00%	0	0.00%	5.55	0.02%	27960.07
8	N/A	N/A	--	819	6.63%	11543	93.37%	0	0.00%	12362	100.00%	0	#DIV/0!	0	#DIV/0!	0	#DIV/0!	0	#DIV/0!	0.00	0.00%	12361.89

Process	Membrane Flux lmh	Temperature °C	F/T	Waste Hauled - by truck							
				Screenings and Grit km/day	Biosolids Hauling to km/day	Inorganic Solids Hauling km/day	PVC Hauling to Recycling km/day	PE Solids Hauling to km/day	PVC Hauling to Recycling km/day	PP Solids Hauling to km/day	**Total km/day**
1	7.5	>25	F1/T1	4.459	16.7	53.0	0.104	0.012	0.003	0.001	**74.227**
1	7.5	<20	F1/T2	4.459	16.7	53.0	0.104	0.012	0.003	0.001	**74.227**
1	15.0	>25	F2/T1	4.459	16.7	53.0	0.052	0.006	0.003	0.001	**74.169**
1	15.0	<20	F2/T2	4.459	16.7	53.0	0.052	0.006	0.003	0.001	**74.169**
1	30.0	>25	F3/T1	4.459	16.7	53.0	0.026	0.003	0.003	0.001	**74.140**
1	30.0	<20	F3/T2	4.459	16.7	53.0	0.026	0.003	0.003	0.001	**74.140**
2	7.5	>25	F1/T1	4.459	16.7	53.0	0.417	0.023	0.003	0.001	**74.551**
2	7.5	<20	F1/T2	4.459	16.7	53.0	0.417	0.023	0.003	0.001	**74.551**
2	15.0	>25	F2/T1	4.459	16.7	53.0	0.208	0.012	0.003	0.001	**74.331**
2	15.0	<20	F2/T2	4.459	16.7	53.0	0.208	0.012	0.003	0.001	**74.331**
2	30.0	>25	F3/T1	4.459	16.7	53.0	0.105	0.006	0.003	0.001	**74.222**
2	30.0	<20	F3/T2	4.459	16.7	53.0	0.105	0.006	0.003	0.001	**74.222**
3	7.5	>25	F1/T1	4.459	16.7	53.0	0.104	0.012	0.003	0.001	**74.227**
3	7.5	<20	F1/T2	4.459	16.7	53.0	0.104	0.012	0.003	0.001	**74.227**
3	15.0	>25	F2/T1	4.459	16.7	53.0	0.052	0.006	0.003	0.001	**74.169**
3	15.0	<20	F2/T2	4.459	16.7	53.0	0.052	0.006	0.003	0.001	**74.169**
3	30.0	>25	F3/T1	4.459	16.7	53.0	0.026	0.003	0.003	0.001	**74.140**
3	30.0	<20	F3/T2	4.459	16.7	53.0	0.026	0.003	0.003	0.001	**74.140**
4	7.5	>25	F1/T1	4.424	18.1	53.0	0.104	0.012	0.003	0.001	**75.680**
4	7.5	<20	F1/T2	4.424	18.1	53.0	0.104	0.012	0.003	0.001	**75.680**
4	15.0	>25	F2/T1	4.424	18.1	53.0	0.052	0.006	0.003	0.001	**75.622**
4	15.0	<20	F2/T2	4.424	18.1	53.0	0.052	0.006	0.003	0.001	**75.622**
4	30.0	>25	F3/T1	4.424	18.1	53.0	0.026	0.003	0.003	0.001	**75.593**
4	30.0	<20	F3/T2	4.424	18.1	53.0	0.026	0.003	0.003	0.001	**75.593**
5	7.5	>25	F1/T1	4.424	18.1	53.0	0.417	0.023	0.003	0.001	**76.004**
5	7.5	<20	F1/T2	4.424	18.1	53.0	0.417	0.023	0.003	0.001	**76.004**
5	15.0	>25	F2/T1	4.424	18.1	53.0	0.208	0.012	0.003	0.001	**75.784**
5	15.0	<20	F2/T2	4.424	18.1	53.0	0.208	0.012	0.003	0.001	**75.784**
5	30.0	>25	F3/T1	4.424	18.1	53.0	0.105	0.006	0.003	0.001	**75.674**
5	30.0	<20	F3/T2	4.424	18.1	53.0	0.105	0.006	0.003	0.001	**75.674**
6	7.5	>25	F1/T1	4.424	18.1	53.0	0.104	0.012	0.003	0.001	**75.680**
6	7.5	<20	F1/T2	4.424	18.1	53.0	0.104	0.012	0.003	0.001	**75.680**
6	15.0	>25	F2/T1	4.424	18.1	53.0	0.052	0.006	0.003	0.001	**75.622**
6	15.0	<20	F2/T2	4.424	18.1	53.0	0.052	0.006	0.003	0.001	**75.622**
6	30.0	>25	F3/T1	4.424	18.1	53.0	0.026	0.003	0.003	0.001	**75.593**
6	30.0	<20	F3/T2	4.424	18.1	53.0	0.026	0.003	0.003	0.001	**75.593**
7	7.5	>25	F1/T1	4.424	18.1	53.0	0.104	0.012	0.000	0.000	**75.675**
7	7.5	<20	F1/T2	4.424	18.1	53.0	0.104	0.012	0.000	0.000	**75.675**
7	15.0	>25	F2/T1	4.424	18.1	53.0	0.052	0.006	0.000	0.000	**75.617**
7	15.0	<20	F2/T2	4.424	18.1	53.0	0.052	0.006	0.000	0.000	**75.617**
7	30.0	>25	F3/T1	4.424	18.1	53.0	0.026	0.003	0.000	0.000	**75.589**
7	30.0	<20	F3/T2	4.424	18.1	53.0	0.026	0.003	0.000	0.000	**75.589**
8	N/A	N/A	--	4.299	30.3	0	0.000	0.000	0.000	0.000	**34.585**

Appendix H

Lifecycle Assessment Material and Energy Inventory for Alum Sensitivity Analysis

				01 - Primary Treatment				
				Energy Consumed	Energy Consumed	Energy Consumed	Waste Produced	Waste Hauled - by truck
Process	Membrane Flux lmh	Temperature °C	F/T	Screening and Grit Removal kWh/day	Equalization kWh/day	Primary Sedimentation kWh/day	Screenings and Grit kg/day	Screenings and Grit Hauled to Landfill km/day
1	7.5	>25	F1/T1	630	35	0	850	4.459
1	7.5	<20	F1/T2	630	35	0	850	4.459
1	15.0	>25	F2/T1	630	35	0	850	4.459
1	15.0	<20	F2/T2	630	35	0	850	4.459
1	30.0	>25	F3/T1	630	35	0	850	4.459
1	30.0	<20	F3/T2	630	35	0	850	4.459
2	7.5	>25	F1/T1	630	35	0	850	4.459
2	7.5	<20	F1/T2	630	35	0	850	4.459
2	15.0	>25	F2/T1	630	35	0	850	4.459
2	15.0	<20	F2/T2	630	35	0	850	4.459
2	30.0	>25	F3/T1	630	35	0	850	4.459
2	30.0	<20	F3/T2	630	35	0	850	4.459
3	7.5	>25	F1/T1	630	35	0	850	4.459
3	7.5	<20	F1/T2	630	35	0	850	4.459
3	15.0	>25	F2/T1	630	35	0	850	4.459
3	15.0	<20	F2/T2	630	35	0	850	4.459
3	30.0	>25	F3/T1	630	35	0	850	4.459
3	30.0	<20	F3/T2	630	35	0	850	4.459
4	7.5	>25	F1/T1	630	35	100	843	4.424
4	7.5	<20	F1/T2	630	35	100	843	4.424
4	15.0	>25	F2/T1	630	35	100	843	4.424
4	15.0	<20	F2/T2	630	35	100	843	4.424
4	30.0	>25	F3/T1	630	35	100	843	4.424
4	30.0	<20	F3/T2	630	35	100	843	4.424
5	7.5	>25	F1/T1	630	35	100	843	4.424
5	7.5	<20	F1/T2	630	35	100	843	4.424
5	15.0	>25	F2/T1	630	35	100	843	4.424
5	15.0	<20	F2/T2	630	35	100	843	4.424
5	30.0	>25	F3/T1	630	35	100	843	4.424
5	30.0	<20	F3/T2	630	35	100	843	4.424
6	7.5	>25	F1/T1	630	35	100	843	4.424
6	7.5	<20	F1/T2	630	35	100	843	4.424
6	15.0	>25	F2/T1	630	35	100	843	4.424
6	15.0	<20	F2/T2	630	35	100	843	4.424
6	30.0	>25	F3/T1	630	35	100	843	4.424
6	30.0	<20	F3/T2	630	35	100	843	4.424
7	7.5	>25	F1/T1	630	35	100	843	4.424
7	7.5	<20	F1/T2	630	35	100	843	4.424
7	15.0	>25	F2/T1	630	35	100	843	4.424
7	15.0	<20	F2/T2	630	35	100	843	4.424
7	30.0	>25	F3/T1	630	35	100	843	4.424
7	30.0	<20	F3/T2	630	35	100	843	4.424
8	N/A	N/A	--	602	0	100	819	4.299

				02 - Secondary Treatment																	
				Energy Consumed	Chem. Consumed - GAC		Chemical Consumed - NaOCl for Membrane Cleaning				Chemical Consumed - Citric Acid for Membrane Cleaning				Membrane Materials Consumed and Disposed				Waste Produced	Total Hauling
Process	Membrane Flux	Temperature	F/T	Biological Treatment	GAC	GAC Delivered to Site by Truck	NaOCl 100%	Dilution H2O	Product Delivered to Site (12.5% Solution)	NaOCl Hauling by Truck	Citric Acid 100%	Dilution H2O	Product Delivered to Site (50% Solution)	Citric Acid Hauling by Truck	UF Membrane Disposal - PVC	UF Membrane Disposal - Polyester	PVC Hauling to Recycling Facility	PE Solids Hauling to Recycling Facility	CO2 Emissions from Biological Metabolism	Operation, lorry 16-13t, EURO5/RER S
	lmh	°C		kWh/day	kg/day	km/day	kg/day	kg/day	kg/day	km/day	kg/day	kg/day	kg/day	km/day	kg/day	kg/day	km/day	km/day	kg/day	km
1	7.5	>25	F1/T1	6621	0	0.000	40	226	265	0.696	149	149	299	0.784	19.9	2.2	0.104	0.012	163	1.480
1	7.5	<20	F1/T2	6621	0	0.000	40	226	265	0.696	149	149	299	0.784	19.9	2.2	0.104	0.012	63	1.480
1	15.0	>25	F2/T1	3665	0	0.000	20	114	134	0.351	75	75	149	0.392	9.9	1.1	0.052	0.006	163	0.743
1	15.0	<20	F2/T2	3665	0	0.000	20	114	134	0.351	75	75	149	0.392	9.9	1.1	0.052	0.006	63	0.743
1	30.0	>25	F3/T1	2187	0	0.000	10	58	68	0.178	37	37	75	0.197	5.0	0.6	0.026	0.003	163	0.375
1	30.0	<20	F3/T2	2187	0	0.000	10	58	68	0.178	37	37	75	0.197	5.0	0.6	0.026	0.003	63	0.375
2	7.5	>25	F1/T1	3604	109	0.286	42	238	280	0.734	154	154	307	0.806	79.4	4.4	0.417	0.023	173	1.826
2	7.5	<20	F1/T2	3604	109	0.286	42	238	280	0.734	154	154	307	0.806	79.4	4.4	0.417	0.023	41	1.826
2	15.0	>25	F2/T1	2157	109	0.286	21	120	141	0.370	77	77	154	0.403	39.7	2.2	0.208	0.012	173	1.058
2	15.0	<20	F2/T2	2157	109	0.286	21	120	141	0.370	77	77	154	0.403	39.7	2.2	0.208	0.012	41	1.058
2	30.0	>25	F3/T1	1433	109	0.286	11	61	71	0.187	39	39	77	0.202	20.0	1.1	0.105	0.006	173	0.675
2	30.0	<20	F3/T2	1433	109	0.286	11	61	71	0.187	39	39	77	0.202	20.0	1.1	0.105	0.006	41	0.675
3	7.5	>25	F1/T1	6621	109	0.286	40	226	265	0.696	149	149	299	0.784	19.9	2.2	0.104	0.012	171	1.766
3	7.5	<20	F1/T2	6621	109	0.286	40	226	265	0.696	149	149	299	0.784	19.9	2.2	0.104	0.012	41	1.766
3	15.0	>25	F2/T1	3665	109	0.286	20	114	134	0.351	75	75	149	0.392	9.9	1.1	0.052	0.006	171	1.028
3	15.0	<20	F2/T2	3665	109	0.286	20	114	134	0.351	75	75	149	0.392	9.9	1.1	0.052	0.006	41	1.028
3	30.0	>25	F3/T1	2187	109	0.286	10	58	68	0.178	37	37	75	0.197	5.0	0.6	0.026	0.003	171	0.660
3	30.0	<20	F3/T2	2187	109	0.286	10	58	68	0.178	37	37	75	0.197	5.0	0.6	0.026	0.003	41	0.660
4	7.5	>25	F1/T1	6621	0	0.000	40	226	265	0.696	149	149	299	0.784	19.9	2.2	0.104	0.012	890	1.480
4	7.5	<20	F1/T2	6621	0	0.000	40	226	265	0.696	149	149	299	0.784	19.9	2.2	0.104	0.012	822	1.480
4	15.0	>25	F2/T1	3665	0	0.000	20	114	134	0.351	75	75	149	0.392	9.9	1.1	0.052	0.006	890	0.743
4	15.0	<20	F2/T2	3665	0	0.000	20	114	134	0.351	75	75	149	0.392	9.9	1.1	0.052	0.006	822	0.743
4	30.0	>25	F3/T1	2187	0	0.000	10	58	68	0.178	37	37	75	0.197	5.0	0.6	0.026	0.003	890	0.375
4	30.0	<20	F3/T2	2187	0	0.000	10	58	68	0.178	37	37	75	0.197	5.0	0.6	0.026	0.003	822	0.375
5	7.5	>25	F1/T1	3604	109	0.286	42	238	280	0.734	154	154	307	0.806	79.4	4.4	0.417	0.023	896	1.826
5	7.5	<20	F1/T2	3604	109	0.286	42	238	280	0.734	154	154	307	0.806	79.4	4.4	0.417	0.023	808	1.826
5	15.0	>25	F2/T1	2157	109	0.286	21	120	141	0.370	77	77	154	0.403	39.7	2.2	0.208	0.012	896	1.058
5	15.0	<20	F2/T2	2157	109	0.286	21	120	141	0.370	77	77	154	0.403	39.7	2.2	0.208	0.012	808	1.058
5	30.0	>25	F3/T1	1433	109	0.286	11	61	71	0.187	39	39	77	0.202	20.0	1.1	0.105	0.006	896	0.675
5	30.0	<20	F3/T2	1433	109	0.286	11	61	71	0.187	39	39	77	0.202	20.0	1.1	0.105	0.006	808	0.675
6	7.5	>25	F1/T1	6621	109	0.286	40	226	265	0.696	149	149	299	0.784	19.9	2.2	0.104	0.012	895	1.766
6	7.5	<20	F1/T2	6621	109	0.286	40	226	265	0.696	149	149	299	0.784	19.9	2.2	0.104	0.012	808	1.766
6	15.0	>25	F2/T1	3665	109	0.286	20	114	134	0.351	75	75	149	0.392	9.9	1.1	0.052	0.006	895	1.028
6	15.0	<20	F2/T2	3665	109	0.286	20	114	134	0.351	75	75	149	0.392	9.9	1.1	0.052	0.006	808	1.028
6	30.0	>25	F3/T1	2187	109	0.286	10	58	68	0.178	37	37	75	0.197	5.0	0.6	0.026	0.003	895	0.660
6	30.0	<20	F3/T2	2187	109	0.286	10	58	68	0.178	37	37	75	0.197	5.0	0.6	0.026	0.003	808	0.660
7	7.5	>25	F1/T1	6621	109	0.286	40	226	265	0.696	149	149	299	0.784	19.9	2.2	0.104	0.012	895	1.766
7	7.5	<20	F1/T2	6621	109	0.286	40	226	265	0.696	149	149	299	0.784	19.9	2.2	0.104	0.012	808	1.766
7	15.0	>25	F2/T1	3665	109	0.286	20	114	134	0.351	75	75	149	0.392	9.9	1.1	0.052	0.006	895	1.028
7	15.0	<20	F2/T2	3665	109	0.286	20	114	134	0.351	75	75	149	0.392	9.9	1.1	0.052	0.006	808	1.028
7	30.0	>25	F3/T1	2187	109	0.286	10	58	68	0.178	37	37	75	0.197	5.0	0.6	0.026	0.003	895	0.660
7	30.0	<20	F3/T2	2187	109	0.286	10	58	68	0.178	37	37	75	0.197	5.0	0.6	0.026	0.003	808	0.660
8	N/A	N/A	--	5322	0	0.000	0	0	0	0.000	0	0	0	0.000	0	0	0.000	0.000	3960	0.000

				03 - Nutrient Removal																	
				Energy Consumed	Chemical Consumed - FeCl3				Chemical Consumed - PACl		Chemical Consumed - Polymer for P Removal					Chemical Consumed - Alum for P Removal				Total Hauling
Process	Membrane Flux	Temperature	F/T	Phosphorous Removal	FeCl3, 100% solution	Dilution H2O	Product Delivered to Site (40% FeCl3)	FeCl3 Hauling to Site	PACl Solution Delivered to Site	PACl Hauling to Site	Polyacrylamide	Hydrotreated Light Petroleum Distillates	Dilution H2O	Product Delivered to Site	Polymer Hauling to Site	100% Aluminum Sulfate	Dilution H2O	Product Delivered to Site (48% Alum Solution)	Alum Hauling to Site	Operation, lorry 16-13t, EURO5/RER S
	lmh	°C		kWh/day	kg/day	kg/day	kg/day	km/day	kg/day	km/day	kg/day	kg/day	kg/day	kg/day	km/day	kg/day	kg/day	kg/day	km/day	km
1	7.5	>25	F1/T1	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
1	7.5	<20	F1/T2	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
1	15.0	>25	F2/T1	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
1	15.0	<20	F2/T2	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
1	30.0	>25	F3/T1	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
1	30.0	<20	F3/T2	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
2	7.5	>25	F1/T1	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
2	7.5	<20	F1/T2	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
2	15.0	>25	F2/T1	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
2	15.0	<20	F2/T2	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
2	30.0	>25	F3/T1	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
2	30.0	<20	F3/T2	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
3	7.5	>25	F1/T1	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
3	7.5	<20	F1/T2	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
3	15.0	>25	F2/T1	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
3	15.0	<20	F2/T2	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
3	30.0	>25	F3/T1	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
3	30.0	<20	F3/T2	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
4	7.5	>25	F1/T1	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
4	7.5	<20	F1/T2	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
4	15.0	>25	F2/T1	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
4	15.0	<20	F2/T2	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
4	30.0	>25	F3/T1	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
4	30.0	<20	F3/T2	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
5	7.5	>25	F1/T1	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
5	7.5	<20	F1/T2	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
5	15.0	>25	F2/T1	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
5	15.0	<20	F2/T2	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
5	30.0	>25	F3/T1	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
5	30.0	<20	F3/T2	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
6	7.5	>25	F1/T1	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
6	7.5	<20	F1/T2	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
6	15.0	>25	F2/T1	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
6	15.0	<20	F2/T2	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
6	30.0	>25	F3/T1	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
6	30.0	<20	F3/T2	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
7	7.5	>25	F1/T1	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
7	7.5	<20	F1/T2	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
7	15.0	>25	F2/T1	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
7	15.0	<20	F2/T2	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
7	30.0	>25	F3/T1	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
7	30.0	<20	F3/T2	301	0	0	0	0	0	0.0	6.8	6.8	9.1	23	0.060	2654	2875	5529	15	14.566
8	N/A	N/A	--	215	0	0	0	0	0	0.0	0	0	0	0	0.000	1008	1092	2100	5.5	5.511

				04 - Sludge Management																		
				Energy Consumed	Energy Consumed	Chemical Consumed - Polymer for Biosolids Thickening+Dewatering					Chemical Consumed - Polymer for Chem Solids Thickening+Dewatering					Chemical Consumed - Quicklime		Waste Produced - Biosolids		Waste Produced		Total Material Hauling
Process	Membrane Flux	Temperature	F/T	Thickening and Dewatering - Biosolids	Thickening and Dewatering - Chem Sludge	Polyacrylamide	Hydrotreated Light Petroleum Distillates	Dilution H2O	Product Shipped to Site	Polymer Hauling to Site by Truck	Polyacrylamide	Hydrotreated Light Petroleum Distillates	Dilution H2O	Product Shipped to Site	Polymer Hauling to Site by Truck	Quicklime	Quicklime Hauling to Site	Biosolids (wet cake)	Biosolids Hauling to Land Application Site	Inorganic Solids (wet cake)	Inorganic Solids Hauling to Land Application Site	Operation, lorry 16-13t, EURO5/RER S
	lmh	°C		kWh/day	kWh/day	kg/day	kg/day	kg/day	kg/day	km/day	kg/day	kg/day	kg/day	kg/day	km/day	kg/day	km/day	kg/day	km/day	kg/day	km/day	km
1	7.5	>25	F1/T1	143	48	4	4	5	14	0.036	2	2	3	7	0.017	1058	2.78	6346	16.7	3624	9.5	2.829
1	7.5	<20	F1/T2	143	48	4	4	5	14	0.036	2	2	3	7	0.017	1058	2.78	6346	16.7	3624	9.5	2.829
1	15.0	>25	F2/T1	143	48	4	4	5	14	0.036	2	2	3	7	0.017	1058	2.78	6346	16.7	3624	9.5	2.829
1	15.0	<20	F2/T2	143	48	4	4	5	14	0.036	2	2	3	7	0.017	1058	2.78	6346	16.7	3624	9.5	2.829
1	30.0	>25	F3/T1	143	48	4	4	5	14	0.036	2	2	3	7	0.017	1058	2.78	6346	16.7	3624	9.5	2.829
1	30.0	<20	F3/T2	143	48	4	4	5	14	0.036	2	2	3	7	0.017	1058	2.78	6346	16.7	3624	9.5	2.829
2	7.5	>25	F1/T1	143	48	4	4	5	14	0.036	2	2	3	7	0.017	1058	2.78	6346	16.7	3624	9.5	2.829
2	7.5	<20	F1/T2	143	48	4	4	5	14	0.036	2	2	3	7	0.017	1058	2.78	6346	16.7	3624	9.5	2.829
2	15.0	>25	F2/T1	143	48	4	4	5	14	0.036	2	2	3	7	0.017	1058	2.78	6346	16.7	3624	9.5	2.829
2	15.0	<20	F2/T2	143	48	4	4	5	14	0.036	2	2	3	7	0.017	1058	2.78	6346	16.7	3624	9.5	2.829
2	30.0	>25	F3/T1	143	48	4	4	5	14	0.036	2	2	3	7	0.017	1058	2.78	6346	16.7	3624	9.5	2.829
2	30.0	<20	F3/T2	143	48	4	4	5	14	0.036	2	2	3	7	0.017	1058	2.78	6346	16.7	3624	9.5	2.829
3	7.5	>25	F1/T1	143	48	4	4	5	14	0.036	2	2	3	7	0.017	1058	2.78	6346	16.7	3624	9.5	2.829
3	7.5	<20	F1/T2	143	48	4	4	5	14	0.036	2	2	3	7	0.017	1058	2.78	6346	16.7	3624	9.5	2.829
3	15.0	>25	F2/T1	143	48	4	4	5	14	0.036	2	2	3	7	0.017	1058	2.78	6346	16.7	3624	9.5	2.829
3	15.0	<20	F2/T2	143	48	4	4	5	14	0.036	2	2	3	7	0.017	1058	2.78	6346	16.7	3624	9.5	2.829
3	30.0	>25	F3/T1	143	48	4	4	5	14	0.036	2	2	3	7	0.017	1058	2.78	6346	16.7	3624	9.5	2.829
3	30.0	<20	F3/T2	143	48	4	4	5	14	0.036	2	2	3	7	0.017	1058	2.78	6346	16.7	3624	9.5	2.829
4	7.5	>25	F1/T1	143	48	7	7	10	25	0.065	2	2	3	7	0.017	0	0.00	6912	18.1	3624	9.5	0.082
4	7.5	<20	F1/T2	143	48	7	7	10	25	0.065	2	2	3	7	0.017	0	0.00	6912	18.1	3624	9.5	0.082
4	15.0	>25	F2/T1	143	48	7	7	10	25	0.065	2	2	3	7	0.017	0	0.00	6912	18.1	3624	9.5	0.082
4	15.0	<20	F2/T2	143	48	7	7	10	25	0.065	2	2	3	7	0.017	0	0.00	6912	18.1	3624	9.5	0.082
4	30.0	>25	F3/T1	143	48	7	7	10	25	0.065	2	2	3	7	0.017	0	0.00	6912	18.1	3624	9.5	0.082
4	30.0	<20	F3/T2	143	48	7	7	10	25	0.065	2	2	3	7	0.017	0	0.00	6912	18.1	3624	9.5	0.082
5	7.5	>25	F1/T1	143	48	7	7	10	25	0.065	2	2	3	7	0.017	0	0.00	6912	18.1	3624	9.5	0.082
5	7.5	<20	F1/T2	143	48	7	7	10	25	0.065	2	2	3	7	0.017	0	0.00	6912	18.1	3624	9.5	0.082
5	15.0	>25	F2/T1	143	48	7	7	10	25	0.065	2	2	3	7	0.017	0	0.00	6912	18.1	3624	9.5	0.082
5	15.0	<20	F2/T2	143	48	7	7	10	25	0.065	2	2	3	7	0.017	0	0.00	6912	18.1	3624	9.5	0.082
5	30.0	>25	F3/T1	143	48	7	7	10	25	0.065	2	2	3	7	0.017	0	0.00	6912	18.1	3624	9.5	0.082
5	30.0	<20	F3/T2	143	48	7	7	10	25	0.065	2	2	3	7	0.017	0	0.00	6912	18.1	3624	9.5	0.082
6	7.5	>25	F1/T1	143	48	7	7	10	25	0.065	2	2	3	7	0.017	0	0.00	6912	18.1	3624	9.5	0.082
6	7.5	<20	F1/T2	143	48	7	7	10	25	0.065	2	2	3	7	0.017	0	0.00	6912	18.1	3624	9.5	0.082
6	15.0	>25	F2/T1	143	48	7	7	10	25	0.065	2	2	3	7	0.017	0	0.00	6912	18.1	3624	9.5	0.082
6	15.0	<20	F2/T2	143	48	7	7	10	25	0.065	2	2	3	7	0.017	0	0.00	6912	18.1	3624	9.5	0.082
6	30.0	>25	F3/T1	143	48	7	7	10	25	0.065	2	2	3	7	0.017	0	0.00	6912	18.1	3624	9.5	0.082
6	30.0	<20	F3/T2	143	48	7	7	10	25	0.065	2	2	3	7	0.017	0	0.00	6912	18.1	3624	9.5	0.082
7	7.5	>25	F1/T1	143	48	7	7	10	25	0.065	2	2	3	7	0.017	0	0.00	6912	18.1	3624	9.5	0.082
7	7.5	<20	F1/T2	143	48	7	7	10	25	0.065	2	2	3	7	0.017	0	0.00	6912	18.1	3624	9.5	0.082
7	15.0	>25	F2/T1	143	48	7	7	10	25	0.065	2	2	3	7	0.017	0	0.00	6912	18.1	3624	9.5	0.082
7	15.0	<20	F2/T2	143	48	7	7	10	25	0.065	2	2	3	7	0.017	0	0.00	6912	18.1	3624	9.5	0.082
7	30.0	>25	F3/T1	143	48	7	7	10	25	0.065	2	2	3	7	0.017	0	0.00	6912	18.1	3624	9.5	0.082
7	30.0	<20	F3/T2	143	48	7	7	10	25	0.065	2	2	3	7	0.017	0	0.00	6912	18.1	3624	9.5	0.082
8	N/A	N/A	--	143	0	9	9	11	28	0.074	0	0	0	0	0.000	0	0.00	11543	30.3	0	0	0.074

				05 - Biogas Handling, Treatment, and Beneficial Use									
				Energy Consumed	Energy Consumed	Energy Consumed	Energy Produced	Energy Produced	Energy Produced	Process Byproduct	Waste Produced		Process Byproduct
Process	Membrane Flux lmh	Temperature °C	F/T	Anaerobic Digester Mixer kWh/day	Anaerobic Digester Heating kWh/day	Biogas Treatment and Storage kWh/day	Bioreactor Methane - AVOIDED PRODUCT kWh/day	AD Methane - AVOIDED PRODUCT kWh/day	Dissolved Methane Recovery - AVOIDED PRODUCT kWh/day	Elemental Sulfur for disposal or recycle - AVOIDED PRODUCT kg/day	CO2 Emissions kg/day	Heat Balance on Digesters kWh/day	Excess Heat - AVOID PRODUCT MJ/day
1	7.5	>25	F1/T1	0	0	351	3317	0	1506	5.8	2691	4647	16729
1	7.5	<20	F1/T2	0	0	294	1287	0	1614	2.2	1700	3315	11933
1	15.0	>25	F2/T1	0	0	351	3317	0	1506	5.8	2691	4647	16729
1	15.0	<20	F2/T2	0	0	294	1287	0	1614	2.2	1700	3315	11933
1	30.0	>25	F3/T1	0	0	351	3317	0	1506	5.8	2691	4647	16729
1	30.0	<20	F3/T2	0	0	294	1287	0	1614	2.2	1700	3315	11933
2	7.5	>25	F1/T1	0	0	357	3526	0	1506	6.1	2800	4801	17283
2	7.5	<20	F1/T2	0	0	282	831	0	1614	1.5	1463	2980	10729
2	15.0	>25	F2/T1	0	0	357	3526	0	1506	6.1	2800	4801	17283
2	15.0	<20	F2/T2	0	0	282	831	0	1614	1.5	1463	2980	10729
2	30.0	>25	F3/T1	0	0	357	3526	0	1506	6.1	2800	4801	17283
2	30.0	<20	F3/T2	0	0	282	831	0	1614	1.5	1463	2980	10729
3	7.5	>25	F1/T1	0	0	356	3492	0	1506	6.1	2782	4776	17193
3	7.5	<20	F1/T2	0	0	282	827	0	1614	1.4	1460	2977	10716
3	15.0	>25	F2/T1	0	0	356	3492	0	1506	6.1	2782	4776	17193
3	15.0	<20	F2/T2	0	0	282	827	0	1614	1.4	1460	2977	10716
3	30.0	>25	F3/T1	0	0	356	3492	0	1506	6.1	2782	4776	17193
3	30.0	<20	F3/T2	0	0	282	827	0	1614	1.4	1460	2977	10716
4	7.5	>25	F1/T1	48	0	433	2156	3907	979	7.3	3848	6271	22574
4	7.5	<20	F1/T2	48	0	395	783	3907	1097	4.9	3206	5349	19257
4	15.0	>25	F2/T1	48	0	433	2156	3907	979	7.3	3848	6271	22574
4	15.0	<20	F2/T2	48	0	395	783	3907	1097	4.9	3206	5349	19257
4	30.0	>25	F3/T1	48	0	433	2156	3907	979	7.3	3848	6271	22574
4	30.0	<20	F3/T2	48	0	395	783	3907	1097	4.9	3206	5349	19257
5	7.5	>25	F1/T1	48	0	437	2292	3907	979	7.6	3919	6370	22933
5	7.5	<20	F1/T2	48	0	386	487	3907	1097	4.4	3052	5132	18475
5	15.0	>25	F2/T1	48	0	437	2292	3907	979	7.6	3919	6370	22933
5	15.0	<20	F2/T2	48	0	386	487	3907	1097	4.4	3052	5132	18475

				05 - Biogas Handling, Treatment, and Beneficial Use									
				Energy Consumed	Energy Consumed	Energy Consumed	Energy Produced	Energy Produced	Energy Produced	Process Byproduct	Waste Produced		Process Byproduct
Process	Membrane Flux lmh	Temperature °C	F/T	Anaerobic Digester Mixer kWh/day	Anaerobic Digester Heating kWh/day	Biogas Treatment and Storage kWh/day	Bioreactor Methane - AVOIDED PRODUCT kWh/day	AD Methane - AVOIDED PRODUCT kWh/day	Dissolved Methane Recovery - AVOIDED PRODUCT kWh/day	Elemental Sulfur for disposal or recycle - AVOIDED PRODUCT kg/day	CO2 Emissions kg/day	Heat Balance on Digesters kWh/day	Excess Heat - AVOID PRODUCT MJ/day
5	30.0	>25	F3/T1	48	0	437	2292	3907	979	7.6	3919	6370	22933
5	30.0	<20	F3/T2	48	0	386	487	3907	1097	4.4	3052	5132	18475
6	7.5	>25	F1/T1	48	0	436	2270	3907	979	7.5	3908	6354	22875
6	7.5	<20	F1/T2	48	0	386	484	3907	1097	4.4	3050	5130	18466
6	15.0	>25	F2/T1	48	0	436	2270	3907	979	7.5	3908	6354	22875
6	15.0	<20	F2/T2	48	0	386	484	3907	1097	4.4	3050	5130	18466
6	30.0	>25	F3/T1	48	0	436	2270	3907	979	7.5	3908	6354	22875
6	30.0	<20	F3/T2	48	0	386	484	3907	1097	4.4	3050	5130	18466
7	7.5	>25	F1/T1	48	0	375	2270	3907	979	7.5	3847	5967	21482
7	7.5	<20	F1/T2	48	0	325	484	3907	1097	4.4	2990	4742	17073
7	15.0	>25	F2/T1	48	0	375	2270	3907	979	7.5	3847	5967	21482
7	15.0	<20	F2/T2	48	0	325	484	3907	1097	4.4	2990	4742	17073
7	30.0	>25	F3/T1	48	0	375	2270	3907	979	7.5	3847	5967	21482
7	30.0	<20	F3/T2	48	0	325	484	3907	1097	4.4	2990	4742	17073
8	N/A	N/A	--	48	0	277	0	4568	0	4.2	2383	3348	12052

				06 - Dissolved Methane Removal						07 - Disinfection			
				Energy Consumed	Membrane Materials Consumed and Disposed				Methane Emissions	Chemical Consumed - NaOCl for Disinfection			
Process	Membrane Flux	Temperature	F/T	Dissolved CH4 Removal	CH4 Contactor Disposal - PVC	CH4 Contactor Disposal - Polypropylene	PVC Hauling to Recycling Facility	PP Solids Hauling to Recycling Facility	Dissolved CH4 Emitted to Atmosphere	100% NaOCl - Disinfection	Dilution H2O	Product Delivered to Facility (12.5% Solution)	NaOCl hauling to site
	lmh	°C		kWh/day	kg/day	kg/day	km/day	km/day	kg/day	kg/day	kg/day	kg/day	km/day
1	7.5	>25	F1/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
1	7.5	<20	F1/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
1	15.0	>25	F2/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
1	15.0	<20	F2/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
1	30.0	>25	F3/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
1	30.0	<20	F3/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
2	7.5	>25	F1/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
2	7.5	<20	F1/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
2	15.0	>25	F2/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
2	15.0	<20	F2/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
2	30.0	>25	F3/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
2	30.0	<20	F3/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
3	7.5	>25	F1/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
3	7.5	<20	F1/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
3	15.0	>25	F2/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
3	15.0	<20	F2/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
3	30.0	>25	F3/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
3	30.0	<20	F3/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
4	7.5	>25	F1/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
4	7.5	<20	F1/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
4	15.0	>25	F2/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
4	15.0	<20	F2/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
4	30.0	>25	F3/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
4	30.0	<20	F3/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
5	7.5	>25	F1/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
5	7.5	<20	F1/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
5	15.0	>25	F2/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
5	15.0	<20	F2/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
5	30.0	>25	F3/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
5	30.0	<20	F3/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
6	7.5	>25	F1/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
6	7.5	<20	F1/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
6	15.0	>25	F2/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
6	15.0	<20	F2/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
6	30.0	>25	F3/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
6	30.0	<20	F3/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
7	7.5	>25	F1/T1	413	0	0	0.000	0.000	20.685	341	1932	2273	6.0
7	7.5	<20	F1/T2	413	0	0	0.000	0.000	23.178	341	1932	2273	6.0
7	15.0	>25	F2/T1	413	0	0	0.000	0.000	20.685	341	1932	2273	6.0
7	15.0	<20	F2/T2	413	0	0	0.000	0.000	23.178	341	1932	2273	6.0
7	30.0	>25	F3/T1	413	0	0	0.000	0.000	20.685	341	1932	2273	6.0
7	30.0	<20	F3/T2	413	0	0	0.000	0.000	23.178	341	1932	2273	6.0
8	N/A	N/A	--	0	0	0	0.000	0.000	0.000	273	1546	1818	4.8

				Total Hauling	**Net Energy Calculation**			**Unit energy**	
				Sum of all Hauling	**Energy From the Grid**	Energy Consumed	Energy Produced	Energy Consumed	Energy Produced
Process	Membrane Flux lmh	Temperature °C	F/T	landfill, land application, and chemical delivery km/day	(+) Energy from Grid (-) Energy to Grid kWh/day	Consumed from Grid kWh/day	Sold Back to the Grid kWh/day	Consumed from Grid kWh/m³	Sold Back to the Grid kWh/m³
1	7.5	>25	F1/T1	55	5778	5778	0	0.305	0.000
1	7.5	<20	F1/T2	55	7644	7644	0	0.404	0.000
1	15.0	>25	F2/T1	55	2822	2822	0	0.149	0.000
1	15.0	<20	F2/T2	55	4688	4688	0	0.248	0.000
1	30.0	>25	F3/T1	54	1344	1344	0	0.071	0.000
1	30.0	<20	F3/T2	54	3210	3210	0	0.170	0.000
2	7.5	>25	F1/T1	56	2558	2558	0	0.135	0.000
2	7.5	<20	F1/T2	56	5069	5069	0	0.268	0.000
2	15.0	>25	F2/T1	55	1110	1110	0	0.059	0.000
2	15.0	<20	F2/T2	55	3622	3622	0	0.191	0.000
2	30.0	>25	F3/T1	55	386	386	0	0.020	0.000
2	30.0	<20	F3/T2	55	2898	2898	0	0.153	0.000
3	7.5	>25	F1/T1	56	5608	5608	0	0.296	0.000
3	7.5	<20	F1/T2	56	8091	8091	0	0.428	0.000
3	15.0	>25	F2/T1	55	2652	2652	0	0.140	0.000
3	15.0	<20	F2/T2	55	5135	5135	0	0.271	0.000
3	30.0	>25	F3/T1	55	1174	1174	0	0.062	0.000
3	30.0	<20	F3/T2	55	3657	3657	0	0.193	0.000
4	7.5	>25	F1/T1	54	3789	3789	0	0.200	0.000
4	7.5	<20	F1/T2	54	5006	5006	0	0.265	0.000
4	15.0	>25	F2/T1	53	833	833	0	0.044	0.000
4	15.0	<20	F2/T2	53	2050	2050	0	0.108	0.000
4	30.0	>25	F3/T1	53	-645	0	645	0.000	0.034
4	30.0	<20	F3/T2	53	572	572	0	0.030	0.000
5	7.5	>25	F1/T1	55	640	640	0	0.034	0.000
5	7.5	<20	F1/T2	55	2276	2276	0	0.120	0.000
5	15.0	>25	F2/T1	54	-808	0	808	0.000	0.043
5	15.0	<20	F2/T2	54	829	829	0	0.044	0.000
5	30.0	>25	F3/T1	53	-1531	0	1531	0.000	0.081
5	30.0	<20	F3/T2	53	105	105	0	0.006	0.000
6	7.5	>25	F1/T1	54	3678	3678	0	0.194	0.000
6	7.5	<20	F1/T2	54	5296	5296	0	0.280	0.000
6	15.0	>25	F2/T1	54	722	722	0	0.038	0.000
6	15.0	<20	F2/T2	54	2340	2340	0	0.124	0.000
6	30.0	>25	F3/T1	53	-756	0	756	0.000	0.040
6	30.0	<20	F3/T2	53	862	862	0	0.046	0.000
7	7.5	>25	F1/T1	54	1559	1559	0	0.082	0.000
7	7.5	<20	F1/T2	54	3177	3177	0	0.168	0.000
7	15.0	>25	F2/T1	54	-1397	0	1397	0.000	0.074
7	15.0	<20	F2/T2	54	221	221	0	0.012	0.000
7	30.0	>25	F3/T1	53	-2875	0	2875	0.000	0.152
7	30.0	<20	F3/T2	53	-1257	0	1257	0.000	0.066
8	N/A	N/A	--	45	2139	2139	0	0.113	0.000

Appendix H

Lifecycle Assessment Waste Inventory for Alum Sensitivity Analysis

				Sludge								Membrane Recycling								
	Membrane Flux	Temperature	F/T	Screenings and Grit		Biosolids (wet cake)		Inorganic Solids (wet cake)		Total		UF Membrane Disposal - PVC		UF Membrane Disposal - Polyester		CH4 Contactor Disposal - PVC		CH4 Contactor Disposal - Polypropylene		Total		
Process	lmh	°C		kg/day	%	kg/day	%	kg/day	%	kg/day	% overall waste	kg/day	%	kg/day	%	kg/day	%	kg/day	%	kg/day	% overall waste	kg/day
1	7.5	>25	F1/T1	850	7.85%	6346	58.65%	3624	33.50%	10820	99.79%	19.9	86.74%	2.2	9.64%	0.66	2.90%	0.17	0.72%	22.88	0.21%	10842.50
1	7.5	<20	F1/T2	850	7.85%	6346	58.65%	3624	33.50%	10820	99.79%	19.9	86.74%	2.2	9.64%	0.66	2.90%	0.17	0.72%	22.88	0.21%	10842.50
1	15.0	>25	F2/T1	850	7.85%	6346	58.65%	3624	33.50%	10820	99.89%	9.9	83.71%	1.1	9.30%	0.66	5.59%	0.17	1.40%	11.86	0.11%	10831.47
1	15.0	<20	F2/T2	850	7.85%	6346	58.65%	3624	33.50%	10820	99.89%	9.9	83.71%	1.1	9.30%	0.66	5.59%	0.17	1.40%	11.86	0.11%	10831.47
1	30.0	>25	F3/T1	850	7.85%	6346	58.65%	3624	33.50%	10820	99.94%	5.0	78.31%	0.6	8.70%	0.66	10.39%	0.17	2.60%	6.38	0.06%	10825.99
1	30.0	<20	F3/T2	850	7.85%	6346	58.65%	3624	33.50%	10820	99.94%	5.0	78.31%	0.6	8.70%	0.66	10.39%	0.17	2.60%	6.38	0.06%	10825.99
2	7.5	>25	F1/T1	850	7.85%	6346	58.65%	3624	33.50%	10820	99.22%	79.4	93.81%	4.4	5.21%	0.66	0.78%	0.17	0.20%	84.64	0.78%	10904.26
2	7.5	<20	F1/T2	850	7.85%	6346	58.65%	3624	33.50%	10820	99.22%	79.4	93.81%	4.4	5.21%	0.66	0.78%	0.17	0.20%	84.64	0.78%	10904.26
2	15.0	>25	F2/T1	850	7.85%	6346	58.65%	3624	33.50%	10820	99.61%	39.7	92.90%	2.2	5.16%	0.66	1.55%	0.17	0.39%	42.74	0.39%	10862.35
2	15.0	<20	F2/T2	850	7.85%	6346	58.65%	3624	33.50%	10820	99.61%	39.7	92.90%	2.2	5.16%	0.66	1.55%	0.17	0.39%	42.74	0.39%	10862.35
2	30.0	>25	F3/T1	850	7.85%	6346	58.65%	3624	33.50%	10820	99.80%	20.0	91.16%	1.1	5.06%	0.66	3.02%	0.17	0.76%	21.92	0.20%	10841.54
2	30.0	<20	F3/T2	850	7.85%	6346	58.65%	3624	33.50%	10820	99.80%	20.0	91.16%	1.1	5.06%	0.66	3.02%	0.17	0.76%	21.92	0.20%	10841.54
3	7.5	>25	F1/T1	850	7.85%	6346	58.65%	3624	33.50%	10820	99.79%	19.9	86.74%	2.2	9.64%	0.66	2.90%	0.17	0.72%	22.88	0.21%	10842.50
3	7.5	<20	F1/T2	850	7.85%	6346	58.65%	3624	33.50%	10820	99.79%	19.9	86.74%	2.2	9.64%	0.66	2.90%	0.17	0.72%	22.88	0.21%	10842.50
3	15.0	>25	F2/T1	850	7.85%	6346	58.65%	3624	33.50%	10820	99.89%	9.9	83.71%	1.1	9.30%	0.66	5.59%	0.17	1.40%	11.86	0.11%	10831.47
3	15.0	<20	F2/T2	850	7.85%	6346	58.65%	3624	33.50%	10820	99.89%	9.9	83.71%	1.1	9.30%	0.66	5.59%	0.17	1.40%	11.86	0.11%	10831.47
3	30.0	>25	F3/T1	850	7.85%	6346	58.65%	3624	33.50%	10820	99.94%	5.0	78.31%	0.6	8.70%	0.66	10.39%	0.17	2.60%	6.38	0.06%	10825.99
3	30.0	<20	F3/T2	850	7.85%	6346	58.65%	3624	33.50%	10820	99.94%	5.0	78.31%	0.6	8.70%	0.66	10.39%	0.17	2.60%	6.38	0.06%	10825.99
4	7.5	>25	F1/T1	843	7.41%	6912	60.74%	3624	31.85%	11380	99.80%	19.9	86.74%	2.2	9.64%	0.66	2.90%	0.17	0.72%	22.88	0.20%	11402.64
4	7.5	<20	F1/T2	843	7.41%	6912	60.74%	3624	31.85%	11380	99.80%	19.9	86.74%	2.2	9.64%	0.66	2.90%	0.17	0.72%	22.88	0.20%	11402.64
4	15.0	>25	F2/T1	843	7.41%	6912	60.74%	3624	31.85%	11380	99.90%	9.9	83.71%	1.1	9.30%	0.66	5.59%	0.17	1.40%	11.86	0.10%	11391.61
4	15.0	<20	F2/T2	843	7.41%	6912	60.74%	3624	31.85%	11380	99.90%	9.9	83.71%	1.1	9.30%	0.66	5.59%	0.17	1.40%	11.86	0.10%	11391.61
4	30.0	>25	F3/T1	843	7.41%	6912	60.74%	3624	31.85%	11380	99.94%	5.0	78.31%	0.6	8.70%	0.66	10.39%	0.17	2.60%	6.38	0.06%	11386.14
4	30.0	<20	F3/T2	843	7.41%	6912	60.74%	3624	31.85%	11380	99.94%	5.0	78.31%	0.6	8.70%	0.66	10.39%	0.17	2.60%	6.38	0.06%	11386.14
5	7.5	>25	F1/T1	843	7.41%	6912	60.74%	3624	31.85%	11380	99.26%	79.4	93.81%	4.4	5.21%	0.66	0.78%	0.17	0.20%	84.64	0.74%	11464.40
5	7.5	<20	F1/T2	843	7.41%	6912	60.74%	3624	31.85%	11380	99.26%	79.4	93.81%	4.4	5.21%	0.66	0.78%	0.17	0.20%	84.64	0.74%	11464.40
5	15.0	>25	F2/T1	843	7.41%	6912	60.74%	3624	31.85%	11380	99.63%	39.7	92.90%	2.2	5.16%	0.66	1.55%	0.17	0.39%	42.74	0.37%	11422.49
5	15.0	<20	F2/T2	843	7.41%	6912	60.74%	3624	31.85%	11380	99.63%	39.7	92.90%	2.2	5.16%	0.66	1.55%	0.17	0.39%	42.74	0.37%	11422.49
5	30.0	>25	F3/T1	843	7.41%	6912	60.74%	3624	31.85%	11380	99.81%	20.0	91.16%	1.1	5.06%	0.66	3.02%	0.17	0.76%	21.92	0.19%	11401.68
5	30.0	<20	F3/T2	843	7.41%	6912	60.74%	3624	31.85%	11380	99.81%	20.0	91.16%	1.1	5.06%	0.66	3.02%	0.17	0.76%	21.92	0.19%	11401.68
6	7.5	>25	F1/T1	843	7.41%	6912	60.74%	3624	31.85%	11380	99.80%	19.9	86.74%	2.2	9.64%	0.66	2.90%	0.17	0.72%	22.88	0.20%	11402.64
6	7.5	<20	F1/T2	843	7.41%	6912	60.74%	3624	31.85%	11380	99.80%	19.9	86.74%	2.2	9.64%	0.66	2.90%	0.17	0.72%	22.88	0.20%	11402.64
6	15.0	>25	F2/T1	843	7.41%	6912	60.74%	3624	31.85%	11380	99.90%	9.9	83.71%	1.1	9.30%	0.66	5.59%	0.17	1.40%	11.86	0.10%	11391.61
6	15.0	<20	F2/T2	843	7.41%	6912	60.74%	3624	31.85%	11380	99.90%	9.9	83.71%	1.1	9.30%	0.66	5.59%	0.17	1.40%	11.86	0.10%	11391.61
6	30.0	>25	F3/T1	843	7.41%	6912	60.74%	3624	31.85%	11380	99.94%	5.0	78.31%	0.6	8.70%	0.66	10.39%	0.17	2.60%	6.38	0.06%	11386.14
6	30.0	<20	F3/T2	843	7.41%	6912	60.74%	3624	31.85%	11380	99.94%	5.0	78.31%	0.6	8.70%	0.66	10.39%	0.17	2.60%	6.38	0.06%	11386.14
7	7.5	>25	F1/T1	843	7.41%	6912	60.74%	3624	31.85%	11380	99.81%	19.9	90.00%	2.2	10.00%	0	0.00%	0	0.00%	22.06	0.19%	11401.81
7	7.5	<20	F1/T2	843	7.41%	6912	60.74%	3624	31.85%	11380	99.81%	19.9	90.00%	2.2	10.00%	0	0.00%	0	0.00%	22.06	0.19%	11401.81
7	15.0	>25	F2/T1	843	7.41%	6912	60.74%	3624	31.85%	11380	99.90%	9.9	90.00%	1.1	10.00%	0	0.00%	0	0.00%	11.03	0.10%	11390.79
7	15.0	<20	F2/T2	843	7.41%	6912	60.74%	3624	31.85%	11380	99.90%	9.9	90.00%	1.1	10.00%	0	0.00%	0	0.00%	11.03	0.10%	11390.79
7	30.0	>25	F3/T1	843	7.41%	6912	60.74%	3624	31.85%	11380	99.95%	5.0	90.00%	0.6	10.00%	0	0.00%	0	0.00%	5.55	0.05%	11385.31
7	30.0	<20	F3/T2	843	7.41%	6912	60.74%	3624	31.85%	11380	99.95%	5.0	90.00%	0.6	10.00%	0	0.00%	0	0.00%	5.55	0.05%	11385.31
8	N/A	N/A	--	819	6.63%	11543	93.37%	0	0.00%	12362	100.00%	0	#DIV/0!	0	#DIV/0!	0	#DIV/0!	0	#DIV/0!	0.00	0.00%	12361.89

Process	Membrane Flux lmh	Temperature °C	F/T	Waste Hauled - by truck							
				Screenings and Grit km/day	Biosolids Hauling to km/day	Inorganic Solids Hauling km/day	PVC Hauling to Recycling km/day	PE Solids Hauling to km/day	PVC Hauling to Recycling km/day	PP Solids Hauling to km/day	**Total km/day**
1	7.5	>25	F1/T1	4.459	16.7	9.5	0.104	0.012	0.003	0.001	**30.738**
1	7.5	<20	F1/T2	4.459	16.7	9.5	0.104	0.012	0.003	0.001	**30.738**
1	15.0	>25	F2/T1	4.459	16.7	9.5	0.052	0.006	0.003	0.001	**30.680**
1	15.0	<20	F2/T2	4.459	16.7	9.5	0.052	0.006	0.003	0.001	**30.680**
1	30.0	>25	F3/T1	4.459	16.7	9.5	0.026	0.003	0.003	0.001	**30.651**
1	30.0	<20	F3/T2	4.459	16.7	9.5	0.026	0.003	0.003	0.001	**30.651**
2	7.5	>25	F1/T1	4.459	16.7	9.5	0.417	0.023	0.003	0.001	**31.062**
2	7.5	<20	F1/T2	4.459	16.7	9.5	0.417	0.023	0.003	0.001	**31.062**
2	15.0	>25	F2/T1	4.459	16.7	9.5	0.208	0.012	0.003	0.001	**30.842**
2	15.0	<20	F2/T2	4.459	16.7	9.5	0.208	0.012	0.003	0.001	**30.842**
2	30.0	>25	F3/T1	4.459	16.7	9.5	0.105	0.006	0.003	0.001	**30.733**
2	30.0	<20	F3/T2	4.459	16.7	9.5	0.105	0.006	0.003	0.001	**30.733**
3	7.5	>25	F1/T1	4.459	16.7	9.5	0.104	0.012	0.003	0.001	**30.738**
3	7.5	<20	F1/T2	4.459	16.7	9.5	0.104	0.012	0.003	0.001	**30.738**
3	15.0	>25	F2/T1	4.459	16.7	9.5	0.052	0.006	0.003	0.001	**30.680**
3	15.0	<20	F2/T2	4.459	16.7	9.5	0.052	0.006	0.003	0.001	**30.680**
3	30.0	>25	F3/T1	4.459	16.7	9.5	0.026	0.003	0.003	0.001	**30.651**
3	30.0	<20	F3/T2	4.459	16.7	9.5	0.026	0.003	0.003	0.001	**30.651**
4	7.5	>25	F1/T1	4.424	18.1	9.5	0.104	0.012	0.003	0.001	**32.190**
4	7.5	<20	F1/T2	4.424	18.1	9.5	0.104	0.012	0.003	0.001	**32.190**
4	15.0	>25	F2/T1	4.424	18.1	9.5	0.052	0.006	0.003	0.001	**32.133**
4	15.0	<20	F2/T2	4.424	18.1	9.5	0.052	0.006	0.003	0.001	**32.133**
4	30.0	>25	F3/T1	4.424	18.1	9.5	0.026	0.003	0.003	0.001	**32.104**
4	30.0	<20	F3/T2	4.424	18.1	9.5	0.026	0.003	0.003	0.001	**32.104**
5	7.5	>25	F1/T1	4.424	18.1	9.5	0.417	0.023	0.003	0.001	**32.515**
5	7.5	<20	F1/T2	4.424	18.1	9.5	0.417	0.023	0.003	0.001	**32.515**
5	15.0	>25	F2/T1	4.424	18.1	9.5	0.208	0.012	0.003	0.001	**32.295**
5	15.0	<20	F2/T2	4.424	18.1	9.5	0.208	0.012	0.003	0.001	**32.295**
5	30.0	>25	F3/T1	4.424	18.1	9.5	0.105	0.006	0.003	0.001	**32.185**
5	30.0	<20	F3/T2	4.424	18.1	9.5	0.105	0.006	0.003	0.001	**32.185**
6	7.5	>25	F1/T1	4.424	18.1	9.5	0.104	0.012	0.003	0.001	**32.190**
6	7.5	<20	F1/T2	4.424	18.1	9.5	0.104	0.012	0.003	0.001	**32.190**
6	15.0	>25	F2/T1	4.424	18.1	9.5	0.052	0.006	0.003	0.001	**32.133**
6	15.0	<20	F2/T2	4.424	18.1	9.5	0.052	0.006	0.003	0.001	**32.133**
6	30.0	>25	F3/T1	4.424	18.1	9.5	0.026	0.003	0.003	0.001	**32.104**
6	30.0	<20	F3/T2	4.424	18.1	9.5	0.026	0.003	0.003	0.001	**32.104**
7	7.5	>25	F1/T1	4.424	18.1	9.5	0.104	0.012	0.000	0.000	**32.186**
7	7.5	<20	F1/T2	4.424	18.1	9.5	0.104	0.012	0.000	0.000	**32.186**
7	15.0	>25	F2/T1	4.424	18.1	9.5	0.052	0.006	0.000	0.000	**32.128**
7	15.0	<20	F2/T2	4.424	18.1	9.5	0.052	0.006	0.000	0.000	**32.128**
7	30.0	>25	F3/T1	4.424	18.1	9.5	0.026	0.003	0.000	0.000	**32.100**
7	30.0	<20	F3/T2	4.424	18.1	9.5	0.026	0.003	0.000	0.000	**32.100**
8	N/A	N/A	--	4.299	30.3	0	0.000	0.000	0.000	0.000	**34.585**

Appendix H

Lifecycle Assessment Material and Energy Inventory for Nutrient Removal Sensitivity Analysis

				01 - Primary Treatment				
				Energy Consumed	Energy Consumed	Energy Consumed	Waste Produced	Waste Hauled - by truck
Process	Membrane Flux lmh	Temperature °C	F/T	Screening and Grit Removal kWh/day	Equalization kWh/day	Primary Sedimentation kWh/day	Screenings and Grit kg/day	Screenings and Grit Hauled to Landfill km/day
1	7.5	>25	F1/T1	630	35	0	850	4.459
1	7.5	<20	F1/T2	630	35	0	850	4.459
1	15.0	>25	F2/T1	630	35	0	850	4.459
1	15.0	<20	F2/T2	630	35	0	850	4.459
1	30.0	>25	F3/T1	630	35	0	850	4.459
1	30.0	<20	F3/T2	630	35	0	850	4.459
2	7.5	>25	F1/T1	630	35	0	850	4.459
2	7.5	<20	F1/T2	630	35	0	850	4.459
2	15.0	>25	F2/T1	630	35	0	850	4.459
2	15.0	<20	F2/T2	630	35	0	850	4.459
2	30.0	>25	F3/T1	630	35	0	850	4.459
2	30.0	<20	F3/T2	630	35	0	850	4.459
3	7.5	>25	F1/T1	630	35	0	850	4.459
3	7.5	<20	F1/T2	630	35	0	850	4.459
3	15.0	>25	F2/T1	630	35	0	850	4.459
3	15.0	<20	F2/T2	630	35	0	850	4.459
3	30.0	>25	F3/T1	630	35	0	850	4.459
3	30.0	<20	F3/T2	630	35	0	850	4.459
4	7.5	>25	F1/T1	630	35	100	843	4.424
4	7.5	<20	F1/T2	630	35	100	843	4.424
4	15.0	>25	F2/T1	630	35	100	843	4.424
4	15.0	<20	F2/T2	630	35	100	843	4.424
4	30.0	>25	F3/T1	630	35	100	843	4.424
4	30.0	<20	F3/T2	630	35	100	843	4.424
5	7.5	>25	F1/T1	630	35	100	843	4.424
5	7.5	<20	F1/T2	630	35	100	843	4.424
5	15.0	>25	F2/T1	630	35	100	843	4.424
5	15.0	<20	F2/T2	630	35	100	843	4.424
5	30.0	>25	F3/T1	630	35	100	843	4.424
5	30.0	<20	F3/T2	630	35	100	843	4.424
6	7.5	>25	F1/T1	630	35	100	843	4.424
6	7.5	<20	F1/T2	630	35	100	843	4.424
6	15.0	>25	F2/T1	630	35	100	843	4.424
6	15.0	<20	F2/T2	630	35	100	843	4.424
6	30.0	>25	F3/T1	630	35	100	843	4.424
6	30.0	<20	F3/T2	630	35	100	843	4.424
7	7.5	>25	F1/T1	630	35	100	843	4.424
7	7.5	<20	F1/T2	630	35	100	843	4.424
7	15.0	>25	F2/T1	630	35	100	843	4.424
7	15.0	<20	F2/T2	630	35	100	843	4.424
7	30.0	>25	F3/T1	630	35	100	843	4.424
7	30.0	<20	F3/T2	630	35	100	843	4.424
8	N/A	N/A	--	602	0	100	819	4.299

				02 - Secondary Treatment															
				Energy Consumed	Chem. Consumed - GAC		Chemical Consumed - NaOCl for Membrane Cleaning			Chemical Consumed - Citric Acid for Membrane Cleaning				Membrane Materials Consumed and Disposed				Waste Produced	Total Hauling
Process	Membrane Flux	Temperature	F/T	Biological Treatment	GAC	GAC Delivered to Site by Truck	NaOCl 100%	Dilution H2O	NaOCl Hauling by Truck	Citric Acid 100%	Dilution H2O	Product Delivered to Site (50% Solution)	Citric Acid Hauling by Truck	UF Membrane Disposal - PVC	UF Membrane Disposal - Polyester	PVC Hauling to Recycling Facility	PE Solids Hauling to Recycling Facility	CO2 Emissions from Biological Metabolism	Operation, lorry 16-13t, EURO5/RER S
	lmh	°C		kWh/day	kg/day	km/day	kg/day	kg/day	km/day	kg/day	kg/day	kg/day	km/day	kg/day	kg/day	km/day	km/day	kg/day	km
1	7.5	>25	F1/T1	6621	0	0.000	40	226	0.696	149	149	299	0.784	19.9	2.2	0.104	0.012	163	1.480
1	7.5	<20	F1/T2	6621	0	0.000	40	226	0.696	149	149	299	0.784	19.9	2.2	0.104	0.012	63	1.480
1	15.0	>25	F2/T1	3665	0	0.000	20	114	0.351	75	75	149	0.392	9.9	1.1	0.052	0.006	163	0.743
1	15.0	<20	F2/T2	3665	0	0.000	20	114	0.351	75	75	149	0.392	9.9	1.1	0.052	0.006	63	0.743
1	30.0	>25	F3/T1	2187	0	0.000	10	58	0.178	37	37	75	0.197	5.0	0.6	0.026	0.003	163	0.375
1	30.0	<20	F3/T2	2187	0	0.000	10	58	0.178	37	37	75	0.197	5.0	0.6	0.026	0.003	63	0.375
2	7.5	>25	F1/T1	3604	109	0.286	42	238	0.734	154	154	307	0.806	79.4	4.4	0.417	0.023	173	1.826
2	7.5	<20	F1/T2	3604	109	0.286	42	238	0.734	154	154	307	0.806	79.4	4.4	0.417	0.023	41	1.826
2	15.0	>25	F2/T1	2157	109	0.286	21	120	0.370	77	77	154	0.403	39.7	2.2	0.208	0.012	173	1.058
2	15.0	<20	F2/T2	2157	109	0.286	21	120	0.370	77	77	154	0.403	39.7	2.2	0.208	0.012	41	1.058
2	30.0	>25	F3/T1	1433	109	0.286	11	61	0.187	39	39	77	0.202	20.0	1.1	0.105	0.006	173	0.675
2	30.0	<20	F3/T2	1433	109	0.286	11	61	0.187	39	39	77	0.202	20.0	1.1	0.105	0.006	41	0.675
3	7.5	>25	F1/T1	6621	109	0.286	40	226	0.696	149	149	299	0.784	19.9	2.2	0.104	0.012	171	1.766
3	7.5	<20	F1/T2	6621	109	0.286	40	226	0.696	149	149	299	0.784	19.9	2.2	0.104	0.012	41	1.766
3	15.0	>25	F2/T1	3665	109	0.286	20	114	0.351	75	75	149	0.392	9.9	1.1	0.052	0.006	171	1.028
3	15.0	<20	F2/T2	3665	109	0.286	20	114	0.351	75	75	149	0.392	9.9	1.1	0.052	0.006	41	1.028
3	30.0	>25	F3/T1	2187	109	0.286	10	58	0.178	37	37	75	0.197	5.0	0.6	0.026	0.003	171	0.660
3	30.0	<20	F3/T2	2187	109	0.286	10	58	0.178	37	37	75	0.197	5.0	0.6	0.026	0.003	41	0.660
4	7.5	>25	F1/T1	6621	0	0.000	40	226	0.696	149	149	299	0.784	19.9	2.2	0.104	0.012	890	1.480
4	7.5	<20	F1/T2	6621	0	0.000	40	226	0.696	149	149	299	0.784	19.9	2.2	0.104	0.012	822	1.480
4	15.0	>25	F2/T1	3665	0	0.000	20	114	0.351	75	75	149	0.392	9.9	1.1	0.052	0.006	890	0.743
4	15.0	<20	F2/T2	3665	0	0.000	20	114	0.351	75	75	149	0.392	9.9	1.1	0.052	0.006	822	0.743
4	30.0	>25	F3/T1	2187	0	0.000	10	58	0.178	37	37	75	0.197	5.0	0.6	0.026	0.003	890	0.375
4	30.0	<20	F3/T2	2187	0	0.000	10	58	0.178	37	37	75	0.197	5.0	0.6	0.026	0.003	822	0.375
5	7.5	>25	F1/T1	3604	109	0.286	42	238	0.734	154	154	307	0.806	79.4	4.4	0.417	0.023	896	1.826
5	7.5	<20	F1/T2	3604	109	0.286	42	238	0.734	154	154	307	0.806	79.4	4.4	0.417	0.023	808	1.826
5	15.0	>25	F2/T1	2157	109	0.286	21	120	0.370	77	77	154	0.403	39.7	2.2	0.208	0.012	896	1.058
5	15.0	<20	F2/T2	2157	109	0.286	21	120	0.370	77	77	154	0.403	39.7	2.2	0.208	0.012	808	1.058
5	30.0	>25	F3/T1	1433	109	0.286	11	61	0.187	39	39	77	0.202	20.0	1.1	0.105	0.006	896	0.675
5	30.0	<20	F3/T2	1433	109	0.286	11	61	0.187	39	39	77	0.202	20.0	1.1	0.105	0.006	808	0.675
6	7.5	>25	F1/T1	6621	109	0.286	40	226	0.696	149	149	299	0.784	19.9	2.2	0.104	0.012	895	1.766
6	7.5	<20	F1/T2	6621	109	0.286	40	226	0.696	149	149	299	0.784	19.9	2.2	0.104	0.012	808	1.766
6	15.0	>25	F2/T1	3665	109	0.286	20	114	0.351	75	75	149	0.392	9.9	1.1	0.052	0.006	895	1.028
6	15.0	<20	F2/T2	3665	109	0.286	20	114	0.351	75	75	149	0.392	9.9	1.1	0.052	0.006	808	1.028
6	30.0	>25	F3/T1	2187	109	0.286	10	58	0.178	37	37	75	0.197	5.0	0.6	0.026	0.003	895	0.660
6	30.0	<20	F3/T2	2187	109	0.286	10	58	0.178	37	37	75	0.197	5.0	0.6	0.026	0.003	808	0.660
7	7.5	>25	F1/T1	6621	109	0.286	40	226	0.696	149	149	299	0.784	19.9	2.2	0.104	0.012	895	1.766
7	7.5	<20	F1/T2	6621	109	0.286	40	226	0.696	149	149	299	0.784	19.9	2.2	0.104	0.012	808	1.766
7	15.0	>25	F2/T1	3665	109	0.286	20	114	0.351	75	75	149	0.392	9.9	1.1	0.052	0.006	895	1.028
7	15.0	<20	F2/T2	3665	109	0.286	20	114	0.351	75	75	149	0.392	9.9	1.1	0.052	0.006	808	1.028
7	30.0	>25	F3/T1	2187	109	0.286	10	58	0.178	37	37	75	0.197	5.0	0.6	0.026	0.003	895	0.660
7	30.0	<20	F3/T2	2187	109	0.286	10	58	0.178	37	37	75	0.197	5.0	0.6	0.026	0.003	808	0.660
8	N/A	N/A	--	5322	0	0.000	0	0	0.000	0	0	0	0.000	0	0	0.000	0.000	3960	0.000

				04 - Sludge Management																		
				Energy Consumed	Energy Consumed	Chemical Consumed - Polymer for Biosolids Thickening+Dewatering					Chemical Consumed - Polymer for Chem Solids Thickening+Dewatering					Chemical Consumed - Quicklime		Waste Produced - Biosolids		Waste Produced - Inorganic Solids		Total Material Hauling
Process	Membrane Flux	Temperature	F/T	Thickening and Dewatering - Biosolids	Thickening and Dewatering - Chem Sludge	Polyacrylamide	Hydrotreated Light Petroleum Distillates	Dilution H2O	Product Shipped to Site	Polymer Hauling to Site by Truck	Polyacrylamide	Hydrotreated Light Petroleum Distillates	Dilution H2O	Product Shipped to Site	Polymer Hauling to Site by Truck	Quicklime	Quicklime Hauling to Site	Biosolids (wet cake)	Biosolids Hauling to Land Application Site	Inorganic Solids (wet cake)	Inorganic Solids Hauling to Land Application Site	Operation, lorry 16-13t, EURO5/RER S
	lmh	°C		kWh/day	kWh/day	kg/day	kg/day	kg/day	kg/day	km/day	kg/day	kg/day	kg/day	kg/day	km/day	kg/day	km/day	kg/day	km/day	kg/day	km/day	km
1	7.5	>25	F1/T1	143	48	4	4	5	14	0.036	0	0	0	0.0	0.000	1058	2.78	6346	16.7	0.0	0.0	2.811
1	7.5	<20	F1/T2	143	48	4	4	5	14	0.036	0	0	0	0.0	0.000	1058	2.78	6346	16.7	0.0	0.0	2.811
1	15.0	>25	F2/T1	143	48	4	4	5	14	0.036	0	0	0	0.0	0.000	1058	2.78	6346	16.7	0.0	0.0	2.811
1	15.0	<20	F2/T2	143	48	4	4	5	14	0.036	0	0	0	0.0	0.000	1058	2.78	6346	16.7	0.0	0.0	2.811
1	30.0	>25	F3/T1	143	48	4	4	5	14	0.036	0	0	0	0.0	0.000	1058	2.78	6346	16.7	0.0	0.0	2.811
1	30.0	<20	F3/T2	143	48	4	4	5	14	0.036	0	0	0	0.0	0.000	1058	2.78	6346	16.7	0.0	0.0	2.811
2	7.5	>25	F1/T1	143	48	4	4	5	14	0.036	0	0	0	0.0	0.000	1058	2.78	6346	16.7	0.0	0.0	2.811
2	7.5	<20	F1/T2	143	48	4	4	5	14	0.036	0	0	0	0.0	0.000	1058	2.78	6346	16.7	0.0	0.0	2.811
2	15.0	>25	F2/T1	143	48	4	4	5	14	0.036	0	0	0	0.0	0.000	1058	2.78	6346	16.7	0.0	0.0	2.811
2	15.0	<20	F2/T2	143	48	4	4	5	14	0.036	0	0	0	0.0	0.000	1058	2.78	6346	16.7	0.0	0.0	2.811
2	30.0	>25	F3/T1	143	48	4	4	5	14	0.036	0	0	0	0.0	0.000	1058	2.78	6346	16.7	0.0	0.0	2.811
2	30.0	<20	F3/T2	143	48	4	4	5	14	0.036	0	0	0	0.0	0.000	1058	2.78	6346	16.7	0.0	0.0	2.811
3	7.5	>25	F1/T1	143	48	4	4	5	14	0.036	0	0	0	0.0	0.000	1058	2.78	6346	16.7	0.0	0.0	2.811
3	7.5	<20	F1/T2	143	48	4	4	5	14	0.036	0	0	0	0.0	0.000	1058	2.78	6346	16.7	0.0	0.0	2.811
3	15.0	>25	F2/T1	143	48	4	4	5	14	0.036	0	0	0	0.0	0.000	1058	2.78	6346	16.7	0.0	0.0	2.811
3	15.0	<20	F2/T2	143	48	4	4	5	14	0.036	0	0	0	0.0	0.000	1058	2.78	6346	16.7	0.0	0.0	2.811
3	30.0	>25	F3/T1	143	48	4	4	5	14	0.036	0	0	0	0.0	0.000	1058	2.78	6346	16.7	0.0	0.0	2.811
3	30.0	<20	F3/T2	143	48	4	4	5	14	0.036	0	0	0	0.0	0.000	1058	2.78	6346	16.7	0.0	0.0	2.811
4	7.5	>25	F1/T1	143	48	7	7	10	25	0.065	0	0	0	0.0	0.000	0	0.00	6912	18.1	0.0	0.0	0.065
4	7.5	<20	F1/T2	143	48	7	7	10	25	0.065	0	0	0	0.0	0.000	0	0.00	6912	18.1	0.0	0.0	0.065
4	15.0	>25	F2/T1	143	48	7	7	10	25	0.065	0	0	0	0.0	0.000	0	0.00	6912	18.1	0.0	0.0	0.065
4	15.0	<20	F2/T2	143	48	7	7	10	25	0.065	0	0	0	0.0	0.000	0	0.00	6912	18.1	0.0	0.0	0.065
4	30.0	>25	F3/T1	143	48	7	7	10	25	0.065	0	0	0	0.0	0.000	0	0.00	6912	18.1	0.0	0.0	0.065
4	30.0	<20	F3/T2	143	48	7	7	10	25	0.065	0	0	0	0.0	0.000	0	0.00	6912	18.1	0.0	0.0	0.065
5	7.5	>25	F1/T1	143	48	7	7	10	25	0.065	0	0	0	0.0	0.000	0	0.00	6912	18.1	0.0	0.0	0.065
5	7.5	<20	F1/T2	143	48	7	7	10	25	0.065	0	0	0	0.0	0.000	0	0.00	6912	18.1	0.0	0.0	0.065
5	15.0	>25	F2/T1	143	48	7	7	10	25	0.065	0	0	0	0.0	0.000	0	0.00	6912	18.1	0.0	0.0	0.065
5	15.0	<20	F2/T2	143	48	7	7	10	25	0.065	0	0	0	0.0	0.000	0	0.00	6912	18.1	0.0	0.0	0.065
5	30.0	>25	F3/T1	143	48	7	7	10	25	0.065	0	0	0	0.0	0.000	0	0.00	6912	18.1	0.0	0.0	0.065
5	30.0	<20	F3/T2	143	48	7	7	10	25	0.065	0	0	0	0.0	0.000	0	0.00	6912	18.1	0.0	0.0	0.065
6	7.5	>25	F1/T1	143	48	7	7	10	25	0.065	0	0	0	0.0	0.000	0	0.00	6912	18.1	0.0	0.0	0.065
6	7.5	<20	F1/T2	143	48	7	7	10	25	0.065	0	0	0	0.0	0.000	0	0.00	6912	18.1	0.0	0.0	0.065
6	15.0	>25	F2/T1	143	48	7	7	10	25	0.065	0	0	0	0.0	0.000	0	0.00	6912	18.1	0.0	0.0	0.065
6	15.0	<20	F2/T2	143	48	7	7	10	25	0.065	0	0	0	0.0	0.000	0	0.00	6912	18.1	0.0	0.0	0.065
6	30.0	>25	F3/T1	143	48	7	7	10	25	0.065	0	0	0	0.0	0.000	0	0.00	6912	18.1	0.0	0.0	0.065
6	30.0	<20	F3/T2	143	48	7	7	10	25	0.065	0	0	0	0.0	0.000	0	0.00	6912	18.1	0.0	0.0	0.065
7	7.5	>25	F1/T1	143	48	7	7	10	25	0.065	0	0	0	0.0	0.000	0	0.00	6912	18.1	0.0	0.0	0.065
7	7.5	<20	F1/T2	143	48	7	7	10	25	0.065	0	0	0	0.0	0.000	0	0.00	6912	18.1	0.0	0.0	0.065
7	15.0	>25	F2/T1	143	48	7	7	10	25	0.065	0	0	0	0.0	0.000	0	0.00	6912	18.1	0.0	0.0	0.065
7	15.0	<20	F2/T2	143	48	7	7	10	25	0.065	0	0	0	0.0	0.000	0	0.00	6912	18.1	0.0	0.0	0.065
7	30.0	>25	F3/T1	143	48	7	7	10	25	0.065	0	0	0	0.0	0.000	0	0.00	6912	18.1	0.0	0.0	0.065
7	30.0	<20	F3/T2	143	48	7	7	10	25	0.065	0	0	0	0.0	0.000	0	0.00	6912	18.1	0.0	0.0	0.065
8	N/A	N/A	--	143	0	9	9	11	28	0.074	0	0	0	0	0.000	0	0.00	11543	30.3	0	0	0.074

				05 - Biogas Handling, Treatment, and Beneficial Use									
				Energy Consumed	Energy Consumed	Energy Consumed	Energy Produced	Energy Produced	Energy Produced	Process Byproduct	Waste Produced		Process Byproduct
Process	Membrane Flux	Temperature	F/T	Anaerobic Digester Mixer	Anaerobic Digester Heating	Biogas Treatment and Storage	Bioreactor Methane - AVOIDED PRODUCT	AD Methane - AVOIDED PRODUCT	Dissolved Methane Recovery - AVOIDED PRODUCT	Elemental Sulfur for disposal or recycle - AVOIDED PRODUCT	CO2 Emissions	Heat Balance on Digesters	Excess Heat - AVOID PRODUCT
	lmh	°C		kWh/day	kWh/day	kWh/day	kWh/day	kWh/day	kWh/day	kg/day	kg/day	kWh/day	MJ/day
1	7.5	>25	F1/T1	0	0	351	3317	0	1506	5.8	2691	4647	16729
1	7.5	<20	F1/T2	0	0	294	1287	0	1614	2.2	1700	3315	11933
1	15.0	>25	F2/T1	0	0	351	3317	0	1506	5.8	2691	4647	16729
1	15.0	<20	F2/T2	0	0	294	1287	0	1614	2.2	1700	3315	11933
1	30.0	>25	F3/T1	0	0	351	3317	0	1506	5.8	2691	4647	16729
1	30.0	<20	F3/T2	0	0	294	1287	0	1614	2.2	1700	3315	11933
2	7.5	>25	F1/T1	0	0	357	3526	0	1506	6.1	2800	4801	17283
2	7.5	<20	F1/T2	0	0	282	831	0	1614	1.5	1463	2980	10729
2	15.0	>25	F2/T1	0	0	357	3526	0	1506	6.1	2800	4801	17283
2	15.0	<20	F2/T2	0	0	282	831	0	1614	1.5	1463	2980	10729
2	30.0	>25	F3/T1	0	0	357	3526	0	1506	6.1	2800	4801	17283
2	30.0	<20	F3/T2	0	0	282	831	0	1614	1.5	1463	2980	10729
3	7.5	>25	F1/T1	0	0	356	3492	0	1506	6.1	2782	4776	17193
3	7.5	<20	F1/T2	0	0	282	827	0	1614	1.4	1460	2977	10716
3	15.0	>25	F2/T1	0	0	356	3492	0	1506	6.1	2782	4776	17193
3	15.0	<20	F2/T2	0	0	282	827	0	1614	1.4	1460	2977	10716
3	30.0	>25	F3/T1	0	0	356	3492	0	1506	6.1	2782	4776	17193
3	30.0	<20	F3/T2	0	0	282	827	0	1614	1.4	1460	2977	10716
4	7.5	>25	F1/T1	48	0	433	2156	3907	979	7.3	3848	6271	22574
4	7.5	<20	F1/T2	48	0	395	783	3907	1097	4.9	3206	5349	19257
4	15.0	>25	F2/T1	48	0	433	2156	3907	979	7.3	3848	6271	22574
4	15.0	<20	F2/T2	48	0	395	783	3907	1097	4.9	3206	5349	19257
4	30.0	>25	F3/T1	48	0	433	2156	3907	979	7.3	3848	6271	22574
4	30.0	<20	F3/T2	48	0	395	783	3907	1097	4.9	3206	5349	19257
5	7.5	>25	F1/T1	48	0	437	2292	3907	979	7.6	3919	6370	22933
5	7.5	<20	F1/T2	48	0	386	487	3907	1097	4.4	3052	5132	18475
5	15.0	>25	F2/T1	48	0	437	2292	3907	979	7.6	3919	6370	22933
5	15.0	<20	F2/T2	48	0	386	487	3907	1097	4.4	3052	5132	18475
5	30.0	>25	F3/T1	48	0	437	2292	3907	979	7.6	3919	6370	22933
5	30.0	<20	F3/T2	48	0	386	487	3907	1097	4.4	3052	5132	18475
6	7.5	>25	F1/T1	48	0	436	2270	3907	979	7.5	3908	6354	22875
6	7.5	<20	F1/T2	48	0	386	484	3907	1097	4.4	3050	5130	18466
6	15.0	>25	F2/T1	48	0	436	2270	3907	979	7.5	3908	6354	22875
6	15.0	<20	F2/T2	48	0	386	484	3907	1097	4.4	3050	5130	18466
6	30.0	>25	F3/T1	48	0	436	2270	3907	979	7.5	3908	6354	22875
6	30.0	<20	F3/T2	48	0	386	484	3907	1097	4.4	3050	5130	18466
7	7.5	>25	F1/T1	48	0	375	2270	3907	979	7.5	3847	5967	21482
7	7.5	<20	F1/T2	48	0	325	484	3907	1097	4.4	2990	4742	17073
7	15.0	>25	F2/T1	48	0	375	2270	3907	979	7.5	3847	5967	21482
7	15.0	<20	F2/T2	48	0	325	484	3907	1097	4.4	2990	4742	17073
7	30.0	>25	F3/T1	48	0	375	2270	3907	979	7.5	3847	5967	21482
7	30.0	<20	F3/T2	48	0	325	484	3907	1097	4.4	2990	4742	17073
8	N/A	N/A	--	48	0	277	0	4568	0	4.2	2383	3348	12052

				06 - Dissolved Methane Removal						07 - Disinfection			
				Energy Consumed	Membrane Materials Consumed and Disposed				Methane Emissions	Chemical Consumed - NaOCl for Disinfection			
Process	Membrane Flux	Temperature	F/T	Dissolved CH4 Removal	CH4 Contactor Disposal - PVC	CH4 Contactor Disposal - Polypropylene	PVC Hauling to Recycling Facility	PP Solids Hauling to Recycling Facility	Dissolved CH4 Emitted to Atmosphere	100% NaOCl - Disinfection	Dilution H2O	Product Delivered to Facility (12.5% Solution)	NaOCl hauling to site
	lmh	°C		kWh/day	kg/day	kg/day	km/day	km/day	kg/day	kg/day	kg/day	kg/day	km/day
1	7.5	>25	F1/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
1	7.5	<20	F1/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
1	15.0	>25	F2/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
1	15.0	<20	F2/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
1	30.0	>25	F3/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
1	30.0	<20	F3/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
2	7.5	>25	F1/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
2	7.5	<20	F1/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
2	15.0	>25	F2/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
2	15.0	<20	F2/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
2	30.0	>25	F3/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
2	30.0	<20	F3/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
3	7.5	>25	F1/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
3	7.5	<20	F1/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
3	15.0	>25	F2/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
3	15.0	<20	F2/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
3	30.0	>25	F3/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
3	30.0	<20	F3/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
4	7.5	>25	F1/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
4	7.5	<20	F1/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
4	15.0	>25	F2/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
4	15.0	<20	F2/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
4	30.0	>25	F3/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
4	30.0	<20	F3/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
5	7.5	>25	F1/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
5	7.5	<20	F1/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
5	15.0	>25	F2/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
5	15.0	<20	F2/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
5	30.0	>25	F3/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
5	30.0	<20	F3/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
6	7.5	>25	F1/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
6	7.5	<20	F1/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
6	15.0	>25	F2/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
6	15.0	<20	F2/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
6	30.0	>25	F3/T1	2471	0.66	0.17	0.003	0.001	31.823	341	1932	2273	6.0
6	30.0	<20	F3/T2	2471	0.66	0.17	0.003	0.001	34.096	341	1932	2273	6.0
7	7.5	>25	F1/T1	413	0	0	0.000	0.000	20.685	341	1932	2273	6.0
7	7.5	<20	F1/T2	413	0	0	0.000	0.000	23.178	341	1932	2273	6.0
7	15.0	>25	F2/T1	413	0	0	0.000	0.000	20.685	341	1932	2273	6.0
7	15.0	<20	F2/T2	413	0	0	0.000	0.000	23.178	341	1932	2273	6.0
7	30.0	>25	F3/T1	413	0	0	0.000	0.000	20.685	341	1932	2273	6.0
7	30.0	<20	F3/T2	413	0	0	0.000	0.000	23.178	341	1932	2273	6.0
8	N/A	N/A	--	0	0	0	0.000	0.000	0.000	273	1546	1818	4.8

				Total Hauling	Net Energy Calculation			Unit energy	
				Sum of all Hauling	**Energy From the Grid**	Energy Consumed	Energy Produced	Energy Consumed	Energy Produced
Process	Membrane Flux lmh	Temperature °C	F/T	landfill, land application, and chemical delivery km/day	(+) Energy from Grid (-) Energy to Grid kWh/day	Consumed from Grid kWh/day	Sold Back to the Grid kWh/day	Consumed from Grid kWh/m^3	Sold Back to the Grid kWh/m^3
1	7.5	>25	F1/T1	31	5477	5477	0	0.289	0.000
1	7.5	<20	F1/T2	31	7343	7343	0	0.388	0.000
1	15.0	>25	F2/T1	31	2521	2521	0	0.133	0.000
1	15.0	<20	F2/T2	31	4387	4387	0	0.232	0.000
1	30.0	>25	F3/T1	30	1043	1043	0	0.055	0.000
1	30.0	<20	F3/T2	30	2909	2909	0	0.154	0.000
2	7.5	>25	F1/T1	32	2257	2257	0	0.119	0.000
2	7.5	<20	F1/T2	32	4768	4768	0	0.252	0.000
2	15.0	>25	F2/T1	31	809	809	0	0.043	0.000
2	15.0	<20	F2/T2	31	3321	3321	0	0.175	0.000
2	30.0	>25	F3/T1	31	85	85	0	0.005	0.000
2	30.0	<20	F3/T2	31	2597	2597	0	0.137	0.000
3	7.5	>25	F1/T1	32	5307	5307	0	0.280	0.000
3	7.5	<20	F1/T2	32	7790	7790	0	0.412	0.000
3	15.0	>25	F2/T1	31	2351	2351	0	0.124	0.000
3	15.0	<20	F2/T2	31	4834	4834	0	0.255	0.000
3	30.0	>25	F3/T1	31	873	873	0	0.046	0.000
3	30.0	<20	F3/T2	31	3356	3356	0	0.177	0.000
4	7.5	>25	F1/T1	30	3488	3488	0	0.184	0.000
4	7.5	<20	F1/T2	30	4705	4705	0	0.249	0.000
4	15.0	>25	F2/T1	29	532	532	0	0.028	0.000
4	15.0	<20	F2/T2	29	1749	1749	0	0.092	0.000
4	30.0	>25	F3/T1	29	-946	0	946	0.000	0.050
4	30.0	<20	F3/T2	29	270	270	0	0.014	0.000
5	7.5	>25	F1/T1	30	339	339	0	0.018	0.000
5	7.5	<20	F1/T2	30	1975	1975	0	0.104	0.000
5	15.0	>25	F2/T1	30	-1109	0	1109	0.000	0.059
5	15.0	<20	F2/T2	30	528	528	0	0.028	0.000
5	30.0	>25	F3/T1	29	-1833	0	1833	0.000	0.097
5	30.0	<20	F3/T2	29	-196	0	196	0.000	0.010
6	7.5	>25	F1/T1	30	3377	3377	0	0.178	0.000
6	7.5	<20	F1/T2	30	4995	4995	0	0.264	0.000
6	15.0	>25	F2/T1	30	421	421	0	0.022	0.000
6	15.0	<20	F2/T2	30	2039	2039	0	0.108	0.000
6	30.0	>25	F3/T1	29	-1057	0	1057	0.000	0.056
6	30.0	<20	F3/T2	29	561	561	0	0.030	0.000
7	7.5	>25	F1/T1	30	1258	1258	0	0.066	0.000
7	7.5	<20	F1/T2	30	2876	2876	0	0.152	0.000
7	15.0	>25	F2/T1	30	-1698	0	1698	0.000	0.090
7	15.0	<20	F2/T2	30	-80	0	80	0.000	0.004
7	30.0	>25	F3/T1	29	-3176	0	3176	0.000	0.168
7	30.0	<20	F3/T2	29	-1558	0	1558	0.000	0.082
8	N/A	N/A	--	39	1924	1924	0	0.102	0.000

Appendix H

Lifecycle Assessment Waste Inventory for Nutrient Removal Sensitivity Analysis

				Sludge								Membrane Recycling										Overall Waste (sludge &
	Membrane Flux	Temperature	F/T	Screenings and Grit		Biosolids (wet cake)		Inorganic Solids (wet cake)		Total		UF Membrane Disposal PVC		UF Membrane Disposal Polyester		CH4 Contactor Disposal - PVC		CH4 Contactor Disposal - Polypropylene		Total		
Process	lmh	°C		kg/day	%	kg/day	%	kg/day	%	kg/day	% overall waste	kg/day	%	kg/day	%	kg/day	%	kg/day	%	kg/day	% overall waste	kg/day
1	7.5	>25	F1/T1	850	11.81%	6346	88.19%	0	0.00%	7195	99.68%	19.9	86.74%	2.2	9.64%	0.66	2.90%	0.17	0.72%	22.88	0.32%	7218.26
1	7.5	<20	F1/T2	850	11.81%	6346	88.19%	0	0.00%	7195	99.68%	19.9	86.74%	2.2	9.64%	0.66	2.90%	0.17	0.72%	22.88	0.32%	7218.26
1	15.0	>25	F2/T1	850	11.81%	6346	88.19%	0	0.00%	7195	99.84%	9.9	83.71%	1.1	9.30%	0.66	5.59%	0.17	1.40%	11.86	0.16%	7207.23
1	15.0	<20	F2/T2	850	11.81%	6346	88.19%	0	0.00%	7195	99.84%	9.9	83.71%	1.1	9.30%	0.66	5.59%	0.17	1.40%	11.86	0.16%	7207.23
1	30.0	>25	F3/T1	850	11.81%	6346	88.19%	0	0.00%	7195	99.91%	5.0	78.31%	0.6	8.70%	0.66	10.39%	0.17	2.60%	6.38	0.09%	7201.75
1	30.0	<20	F3/T2	850	11.81%	6346	88.19%	0	0.00%	7195	99.91%	5.0	78.31%	0.6	8.70%	0.66	10.39%	0.17	2.60%	6.38	0.09%	7201.75
2	7.5	>25	F1/T1	850	11.81%	6346	88.19%	0	0.00%	7195	98.84%	79.4	93.81%	4.4	5.21%	0.66	0.78%	0.17	0.20%	84.64	1.16%	7280.01
2	7.5	<20	F1/T2	850	11.81%	6346	88.19%	0	0.00%	7195	98.84%	79.4	93.81%	4.4	5.21%	0.66	0.78%	0.17	0.20%	84.64	1.16%	7280.01
2	15.0	>25	F2/T1	850	11.81%	6346	88.19%	0	0.00%	7195	99.41%	39.7	92.90%	2.2	5.16%	0.66	1.55%	0.17	0.39%	42.74	0.59%	7238.11
2	15.0	<20	F2/T2	850	11.81%	6346	88.19%	0	0.00%	7195	99.41%	39.7	92.90%	2.2	5.16%	0.66	1.55%	0.17	0.39%	42.74	0.59%	7238.11
2	30.0	>25	F3/T1	850	11.81%	6346	88.19%	0	0.00%	7195	99.70%	20.0	91.16%	1.1	5.06%	0.66	3.02%	0.17	0.76%	21.92	0.30%	7217.29
2	30.0	<20	F3/T2	850	11.81%	6346	88.19%	0	0.00%	7195	99.70%	20.0	91.16%	1.1	5.06%	0.66	3.02%	0.17	0.76%	21.92	0.30%	7217.29
3	7.5	>25	F1/T1	850	11.81%	6346	88.19%	0	0.00%	7195	99.68%	19.9	86.74%	2.2	9.64%	0.66	2.90%	0.17	0.72%	22.88	0.32%	7218.26
3	7.5	<20	F1/T2	850	11.81%	6346	88.19%	0	0.00%	7195	99.68%	19.9	86.74%	2.2	9.64%	0.66	2.90%	0.17	0.72%	22.88	0.32%	7218.26
3	15.0	>25	F2/T1	850	11.81%	6346	88.19%	0	0.00%	7195	99.84%	9.9	83.71%	1.1	9.30%	0.66	5.59%	0.17	1.40%	11.86	0.16%	7207.23
3	15.0	<20	F2/T2	850	11.81%	6346	88.19%	0	0.00%	7195	99.84%	9.9	83.71%	1.1	9.30%	0.66	5.59%	0.17	1.40%	11.86	0.16%	7207.23
3	30.0	>25	F3/T1	850	11.81%	6346	88.19%	0	0.00%	7195	99.91%	5.0	78.31%	0.6	8.70%	0.66	10.39%	0.17	2.60%	6.38	0.09%	7201.75
3	30.0	<20	F3/T2	850	11.81%	6346	88.19%	0	0.00%	7195	99.91%	5.0	78.31%	0.6	8.70%	0.66	10.39%	0.17	2.60%	6.38	0.09%	7201.75
4	7.5	>25	F1/T1	843	10.87%	6912	89.13%	0	0.00%	7756	99.71%	19.9	86.74%	2.2	9.64%	0.66	2.90%	0.17	0.72%	22.88	0.29%	7778.40
4	7.5	<20	F1/T2	843	10.87%	6912	89.13%	0	0.00%	7756	99.71%	19.9	86.74%	2.2	9.64%	0.66	2.90%	0.17	0.72%	22.88	0.29%	7778.40
4	15.0	>25	F2/T1	843	10.87%	6912	89.13%	0	0.00%	7756	99.85%	9.9	83.71%	1.1	9.30%	0.66	5.59%	0.17	1.40%	11.86	0.15%	7767.37
4	15.0	<20	F2/T2	843	10.87%	6912	89.13%	0	0.00%	7756	99.85%	9.9	83.71%	1.1	9.30%	0.66	5.59%	0.17	1.40%	11.86	0.15%	7767.37
4	30.0	>25	F3/T1	843	10.87%	6912	89.13%	0	0.00%	7756	99.92%	5.0	78.31%	0.6	8.70%	0.66	10.39%	0.17	2.60%	6.38	0.08%	7761.89
4	30.0	<20	F3/T2	843	10.87%	6912	89.13%	0	0.00%	7756	99.92%	5.0	78.31%	0.6	8.70%	0.66	10.39%	0.17	2.60%	6.38	0.08%	7761.89
5	7.5	>25	F1/T1	843	10.87%	6912	89.13%	0	0.00%	7756	98.92%	79.4	93.81%	4.4	5.21%	0.66	0.78%	0.17	0.20%	84.64	1.08%	7840.16
5	7.5	<20	F1/T2	843	10.87%	6912	89.13%	0	0.00%	7756	98.92%	79.4	93.81%	4.4	5.21%	0.66	0.78%	0.17	0.20%	84.64	1.08%	7840.16
5	15.0	>25	F2/T1	843	10.87%	6912	89.13%	0	0.00%	7756	99.45%	39.7	92.90%	2.2	5.16%	0.66	1.55%	0.17	0.39%	42.74	0.55%	7798.25
5	15.0	<20	F2/T2	843	10.87%	6912	89.13%	0	0.00%	7756	99.45%	39.7	92.90%	2.2	5.16%	0.66	1.55%	0.17	0.39%	42.74	0.55%	7798.25
5	30.0	>25	F3/T1	843	10.87%	6912	89.13%	0	0.00%	7756	99.72%	20.0	91.16%	1.1	5.06%	0.66	3.02%	0.17	0.76%	21.92	0.28%	7777.43
5	30.0	<20	F3/T2	843	10.87%	6912	89.13%	0	0.00%	7756	99.72%	20.0	91.16%	1.1	5.06%	0.66	3.02%	0.17	0.76%	21.92	0.28%	7777.43
6	7.5	>25	F1/T1	843	10.87%	6912	89.13%	0	0.00%	7756	99.71%	19.9	86.74%	2.2	9.64%	0.66	2.90%	0.17	0.72%	22.88	0.29%	7778.40
6	7.5	<20	F1/T2	843	10.87%	6912	89.13%	0	0.00%	7756	99.71%	19.9	86.74%	2.2	9.64%	0.66	2.90%	0.17	0.72%	22.88	0.29%	7778.40
6	15.0	>25	F2/T1	843	10.87%	6912	89.13%	0	0.00%	7756	99.85%	9.9	83.71%	1.1	9.30%	0.66	5.59%	0.17	1.40%	11.86	0.15%	7767.37
6	15.0	<20	F2/T2	843	10.87%	6912	89.13%	0	0.00%	7756	99.85%	9.9	83.71%	1.1	9.30%	0.66	5.59%	0.17	1.40%	11.86	0.15%	7767.37
6	30.0	>25	F3/T1	843	10.87%	6912	89.13%	0	0.00%	7756	99.92%	5.0	78.31%	0.6	8.70%	0.66	10.39%	0.17	2.60%	6.38	0.08%	7761.89
6	30.0	<20	F3/T2	843	10.87%	6912	89.13%	0	0.00%	7756	99.92%	5.0	78.31%	0.6	8.70%	0.66	10.39%	0.17	2.60%	6.38	0.08%	7761.89
7	7.5	>25	F1/T1	843	10.87%	6912	89.13%	0	0.00%	7756	99.72%	19.9	90.00%	2.2	10.00%	0	0.00%	0	0.00%	22.06	0.28%	7777.57
7	7.5	<20	F1/T2	843	10.87%	6912	89.13%	0	0.00%	7756	99.72%	19.9	90.00%	2.2	10.00%	0	0.00%	0	0.00%	22.06	0.28%	7777.57
7	15.0	>25	F2/T1	843	10.87%	6912	89.13%	0	0.00%	7756	99.86%	9.9	90.00%	1.1	10.00%	0	0.00%	0	0.00%	11.03	0.14%	7766.54
7	15.0	<20	F2/T2	843	10.87%	6912	89.13%	0	0.00%	7756	99.86%	9.9	90.00%	1.1	10.00%	0	0.00%	0	0.00%	11.03	0.14%	7766.54
7	30.0	>25	F3/T1	843	10.87%	6912	89.13%	0	0.00%	7756	99.93%	5.0	90.00%	0.6	10.00%	0	0.00%	0	0.00%	5.55	0.07%	7761.06
7	30.0	<20	F3/T2	843	10.87%	6912	89.13%	0	0.00%	7756	99.93%	5.0	90.00%	0.6	10.00%	0	0.00%	0	0.00%	5.55	0.07%	7761.06
8	N/A	N/A	--	819	6.63%	11543	93.37%	0	0.00%	12362	100.00%	0	#DIV/0!	0	#DIV/0!	0	#DIV/0!	0	#DIV/0!	0.00	0.00%	12361.89

Process	Waste Hauled - by truck							
	Screenings and Grit km/day	Biosolids Hauling to km/day	Inorganic Solids Hauling km/day	PVC Hauling to Recycling km/day	PE Solids Hauling to km/day	PVC Hauling to Recycling km/day	PP Solids Hauling to km/day	**Total km/day**
1	4.459	16.7	0.0	0.104	0.012	0.003	0.001	**21.229**
1	4.459	16.7	0.0	0.104	0.012	0.003	0.001	**21.229**
1	4.459	16.7	0.0	0.052	0.006	0.003	0.001	**21.171**
1	4.459	16.7	0.0	0.052	0.006	0.003	0.001	**21.171**
1	4.459	16.7	0.0	0.026	0.003	0.003	0.001	**21.142**
1	4.459	16.7	0.0	0.026	0.003	0.003	0.001	**21.142**
2	4.459	16.7	0.0	0.417	0.023	0.003	0.001	**21.553**
2	4.459	16.7	0.0	0.417	0.023	0.003	0.001	**21.553**
2	4.459	16.7	0.0	0.208	0.012	0.003	0.001	**21.333**
2	4.459	16.7	0.0	0.208	0.012	0.003	0.001	**21.333**
2	4.459	16.7	0.0	0.105	0.006	0.003	0.001	**21.224**
2	4.459	16.7	0.0	0.105	0.006	0.003	0.001	**21.224**
3	4.459	16.7	0.0	0.104	0.012	0.003	0.001	**21.229**
3	4.459	16.7	0.0	0.104	0.012	0.003	0.001	**21.229**
3	4.459	16.7	0.0	0.052	0.006	0.003	0.001	**21.171**
3	4.459	16.7	0.0	0.052	0.006	0.003	0.001	**21.171**
3	4.459	16.7	0.0	0.026	0.003	0.003	0.001	**21.142**
3	4.459	16.7	0.0	0.026	0.003	0.003	0.001	**21.142**
4	4.424	18.1	0.0	0.104	0.012	0.003	0.001	**22.681**
4	4.424	18.1	0.0	0.104	0.012	0.003	0.001	**22.681**
4	4.424	18.1	0.0	0.052	0.006	0.003	0.001	**22.623**
4	4.424	18.1	0.0	0.052	0.006	0.003	0.001	**22.623**
4	4.424	18.1	0.0	0.026	0.003	0.003	0.001	**22.595**
4	4.424	18.1	0.0	0.026	0.003	0.003	0.001	**22.595**
5	4.424	18.1	0.0	0.417	0.023	0.003	0.001	**23.005**
5	4.424	18.1	0.0	0.417	0.023	0.003	0.001	**23.005**
5	4.424	18.1	0.0	0.208	0.012	0.003	0.001	**22.785**
5	4.424	18.1	0.0	0.208	0.012	0.003	0.001	**22.785**
5	4.424	18.1	0.0	0.105	0.006	0.003	0.001	**22.676**
5	4.424	18.1	0.0	0.105	0.006	0.003	0.001	**22.676**
6	4.424	18.1	0.0	0.104	0.012	0.003	0.001	**22.681**
6	4.424	18.1	0.0	0.104	0.012	0.003	0.001	**22.681**

Process	Waste Hauled - by truck							
	Screenings and Grit km/day	Biosolids Hauling to km/day	Inorganic Solids Hauling km/day	PVC Hauling to Recycling km/day	PE Solids Hauling to km/day	PVC Hauling to Recycling km/day	PP Solids Hauling to km/day	**Total km/day**
6	4.424	18.1	0.0	0.052	0.006	0.003	0.001	**22.623**
6	4.424	18.1	0.0	0.052	0.006	0.003	0.001	**22.623**
6	4.424	18.1	0.0	0.026	0.003	0.003	0.001	**22.595**
6	4.424	18.1	0.0	0.026	0.003	0.003	0.001	**22.595**
7	4.424	18.1	0.0	0.104	0.012	0.000	0.000	**22.677**
7	4.424	18.1	0.0	0.104	0.012	0.000	0.000	**22.677**
7	4.424	18.1	0.0	0.052	0.006	0.000	0.000	**22.619**
7	4.424	18.1	0.0	0.052	0.006	0.000	0.000	**22.619**
7	4.424	18.1	0.0	0.026	0.003	0.000	0.000	**22.590**
7	4.424	18.1	0.0	0.026	0.003	0.000	0.000	**22.590**
8	4.299	30.3	0	0.000	0.000	0.000	0.000	**34.585**

Appendix H

Lifecycle Assessment Material and Energy Inventory for Biological Sulfide Removal Sensitivity Analysis

				01 - Primary Treatment					02 - Secondary Treatment															
				Energy Consumed	Energy Consumed	Energy Consumed	Waste Produced	Waste Hauled by truck	Energy Consumed	Chem. Consumed - GAC		Chemical Consumed - NaOCl for Membrane Cleaning			Chemical Consumed - Citric Acid for Membrane Cleaning				Membrane Materials Consumed and Disposed				Waste Produced	Total Hauling
Process	Membrane Flux	Temperature	F/T	Screening and Grit Removal	Equalization	Primary Sedimentation	Screenings and Grit	Screenings and Grit Hauled to Landfill	Biological Treatment	GAC	GAC Delivered to Site by Truck	NaOCl 100%	Dilution H2O	NaOCl Hauling by Truck	Citric Acid 100%	Dilution H2O	Product Delivered to Site (50% Solution)	Citric Acid Hauling by Truck	UF Membrane Disposal - PVC	UF Membrane Disposal - Polyester	PVC Hauling to Recycling Facility	PE Solids Hauling to Recycling Facility	CO2 Emissions from Biological Metabolism	Operation, lorry 16-13t, EURO5/RER S
	lmh	°C		kWh/day	kWh/day	kWh/day	kg/day	km/day	kWh/day	kg/day	km/day	kg/day	kg/day	km/day	kg/day	kg/day	kg/day	km/day	kg/day	kg/day	km/day	km/day	kg/day	km
7 Bio S Ox	15.0	>25	F2/T1	630	35	100	843	4.424	3665	109	0.286	20	114	0.351	75	75	149	0.392	9.9	1.1	0.052	0.006	895	1.028
8	N/A	N/A	--	602	0	100	819	4.299	5322	0	0.000	0	0	0.000	0	0	0	0.000	0	0	0.000	0.000	3960	0.000

				03 - Nutrient Removal																		
				Energy Consumed	Chemical Consumed - FeCl3				Chemical Consumed - PACl		Chemical Consumed - Polymer for P Removal						Chemical Consumed - Alum for P Removal				Total Hauling
Process	Membrane Flux	Temperature	F/T	Phosphorous Removal	FeCl3, 100% solution	Dilution H2O	Product Delivered to Site (40% FeCl3)	FeCl3 Hauling to Site	PACl Solution Delivered to Site	PACl Hauling to Site	Polyacrylamide	Hydrotreated Light Petroleum Distillates	Dilution H2O	Product Delivered to Site	Polymer Hauling to Site	100% Aluminum Sulfate	Dilution H2O	Product Delivered to Site (48% Alum Solution)	Alum Hauling to Site	Operation, lorry 16-13t, EURO5/RER S
	lmh	°C		kWh/day	kg/day	kg/day	kg/day	km/day	kg/day	km/day	kg/day	kg/day	kg/day	kg/day	km/day	kg/day	kg/day	kg/day	km/day	km
7 Bio S Ox	15.0	>25	F2/T1	977	0	0	0	0	0	0.0	0	0	0	0	0.000	1008	1092	2100	5.5	5.511
8	N/A	N/A	--	215	0	0	0	0	0	0.0	0	0	0	0	0.000	1008	1092	2100	5.5	5.511

				04 - Sludge Management																		
				Energy Consumed	Energy Consumed	Chemical Consumed - Polymer for Biosolids Thickening+Dewatering					Chemical Consumed - Polymer for Chem Solids Thickening+Dewatering					Chemical Consumed - Quicklime		Waste Produced - Biosolids		Waste Produced - Inorganic Solids		Total Material Hauling
Process	Membrane Flux	Temperature	F/T	Thickening and Dewatering - Biosolids	Thickening and Dewatering - Chem Sludge	Polyacrylamide	Hydrotreated Light Petroleum Distillates	Dilution H2O	Product Shipped to Site	Polymer Hauling to Site by Truck	Polyacrylamide	Hydrotreated Light Petroleum Distillates	Dilution H2O	Product Shipped to Site	Polymer Hauling to Site by Truck	Quicklime	Quicklime Hauling to Site	Biosolids (wet cake)	Biosolids Hauling to Land Application Site	Inorganic Solids (wet cake)	Inorganic Solids Hauling to Land Application Site	Operation, lorry 16-13t, EURO5/RER S
	lmh	°C		kWh/day	kWh/day	kg/day	kg/day	kg/day	kg/day	km/day	kg/day	kg/day	kg/day	kg/day	km/day	kg/day	km/day	kg/day	km/day	kg/day	km/day	km
7 Bio S Ox	15.0	>25	F2/T1	143	0	7	7	10	25	0.065	0	0	0	0	0.000	0	0.00	7857	20.6	0	0	0.065
8	N/A	N/A	--	143	0	9	9	11	28	0.074	0	0	0	0	0.000	0	0.00	11543	30.3	0	0	0.074

				05 - Biogas Handling, Treatment, and Beneficial Use									
				Energy Consumed	Energy Consumed	Energy Consumed	Energy Produced	Energy Produced	Energy Produced	Process Byproduct	Waste Produced		Process Byproduct
Process	Membrane Flux lmh	Temperature °C	F/T	Anaerobic Digester Mixer kWh/day	Anaerobic Digester Heating kWh/day	Biogas Treatment and Storage kWh/day	Bioreactor Methane - AVOIDED PRODUCT kWh/day	AD Methane - AVOIDED PRODUCT kWh/day	Dissolved Methane Recovery - AVOIDED PRODUCT kWh/day	Elemental Sulfur for disposal or recycle - AVOIDED PRODUCT kg/day	CO2 Emissions kg/day	Heat Balance on Digesters kWh/day	Excess Heat - AVOID PRODUCT MJ/day
7 Bio S Ox	15.0	>25	F2/T1	48	0	375	2270	3907	979	7.5	3847	5967	21482
8	N/A	N/A	--	48	0	277	0	4568	0	4.2	2383	3348	12052

				06 - Dissolved Methane Removal						07 - Disinfection			
				Energy Consumed	Membrane Materials Consumed and Disposed				Methane Emissions	Chemical Consumed - NaOCl for Disinfection			
Process	Membrane Flux lmh	Temperature °C	F/T	Dissolved CH4 Removal kWh/day	CH4 Contactor Disposal - PVC kg/day	CH4 Contactor Disposal - Polypropylene kg/day	PVC Hauling to Recycling Facility km/day	PP Solids Hauling to Recycling Facility km/day	Dissolved CH4 Emitted to Atmosphere kg/day	100% NaOCl - Disinfection kg/day	Dilution H2O kg/day	Product Delivered to Facility (12.5% Solution) kg/day	NaOCl hauling to site km/day
7 Bio S Ox	15.0	>25	F2/T1	413	0	0	0.000	0.000	20.685	341	1932	2273	6.0
8	N/A	N/A	--	0	0	0	0.000	0.000	0.000	273	1546	1818	4.8

				Total Hauling	**Net Energy Calculation**			**Unit energy**	
				Sum of all Hauling	**Energy From the Grid**	Energy Consumed	Energy Produced	Energy Consumed	Energy Produced
Process	Membrane Flux lmh	Temperature °C	F/T	landfill, land application, and chemical delivery km/day	(+) Energy from Grid (-) Energy to Grid kWh/day	Consumed from Grid kWh/day	Sold Back to the Grid kWh/day	Consumed from Grid kWh/m^3	Sold Back to the Grid kWh/m^3
7 Bio S Ox	15.0	>25	F2/T1	38	-769	0	769	0.000	0.041
8	N/A	N/A	--	45	2139	2139	0	0.113	0.000

Appendix H

Lifecycle Assessment Waste Inventory for Biological Sulfide Removal Sensitivity Analysis

				Sludge								Membrane Recycling										Overall Waste (sludge &
	Membrane Flux	Temperature	F/T	Screenings and Grit		Biosolids (wet cake)		Inorganic Solids (wet cake)		Total		UF Membrane Disposal PVC		UF Membrane Disposal Polyester		CH4 Contactor Disposal - PVC		CH4 Contactor Disposal - Polypropylene		Total		
Process	lmh	°C		kg/day	%	kg/day	%	kg/day	%	kg/day	% overall waste	kg/day	%	kg/day	%	kg/day	%	kg/day	%	kg/day	% overall waste	kg/day
7	15.0	>25	F2/T1	843	*9.69%*	7857	*90.31%*	0	*0.00%*	8701	*99.87%*	9.9	*90.00%*	1.1	*10.00%*	0	*0.00%*	0	*0.00%*	11.03	*0.13%*	8711.54
8	N/A	N/A	--	819	*6.63%*	11543	*93.37%*	0	*0.00%*	12362	*100.00%*	0	*#DIV/0!*	0	*#DIV/0!*	0	*#DIV/0!*	0	*#DIV/0!*	0.00	*0.00%*	12361.89

Process	Membrane Flux lmh	Temperature °C	F/T	Waste Hauled - by truck							
				Screenings and Grit km/day	Biosolids Hauling to km/day	Inorganic Solids Hauling km/day	PVC Hauling to Recycling km/day	PE Solids Hauling to km/day	PVC Hauling to Recycling km/day	PP Solids Hauling to km/day	**Total km/day**
7	15.0	>25	F2/T1	4.424	20.6	0.0	0.052	0.006	0.000	0.000	**25.098**
8	N/A	N/A	--	4.299	30.3	0	0.000	0.000	0.000	0.000	**34.585**