Naval Surface Warfare Center
Carderock Division
West Bethesda, MD 20817-5700

NSWCCD-63-TR–2024/01 April 2024

Platform Integrity Department

Technical Report

Demonstration of High Shear Rotary Membrane System (HSRMS) for Shipboard Bilgewater Treatment – ESTCP Project WP-201708 Final Report

by

Dr. Jared Church and Ms. Danielle Paynter, NSWCCD, Code 633

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
02/04/2024	**Final Report**	10/1/2017-9/30/2022

4. TITLE AND SUBTITLE
Demonstration of High Shear Rotary Membrane System (HSRMS) for Shipboard Bilgewater Treatment – ESTCP Project WP-201708 - Final Report

5a. CONTRACT NUMBER
5b. GRANT NUMBER
5c. PROGRAM ELEMENT NUMBER
5d. PROJECT NUMBER WP-201708
5e. TASK NUMBER
5f. WORK UNIT NUMBER

6. AUTHOR(S)
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Ms. Danielle Paynter

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) AND ADDRESS(ES)
Naval Surface Warfare Center
Carderock Division (Code 633)
9500 MacArthur Boulevard
West Bethesda, MD 20817-5700

8. PERFORMING ORGANIZATION REPORT NUMBER
NSWCCD-63-TR-2024/01

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of the Deputy Assistant Secretary of Defense (Energy Resilience & Optimization)
3500 Defense Pentagon, RM 5C646
Washington, DC 20301-3500

10. SPONSOR/MONITOR'S ACRONYM(S) ESTCP

11. SPONSOR/MONITOR'S REPORT NUMBER(S) WP-201708

12. DISTRIBUTION / AVAILABILITY STATEMENT

DISTRIBUTION STATEMENT A. Approved for public release: distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT:
Naval Surface Warfare Center Carderock Division, Environmental Engineering, Science and Technology Branch (Code 633) performed a full-scale performance evaluation of an advanced high shear rotary membrane system (HSRMS) technology through laboratory performance verification and shipboard demonstration. Previous research for the development of the HSRMS disk technology was executed by NSWCCD through SERDP/ONR (SERDP WP-1671). Results showed the effective treatment of chemically emulsified and solids laden simulated bilgewater, which in some instances is the most challenging waste stream to treat. Through the Environmental Security Technology Certification Program (ESTCP) Project WP-201520, NSWCCD Code 633 investigated currently available commercial HSRMSs that could be recommended for shipboard applications. The Novoflow NDCF-10 HSRMS was identified as a potential alternative to existing shipboard OWSs based on its compact configuration and ability to accept the KERAFOL ceramic disks. With endorsements from Naval Sea Systems Command (NAVSEA) Wet Environmental Systems and Discharges (WESD) Technical Warrant Holder (TWH) and the Future Fleet Project Office for Product Director Army Watercraft Systems (PD AWS), ESTCP awarded the NSWCCD Environmental Engineering, Science, and Technology Branch (Code 633) a proposal to evaluate the Novoflow HSRMS as project WP-201708. The objective of this effort was to demonstrate the full-scale performance and integrated operation of the HSRMS technology through (1) a laboratory performance verification and (2) a shipboard installation and performance demonstration and validation. This report summarizes the overall findings of the full-scale evaluation as well as presents estimated 30-year operation, maintenance, and repair costs and potential implementation challenges.

15. SUBJECT TERMS: High Shear Rotary Membrane System, HSRMS, Novoflow, Ceramic Disk, Kerafol

16. SECURITY CLASSIFICATION OF: UNCLASSIFIED			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Dr. Jared Church
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED		312	19b. TELEPHONE NUMBER 301-204-1691

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ADMINISTRATIVE INFORMATION

The work described in this report was performed by the Environmental Engineering, Science, and Technology Branch (Code 633) of the Platform Integrity Department at the Naval Surface Warfare Center, Carderock Division (NSWCCD).

ACKNOWLEDGEMENTS

The authors would like to thank Environmental Security Technology Certification Program, Weapon Systems and Platforms (ESTCP WP) for providing Research, Development, Test, and Evaluation (RDT&E) funding for the development of this test report; Naval Sea Systems Command (NAVSEA) 05PF for leverage funding to support the shipboard demonstration, Military Sealift Command (MSC) N75 Life Cycle Management Division for identification and support of a shipboard test platform, and NAVSEA 05P5 for technical feedback. This task represents a leveraged effort that will potentially benefit Armed Forces interests and applications.

LIST OF ACRONYMS

ABS	American Bureau of Shipping
AFFF	Aqueous Film Forming Foam
A_o	Operational Availability
A_i	Inherent Availability
CASREP	Casualty Report
CIP	Clean-in-Place
CFR	Code of Federal Regulations
COC	Chain of Custody
COTS	Commercial-off-the-Shelf
CP	Concentration Polarization
DAS	Data Acquisition System
DoD	Department of Defense
EMI	Electromagnetic Interference
EPA	Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
gpm	gallons per minute
HMI	Human-Machine Interface
HSRMS	High Shear Rotary Membrane System
ILS	Integrated Logistics Support
IMO	International Maritime Organization
Max TTR	Maximum Time to Repair
MTTR	Mean Time to Repair
MDT	Mean Down Time
MEPC	Marine Environmental Protection Committee
MLDT	Mean Logistical Delay Time
MCCS	Machinery Plant Centralized Control System
MSC	Military Sealift Command
MTBF	Mean Time between Failures
NAVSEA	Naval Sea Systems Command
NSWCCD	Naval Surface Warfare Center, Carderock Division
O&G	Oil and Grease
OCM	Oil Content Monitor
ONR	Office of Naval Research

OOC	Out of Commission
OPA	Oil Pollution Abatement
OPNAVINST	Chief of Naval Operations Instruction
OWHT	Oily Waste Holding Tank
OWS	Oil/Water Separator
PD AWS	Product Director Army Watercraft Systems
PLC	Programmable Logic Controller
PM	Preventative Maintenance
ppm	part per million (volume)
QA/QC	Quality Assurance/Quality Control
RDT&E	Research, Development, Test, and Evaluation
RMA	Reliability, Maintenance, and Availability
RPM	Revolutions per Minute
SAP	Sampling and Analysis Plan
SERDP	Strategic Environmental Research and Development Program
SSDF	Single Shaft Disk Filter
TMP	Transmembrane Pressure
TPH	Total Petroleum Hydrocarbon
TWH	Technical Warrant Holder
UNDS	Uniform National Discharge Standards
UMBC	University of Maryland, Baltimore County
USCG	United States Coast Guard
VFD	Variable Frequency Drive
WESD	Wet Environmental Systems and Discharges
WOT	Waste Oil Tank
WP	Weapon Systems and Platforms

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EXECUTIVE SUMMARY

Naval Surface Warfare Center Carderock Division, Environmental Engineering, Science and Technology Branch (Code 633) performed a full-scale performance evaluation of an advanced high shear rotary membrane system (HSRMS) technology through laboratory performance verification and shipboard demonstration. Previous research for the development of the HSRMS disk technology was executed by NSWCCD through SERDP/ONR (SERDP WP-1671). Results showed the effective treatment of chemically emulsified and solids laden simulated bilgewater, which is in some instances the most challenging waste stream to treat. Through the Environmental Security Technology Certification Program (ESTCP) Project WP-201520, NSWCCD Code 633 investigated currently available commercial HSRMSs that could recommended for shipboard applications. The Novoflow NDCF-10 HSRMS was identified as a potential alternative to existing shipboard OWSs based on its compact configuration and ability to accept the KERAFOL ceramic disks. With endorsements from Naval Sea Systems Command (NAVSEA) Wet Environmental Systems and Discharges (WESD) Technical Warrant Holder (TWH) and the Future Fleet Project Office for Product Director Army Watercraft Systems (PD AWS), ESTCP awarded the NSWCCD Environmental Engineering, Science, and Technology Branch (Code 633) proposal to evaluate the Novoflow HSRMS as project WP-201708.

The laboratory evaluation was completed between March and October 2018. The Novoflow HSRMS was able to process oil, detergent, solids, and salt water mixtures and produce high quality effluent under all test conditions. Oil concentration, measured by EPA 1664, was below 15 ppm for all samples. However, membrane life did not meet the criteria of greater than 300 hours and was found to be between 147-415 hours. During the laboratory evaluation, the HSRMS operated for a total of 959 hours with zero “relevant critical failures” and zero “relevant major failures”, thereby satisfying the MTBF acceptance criteria. The failures that did occur include the following: 1) at 50 hours into testing, the upper bearing assembly of the membrane stack leaked grease due to scoring on the silicon carbide seal and 2) at 850 hours into testing, the silicon carbide seal was found to be chipped after disassembling the membrane stack for inspection. The manufacturer identified the cause of the first failure as a torsion spring with insufficient clearance pressing the seal faces too tightly. Novoflow provided a redesigned bearing assembly as a replacement. The second failure was due to operator error.

The shipboard demonstration was completed between July 2021 and April 2022. The system treated a total of 7,963 gallons while underway with an average effluent flow rate of 4.0 gpm. The effluent oil concentration was below regulatory limits (15 ppm) for the full shipboard evaluation. The MEPC.107(49) approved commercial-off-the-shelf (COTS) oil content monitor (OCM), Turner TD-107, did not trigger any high oil content alarms and made the decision to discharge 100% of the time. Overall, the system was able to treat bilgewater under shipboard conditions and produce high quality effluent. The HSRMS did not meet the performance criteria of exceeding 300 hours of operation before requiring a membrane regeneration. After 28 hours the membrane resistance exceeded the maximum threshold (1.49 psi/gfd @ 68°F), indicating the need for membrane regeneration or replacement. However, it was discovered that the system was unintentionally operated as a dead end filtration after 26 hours, which expedited the membrane fouling. In addition, the Novoflow HSRMS, in its current configuration, did not meet the reliability criteria for maintenance ratio. This was due to corrective maintenance needed to clean a level sensor and correct tolerances with the feed pump variable frequency drive (VFD).

Reliability criteria could be met with the following considerations, 1) an automatic rinse function during shut down to prevent oil fouling sensors, 2) relocating sensors to avoid fouling from oil, 3) redesign to avoid the use of VFDs, and 4) redesign processing capacity using full scale evaluation results.

Overall, the results indicate HSRMS as a promising technology for bilgewater treatment; however, its current design would need to be repackaged for DoD shipboard applications. Further considerations would be needed for militarized ships, including redesign for shock, vibration, EMI and other requirements (e.g. cyber security). A reliability study of the redesigned system needs to be performed to ensure design changes meet the OWS requirements for DoD ship platforms. Based on the results of the laboratory study and shipboard evaluation, a redesigned HSRMS with disk membranes as the core treatment technology could be a candidate for new Army, MSC, Navy, and USCG ship acquisition programs that are seeking a small, compact and complete OWS system.

BACKGROUND

In accordance with the current DoD Instruction 4715.06, Volume 2, "Regulation on Vessels Owned or Operated by the Department of Defense: Oil Pollution Prevention" [1] and the Uniform National Discharge Standards (UNDS) [2], Armed Forces vessels must limit oily waste discharges to 15 parts per million (ppm) or less under normal shipboard operating conditions. Most Armed Forces vessels are equipped with an oil pollution abatement (OPA) system to comply with this requirement. The OPA system functions by collecting oily water in ancillary holding points where the fluid is then pumped to an oily waste holding tank (OWHT). The wastewater in the OWHT is treated by an oil/water separator (OWS). An oil content monitor (OCM) measures the OWS effluent's oil concentration to determine if it is within regulatory limits and acceptable for overboard discharge. If the oil concentration is above 15 ppm, the effluent is recirculated back to the OWHT for additional treatment. Separated waste oil is sent to the waste oil tank (WOT) and held for shore side disposal.

Commercial-off-the-shelf (COTS) OWSs are designed and certified to meet International Maritime Organization (IMO) Marine Environmental Protection Committee (MEPC) MEPC.107(49) and United States Coast Guard (USCG) requirements for processing oily wastewater [3, 4]. Shipbuilders are presented with these certified systems as viable options for use aboard existing and future ship classes. However, these COTS systems may not be suitable for Armed Forces' operational profiles. In order to acquire effective and efficient OWSs and allow the unrestricted operations of vessels with minimal ship impact or life cycle cost, COTS OWSs are identified, assessed, and evaluated by Naval Surface Warfare Center, Carderock Division (NSWCCD) for their applicability aboard Armed Forces' vessels.

One such option is high shear rotary membrane systems (HSRMSs), which use rotating membrane disks to create a shear force at the membrane surface to reduce face plugging and concentration polarization (CP). This alternate treatment method can give the HSRMS potential improvements over traditional ceramic cross-flow membrane based OWSs because their simpler configurations and lower operational transmembrane pressures (TMP) can lead to extended membrane life and reduced cleaning frequencies.

Previous research investigating HSRMS and ceramic membrane disk performance was conducted by NSWCCD and University of Maryland, Baltimore County (UMBC). The program was supported through the Strategic Environmental Research and Development Program (SERDP), project WP-1671, and co-sponsored by the Office of Naval Research (ONR). The study determined the correlation between membrane disk diameter, material, pore size, rotation speed, and the effects of back pulsing and continuous surface cleaning on the treatment performance of Navy shipboard waste streams, specifically bilgewater. Ceramic disk membranes manufactured by KERAFOL proved capable of treating simulated bilgewater containing chemical emulsions and solids to overboard discharge requirements. Through the Environmental Security Technology Certification Program (ESTCP) Project WP-201520, NSWCCD investigated currently available commercial HSRMSs that could accept the KERAFOL ceramic disks and could be recommended for shipboard applications. The Novoflow NDCF-10 HSRMS was identified as a potential alternative to existing shipboard OWSs based on its compact configuration and ability to meet shipboard maintenance requirements.

With endorsements from Naval Sea Systems Command (NAVSEA) Wet Environmental Systems and Discharges (WESD) Technical Warrant Holder (TWH) and the Future Fleet Project

Office for Product Director Army Watercraft Systems (PD AWS), ESTCP awarded the NSWCCD Environmental Engineering, Science, and Technology Branch (Code 633) proposal to evaluate the Novoflow HSRMS as project WP-201708. This final report documents the evaluation for the Novoflow HSRMS aboard USNS Matthew Perry (T-AKE 9).

OBJECTIVE

The primary objective of this effort was to demonstrate and validate the full-scale performance and integrated operation of an advanced high shear rotary membrane technology through purpose driven design, fabrication, laboratory performance verification, and shipboard demonstration and validation for subsequent approval and use. This effort integrated advanced high shear rotary membrane technology and performance based operating configurations for the effective treatment of shipboard bilgewater. The overall objective of this effort was to evaluate the Novoflow HSRMS and document the OWS system's capability in terms of: reliability, maintainability, operability, and performance. The Novoflow HSRMS was expected to meet the requirements and criteria for acceptance as described in the Oil Pollution Abatement (OPA) Design and Installation Requirements [5] and Uniform Test Plan for Oily Water Separators [6]. The objective of this effort was accomplished through the following goals:

1. Validate the HSRMS in accordance with current guidance of the OPA Design and Installation Requirements [5] and Uniform Test Plan for Oily Water Separators [6].
2. Examine the HSRMS to determine if it is suitable for further implementation onboard future Navy or Army ships or as a back fit for current Navy or Army ships.
3. Identify recommended improvements for the in-service system and its logistic support.

By completing a series of system tests and recording passive data obtained through reliability, maintainability, availability (RMA), and operability, this demonstration enabled the determination of system oil removal, performance in the presence of bilge contaminants, effective processing rate, operation and labor requirements, and shipboard integration needs.

Table 1 lists the targeted hazardous material, bilge oil, and other material information associated with investigating COTS HSRMS. While bilge oil may be less harmful than other shipboard materials, its impact on the environment has been well documented and several policies and regulations have been developed to prevent its discharge into the environment. The environmental benefit of the HSRMS includes better prevention of oil discharge into the ocean and a potential reduced carbon footprint compared to conventional pressurized treatment systems.

Table 1. Target Hazardous Material (HazMat) Summary.

Target HazMat	Current Process	Applications	Current Specifications	Affected Programs	Candidate Parts and Substrates
Bilgewater	Gravity Separation, Coalescence, Adsorption, Coagulation/ Flocculation, Membrane Filtration	Armed Forces Vessels	DoD Instruction 4715.6 OPNAVINST 5090.1 Army Technical Bulletin TB-55-1900-206-14	Military Sealift Command Naval Sea Systems Command Product Directorate Army Watercraft Systems	Oil/Water Separator via High Shear Rotary Membrane System (HSRMS)

Regulatory Drivers

The need for effective shipboard treatment of oily wastewater aboard Armed Forces vessels is driven by existing regulations. Based on Clean Water Act (CWA) regulations, oil concentration in excess of 15 ppm can cause a sheen, indicating violation of water quality standards. The Act to Prevent Pollution from Ships (APPS) requires the Department of Defense (DoD) to prescribe standards for Armed Forces vessels that are consistent with Annex I of MARPOL. Annex I limits the oil content of discharges from ships to 15 ppm worldwide. DoD Instruction 4715.06 Volume 2 [1], Navy Instruction OPNAVINST 5090.1 [7], and Army Technical Bulletin TB55-1900-206-14 [8] are consistent with the 15 ppm discharge limit.

Stakeholder/End-User Issues

Primary stakeholders identified for this project include the ESTCP WP Program Manager, who manages the program that selected this project for funding; NAVSEA Wet Environmental Systems and Discharges Technical Warrant Holder (05P5), who is the Navy's technical authority for OPA systems; and NAVSEA Afloat Environmental Quality Program Manager (05PF), who provided additional support funding for the shipboard demonstration. Prior to both laboratory joint test protocol (JTP) and shipboard demonstration test plan submissions to ESTCP, NAVSEA 05P5 was consulted and has concurred on the submitted test design and protocol.

Demonstration of the integrated HSRMS also provided evidence of the technology's ability to meet specific military shipboard requirements for bilgewater treatment for new Army,

MSC, Navy, and USCG ship acquisition programs that are seeking a small, compact, and complete OWS system.

DEMONSTRATION TECHNOLOGY

Technology Description

High Shear Rotary Membrane System (HSRMS)

HSRMSs consist of membrane disks, which can be stacked, that rotate about a hollow shaft inside a cylindrical housing. As seen in Figure 1, the feed stream enters the membrane chamber under pressure and is distributed across the membrane surface. Permeate is forced through the membrane and discharged through the hollow center shaft. When installed shipboard, permeate will be analyzed by an OCM to determine permeate quality. If the oil content is 15 ppm or below, the stream will be discharged; otherwise, the stream will be diverted back to the oily waste holding tank for reprocessing.

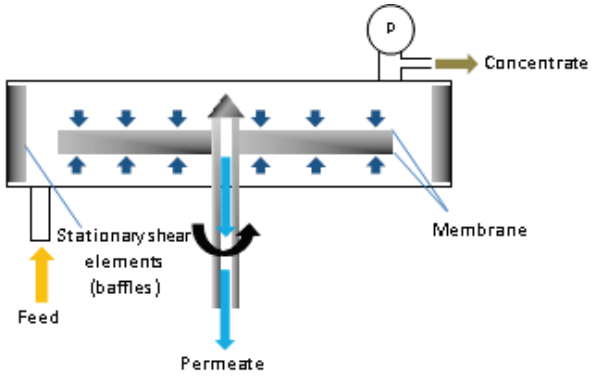


Figure 1. HSRMS single membrane

In conventional cross-flow membrane systems, pumps are used to generate high flow rates that produce large cross-flow velocities near the membrane surface. This reduces the thickness and concentration of the solute boundary layer, which increases the effluent flux. However, the pumping required to maintain high cross flow velocities also creates a large TMP which leads to increased membrane face plugging and a reduction in effluent flux over time.

Because HSRMSs generate shear forces by rotating the membrane within the process fluid, the system allows for simpler configuration, trading pumps for mechanical drives to generate conditions for cross-flow. Methods to further enhance turbulence and shear at the membrane surface include interleaving or nesting multiple disk stacks, as seen in Figure 2, or incorporating stationary shear elements between via baffles, as indicated in Figure 3. Because the feed delivery and pressurization are decoupled from turbulence or shear promotion, HSRMSs can be operated at lower pressures which decreases solute boundary layer compaction and pore plugging in comparison to conventional cross-flow membrane systems.

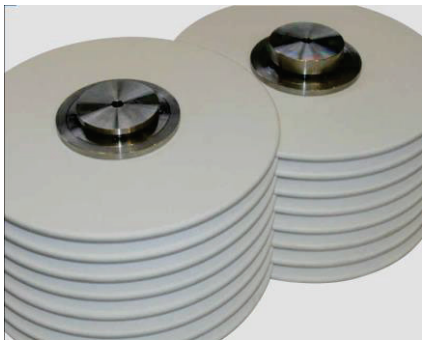


Figure 2. Interleaved or nested disks



Figure 3. Membrane housing interior baffles

Several commercial HSRMSs have been developed that differ in their configuration and how the turbulence/shear is developed: horizontally stacked rotating disks (Metso, Finland; Westfalia, Germany; Hitachi, Japan; SMS, Germany), vertically stacked rotating disks (SpinTek Filtration, CA, USA.; Andritz, Germany), and vibratory vertically stacked disks (New Logic, CA, USA). The Novoflow HSRMS was identified as the candidate for laboratory evaluation and shipboard demonstration during ESTCP Project WP-201520.

Novoflow HSRMS Overview

The Novoflow model NDCF-10 HSRMS is designed with a capacity of 10 gpm and has several unique changes in anticipation of future shipboard operation. This includes the tilting of the membrane housing into a horizontal position to allow access to the membranes under the height limitations found in ship spaces, the separation of the membrane housing into two segments to comply with maintenance weight restrictions, and the use of stainless steel materials for increased robustness. This system consists of a single 53-membrane ceramic disk stack with an effective surface area of 10 m^2 using the 374 mm diameter, 60 nm pore size ceramic KERAFOL (Munich, Germany) membranes. Membrane housing is constructed of 316 stainless steel. Baffles are incorporated into the interior of the housing for turbulence promotion. A clean-in-place (CIP) feature that uses both acidic and caustic cleaners is incorporated into a Siemens programmable logic controller (PLC). The Novoflow HSRMS is configured as a single shaft disk filter (SSDF) where all membrane disks are rotated on a center shaft to reduce the footprint and increase membrane area per module. A photograph of the system is presented in Figure 4.



Figure 4. Novoflow model NDCF-1-10-374 HSRMS

The Novoflow HSRMS measures 51.0” long by 25.0” wide by 75.5” high with a footprint of 8.8 ft^2. The Novoflow HSRMS maintenance envelope measures 140.0” long by 73.0” wide by 105.5” high with an area of 71.1 ft^2 due to the length needed to tilt the membrane over for disassembly procedures (Figure 5). The weight of the HSRMS is 1,530 lbs according to the operating manual [9].



Figure 5. Photographs of HSRMS (a) membrane housing, (b) being tilted, and (c) disassembled for membrane inspection or replacement

Technology Development

Previously, NSWCCD investigated the performance and viability of HSRMS in collaboration with SpinTek and the University of Maryland Baltimore County through SERDP (WP-1671) and ONR research. The work conducted through SERDP/ONR examined the correlation between membrane disk diameter, material, pore size, rotation rate, and the effects of back pulsing and continuous cleaning to performance requirements relevant to Navy shipboard waste streams [10, 11]. Ceramic disk membranes manufactured by KERAFOL proved capable of being configured and used to treat simulated bilgewater containing emulsions and solids to an oil concentration of 15 ppm or less. Based on cumulative findings, recommendations were made to pursue further scale-up, configuration, and demonstration of a larger 10 gpm system using 14.7-inch diameter disks, 10 m^2 surface area, 60 nm pore size, and a membrane rotation of 500 revolutions per minute (RPM) for bilgewater treatment to demonstrate and validate the technology for dynamic shipboard use.

A commercially available HSRMS manufactured by Novoflow was identified as potential full-scale system during the ESTCP funded project, WP-201520. The system accepted the recommended KERAFOL membranes at the desired pore size and disk diameter [12]. Results from this study confirmed HSRMSs as a possible full-scale solution to current shipboard bilgewater treatment based on construction quality and ability to meet maintenance and operational requirements.

Advantages and Limitations of the Technology

There are a number of manufacturers that offer OPA systems that are designed and certified in accordance with MEPC.107(49). This includes gravity coalescence, absorption filters, ceramic membranes, centrifugation, electrocoagulation, and biological treatment [13, 14, 15]. These systems, however, are not necessarily designed for Armed Forces applications. Not only should these systems be able to treat bilgewater to regulatory levels, the system should also be ruggedized, reliable, avoid consumables, simple to operate, easy to maintain, and retain a small footprint. Therefore, cross flow ceramic ultrafiltration membranes have been installed throughout the Fleet to meet these needs. However, the pumping required to maintain high cross flow velocities also creates a large TMP, which leads to increased membrane face plugging and a reduction in effluent flux over time.

The key advantage to HSRMSs over cross flow membrane processes is that the TMP is independent from cross flow velocity [16]. In conventional cross flow systems, large pumps are required to achieve the cross flow velocity needed to reduce concentration polarization and membrane fouling. These pumps contribute to large energy costs and increased TMP, which causes surface pore plugging and reduced membrane life. HSRMSs use rotating filter disks to create a large cross flow velocity at the membrane surface, which allows for low operating pressure and reduced pumping requirements. In theory, this can lead to substantial energy savings, longer membrane life or reduced consumable costs, and a reduced footprint [16]. While HSRMSs have been studied for use in separating solids from a variety of waste streams (e.g., paper, pulp, algae, etc.), the technology is still in its nascent stages for oily wastewater applications. Therefore, operational parameters to extend membrane life and achieve high treatment performance in bilgewater treatment applications are unknown and still need to be optimized.

PERFORMANCE OBJECTIVES

Table 2 lists the performance objectives that are needed for a successful demonstration of the HSRMS for bilgewater treatment. The criteria include system processing performance, membrane life, reliability, maintainability, availability, and operability. These tests are consistent with typical oil/water separator (OWS) testing protocols previously developed by NSWCCD Code 633 with NAVSEA 05P5 concurrence [6]. The listed performance objectives are consistent between both the laboratory JTP (Appendix A) and the shipboard demonstration. Details on the data requirements and success criteria are discussed in Section 5. Results and performance assessment are discussed in Section 6. Points of contact and safety protocols for the evaluation can be found in Appendix B and C, respectively.

Table 2. OWS System Evaluation Metrics

Performance Objective	Data Requirements	Success Criteria	Results	
Quantitative Performance Objectives			**Lab**	**Ship**
System Processing Performance	Oil concentration (ppm)	95% of effluent samples ≤ 15 ppm oil	Pass	Pass
		100% of effluent samples ≤ 100 ppm oil	Pass	Pass
	Measured alarms, indicators and sensors	All of system alarms, indicators, and sensors function as designed in all operating modes	Pass	Pass
Membrane Life	TMP and effluent flow rate	Run time of 300 hrs without reaching 100% resistance	Fail	Inconclusive
Membrane Regeneration	TMP and effluent flow rate	Regeneration observed	Pass	Inconclusive
Reliability, Maintainability, and Availability[+]	-MTBF ≥ 922 hrs -A_0 ≥ 95% -MTTR ≤ 3 hrs -Maintenance Ratio ≤ 0.03 -Preventative Maintenance ≤ 3.5 hrs/week -Max Preventative Maintenance < 16 man hrs -Operable and maintainable by skill level of crew		Fail	Inconclusive
Qualitative Performance Objectives				
Operability	Training time, operating time, operator skill level	-Operable and maintainable by skill level of crew	Pass	Pass

[+]Details of RMA success criteria can be found in Table 6.

PLATFORM DESCRIPTION

USNS Matthew Perry T-AKE 9 Test Platform

MSC and PD AWS were both receptive to offering a platform for demonstrating the Novoflow HSRMS. Through conversations with MSC, it was determined that temporary installation of the HSRMS would be permissible with the concurrent installation of a USCG type approved OCM as the final decision maker for effluent discharge. Based on this determination, MSC provided a preliminary nomination for USNS Matthew Perry (T-AKE 9).

A ship check was executed to confirm footprint availability, review existing piping and foundation, confirm stateside installation availability, and to interview OPA operators on current operations [17]. It was confirmed that existing piping and interface connections in the Auxiliary Machinery Room were suitable and available to process machinery bilgewater with concurrence from MSC support, including a potable water line, which is required for membrane back flushes and chemical cleanings. OPA machinery plant centralized control system (MCCS) screenshots for OPA configuration were obtained. The location and orientation of the system was determined to be adequate for the HSRMS system footprint (Figure 6a) and could use the existing foundation (Figure 6b). Figure 7 shows the planned HSRMS installation schematic aboard USNS Matthew Perry (T-AKE 9).

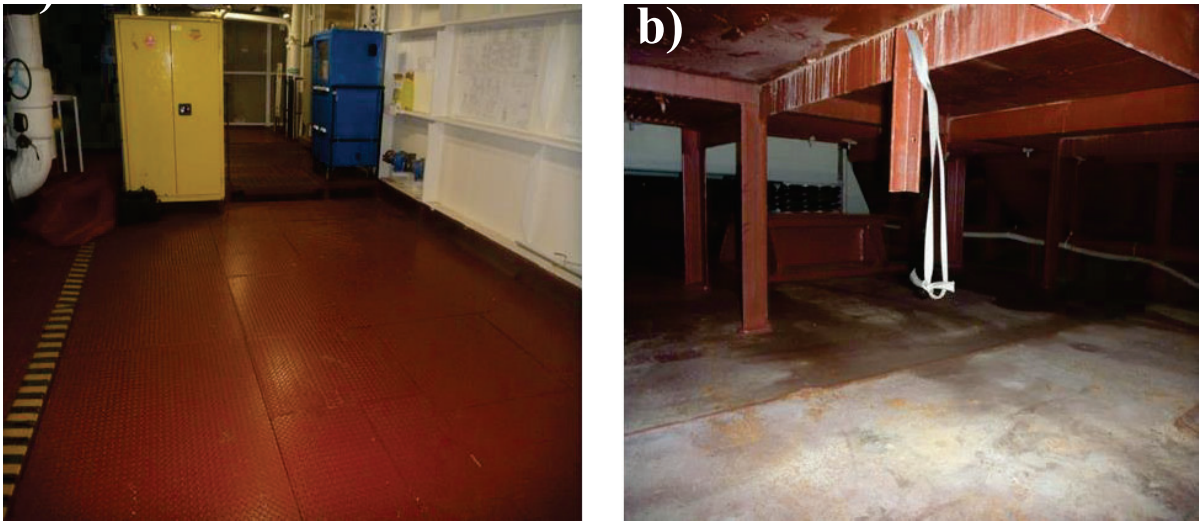


Figure 6. Shipboard demonstration test platform USNS Matthew Perry (T-AKE 9) a) installation location and b) existing foundation

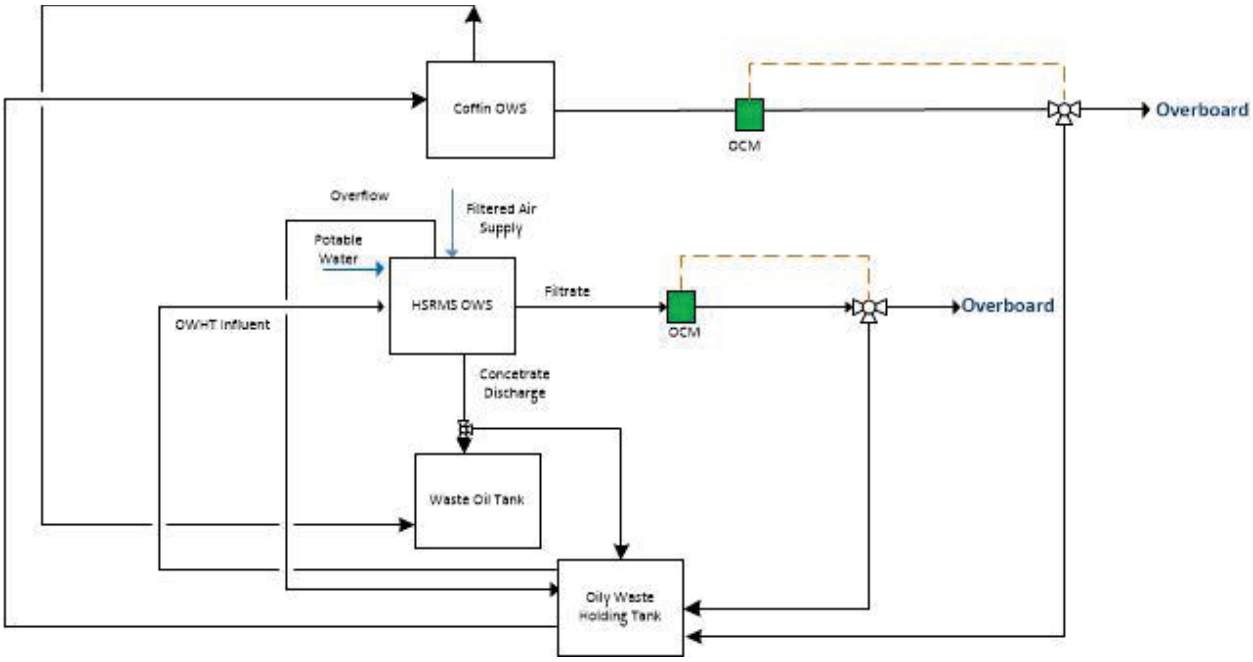


Figure 7. HSRMS Installation Schematic

Present Operations

The current OWS aboard USNS Matthew Perry (T-AKE 9) is the Coffin Ultra-Sep with a Rivertrace SmartCell OCM. The Ultra-Sep uses a coalescing separator for the first stage and a hydrophilic membrane filter for the second stage. Both the Ultra-Sep and SmartCell are IMO MEPC.107(49) type approved. Based on interviews with the Watch Engineer, the primary issue associated with the current OWS is the fuel and other bilge components degrade the secondary filter, which leads to compromised bilgewater treatment and frequent filter replacement and maintenance [17].

USNS Matthew Perry (T-AKE 9) has two bilgewater holding tanks; the machinery oil waste tank which has a capacity of 4,751 gallons and a cargo oily waste tank which has a capacity of 1,268 gallons. The current protocol is to allow bilgewater to accumulate in the holding tanks then process the bilgewater once the tanks are close to full. Based on feedback, the OWS treats the bilgewater from the machinery oil waste tank more frequently due to the greater generation of bilgewater.

Site-Related Permits and Regulations

The temporary installation and removal of the HSRMS aboard USNS Matthew Perry (T-AKE 9) is subject to MEPC.107(49) regulations. A U.S. Coast Guard waiver was approved for the installation and operation of the HSRMS, which can be found in Appendix D. In addition, approval by the American Bureau of Shipping (ABS) was required before the installation of the HSRMS could be performed. The installation package was submitted and approved by ABS on 04 September 2019. The same installation package was reapproved by ABS on 09 May 2020 after the installation was delayed. The approval letter and approved installation drawings are presented in Appendix E.

TEST DESIGN

The demonstration of the HSRMS was completed in two phases, 1) the full scale laboratory evaluation and 2) the shipboard evaluation.

The purpose of the full scale laboratory evaluation was to determine the high shear rotary membrane system's (HSRMS's) ability to reliably and efficiently process the highly variable bilgewater found on Navy ships and produce an effluent that meets the oil discharge requirement of less than 15 ppm. By completing a series of system performance tests and recording passive data obtained regarding reliability, maintainability, availability (RMA) and operability, the full scale laboratory tests were used as a go/no go for the system shipboard evaluation.

The shipboard demonstration mirrored the laboratory evaluation outlined in the Laboratory JTP (Appendix A); however, the system was installed in a dynamic shipboard setting. As in the laboratory evaluation, a set of qualitative and quantitative parameters was used to measure the effectiveness of the HSRMS in meeting the validation objective and goals. The HSRMS validation objective and goals will be measured to determine RMA, operability, and processing performance.

Full-Scale Laboratory Evaluation

Overview

The laboratory evaluation was conducted in accordance with the testing guidelines outlined in the Laboratory JTP (Appendix A). The system's ability to separate oil in the presence of other bilgewater contaminants was determined under a wide variety of conditions that may be present shipboard. This information was also used to determine other information such as chemical resiliency, system processing reliability, and treatment effectiveness. The effective processing efficiency was analyzed by comparing the flowrate of the influent to the flowrate of the effluent with an oil content of less than 15 ppm for each test. This comparison was used to quantify throughput efficiency of the system. Ideally, the difference between influent and effluent flowrates while processing non-bulk oil fluid should only be due to oil content monitor (OCM) usage (approximately 1 gpm/OCM), regular backpulsing, and concentrate bleeds.

Laboratory Setup

The laboratory setup used to test the HSRMS is displayed in Figure 8. The set up consisted of the HSRMS with influent from either the laboratory's potable water supply via a 500-gallon buffer tank or saltwater via a 10,000-gallon above ground storage tank. The test mix was injected into the HSRMS supply line from a 200-gallon mix tank or a 500-gallon oil tank. Potable water was supplied from the building's potable water system. The 500-gallon buffer tank was used to supply influent at near atmospheric pressure and temperature.

The 200-gallon mix tank was used to create a test mixture with an oil concentration of one percent for the 200 ppm oily water tests and five percent for all other tests except the transition test. The 500-gallon oil tank was used to supply Navy Standard Bilge Mix (NSBM) #4 during the transition test. The 200 and 500-gallon mix and oil tanks are located on the mezzanine level of the oily wastewater laboratory. Effluent with an oil concentration less than 15 ppm was discharged to the laboratory floor drain. Effluent with an oil concentration greater than or equal to 15 ppm and waste oil discharges was diverted to one of the two 20,000-gallon laboratory

underground storage tanks (UST) for reprocessing by a laboratory treatment system (not shown in Figure 8).

After each test, the mix tank and recirculation line were cleaned with potable water using the following procedure. First, the mix tank was drained of its contents and sprayed down with a garden hose. Then, fifty gallons of potable water was added to the mix tank and recirculated for five minutes. After draining the fluid to an underground storage tank, the recirculation/flushing procedure was completed three times or until the bottom of the mix tank was visible with the final 50 gallons of rinse water in it.

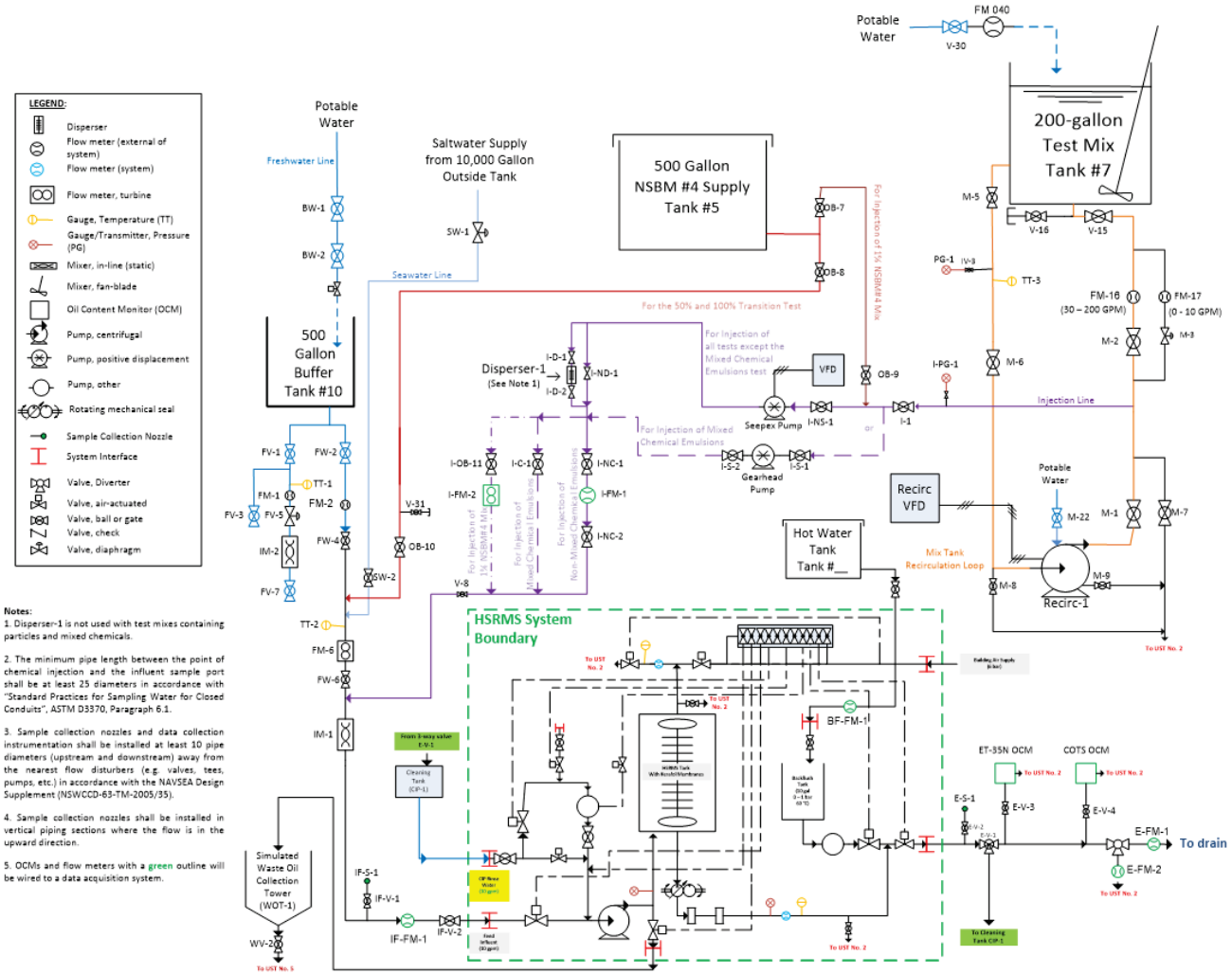


Figure 8. Laboratory Evaluation Piping and Instrumentation Diagram

Data Collection

Data collection protocol followed the data collection plan described in Laboratory JTP (Appendix A). Influent, effluent, overflow, and discharge flowrates, pressures, and temperatures were wired to the laboratory data acquisition system (DAS) and the HSRMS's datalogger; however, the laboratory DAS experienced frequent failure during the evaluation period. Therefore, data pertinent to evaluating system performance were recorded in the operator's manual logs. The HSRMS torque and alarms were recorded using the HSRMS's data-logger. Maintenance, operational down-time, and other data pertinent to calculating RMA were calculated from data recorded in the operator's manual logs (Appendix F). Influent and effluent samples were collected according to NSWCCD Code 633's sampling plan (Appendix G) and delivered to an external laboratory for EPA Method 1664 analysis.

Performance Test

Rationale

The purpose of the laboratory performance test was to determine the HSRMS's ability to treat a series of challenge solutions. The system's performance was determined by analyzing processing rate, effluent quality, and the ability of all alarms, indicators, and sensors to function as designed in all operating modes.

Test Approach

For the performance portion of the evaluation, a sequence of tests was conducted using various concentrations of Navy Standard Bilge Mixture (NSBM) #4, detergent mix #4, and other contaminants to simulate the variable conditions found aboard Armed Forces ships. These tests were used to determine the HSRMS's performance when encountering various potential contaminants. **Error! Reference source not found.** lists the contaminant constituents that were used during these tests. The performance evaluation included different influent oil concentrations and contaminant levels as listed in Table 4. Also included in Table 4 are the sampling frequency collected during the evaluation.

Table 3. Constituents of Influent Contaminants

Phase	Test Standard	Constituents
Oil	NSBM #4	50% by volume Diesel Fuel Marine, MIL-DTL-16884 25% by volume 2190 TEP Steam Lube Oil, MIL-PRF-17331 25% by volume 9250 Diesel Lube Oil, MIL-PRF-9000
	NSBM #4 JP-5 Variant	50% by volume Marine Aviation Fuel, MIL-DTL-5624 25% by volume 2190 TEP Steam Lube Oil, MIL-PRF-17331 25% by volume 9250 Diesel Lube Oil, MIL-PRF-9000
Water	Detergent Mix #4	50% Type 1 General Purpose Non-Ionic Detergent, MIL-D-16791 25% Commercial Detergent 2X “Ultra Tide” Original Scent (liquid) 25% Degreasing Solvent, MIL-PRF-680, Type III
	Other	AFFF, 6%, MIL-F-24385 Arizona Test Dust, ISO-12103-1, A4 Coarse “Clorox” Bleach, 100 mg/L NaOCl Cloth Fibers, lint mostly 25-150 microns in length Acetone, “Barr Klean Strip” Product NO. GAC18 Degreasing Solvent, MIL-PRF-680, Type III Simulated Seawater: Salinity 35,000 ppm(m) +/- 5% (Solar Salt, Med Size)

Table 4. Performance Evaluation Test Conditions and Sampling Frequency

Test #	Test		Influent Mixture	# of Tests	Test Duration[1]	Sampling Frequency
1,11	Oily Water		200-ppm NSBM #4	2	10 hours	Effluent – Two samples (t = 4,9) Influent – One samples (t = 4) Waste Oil – One sample (t = 8) Quality Assurance – One Sample (100 ppm)
2, 12	Oily Water		1,000-ppm NSBM #4	2	10 hours	Effluent – Four samples (t = 4, 9+ triplicates) Influent – One sample (t = 4) Waste Oil – One sample (t = 8) Quality Assurance – One Sample (15 ppm)
3, 13	Oily Water & Mixed Detergent		1,000-ppm NSBM #4 100-ppm Detergent Mix #4	2	10 hours	Effluent – Four samples (t = 4,9+ triplicates) Influent – One sample (t = 4) Waste Oil – One sample (t = 8) Quality Assurance – One Sample (100 ppm)
4,14	Oily Water & Detergent		1,000-ppm NSBM #4 100-ppm Type 1 Detergent	2	10 hours	Effluent – Two samples (t = 4,9) Influent – One sample (t = 4) Waste Oil – One sample (t = 8) Quality Assurance – One Sample (15 ppm)
5,15	Oily Water & Mixed Chemicals		1,000-ppm NSBM #4 0.17% "Clorox" bleach (100 mg/L NaOCl)[2] 0.17% Acetone 0.17% Paint Thinner	2	10 hours	Effluent – Two samples (t = 4,9) Influent – One sample (t = 4) Waste Oil – One sample (t = 8) Quality Assurance – One Sample (15 ppm)
6,16	Oily Water & AFFF		1,000-ppm NSBM #4, 100-ppm AFFF	2	10 hours	Effluent – Four samples (t = 4,9+ triplicates) Influent – One sample (t = 4) Waste Oil – One sample (t = 8) Quality Assurance – One Sample (100 ppm)
7,17	Oily Water, Mixed Detergent, & Particles		1,000-ppm NSBM #4 100-ppm Detergent Mix #4 100-ppm (m) Arizona Test Dust (coarse) 0.70-ppm (m) Cloth Fibers (lint mostly 25-150 microns in length)	2	10 hours	Effluent – Four samples (t = 4,9+ triplicates) Influent – One sample (t = 4) Waste Oil – One sample (t=8) Quality Assurance – One Sample (100 ppm)
8,18	JP-5 Oily Water & Mixed Detergent		1,000-ppm NSBM #4 JP-5 Variant 100-ppm Detergent Mix #4	2	10 hours	Effluent – Four samples (t = 4,9+ triplicates) Influent – One sample (t = 4) Waste Oil – One sample (t = 8) Quality Assurance – One Sample (100 ppm)
9,19	Oily Water & Seawater		1,000-ppm NSBM #4 35,000-ppm(m) Synthetic Seawater	2	10 hours	Effluent – Two samples (t = 4,9) Influent – One sample (t = 4) Waste Oil – One sample (t = 8) Quality Assurance – One Sample (15 ppm)
10a, 20a	OWHT Transition Test	1% Oil	1% NSBM #4	2	6 hours	Effluent (1% test) – One samples (t = 4) Influent (1% test) – One sample (t = 4) Effluent (50% Test) – One sample (t = 10 min) Effluent (100% Test) – One sample (t = 0.5) Waste Oil – One sample (t = 6.5) Quality Assurance – One Sample (100 ppm)
10b, 20b		Interface	50% NSBM #4 50% Water		10 min	
10c, 20c		Bulk Oil	100% NSBM #4		30 min	

[1]Tests with a planned duration of ten hours may have been shortened if breakthrough occurred where the effluent was cloudy and the OCMs were indicating oil content at or above their upper detection limit and/or alarms are indicating the presence of emulsions. The test was stopped after processing under breakthrough conditions for four hours. If four hours or less remained in the test when breakthrough occurs, the test was conducted as normal.

[2]The concentration of bleach was incorrectly calculated at 260 mg/L NaOCl in the JTP and fixed for this report.

Effective Processing Efficiency and Overboard Discharge

The effective processing efficiency of the system was calculated for each test using flow totalizer data from the influent and discharge effluent flow meters. For a given performance test, or non-degradation test, effective processing efficiencies were calculated using the following formula:

$$\frac{(\text{Effluent Total Final} - \text{Effluent Total Initial})}{(\text{Influent Total Final} - \text{Influent Total Initial})} \times 100 = \text{Effective Processing Efficiency}$$

The effective processing efficiencies were affected by the discharge decision of the TD-107 OCM, OCM sampling and backwashing events.

Overboard discharge was also calculated as a percentage of decisions for overboard discharge based on the hourly manual readings of both OCMs. This provides an indication of the impact of OCMs on the overboard discharge. It does not necessarily relate to the volume of overboard discharge.

Membrane Life

Rationale

The membrane life portion of testing determined the life span of the membranes prior to requiring cleaning. Per the evaluation's success criteria, the ceramic membranes were expected to reach at least 300 hours of operation prior to cleaning. By collecting this data, the failure mechanism, rate, and frequency were determined to provide a better estimation of total life cycle cost, including membrane replacement and maintenance costs.

Test Approach

The membrane life test was incorporated into the performance and reliability portion of the testing. Therefore, the membranes were subjected to a range of contaminants including 394 hours of building potable water, 254 hours of oil and detergent, and 190 hours of challenge bilgewater used in the performance testing. The test duration was determined when the system produced effluent with greater than 15 ppm oil or reached 100% resistance. One microdosing regeneration and four full membrane regenerations [18] were performed during the evaluation, which included two membrane regenerations that were performed at the end of the evaluation to determine the effect of heat on membrane regeneration. These regenerations were not used to determine membrane life. Components of the test mixture and duration are described in Table 5.

Membrane Resistance

Resistance represents the hydraulic life of the membrane stack and is indicative of the extent of membrane fouling. Per the test protocol, a membrane regeneration procedure is required once the membranes reach 100% resistance (1.49 psi/gfd @ 68°F). For a given test, the resistance was determined using the following formula applied by NSWCCD in previous membrane evaluations [18]:

$$R = \frac{TMP}{F} \times \frac{0.3 + 1.38e^{\frac{-68}{27.6}}}{0.3 + 1.38e^{\frac{-T}{27.6}}}$$

Where: R = Resistance (psi/gfd)

TMP = Transmembrane Pressure (psi)

F = Flux (gfd)

T = Temperature in chamber (°F)

Resistance is expressed as the pressure required to produce a unit of flux, or the psi needed to generate one gallon of permeate per one square foot of membrane area per day. A temperature correction factor is used in the equation to normalize flow to room temperature to eliminate the effect of viscosity changes in water with temperature.

A maximum resistance scenario for the HSRMS was determined to be 1.49 psi/gfd based on the following assumptions:

- Maximum allowable TMP of 3.0 bar (43.5 psi) based on the manufacturer's recommendations
- Minimum allowable processing efficiency of 2.19 gpm based on the baseline generation rate for a Navy DDG (assuming 1,000 gpd of treated oily water discharge for an 8 hour workday with 95% of the fluid going overboard)
- Total membrane surface area of 10.0 m^2 (107.6 ft^2)
- Operation at room temperature, 68 °F

Membrane Regeneration

Rationale

Previous ceramic membrane research conducted at NSWCCD has found chemical cleanings of fouled ceramic membranes greatly improve membrane flux. As a part of this study, the chemical cleaning procedure developed for crossflow ceramic membranes was modified and applied to determine the cleaning benefit of the HSRMS. The purpose of this test was only to quantify the amount of regeneration achieved through the cleaning process. Any level of regeneration was considered "successful" according to the success criteria; however, this information coupled with the membrane failure rate will assist in determining maintenance and life cycle costs.

Test Approach

The membranes were regenerated when they reached 100% resistance or when the OCMs consistently alarmed from high oil concentration. The membranes were also regenerated two times at the end of the evaluation to see the effect of heat on membrane regeneration. The 5 GPM Oily Waste Membrane System (OWMS) Regeneration Procedure was used for the HSRMS. However, a heat exchanger was used to heat the influent since the HSRMS does not produce enough heat to meet the temperature (120 °F) defined in the regeneration procedure. As in the listed regeneration protocol, hot water flushes and a dual detergent approach was used, first regenerating with the basic cleaner, Micro-90, for 4 hours then regenerating with the acidic counterpart, Micro A07, for 4 hours. The water used during recirculation was slowly heated and maintained at 120 ºF. The manufacturer recommended refraining from temperature changes of more than 5.2 °F/min to avoid cracking the ceramic membranes. The HSRMS manufacturer stated that if the unit was filled with room temperature water, adding 120°F water for cleaning should not exceed a temperature change of more than 5.2 °F/min. However, a preliminary test

showed a temperature change of 4.0 °F/min when adding 70-100°F water directly to the system. Therefore, as a precaution, the water was slowly heated using the heat exchanger as it was added to the HSRMS at 2.9 °F/min. After the first 30 minutes of cleaning with Micro-90, all recirculated water was directed to the UST for removal of gross contamination. New Micro-90 solution was prepared for system feed and used for the remaining 3.5 hours. The 4-hour cleaning cycle was repeated with Micro A07 excluding the discharge of the cleaning solution after the first 30 minutes.

Reliability, Maintainability, and Availability Testing

Rationale

The primary purpose for collecting reliability, maintainability, and availability (RMA) data was to better understand shipboard needs and sailor burden prior to the shipboard demonstration. The information collected via RMA calculations will enable a better estimation of NSWCCD Code 633 support required throughout the evaluation, operator training prior to the shipboard demonstration, and spare part procurements.

Test Approach

The Uniform Test Plan for Oily Water Separators [6] was used as the foundation for testing of the HSRMS. Consistent OWS testing regimen allows for the potential comparisons of evaluated OWSs. In addition to the performance tests, the reliability tests extended the system's total operating time to at least 922 hours. For every 100 hours of reliability testing, the HSRMS processed a mixture of NSBM #4, solids, and fibers for 10 hours to demonstrate non-degraded performance. For the remaining 90 hours, the HSRMS processed a mixture of NSBM #4 and detergent mix #4 until the membranes were fouled. After the membranes were fouled (100% resistance), the membranes were regenerated. The HSRMS processed potable water for subsequent reliability tests after initial membrane fouling and regeneration. Table 5 summarizes the influent conditions and test durations for the reliability evaluation.

Table 5. Reliability Evaluation Test Conditions

Test	Influent Mixture	Duration (hours)	Sampling
Reliability: Oily Water and Detergent Mix No. 4	Potable (building) Water 1,000-ppm NSBM #4 100-ppm Detergent Mix No.4	90 out of every 100 hours	N/A
Reliability: Water	Potable (building) Water	90 out of every 100 hours	N/A
Reliability Non-Degradation: Oily Water & Particles	1,000-ppm NSBM #4 100-ppm (m) Arizona Test Dust (coarse) 0.70-ppm (m) Cloth Fibers (lint 25-150 microns in length)	10 out of every 100 hours	Effluent – Two samples (t=4, 9) Waste Oil – One sample (t=8)

Success criteria

The Uniform Test Plan for Oily Water Separators requires a reliability evaluation that demonstrates a 400-hour MTBF with a 90% confidence level [6]. In order to achieve this level of confidence, no operational failures (critical or major) can occur during 922 hours of operation. RMA objectives are listed in Table 6 and were measured throughout the performance and membrane testing. Reliability and maintainability of the HSRMS were measured using the concepts of operational availability (A_o) and Mean Time Between Failure (MTBF). A_o addressed supportability factors and MTBF quantitatively measured the system's reliability. Mean Time to Repair (MTTR) was used to quantitatively measure system maintainability. Maximum Time to Repair (Max TTR) is the total allowed time for a single repair event to occur. The maintenance ratio is the ratio of total active maintenance man hours (scheduled and unscheduled) to the total operating time. Failures were categorized as follows:

- Critical – any failure that prevents attainment of a key performance parameter (e.g. effluent oil concentration greater than 15 ppm)
- Major – any failure that causes the system to lose capability to process oily waste, or a malfunction that requires more than five hours of corrective maintenance action to remedy (e.g. repeated plugging of membrane disks, OCM malfunction).
- Relevant – includes failure attributed to equipment design defects or equipment manufacturing defects.
- Non-relevant – includes failure attributed to operator or procedural error, or accident, mishandling, and improper storage or installation.

Table 6. RMA Definitions

Performance Objective	Metric Definition
Reliability	$\text{MTBF} = \frac{\text{Total Number of Operating Hours}}{\text{Total Number of Failures}}$
	$\text{K'} = \frac{\text{Total Calendar Time} - \text{Downtime}}{\text{Total Number of Operating Hours}}$ $\text{K'(MTBF)} = \frac{\text{Total Calendar Time} - \text{Downtime}}{\text{Total Number of Failures}}$

Performance Objective	Metric Definition
Availability	$A_O = \frac{\text{Uptime}}{\text{Total Time}}$ $= \frac{\text{Uptime}}{(\text{Uptime} + \text{Downtime})}$ $A_O = \frac{(\text{Total Time} - \text{Downtime})}{\text{Total Time}}$ $A_O = \frac{K'(\text{MTBF}) - \text{MDT}}{K'(\text{MTBF})}$
Maintainability	$\text{MLDT} = \frac{\text{Total Logistic Time Delay}}{\text{Total Number of Failures}}$
	$\text{MTTR} = \frac{\text{Total Corrective Maintenance Time}}{\text{Total Number of Failures}}$
	$\text{MDT} = \frac{\text{Total Downtime}}{\text{Total Number of Failures}}$ $\text{MDT} = (\text{MTTR} + \text{MLDT})$
	Maintenance Ratio $= \frac{\text{Total Active Maintenance Man Hrs}}{\text{Total Operating Time}}$
Operability	Training time
	Operating time
	Maintenance time (Corrective and Preventative)
	Operator skill level

Shipboard Evaluation

Installation

The Novoflow HSRMS was installed aboard USNS Matthew Perry (T-AKE 9) during April-May 2020. Installation and removal drawings were developed by CACI and reviewed by USCG Office of Commercial Vessel Compliance and American Bureau of Shipping (ABS) prior to the installation. The ABS-approved installation drawings are included as Appendix E. The installation contract was awarded to Vigor Marine in Portland, OR. NSWCCD Code 633 was on site for installation and operational testing of the system, connection and testing of system data logger, replacement of system membranes, and recommended system maintenance. During the week of 10 May 2021, the system was successfully demonstrated to ABS and received inspection approval. Additionally, Code 633 completed data logger testing (Appendix H) and trained ship's force on the operation of the HSRMS (Appendix I). Detailed operating instructions were updated to reflect changes in valve alignments made during the installation and were provided to ship's force during the week of 10 May 2021.

Figure 9 shows the HSRMS landed next to the cleaning tank and hot potable water connections. Figure 10 shows the installation location of the Turner TD-107 oil content monitor, ET-35N oil content monitor, and cleaning tank heater control cabinet. Figure 11 and Figure 12 shows relevant valve locations.

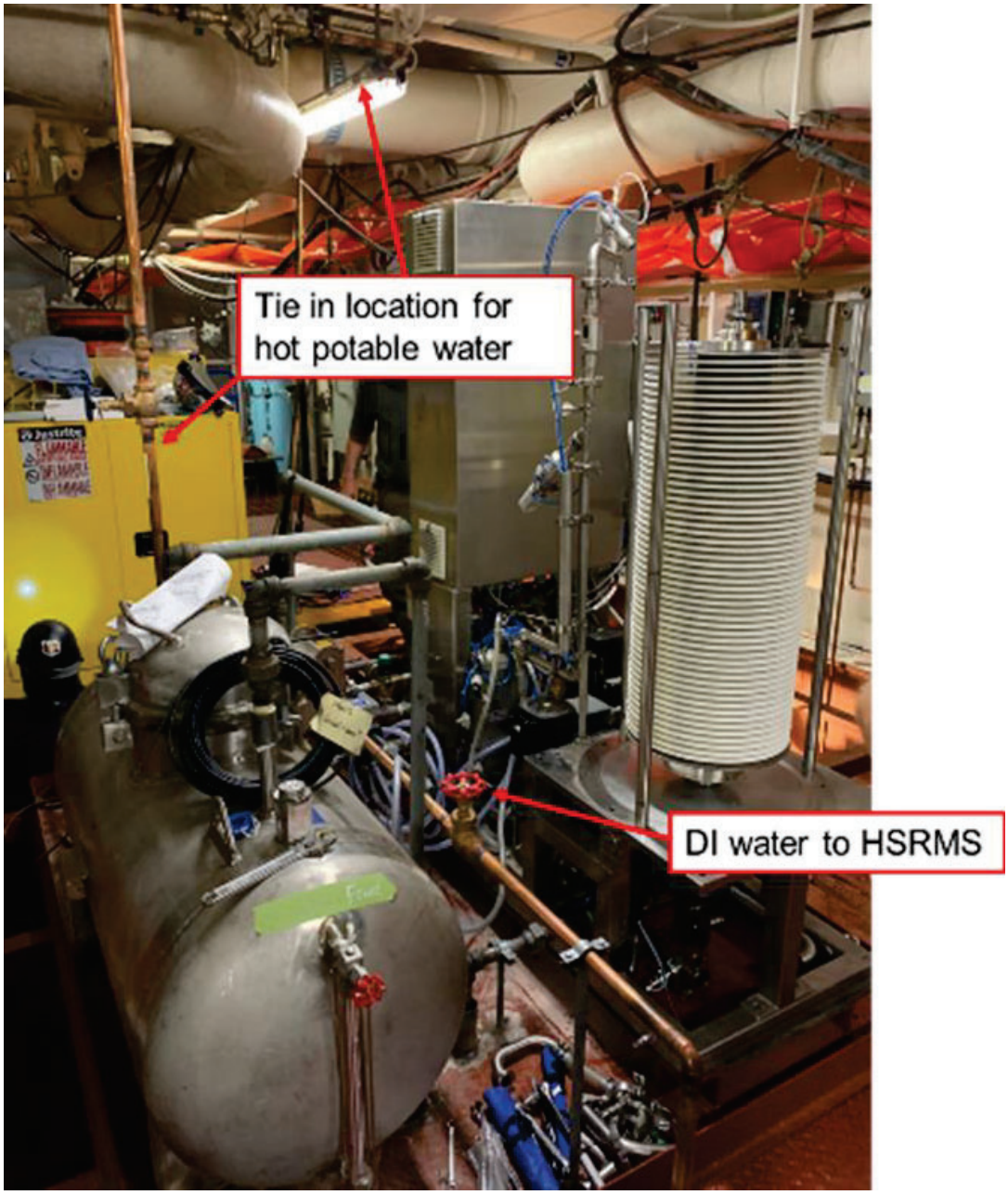


Figure 9. Tie in locations for hot potable water and deionized (DI) water on USNS Matthew Perry (T-AKE 9)

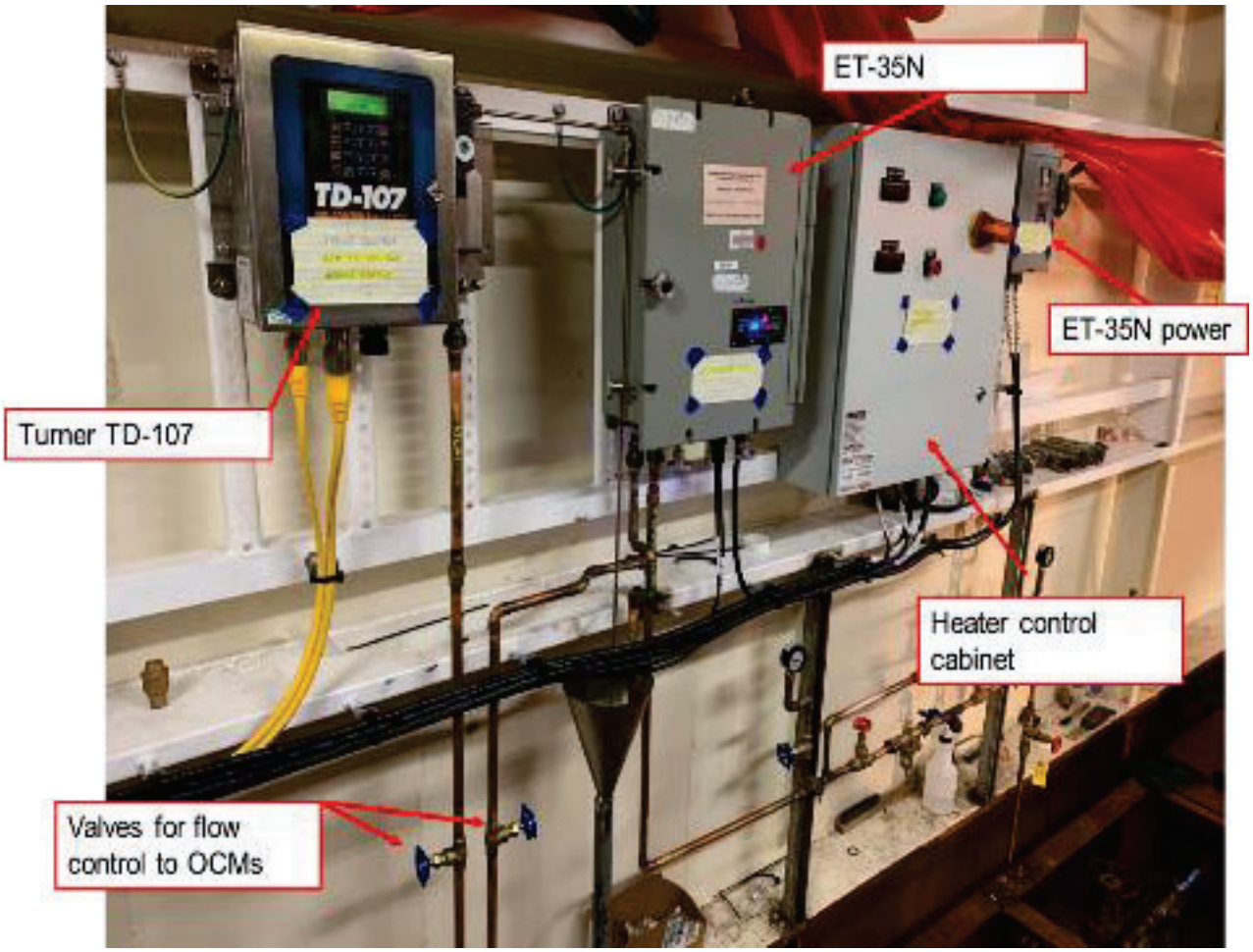


Figure 10. Turner TD-107 OCM, ET-35N OCM and heater control cabinet installed on USNS Matthew Perry (T-AKE 9)

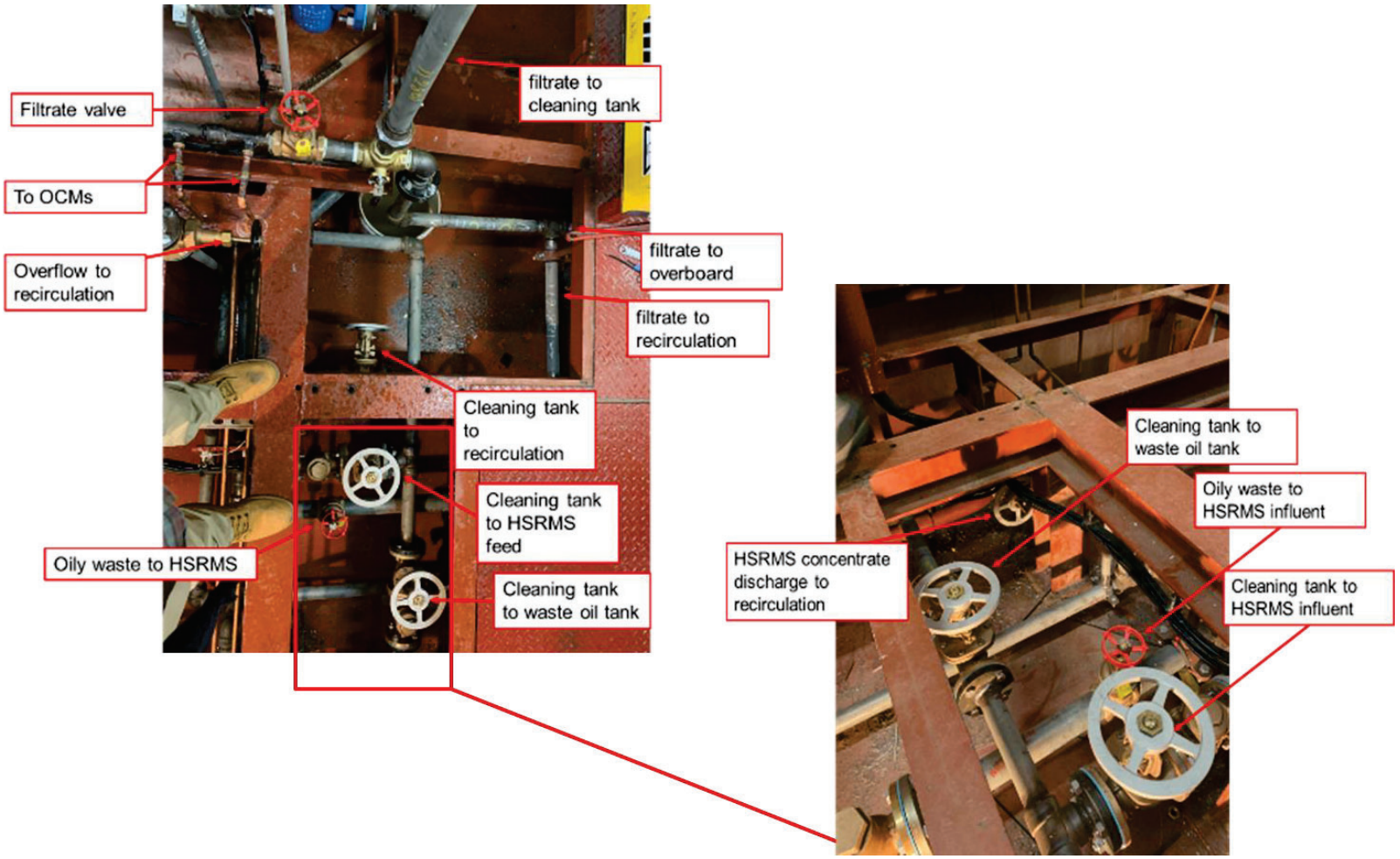


Figure 11. Arrangements of sensors, piping, and valves used to support the HSRMS installed on USNS Matthew Perry (T-AKE 9)

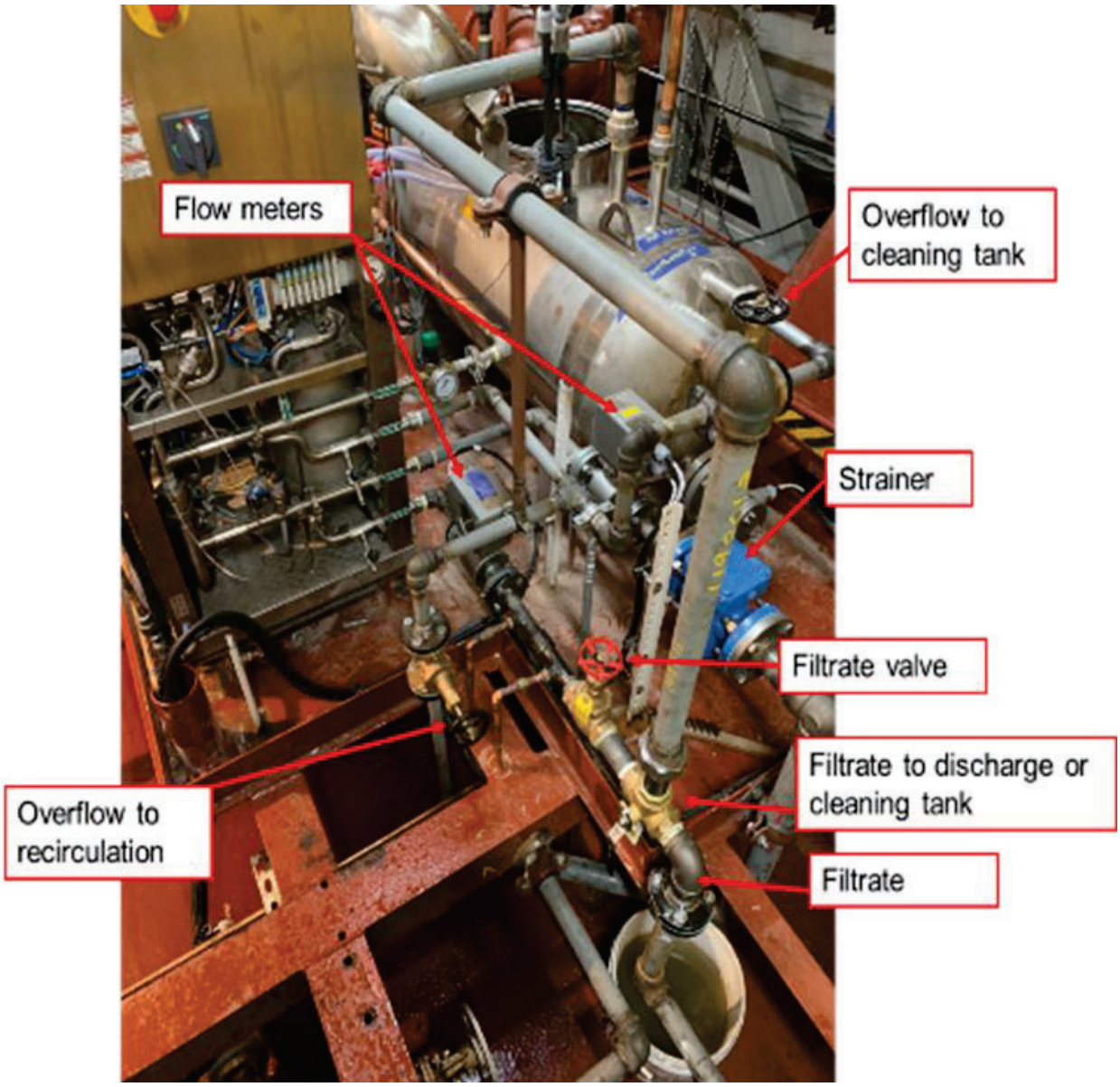


Figure 12. Flowmeters, HSRMS piping interface, and valves used to support the HSRMS installed on USNS Matthew Perry (T-AKE 9)

Ship's Force Training

Ship's force was trained by NSWCCD Code 633 to operate the HSRMS and troubleshoot common issues. This included system start-up procedures, standard processing protocols, warnings and alarms, system shutdown, and troubleshooting. An operations manual, training brief, and an engineering operational sequencing system (EOSS) were also developed as a reference for ship's force (Appendix J). NSWCCD Code 633 also kept an open line of communication for any questions.

System Operation

The system was expected to be operated in place of the ship's current OWS (e.g. Ultra-Sep). Therefore, decisions on when to process the bilgewater was at the discretion of the ship's force; however, it was strongly encouraged to operate the system as much as possible, particularly when the ship was underway.

Start-up procedures were pre-programed into the Novoflow HSRMS, which included tasks such as start-up of the human-machine interface (HMI), the filling of the membrane chamber, and start of filtrate production. For normal operation, the PLC automatically managed all pumps, valves, and the gear drive. No operator supervision was required except to stop the production process or to address warnings and alarms. For shutdown, the operator was required to manually discharge the concentrate discharge and perform a rinse with potable water. Automatic shutdown would only occur when the bulk oil was processed through the HSRMS.

System Settings

Unlike traditional OWSs, the Novoflow HSRMS is not designed solely for oily wastewater treatment; therefore, no pre-established operational parameters for oily wastewater exists. The manufacturer offered some recommendations during the system commissioning, but most settings were optimized after observing the system response during the laboratory testing defined in the JTP. For the shipboard demonstration, the system settings listed in Table 7 were used.

Table 7. Recommended Operational Parameters for Shipboard Demonstration

Setting	Description	Set value
Sp pressure	Maintains feed pressure to selected value	3.0 bar (43.5 psi)
Overflow controller-flowrate	Regulates overflow rate based on selected value (sp overflow)	100 lph (0.4 gpm)
Overflow controller-torque	Regulates overflow rate based on torque of membrane stack	Not Used
Speed drive	Controls rotational speed of the membrane stack	100% (400 rpm)
Backflush every	Controls frequency of backflush event	2 mins
Backflush duration	Controls duration of a backflush event	2 secs

Data Collection

Two methods of data collection were used during the OWS system evaluation, including: (1) interviews of ship's force, and (2) the use of an automatic DAS for continuous data collection. Interviews took place during the ship's force training to document the historic baseline operation of the legacy OWS system. Additional contact with ship's force throughout the evaluation was also used to collect data on system operation. The installed data acquisition

system (DAS) automatically collected data on a continuous basis. Details regarding how the collected information was used are provided below.

Interviews of Ship's Force

Preliminary Data Collection Phase

The preliminary phase of data collection consisted of an interview of ship's force to document the historic baseline operation of the legacy Coffin OWS system. NSWCCD Code 633 administered an interview to ship's force to collect historic OWS system baseline information on reliability, maintainability, and operability [17]. This interview covered historic OPA factors such as: (1) oily waste generation rates, (2) system operational procedures, (3) frequency and location of system operation, (4) ship's force labor requirements, (5) system preventative maintenance requirements, (6) system corrective maintenance requirements, and (7) adequacy of system documentation and integrated logistics support.

Continuous Support

NSWCCD Code 633 maintained regular communication with ship's force during the evaluation. Ship's force provided feedback on the operation of the HSRMS five times over the 6-month evaluation period. The feedback was used to help determine if the system was able to meet RMA criteria for the shipboard demonstration.

Continuous Data Collection

DAS information was collected continuously to document OPA system performance, reliability, and maintainability. DAS information was compared to Ship's force feedback to check for consistency and troubleshoot the OPA system and its associated instrumentation.

The DAS continuously collected data from OPA system components including the HSRMS and OCMs. Digital signals were associated with "the state" of data. For example, a pump could be either in an on or off "state". Analog signals were associated with continuous sensor measurements such as pump discharge pressure or the volume of fluid in a tank. Appendix K lists a tabular explanation for each signal, showing: (1) name and description, (2) the event to be logged, (3) the justification for collecting the data, (4) the frequency of measurement, and (5) whether it is an analog or digital signal. The DAS recording frequency was every 5 seconds.

Ship's force sent downloaded logged data from the DAS four times during the evaluation. During the second data download, the datalogger stopped including date stamps. However, all of the data points were still able to be recovered with time stamps. NSWCCD Code 633 used data download dates and context to determine when events reported by ship's force occurred in the data set. The Turner Designs TD-107 OCM was planned to serve as a back-up data logger, recording information such as time, whether the system is processing, oil concentration, and common alarm conditions. However, the OCM's internal data logger failed during the evaluation and no data was recovered from the OCM.

Data Collection Summary

Appendix L organizes the summary of OWS evaluation data by system function or criteria. The data collection methods that were used to validate each function or criteria are also listed. Data collection methods include DAS component (from Appendix K), manual data collection, and

crew interview. Appendix L also provides the category of system characterization (i.e. reliability, maintainability, etc.) to which the data items are associated.

System Removal

After completion of the shipboard evaluation, the system was removed from the vessel on 04 May 2022 and shipped to NSWCCD. All ancillary equipment including data logging equipment and flow meters was also removed and original OWS configuration was restored.

Performance Assessment Plan

Based on the laboratory JTP (Appendix A) and Uniform Test Plan for OPA systems [6], the performance objectives that are needed for a successful demonstration of the HSRMS for bilgewater treatment includes system processing performance, membrane life, reliability, maintainability, availability, and operability [6]. Table 8 lists the performance objectives and criteria that were needed for a successful demonstration of the HSRMS for bilgewater treatment. The listed performance objectives are consistent between both the laboratory JTP (Appendix A) and the shipboard demonstration.

The DAS provided run time and identified certain system failures, such as OWS alarm states or low flow. Crew interviews provided information on the number, type, and duration of maintenance events performed during the evaluation. Preventative maintenance (PM) during the evaluation occurred when the OWS system would otherwise be in stand-by, and therefore, PM did not cause the OWS system to be unavailable for use when required to process oily waste. In addition, some supportability factors (operator training and stocking of spare parts) were addressed prior to the initiation of the evaluation.

Operability of the OWS system was monitored throughout the evaluation using qualitative and quantitative system metrics. Operability was measured primarily through crew interviews. While there were no specific criteria for acceptance concerning operator involvement, a complex system that requires significant operator involvement is not desired.

Performance of the OWS system was measured in terms of effluent quality, as shown in Table 8. Performance success criteria is defined with respect to the 15 ppm oil concentration criteria for the OWS effluent. Two OCMs (Turner Designs Model TD-107 and Admartec Model ET-35N) were used to continuously monitor effluent whenever the OWS is in operation. Although the TD-107 OCM is MEPC.107(49)-certified and controlled the overboard discharge, the ET-35N was installed as a secondary OCM as it is the Navy in-service OCM. The DAS logged measurements from both OCMs.

Additional performance criteria are referenced from past evaluations [13, 14, 15]. More than 95% of the OWS effluent samples should contain concentration of less than or equal to 15 ppm oil in water. All OWS effluent samples should contain concentrations of less than or equal to 100 ppm oil in water. All of the system alarms, indicators, and sensors should function as designed.

Table 8. OWS System Evaluation Metrics

Performance Objective	Metric Definition	Metric	Success Criteria
Performance	Determines system ability to process effluent measured by effluent quality, appropriate system response and processing rate.	Oil concentration (ppm)	95% of effluent samples ≤ 15 ppm 100% of effluent samples ≤ 100 ppm
		Alarms, Indicators and Sensors	Alarms, Indicators and Sensors operate as designed
		Effluent Flow Rate	OWS must process the daily oily waste without accumulation in the OWHT within a 10 hr workday
Membrane Life	Time before membrane reaches 100% resistance	TMP and effluent flow rate	Run time of 300 hrs without reaching 100% resistance
Reliability	$\text{MTBF} = \frac{\text{Total Number of Operating Hours}}{\text{Total Number of Failures}}$ $\text{K}' = \frac{\text{Total Calendar Time} - \text{Downtime}}{\text{Total Number of Operating Hours}}$ $\text{K}'(\text{MTBF}) = \frac{\text{Total Calendar Time} - \text{Downtime}}{\text{Total Number of Failures}}$	Logged Operation Data	$^{+}$MTBF ≥ 922 Hours with No Failures (Relevant Critical or Relevant Major)

Performance Objective	Metric Definition	Metric	Success Criteria
Availability	$A_O = \frac{\text{Uptime}}{\text{Total Time}}$ $= \frac{\text{Uptime}}{(\text{Uptime} + \text{Downtime})}$ $A_O = \frac{(\text{Total Time} - \text{Downtime})}{\text{Total Time}}$ $A_O = \frac{K'(\text{MTBF}) - \text{MDT}}{K'(\text{MTBF})}$ $= \frac{1 - [\text{MTTR} + \text{MLDT}]}{K'(\text{MTBF})}$	Logged Operation Data	$^{+}A_O \geq 95\%$
Maintainability	$\text{MLDT} = \frac{\text{Total Logistic Time Delay}}{\text{Total Number of Failures}}$	Logged Operation Data	$^{+}\text{MTTR} \leq 3$ Hours
	$\text{MTTR} = \frac{\text{Total Corrective Maintenance Time}}{\text{Total Number of Failures}}$		$^{+}\text{Max TTR} \leq 8$ Hours
	$\text{MDT} = \frac{\text{Total Downtime}}{\text{Total Number of Failures}}$ $\text{MDT} = (\text{MTTR} + \text{MLDT})$		$^{+}$Maintenance Ratio $\leq .03$
	Maintenance Ratio $= \frac{\text{Total Active Maintenance Man Hrs}}{\text{Total Operating Time}}$		$^{+}$Preventative Maintenance ≤ 3.5 Hrs per Week
Operability	Training time Operating time	Crew Interviews (see Appendix M)	$^{+}$No Preventative Maintenance Action Shall Take > 16 Man hrs

Performance Objective	Metric Definition	Metric	Success Criteria
	Maintenance time (Corrective and Preventative)		
	Operator skill level	Operator Interview	Displays skill level required to operate and maintain equipment

[+] OWS Evaluation Metric [6, 19, 20]

PERFORMANCE ASSESSMENT

Full Scale Laboratory Testing Results

System Processing Performance

The first success criteria for the performance testing was that 95% of samples had an oil concentration below 15 ppm and that 100% of effluent samples were below 100 ppm (Table 2) The Novoflow HSRMS demonstrated its capability to maintain permeate quality within these metrics while treating non-emulsified, mechanically emulsified, and chemically emulsified oil containing contaminants. The HSRMS did not experience oil breakthrough of the membranes (>15 ppm) for the entirety of performance. The capability of the system to process simulated bilgewater mixtures was assessed using EPA Method 1664 results (Appendix N, Appendix O) and the discharge decisions from the ET-35N and TD-107 OCM measurements. Table 9 summarizes the oil concentrations, average flowrates, and processing rates of the performances tests. Nearly all performance tests resulted with TD-107 measurements below 15 ppm, and the rare instances of TD-107 measurements greater than 15 ppm were attributed to the presence of detergent foam interfering with sensor readings. The laboratory analyses for these corresponding effluent samples confirmed that no oil content was detected. The quality of the effluent samples was consistent with the results documented in SERDP Project WP-1671 [6]. Table 10 details the EPA 1664 results and corresponding OCM readings for all samples drawn during the performance evaluation. Results highlighted in gray indicate a recirculation condition or system unavailability.

The second success criteria was that all system alarms, indicators, and sensors function as designed in all operating modes. The HSRMS was able to meet this objective throughout the laboratory testing.

Membrane life was also evaluated using success criteria of operating more than 300 hrs before reaching 100% resistance. Throughout the evaluation, the HSRMS exceeded 100% resistance during one instance, this occurred 147 hrs after the previous membrane cleaning. Therefore, the system was not able to meet the membrane life criteria. Prior to this event, the system experienced periods of fluctuating membrane resistance that increased over subsequent tests. Fouling of the membranes was therefore cumulative, and the system exhibited diminishing performance over time. The membrane resistance decreased following a membrane regeneration procedure (67% flux recovery), therefore passed the membrane regeneration success criteria of “regeneration observed”.

Lastly, the average processing rate was significantly lower than designed (i.e. 10 gpm). The average processing rate for the laboratory demonstration was 4.0 gpm. The processing rate for each performance test with 1,000 ppm oil were within the error of each other. The “Oily & Seawater” performance tests (Performance Tests #9 and 19) demonstrated the lowest average processing rate of 3.05 gpm, and the “200-ppm Oily Water” performance tests (Performance Tests #1 and 11) demonstrated the highest processing rate of 5.9 gpm.

Table 9. Summary of HSRMS Performance Analyses

Test Condition	Test #	Processing Efficiency[1] (%)	Initial Effluent Flowrate (gpm)	Final Effluent Flowrate (gpm)	Effective Processing Capacity (gpm)	Effluent Flowrate Recovery (after rinse)	Average Oil Concentration (ppm)		% Overboard	
							ET-35N	TD-107	ET-35N[1]	TD-107
200-ppm Oily Water	1	79	8.5	2.2	5.6	5.7	0 ± 0	0.1 ± 0.2	55	100
	11	83	7.0	6.0	6.1	6.7	0 ± 0	0.4 ± 0.1	82	100
1,000-ppm Oily Water	2	77	5.5	2.5	3.7	3.8	0 ± 0	1.0 ± 0.2	100	100
	12	78	5.0	2.5	4.3	4.4	0 ± 0	0.9 ± 0.2	100	100
Oily Water & Mixed Detergent	3	81	3.0	4.9	4.4	6.0	0 ± 0	6.6 ± 2.2	91	100
	13	70	2.5	3.0	2.6	4.1	0 ± 0	1.5 ± 0.7	100	100
Oily Water & Type 1 Detergent	4	11	7.0	3.5	0.6	6.0	4.9 ± 8.2	24.9 ± 6.4	36	13
	14	70	4.1	3.0	2.7	4.8	5.5 ± 7.8	15.3 ± 8.7	91	99
Oily Water & Mixed Chemicals	5	79	7.0	4.8	5.3	5.8	1.5 ± 2.4	0.6 ± 0.2	100	100
	15	74	5.0	0.0	3.2	1.8	1.3 ± 2.1	2.8 ± 0.4	88	100
Oily Water & AFFF	6	77	6.0	3.0	3.7	4.1	0 ± 0	1.0 ± 0.3	100	100
	16	75	8.5	2.5	4.2	5.7	0 ± 0	1.0 ± 0.3	82	100
Oily Water, Mixed Detergent, & Particles	7	79	4.0	5.5	4.4	7.1	0.6 ± 2.1	8.1 ± 2.0	64	100
	17	79	6.0	5.8	5.6	7.0	0 ± 0	1.7± 0.3	46	100
JP-5 Oily Water & Mixed Detergent	8	77	7.0	3.2	3.6	5.3	0 ± 0	1.2 ± 0.3	100	100
	18	78	7.5	4.8	4.6	6.2	0 ± 0	0.3 ± 0.1	36	100
Oily Water & Seawater	9	68	4.5	2.2	2.3	2.4	0 ± 0	0.8 ± 0.1	100	100
	19	75	6.5	3.6	3.8	4.2	0.3 ± 0.6	0.7 ± 0.2	100	100
OWHT Transition Test	10	77	5.2	5.1	4.5	5.0	0 ± 0	0.8 ± 0.1	100	100
	20	78	5.2	4.4	4.7	4.9	0 ± 0	0.8 ± 0.2	100	100

[1] Percent overboard discharge for ET-35N was only based on manually recorded data and did not include alarms from backpulsing events

Table 10. Performance Evaluation EPA Method 1664 Results and Corresponding OCM Readings

Test Number	Influent Condition	Time (hrs.)	Sample ID	Sample Type	Lab Analysis EPA 1664 (mg/l) [1]		OCM Readings (ppm) [2]	
					HEM	SGT-HEM	TD-107	ET-35N
1	200-ppm Oily Water	4	1-B-4	Influent	110	63	N/A	N/A
		4	1-A-4	Effluent	Non-Detect (ND)	ND	0.4	0
		9	1-A-9	Effluent	ND	ND	0.6	0
11		4	11-B-4	Influent	63	27	N/A	N/A
		4	11-A-4	Effluent	ND	ND	0.3	1
		9	11-A-9	Effluent	ND	ND	0.4	3
2	1,000-ppm Oily Water	4	2-B-4	Influent	960	420	N/A	N/A
		4	2-A-4	Effluent	ND	ND	0.9	2
		9	2-A-9-T1	Effluent	ND	ND	0.9	0
		9	2-A-9-T2	Effluent	ND	ND	0.9	0
		9	2-A-9-T3	Effluent	ND	ND	0.9	0
12		4	12-B-4	Influent	760	450	N/A	N/A
		4	12-A-4	Effluent	ND	ND	0.8	0
		9	12-A-9-T1	Effluent	ND	ND	0.9	3
		9	12-A-9-T2	Effluent	ND	ND	0.9	2
		9	12-A-9-T3	Effluent	ND	ND	0.9	0
3	Oily Water & Mixed Detergent	4	3-B-4	Influent	730	300	N/A	N/A
		4	3-A-4	Effluent	ND	ND	5.3	2
		9	3-A-9-T1	Effluent	ND	ND	3.7	4
		9	3-A-9-T2	Effluent	ND	ND	3.8	2

Test Number	Influent Condition	Time (hrs.)	Sample ID	Sample Type	Lab Analysis EPA 1664 (mg/l) [1]		OCM Readings (ppm) [2]	
					HEM	SGT-HEM	TD-107	ET-35N
		9	3-A-9-T3	Effluent	ND	ND	3.2	2
13		4	13-B-4	Influent	1000	500	N/A	N/A
		4	13-A-4	Effluent	ND	ND	1.4	2
		9	13-A-9-T1	Effluent	ND	ND	1.4	4
		9	13-A-9-T2	Effluent	ND	ND	1.4	5
		9	13-A-9-T3	Effluent	ND	ND	1.6	7
4	Oily Water & Type 1 Detergent	4	4-B-4	Influent	100	51	N/A	N/A
		4	4-A-4	Effluent	2.5	ND	22.2[3]	2, Warning Light 3[3]
		9	4-A-9	Effluent	ND	ND	18.2[3]	25, Range Alarm[3]
14		4	14-B-4	Influent	76	35	N/A	N/A
		4	14-A-4	Effluent	ND	ND	9.8	0
		9	14-A-9	Effluent	ND	ND	5.6	0
5	Oily Water & Mixed Chemicals	4	5-B-4	Influent	970	430	N/A	N/A
		4	5-A-4	Effluent	ND	ND	0.5	2
		9	5-A-9-T1	Effluent	ND	ND	0.6	0
		9	5-A-9-T2	Effluent	ND	ND	0.6	0
		9	5-A-9-T3	Effluent	ND	ND	0.6	5
15		4	5-B-4	Influent	980	450	N/A	N/A
		4	5-A-4	Effluent	ND	ND	0.6	0
		9	5-A-9-T1	Effluent	N/A[4]	N/A[4]	N/A[4]	N/A[4]
		9	5-A-9-T2	Effluent	N/A[4]	N/A[4]	N/A[4]	N/A[4]
		9	5-A-9-T3	Effluent	N/A[4]	N/A[4]	N/A[4]	N/A[4]

Test Number	Influent Condition	Time (hrs.)	Sample ID	Sample Type	Lab Analysis EPA 1664 (mg/l) [1]		OCM Readings (ppm) [2]	
					HEM	SGT-HEM	TD-107	ET-35N
6	Oily Water & AFFF	4	6-B-4	Influent	990	540	0.9	0
		4	6-A-4	Effluent	ND	ND	0.9	3
		9	6-A-9	Effluent	ND	ND	1.0	0
16		4	16-B-4	Influent	960	460	N/A	N/A
		4	16-A-4	Effluent	ND	ND	0.9	3
		9	16-A-9	Effluent	ND	ND	1.0	0
7	Oily Water, Mixed Detergent, & Particles	4	7-B-4	Influent	460	240	N/A	N/A
		4	7-A-4	Effluent	ND	ND	4.3	3
		9	7-A-9	Effluent	ND	ND	2.3	1, Warning Light 2
17		4	17-B-4	Influent	420	210	N/A	N/A
		4	17-A-4	Effluent	ND	ND	1.1	5
		9	17-A-9	Effluent	ND	ND	1.0	4
8	JP-5 Oily Water & Mixed Detergent	4	8-B-4	Influent	650	330	N/A	N/A
		4	8-A-4	Effluent	ND	ND	0.6	0
		9	8-A-9-T1	Effluent	ND	ND	0.5	0
		9	8-A-9-T2	Effluent	ND	ND	0.5	0
		9	8-A-9-T3	Effluent	ND	ND	0.5	0
18		4	18-B-4	Influent	670	330	N/A	N/A
		4	18-A-4	Effluent	ND	ND	0.2	3, Warning Light 3
		9	18-A-9-T1	Effluent	ND	ND	0.2	1
		9	18-A-9-T2	Effluent	ND	ND	0.2	1
		9	18-A-9-T3	Effluent	ND	ND	0.2	2

Test Number	Influent Condition	Time (hrs.)	Sample ID	Sample Type	Lab Analysis EPA 1664 (mg/l) [1]		OCM Readings (ppm) [2]	
					HEM	SGT-HEM	TD-107	ET-35N
9	Oily Water & Seawater	4	9-B-4	Influent	1000	490	N/A	N/A
		4	9-A-4	Effluent	ND	ND	0.7	0
		9	9-A-9-T1	Effluent	ND	ND	0.8	1
		9	9-A-9-T2	Effluent	ND	ND	0.8	1
		9	9-A-9-T3	Effluent	ND	ND	0.8	0
19		4	19-B-4	Influent	930	450	N/A	N/A
		4	19-A-4	Effluent	ND	ND	0.6	3
		9	19-A-9-T1	Effluent	ND	ND	0.7	2
		9	19-A-9-T2	Effluent	ND	ND	0.7	4
		9	19-A-9-T3	Effluent	ND	ND	0.7	0
10	OWHT Transition Test	4	10-B-4	Influent	970	310	N/A	N/A
		4	10-A-4	Effluent	ND	ND	0.5	0
		6:10	10-A-6:10	Effluent	3.5	ND	0.5	0
		6:30	10-A-6:30	Effluent	N/A[5]	N/A[5]	N/A[5]	N/A[5]
20		4	20-B-4	Influent	6,300	3,100	N/A	N/A
		4	20-A-4	Effluent	ND	ND	0.5	0
		6:10	20-A-6:10	Effluent	ND	ND	0.5	0
		6:30	20-A-6:30	Effluent	N/A[5]	N/A[5]	N/A[5]	N/A[5]

1: “ND” samples are not detected at or below the analytical laboratory’s reporting limit of 2.2 - 2.4 mg/l.

2: “N/A” not applicable, OCM measurements recorded for effluent samples only

3: The Type 1 Detergent foam interfered with both the fluorescence measurements of the TD-107 and optical turbidity measurements of the ET-35N. The oil content readings were inflated, and the ET-35N signaled warnings due to bubbles in the effluent. The effluent had no visible oil content upon inspection, and the EPA 1664 results confirmed that oil breakthrough had not occurred.

4: Performance Test #15 was stopped early due to the low flow rate alarm “FIC-120 Alarm LL underrun” and HSRMS entering standby mode.

5: Performance Test #10 and Performance Test #20 were stopped early due to the high torque alarm “M-100 torque Alarm HH exceeded” and HSRMS entering standby mode.

Performance Test #1 and #11: 200-ppm Oily Water

During these tests, the HSRMS processed 200-ppm NSBM #4 in potable water.

Test #1

The TD-107's internal logs indicated that the OCM made the decision to discharge fluid 100% of the time and did not trigger any high level alarms. Based on the manual logs (alarms from backpulse events not included), the ET-35N made the decision to discharge fluid only 55% of the time due to the signaling of Warning Lights 2 and 3. The effective processing efficiency of the HSRMS over the course of the test was 79% based on the recorded totalizer data. This discrepancy between the 100% discharge decision from the TD-107 and the 79% processing efficiency was due to the HSRMS's overflow requirement and the loss of fluid through the OCMs. The effluent flowmeter data indicated that the system produced an average overboard discharge rate of 5.6 gpm. All EPA 1664 SGT-HEM results reported "non-detectable (ND)" for the effluent samples which corresponds to a concentration of less than 2.4 ppm (Appendix O).

Influent and effluent flow rates were recorded every 5 seconds using the DAS and presented in Figure 13. Effluent flow rate represents all effluent from the HSRMS regardless of effluent quality. The upper peaks are points when the system was operating normally in production mode whereas the lower peaks are points when the system was conducting a backpulse; during a backpulse, flows to and from the system were halted for approximately 7 seconds for every 2 minutes. The performance test results were calculated using the data collected within each 10-hour test period when the contaminant mixtures were being injected. The potable water flush following the test is also captured in Figure 13 (Elapse time=10 hrs), but this period of time is omitted from calculations for the overall processing efficiency and OCM decision percentage since the system was not processing a test mixture. The potable water flush can be identified by the sudden increase in influent flow rate after the 10-hour test. The influent flow rate reached as high as 11.0 gpm when filling the empty membrane housing.

At the start of the test, the influent flow rate was over 10.0 gpm and the effluent flow rate was over 8.5 gpm due to the membrane regeneration conducted the prior day. As the oil mixture began to concentrate within the system, the flow rates began to decrease. The decrease in flow rates slowed after 7 hours of elasped time, and the system was still able to satisfy the 2.19 gpm minimum processing capacity established for the evaluation.

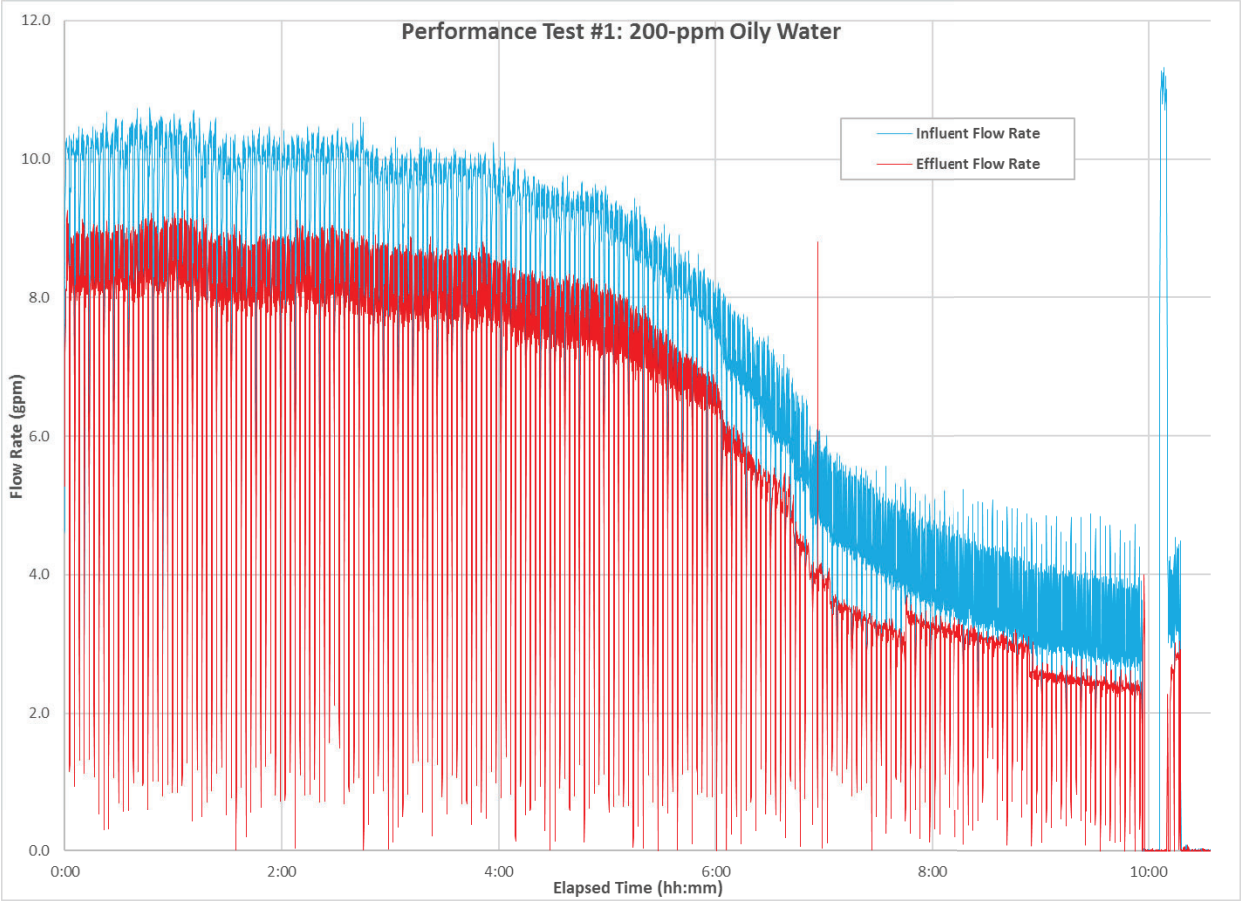


Figure 13. Performance Test #1 - Influent and Effluent Flow

The influent and effluent pressures for Performance Test #1 are presented in Figure 14. The TMP was 18.5 psi at the start of the test. As the membranes became fouled, the TMP increased to 34 psi after 6:00 of operation. The average TMP throughout the 10-hour injection period was 23.4 psi.

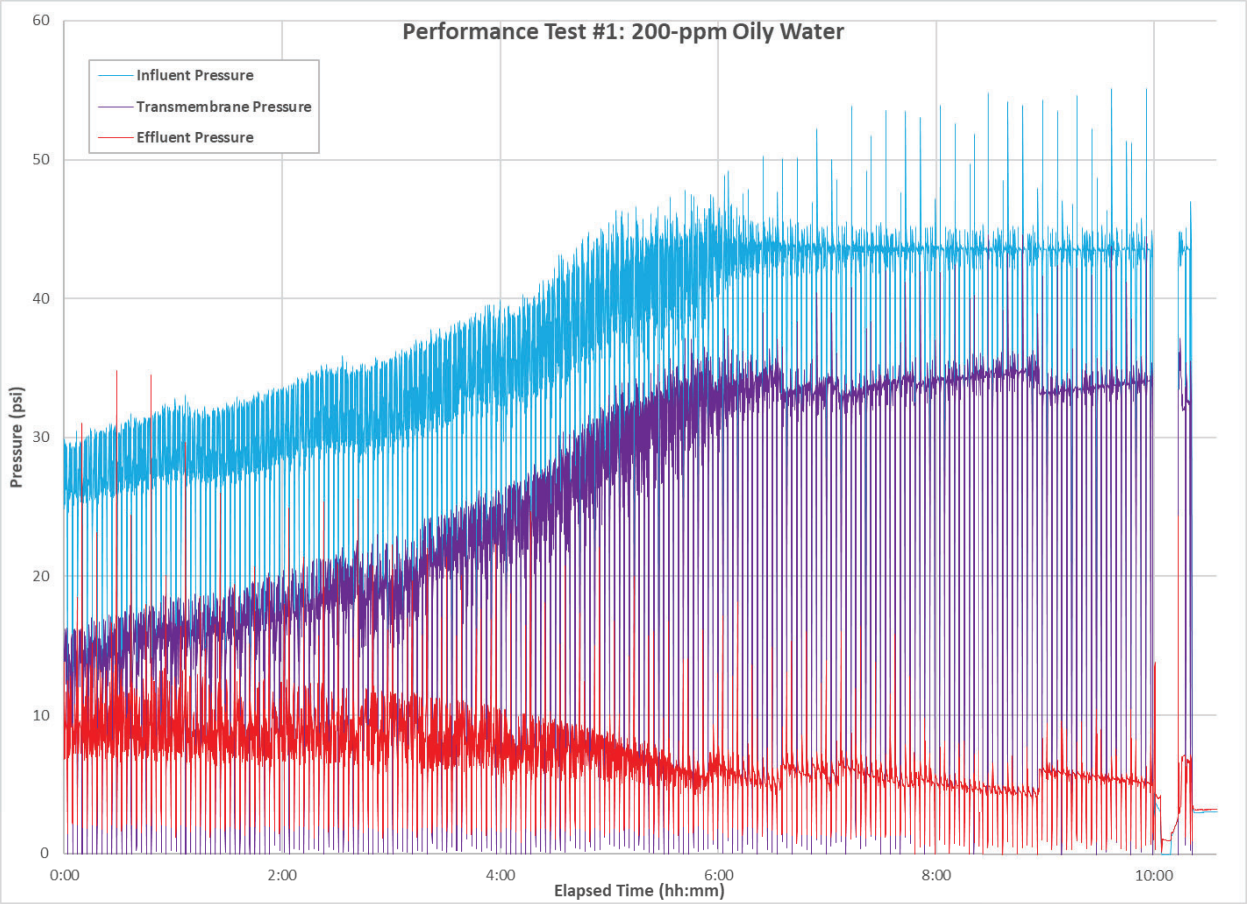


Figure 14. Performance Test #1 - Feed and Discharge Pressure

Test #11

The TD-107's internal logs indicated that the OCM made the decision to discharge fluid 100% of the time and did not trigger any high level alarms. Based on the manual logs (alarms from backpulse events not included), the ET-35N made the decision to discharge fluid 82% of the time due to the signaling of Warning Light 2 & 3. The effective processing efficiency of the HSRMS over the course of the test was 83% based on the recorded totalizer data. The effluent flowmeter data indicated that the system produced an average overboard discharge rate of 6.1 gpm. All EPA 1664 SGT-HEM results returned "ND" for the effluent samples.

Influent and effluent flow rates are presented in Figure 15. At the start of the test, the influent flow rate fluctuated over 8.0 gpm and the effluent flow rate over 7.0 gpm. The reduced initial conditions compared to Performance Test #1 is attributed to Performance Test #11 being conducted following a series of other tests that served to foul or partially recover the membranes. By the end of the test, the processing capacity had decreased to 6.0 gpm.

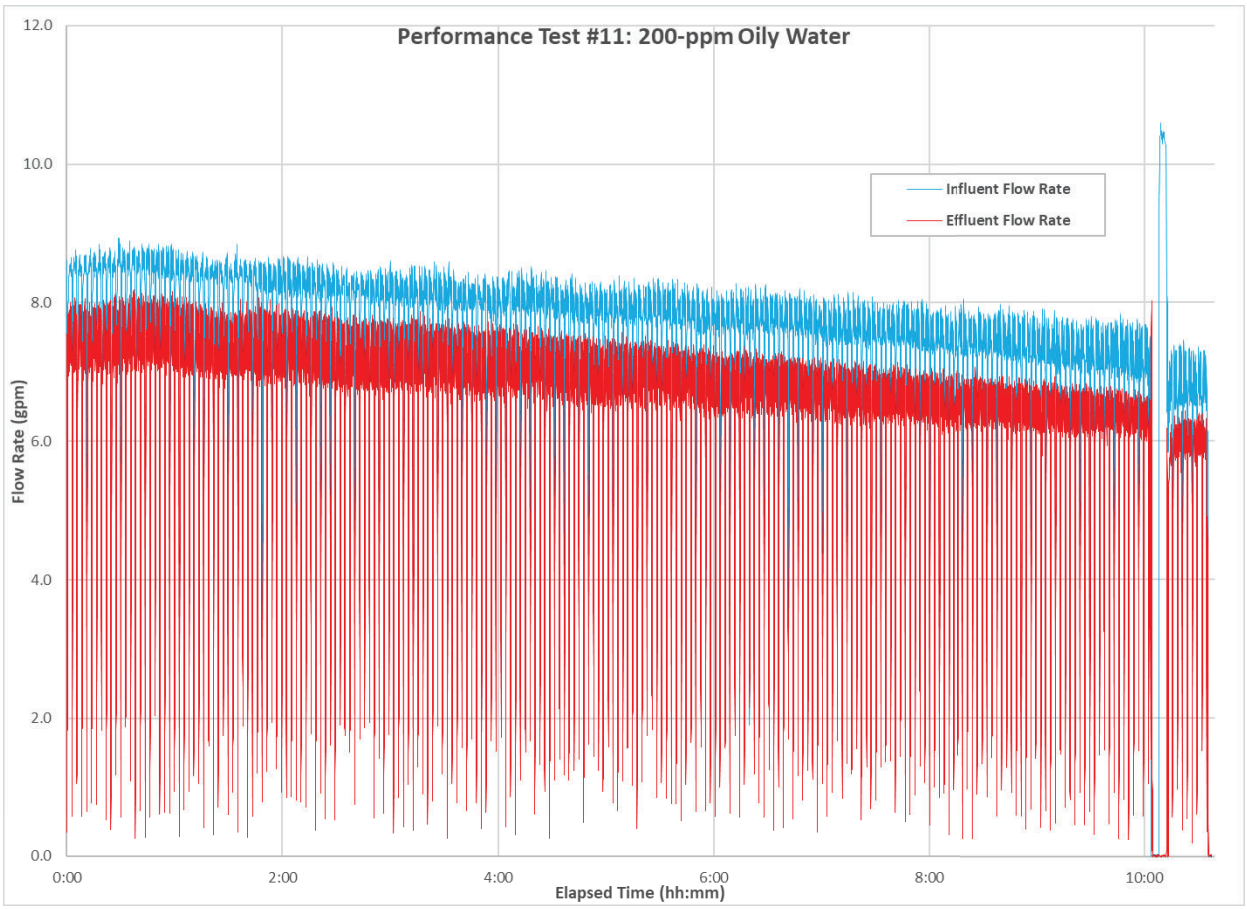


Figure 15. Performance Test #11 - Influent and Effluent Flow

The influent and effluent pressures are presented in Figure 16. The TMP was about 23 psi at the start of the test. As the system processed the oil mixture, the TMP gradually increased until reaching approximately 31 psi. The average TMP throughout the 10-hour test was 25.0 psi. The average TMP for Performance Test #11 was greater in comparison to Performance Test #1 which could be due to the added fouling from other performance tests.

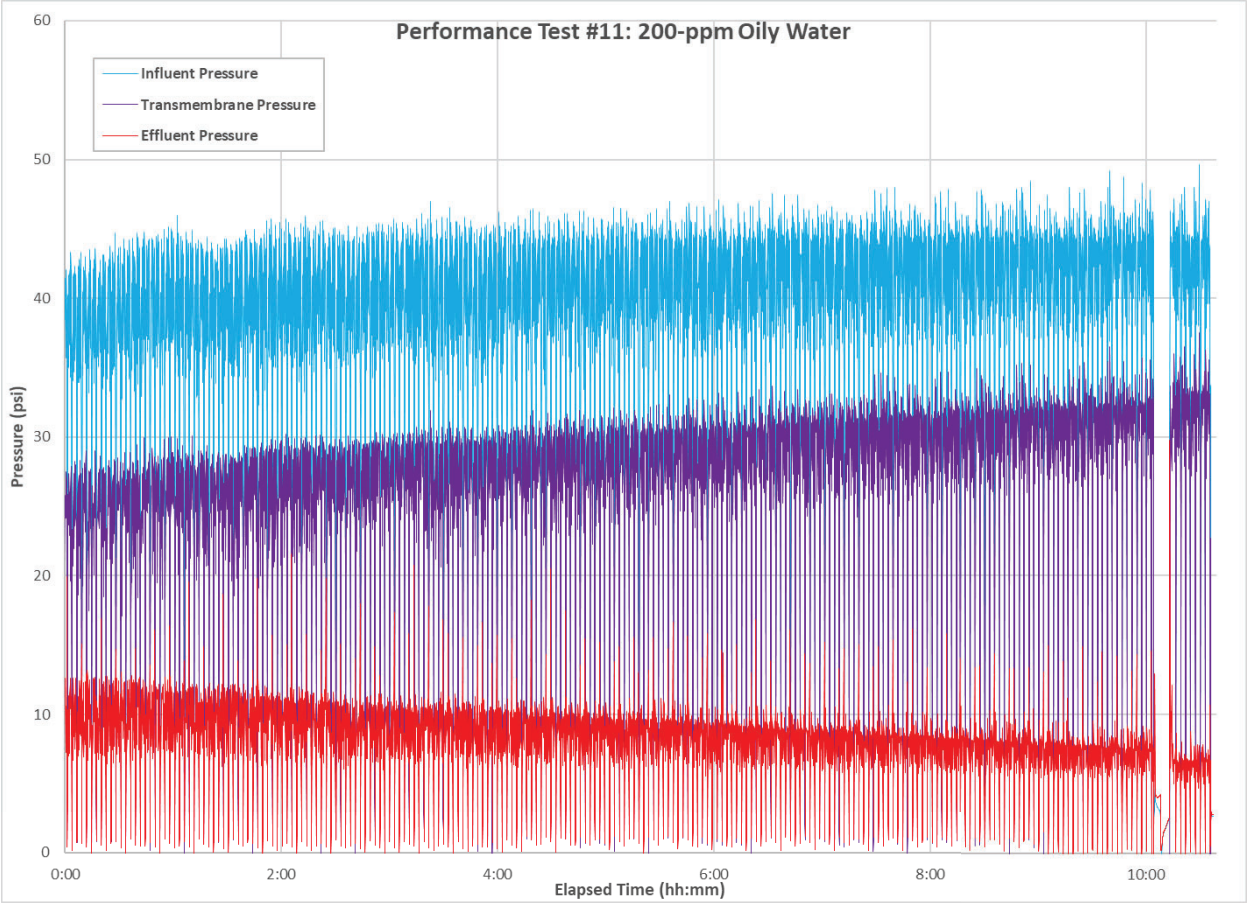


Figure 16. Performance Test #11 - Feed and Discharge Pressure

Performance Tests #2 and #12: 1,000-ppm Oily Water

During these tests, the HSRMS processed 1,000-ppm NSBM #4 in potable water.

Test #2

The TD-107's internal logs indicated that the OCM made the decision to discharge fluid 100% of the time and did not trigger any high level alarms. Based on the manual logs (alarms from backpulse events not included), the ET-35N also made the decision to discharge fluid 100% of the time. The effective processing efficiency of the HSRMS over the course of the test was 77% based on the recorded totalizer data. The effluent flowmeter data indicated that the system produced an average overboard discharge rate of 3.7 gpm. All EPA 1664 SGT-HEM results returned "ND" for the effluent samples.

Influent and effluent flow rates are presented in Figure 17. The previous day's test (Performance Test #1) ended with a processing capacity of 2.4 gpm, but the subsequent potable water flush and soaking of the membranes in potable water overnight restored the processing capacity to 5.5 gpm for the start of Performance Test #2. Over the course of the 10-hour test, the processing capacity decreased steadily to 2.5 gpm. Despite Performance Test #2 injecting a higher concentration of oil than Performance Test #1, the system's processing capacity did not decrease as rapidly. The oil layer coating the membranes had likely reached a point where any

further accumulation of fouling ceased due to rotational shear forces. The missing data between 2:38 to 3:26 elapsed time was due to the DAS crashing and needing to be reconfigured.

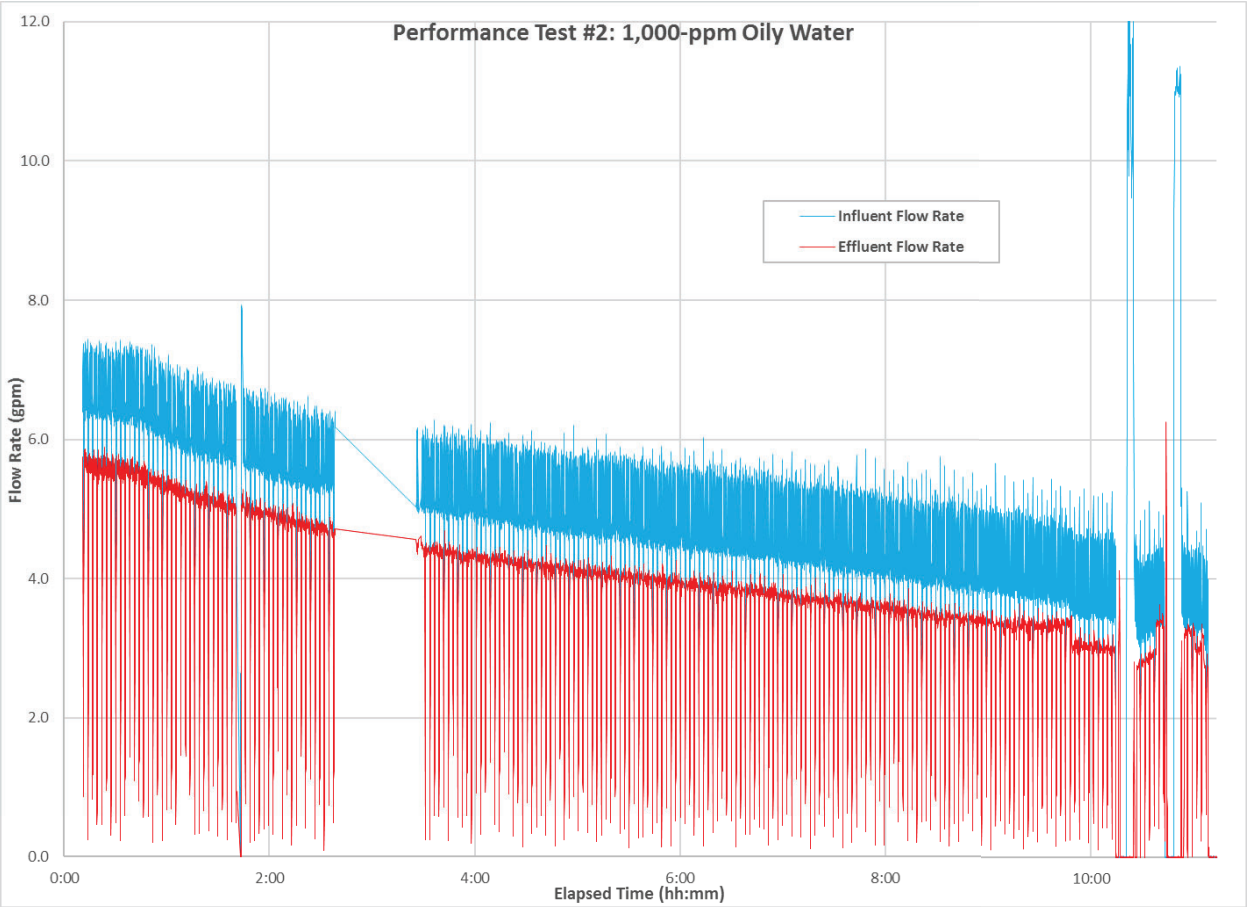


Figure 17. Performance Test #2 - Influent and Effluent Flow

The influent and effluent pressures are presented in Figure 18. The TMP was approximately 26 psi at the start of the test. As the system processed the oily test mixture, the TMP increased to 32 psi by the end of the test. The average TMP throughout the 10-hour injection period was 30.7 psi.

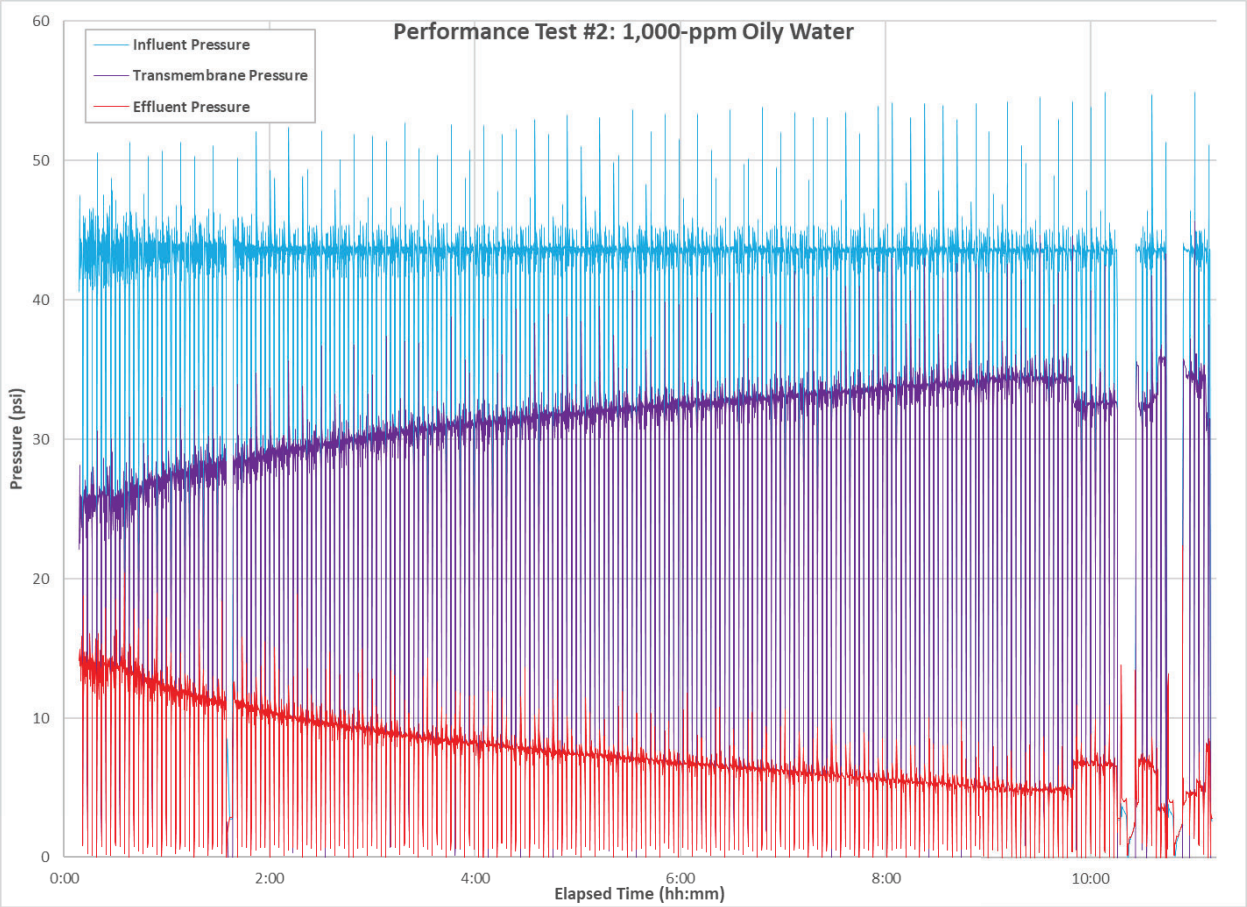


Figure 18. Performance Test #2 - Feed and Discharge Pressure

Test #12

The TD-107's internal logs indicated that the OCM made the decision to discharge fluid 100% of the time and did not trigger any high level alarms. Based on the manual logs (alarms from backpulse events not included), the ET-35N also made the decision to discharge fluid 100% of the time. The effective processing efficiency of the HSRMS over the course of the test was 78% based on the recorded totalizer data. The effluent flowmeter data indicated that the system produced an average overboard discharge rate of 4.3 gpm. All EPA 1664 SGT-HEM results returned "ND" for the effluent samples.

Influent and effluent flow rates are presented in Figure 19. At the start of the test, the influent flow rate fluctuated over 6.0 gpm and the effluent flow rate over 5.0 gpm. The lower initial flow rates were attributed to accumulation of membrane fouling from prior tests. The gradual linear decline of processing capacity is reflective of Performance Test #2; however, the overall decrease in processing capacity was 2.5 gpm in Performance Test #2 whereas the overall decrease in processing capacity was only 1.0 gpm in Performance Test #12. The missing data was due to the DAS crashing and needing to be reconfigured.

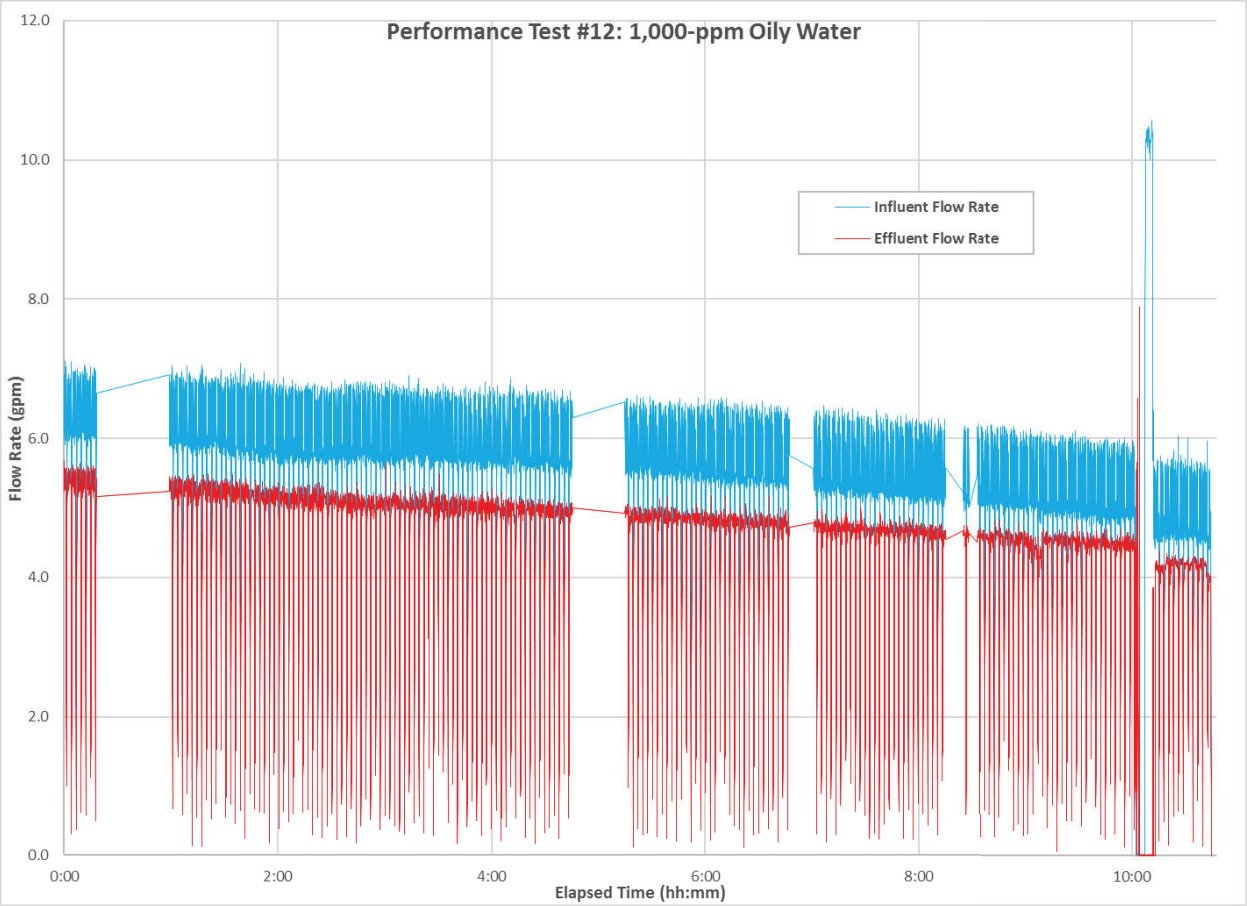


Figure 19. Performance Test #12 - Influent and Effluent Flow

The influent and effluent pressures are presented in Figure 20. The TMP was approximately 30 psi at the start of the test. As the oil mixture was injected and increased the resistance across the membranes, the TMP increased to approximately 34 psi by the end of the test. The average TMP throughout the 10-hour injection period was 28.3 psi.

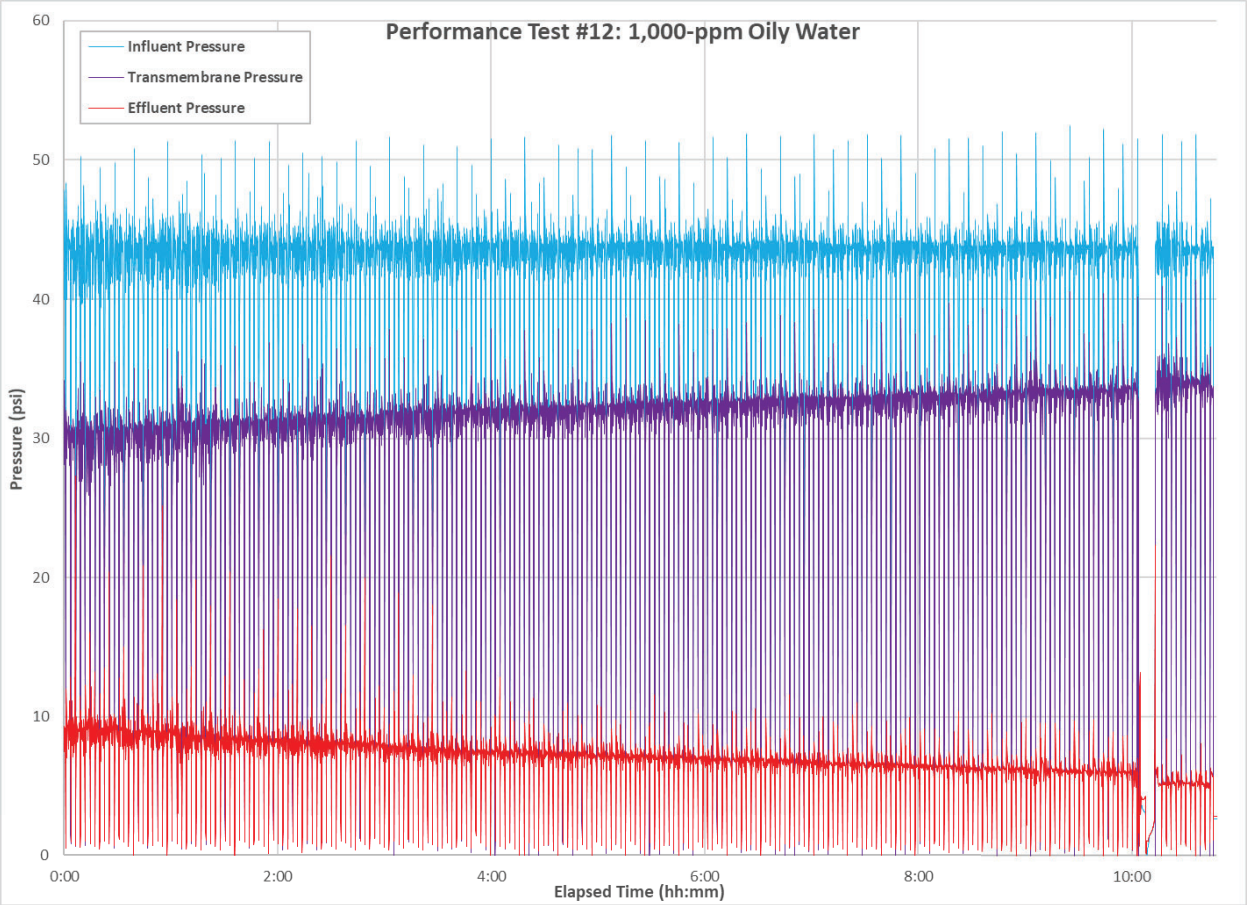


Figure 20. Performance Test #12 - Feed and Discharge Pressure

Performance Tests #3 and #13: Oily Water & Mixed Detergent

During these tests, the HSRMS processed 1,000-ppm NSBM #4 and 100-ppm Detergent Mix #4 in potable water.

Test #3

The TD-107's internal logs indicated that the OCM made the decision to discharge fluid 100% of the time and did not trigger any high level alarms. Based on the manual logs (alarms from backpulse events not included), the ET-35N made the decision to discharge fluid 91% of the time due to Warning Light 3 triggering. The effective processing efficiency of the HSRMS over the course of the test was 81% based on the recorded totalizer data. The effluent flowmeter data indicated that the system produced an average overboard discharge rate of 4.4 gpm. All EPA 1664 SGT-HEM results returned "ND" for the effluent samples.

Influent and effluent flow rates are presented in Figure 21. At the start of the test, the influent flow rate fluctuated over 4.0 gpm and the effluent flow rate fluctuated near 3.0 gpm. The potable water flush conducted at the conclusion of the previous day with Performance Test #2 did not provide a significant amount of recovery to the membranes (an increase of 0.1 gpm), and the test was expected to end early once the processing capacity fell below the minimum threshold or if the membrane resistance reached 100%. However, Figure 21 demonstrates that the influent and effluent flow rates increased during the initial hours of the test. As the influent

mixture was introduced to the system, the detergents restored the membranes and inhibited further fouling from the oil content. The potable water flush for this test was also particularly effective (an increase of 1.8 gpm to processing capacity after 10:00 elapsed time); this is believed to be due to the detergent promoting the removal of membrane fouling. The gaps in the data were due to the data logger crashing frequently and having to be reset throughout the evaluation.

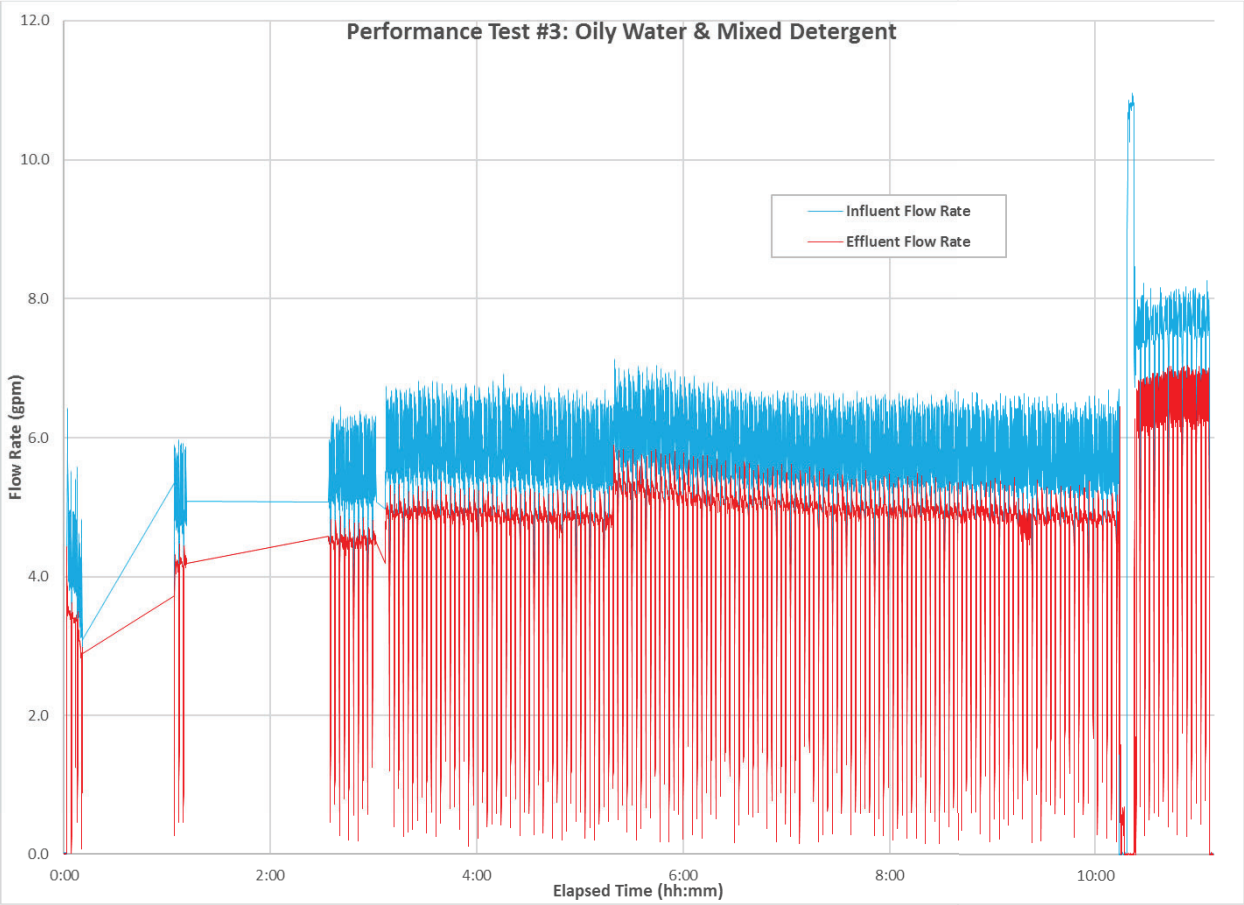


Figure 21. Performance Test #3 - Influent and Effluent Flow

Despite the high concentration of emulsified oil within the HSRMS, the system still produced high quality permeate that satisfied the evaluation metrics. The TD-107 measured 0 to 7 ppm oil for Test #3 which was higher than other tests, but the increased values could have been due to the foam in the effluent interfering with the fluorescence sensor. The suggestion of foam interference was supported by the EPA 1664 analysis detecting no oil in the effluent samples.

The influent and effluent pressures are presented in Figure 22. The TMP was approximately 29 psi at the start of the test. After 3 hours of processing the oil and detergent mixture, the detergent may have helped remove membrane fouling and decreased the TMP to approximately 23 psi. The average TMP throughout the 10-hour test was 25.4 psi.

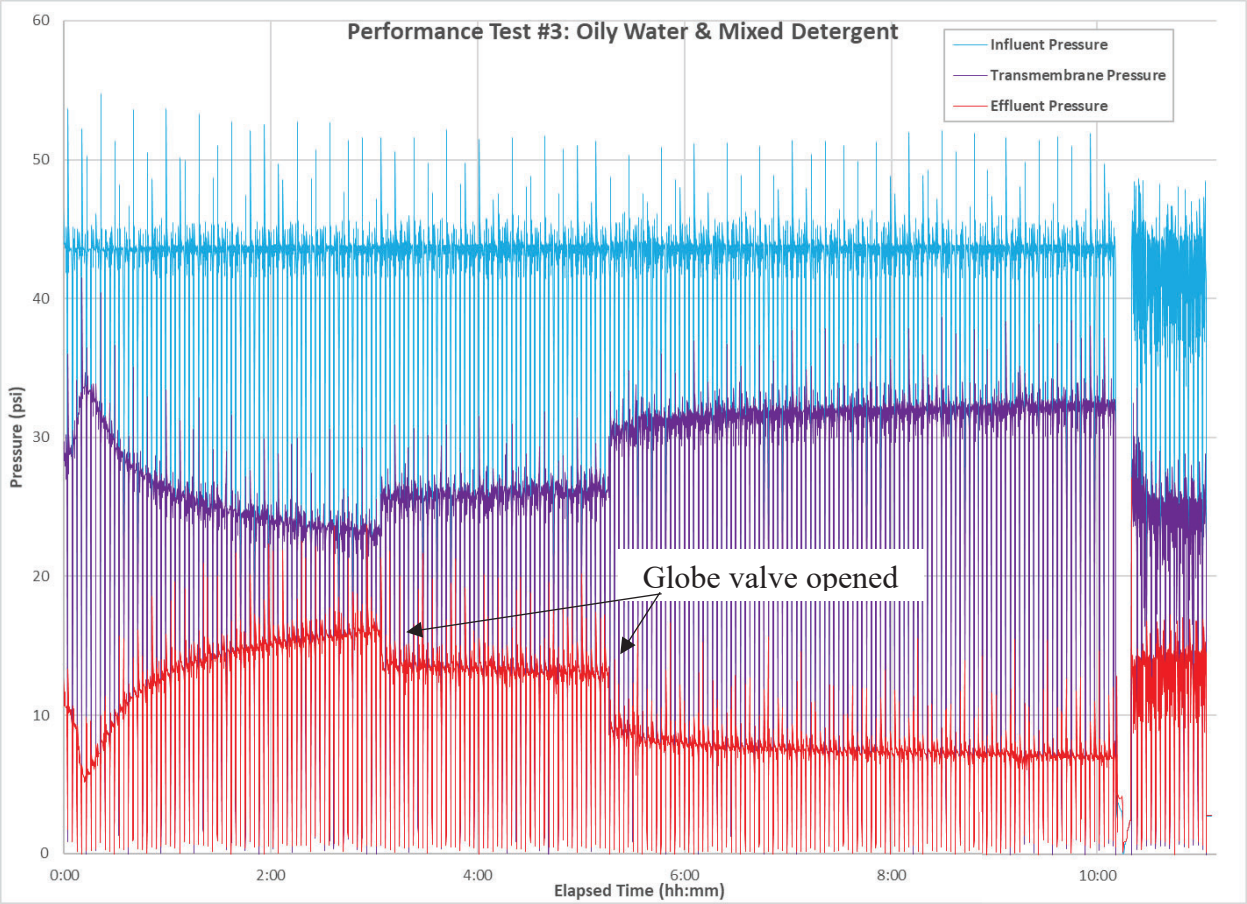


Figure 22. Performance Test #3 - Feed and Discharge Pressure

Test #13

The TD-107's internal logs indicated that the OCM made the decision to discharge fluid 100% of the time and did not trigger any high level alarms. As with Performance Test #3, the TD-107 measured slightly higher readings (0-7 ppm) compared to other test conditions. Based on the manual logs (alarms from backpulse events not included), the ET-35N made the decision to discharge fluid 100% of the time. The effective processing efficiency of the HSRMS over the course of the test was 70% based on the recorded totalizer data. The effluent flowmeter data indicated that the system produced an average overboard discharge rate of 2.6 gpm. All EPA 1664 SGT-HEM results returned "ND" for the effluent samples.

Influent and effluent flow rates are presented in Figure 23. At the start of the test, the influent flow rate fluctuated near 3.0 gpm and the effluent flow rate fluctuated near 2.5 gpm. The potable water flush conducted at the conclusion of Performance Test #9 on the previous day only provided a very minor recovery to the membranes, and the test was expected to be concluded early once the processing capacity decreased below the minimum threshold or once the membrane resistance reached 100%. However, similar to Performance Test #3, the HSRMS processing capacity began to gradually increase over time once the detergent mixture was introduced into the system. The recovery of the membranes was not as substantial as compared to Performance Test #3; the processing capacity only increased about 1.0 gpm overall in comparison to the increase of 2.0 gpm seen during Performance Test #3. The processing capacity

reached 3.0 gpm by the end of the test, and the subsequent potable water flush increased the processing capacity even further to 4.0 gpm.

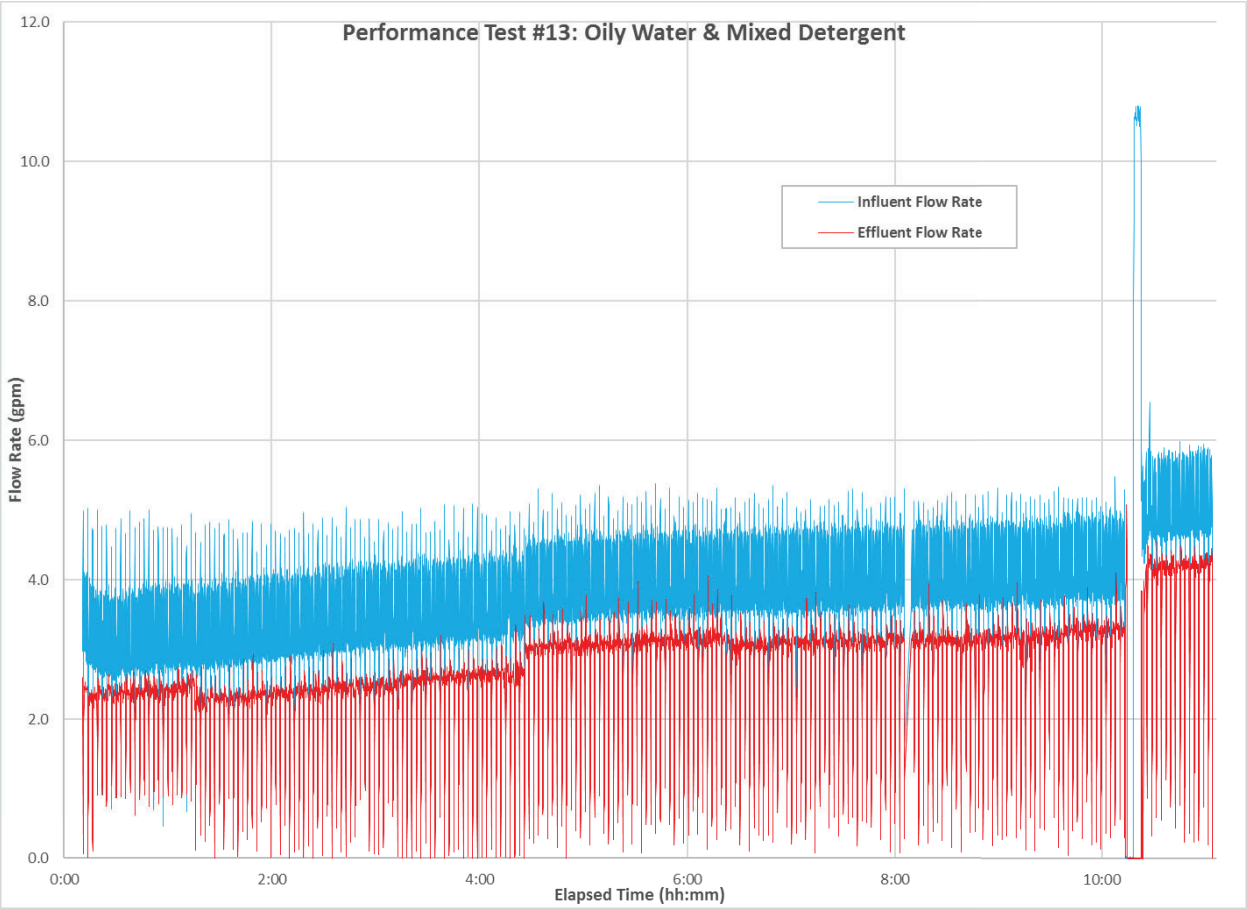


Figure 23. Performance Test #13 - Influent and Effluent Flow

The influent and effluent pressures are presented in Figure 24. The TMP was around 34 psi at the start of the test. The oil and detergent mixture decreased the TMP slightly to approximately 32 psi by the end of the test. The average TMP throughout the 10-hour test was 29.3 psi. The overall TMP for Performance Test #13 was greater than that in Performance Test #3 potentially due to the accumulation of membrane fouling from prior tests.

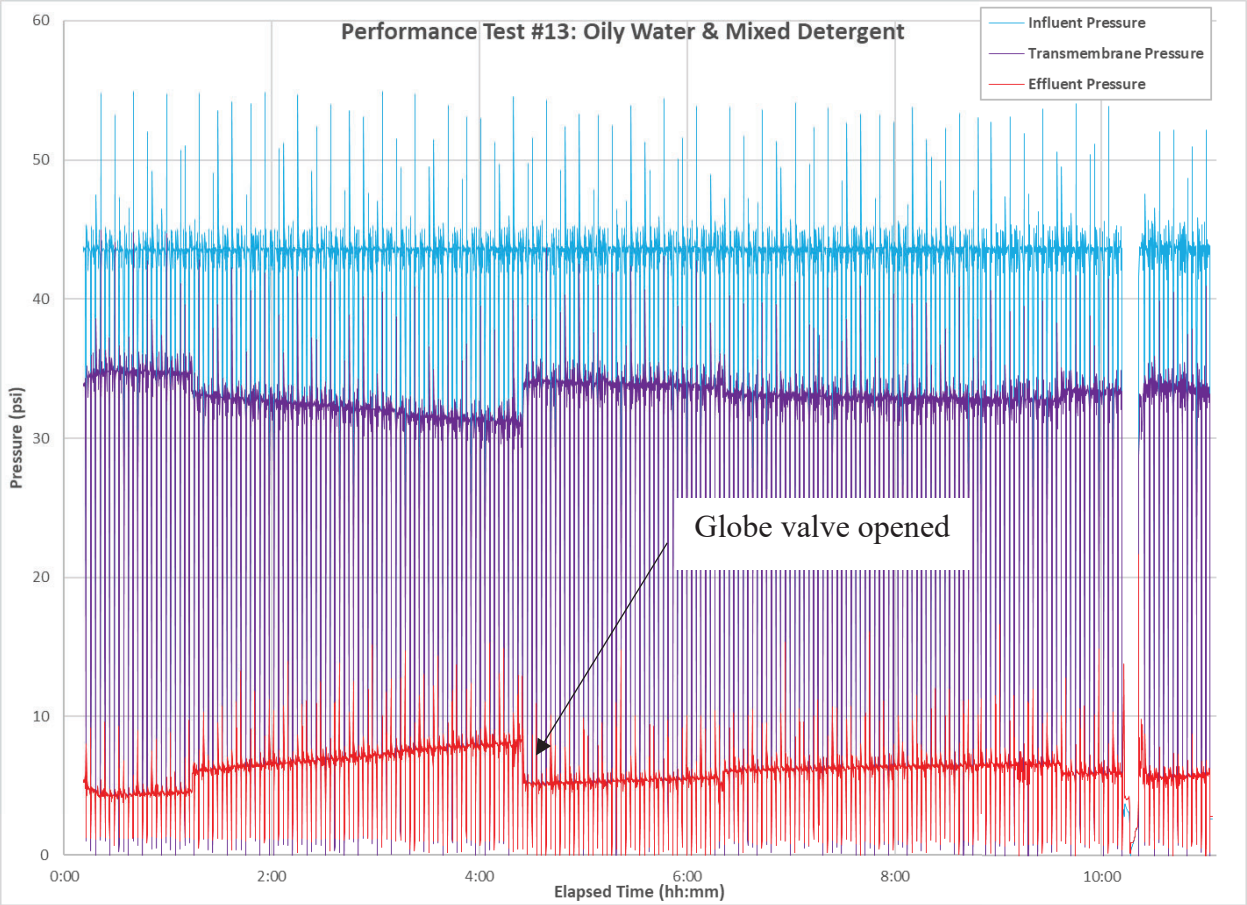


Figure 24. Performance Test #13 - Feed and Discharge Pressure

Figure 25 shows the fluid samples taken from the influent and effluent sample ports. The influent sample had a milky appearance with the entirety of the sample being heavily emulsified. The effluent samples were clear and colorless with no apparent sheen, although foam from the detergents collected at the surface.

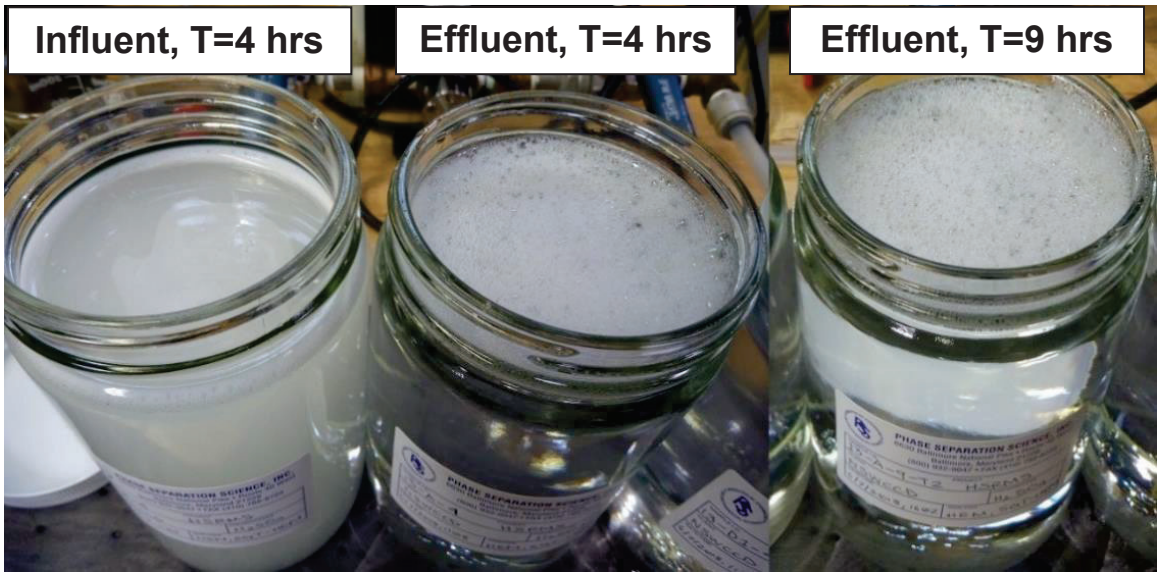


Figure 25. Performance Test #13 – Influent and Effluent Samples

Performance Tests #4 and #14: Oily Water & Type 1 Detergent

During these tests, the HSRMS processed 1,000-ppm NSBM #4 and 100-ppm Type 1 Detergent in potable water.

Test #4

The TD-107 consistently made the decision to recirculate throughout the test and only made the decision to discharge fluid 13% of the time, as shown in Figure 26. Note that the TD-107 measured 0.0 ppm when the HSRMS was in backpulse mode and not discharging any effluent; the OCM reading subsequently returned to the higher value once flow was resumed. The overall frequency of high level alarms resulted in a much lower effective processing efficiency of 11%. Also, based on the manual logs, the ET-35N made the decision to discharge fluid only 36% of the time due to high level alarms and Warning Light 2 & 3 triggering (alarms from backpulse events not included). Both the effluent flowmeter data and corresponding TD-107 rejection signals were used to calculate an average overboard discharge rate of 0.6 gpm.

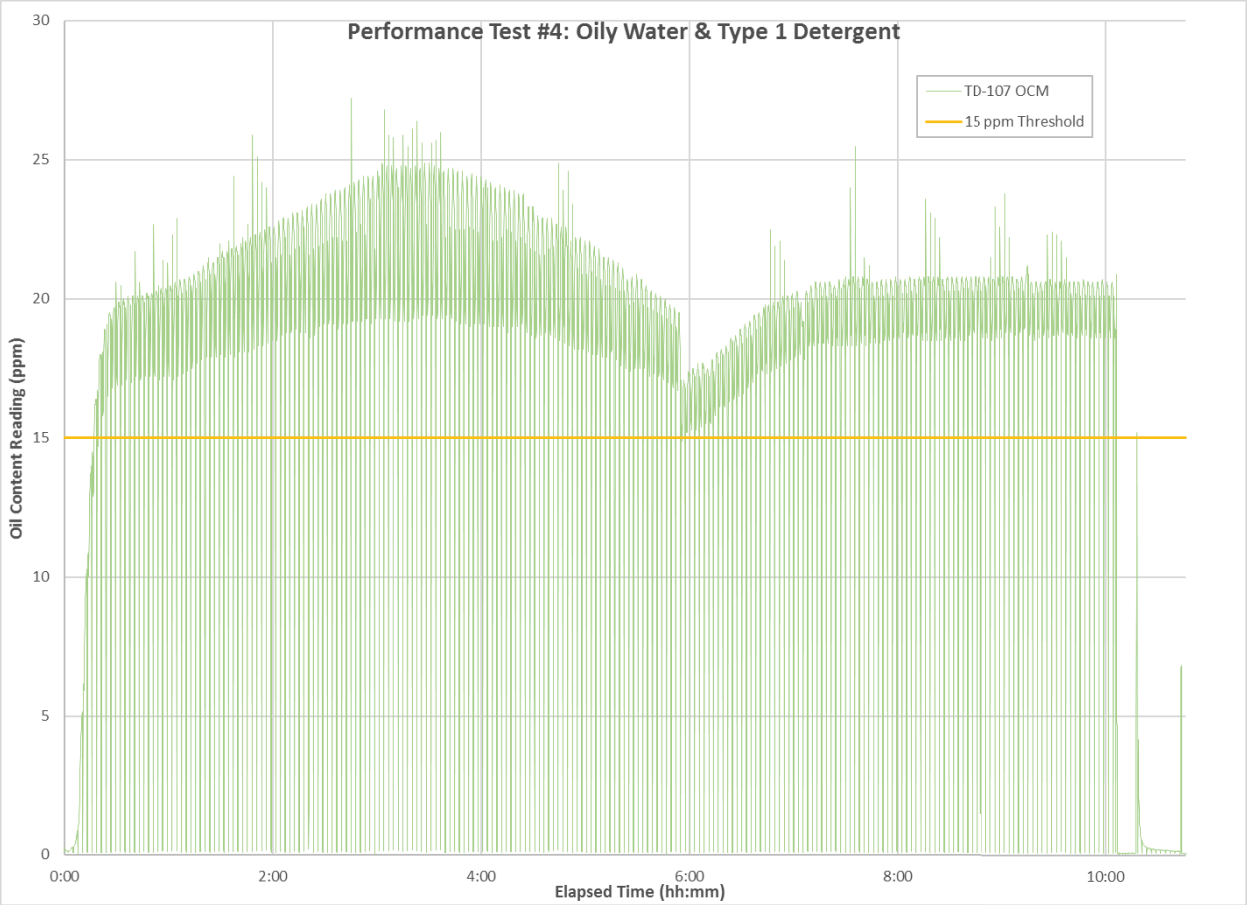


Figure 26. Performance Test #4 - TD-107 OCM Readings

The high OCM readings suggested that there had been a critical failure of the system with the membranes being unable to maintain permeate quality within acceptable levels, but this was found to not be the case since the effluent samples had no visible sheen or emulsified oil. The EPA Method 1664 SGT-HEM laboratory analysis confirmed the lack of oil content when the results returned "ND". The high level alarms were concluded to be the result of the foam remaining in the treated effluent and interfering with the OCM readings. Performance Test #3 and Performance Test #13 presented similar issues of foam affecting the OCMs' readings. It is hypothesized that Type 1 Detergent is the major contributor to foaming. For instance, Performance Tests #4 and 14 had twice the concentration of Type 1 Detergent (i.e. 100 ppm vs 50 ppm) compared to Performance Tests #3 and 13 and demonstrated more foaming.

Influent and effluent flow rates are presented in Figure 27. At the start of the test, the influent flow rate began at 8.0 gpm and the effluent flow rate at 7.0 gpm. After an initial decrease in processing capacity during the first 10 minutes of the test, the system experienced a minor recovery before the flow rates entered a steady decline. The corresponding TD-107 readings increased until the high level alarm was triggered and redirected the 3-way valve. For the remainder of the test, the OCM would continue to divert all processed effluent to the UST. The processing capacity of the system decreased to 3.5 gpm by the end of the test but would be restored to 6.0 gpm following the potable water flush. The decreased processing capacity experienced during the test may have been attributed to the excessive amount of foam interfering

with filtration instead of any significant fouling of the membranes. This temporary reduction in processing capacity also occurred during the membrane regeneration procedures where the cleaning solution would block the membranes until flushed with a potable water flush.

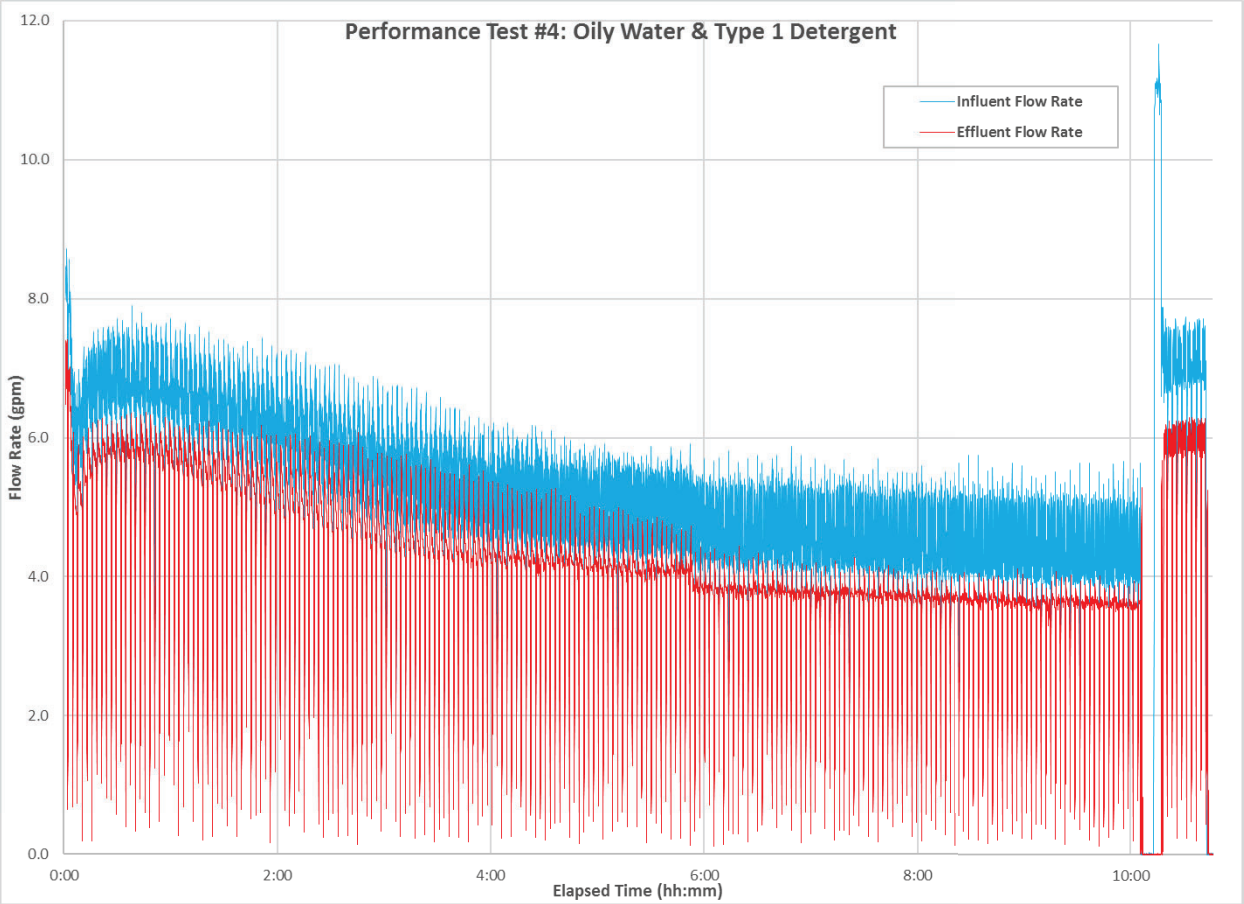


Figure 27. Performance Test #4 - Influent and Effluent Flow

The influent and effluent pressures are presented in Figure 28. The TMP was approximately 24 psi at the start of the test. The system then experienced a decrease in effluent pressure within the first 10 minutes of the test until there was a gradual increase in effluent pressure as the oil and Type 1 Detergent increased the resistance across the membranes. By the end of the 10-hour test, the TMP reached approximately 33 psi. The average TMP throughout the 10-hour test was 28.3 psi.

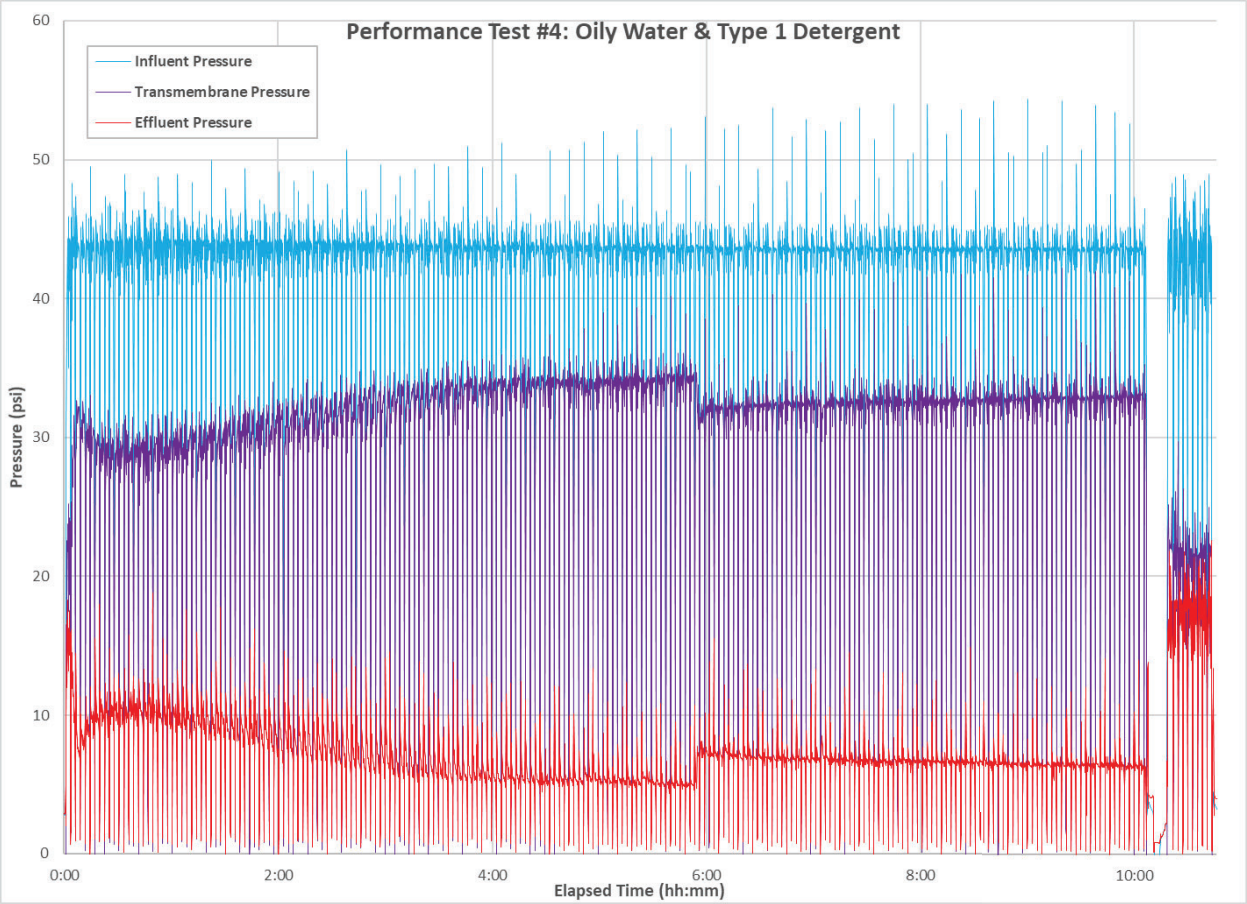


Figure 28. Performance Test #4 - Feed and Discharge Pressure

Test #14

The TD-107's internal logs, depicted in Figure 29, showed a number of high level measurements immediately following some backpulse events. These high level measurements were temporary and the TD-107 returned to measuring below 15 ppm after flow to the OCM stabilized. However, unlike Performance Test #4, the overall oil content readings did not persist at over 15 ppm, and the TD-107's internal logs indicated that the OCM made the decision to discharge fluid 99% of the time. The effective processing efficiency therefore was calculated to 70%, which is consistent with the tests where no high level alarms were triggered. Based on the manual logs (alarms from backpulse events not included), the ET-35N made the decision to discharge fluid 91% of the time due to instances of a high level alarm. Both the effluent flowmeter data and corresponding TD-107 rejection signals were used to calculate an average overboard discharge rate of 2.7 gpm. All EPA Method 1664 SGT-HEM results returned "ND" for the effluent samples.

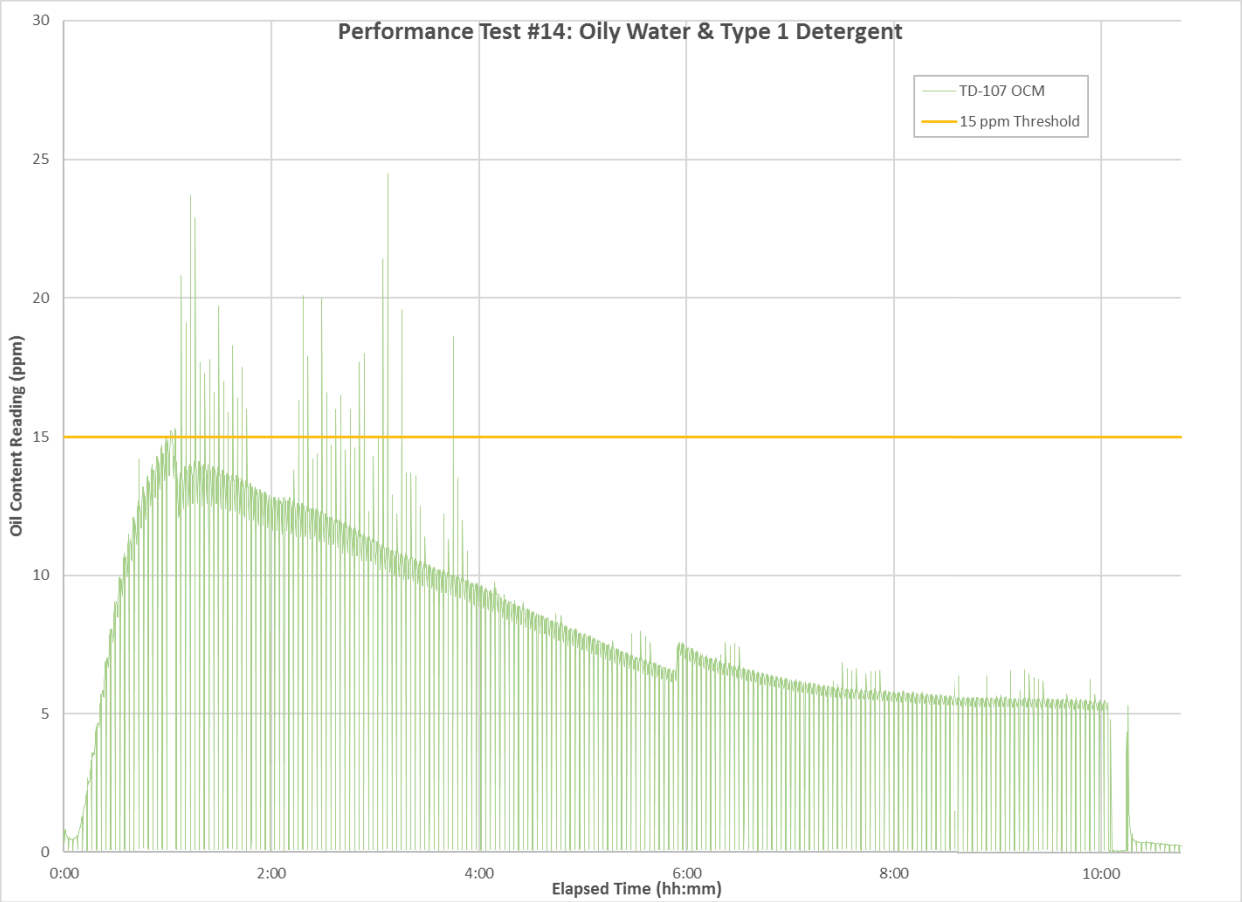


Figure 29. Performance Test #14 - OCM Readings

Influent and effluent flow rates are presented in Figure 30. At the start of the test, the influent flow rate fluctuated at 5.0 gpm and the effluent flow rate at 4.0 gpm. The flow rates decreased to 4.0 and 3.0 gpm for influent and effluent, respectively, as the injection of the contaminant mixture began. The stable processing capacity of 3.0 gpm demonstrated during Performance Test #14 is similar to the processing capacity observed in the latter half of Performance Test #4.

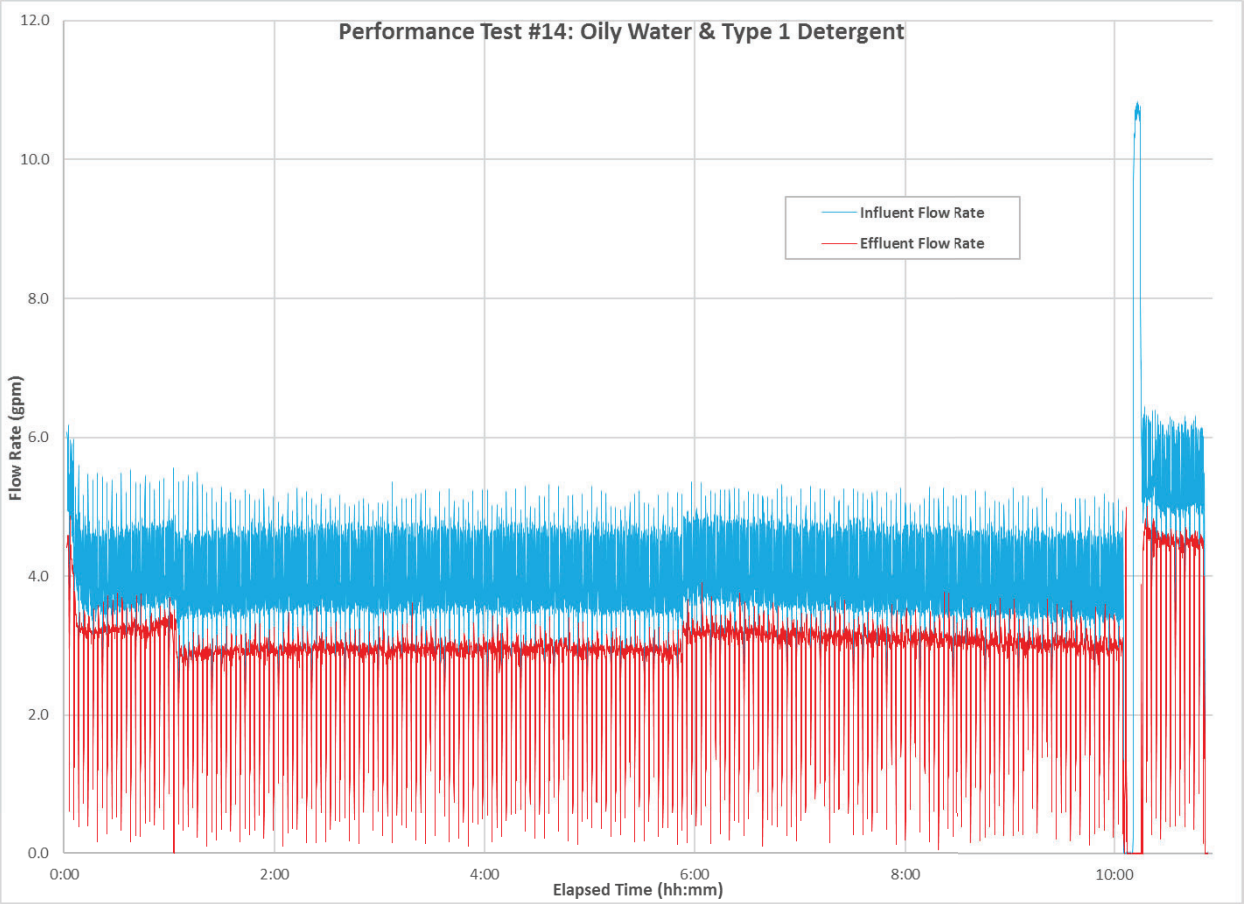


Figure 30. Performance Test #14 - Influent and Effluent Flow

The influent and effluent pressures are presented in Figure 31. The TMP was initially near 32 psi at the start of the test. Throughout the 10-hour test, the system experienced very little change in TMP aside from the sudden increases at 1:08 and 5:53 elapsed time which were attributed to the globe valve being throttled more closed or open to allow the ET-35N to receive the minimum operational flow. By the end of the 10-hour test, the TMP reached approximately 34 psi. The average TMP throughout the 10-hour test was 28.4 psi.

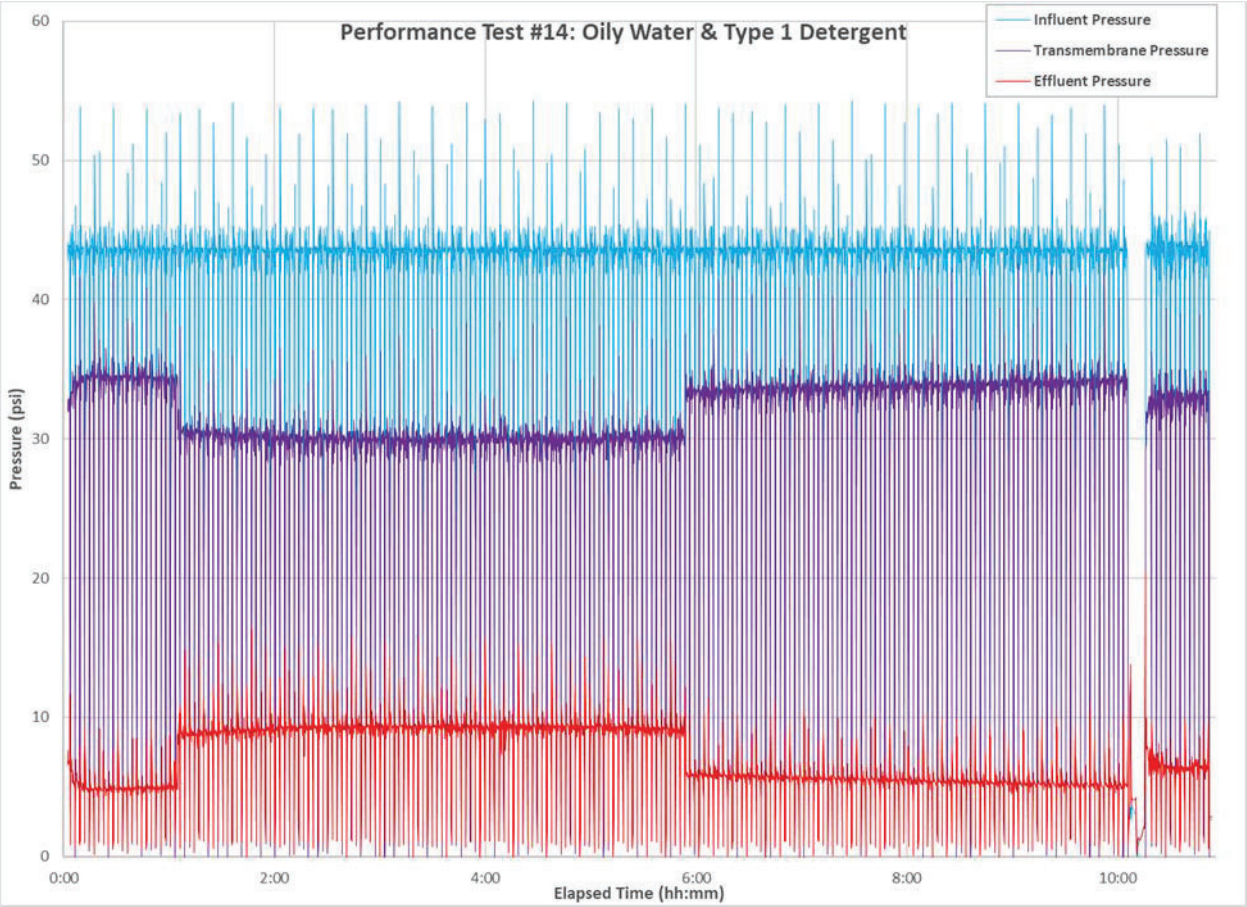


Figure 31. Performance Test #14 - Feed and Discharge Pressure

Figure 32 shows samples collected taken from the influent and effluent sample ports. The influent sample was heavily emulsified and similar to other tests (Appendix P), however, the effluent sample contained a layer of foam on the surface.

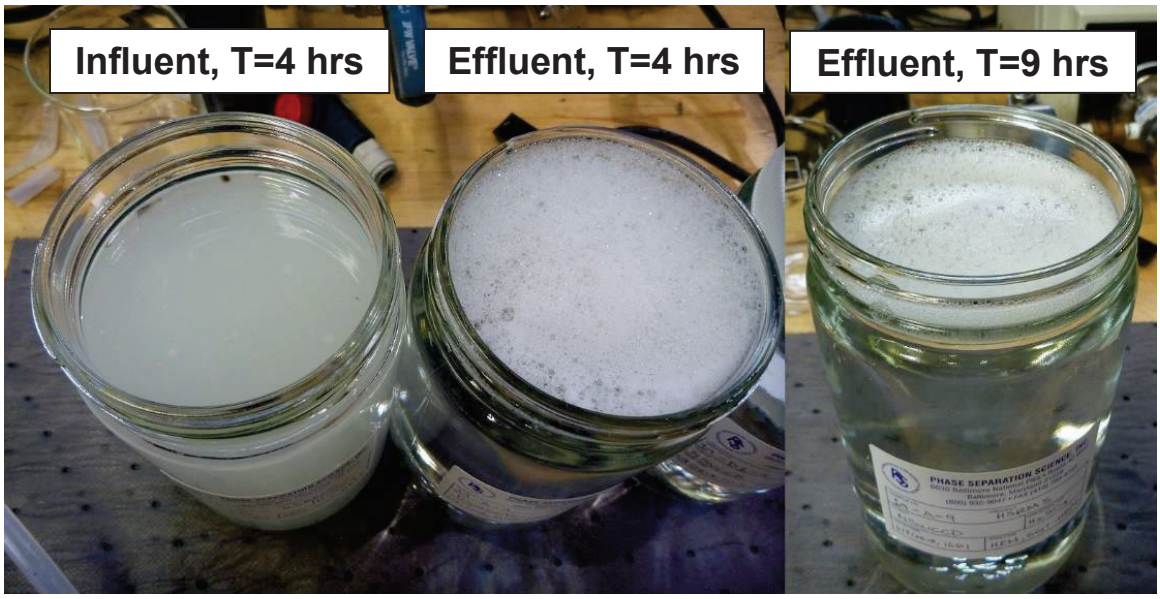


Figure 32. Performance Test #14 – Influent and Effluent Samples

Performance Tests #5 and #15: Oily Water & Mixed Chemicals

During these tests, the HSRMS processed 1,000-ppm NSBM #4, 1,210-ppm 8.25% bleach (100 ppm NaOCl), 1,700-ppm acetone, and 1,700-ppm paint thinner in potable water.

Test #5

The TD-107's internal logs indicated that the OCM made the decision to discharge fluid 100% of the time and did not trigger any high level alarms. Based on the manual logs (alarms from backpulse events not included), the ET-35N made the decision to discharge fluid 100% of the time. The effective processing efficiency of the HSRMS over the course of the test was 79% based on the recorded totalizer data. The effluent flowmeter data indicated that the system produced an average overboard discharge rate of 5.3 gpm. All EPA Method 1664 SGT-HEM results returned "ND" for the effluent samples.

Influent and effluent flow rates are presented in Figure 33. At the start of the test, the influent flow rate fluctuated over 8.0 gpm and the effluent flow rate fluctuated over 7.0 gpm. The initial conditions of the test demonstrated that the system recovered significantly following Performance Test #4 with the Type 1 Detergent. The system demonstrated a slight decrease in processing capacity within the first 4 hours of the test (loss of 0.3 gpm) and then decreased more rapidly for the remainder of the test duration until reaching 4.8 gpm.

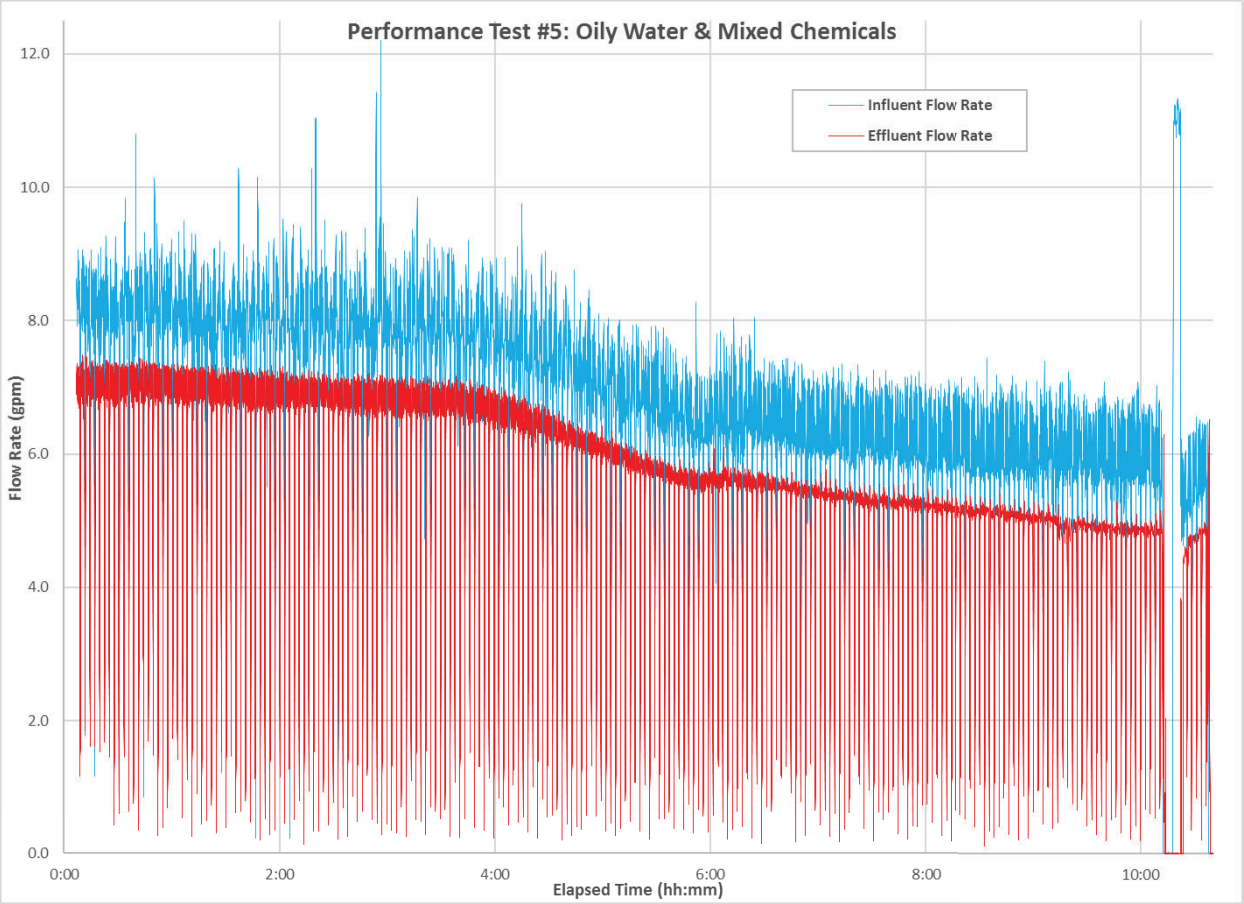


Figure 33. Performance Test #5 - Influent and Effluent Flow

The influent and effluent pressures are presented in Figure 34. The TMP was approximately 22 psi at the start of the test and reached 31 psi by the end of the 10-hour test. The accelerated increase in TMP at 4:00 elapsed time in Figure 34 coincides with the sharper decrease in processing capacity at 4:00 elapsed time from Figure 33. The results demonstrate that exposure to the oil and chemical injection mixture continually increased the TMP. The average TMP throughout the 10-hour test was 23.9 psi.

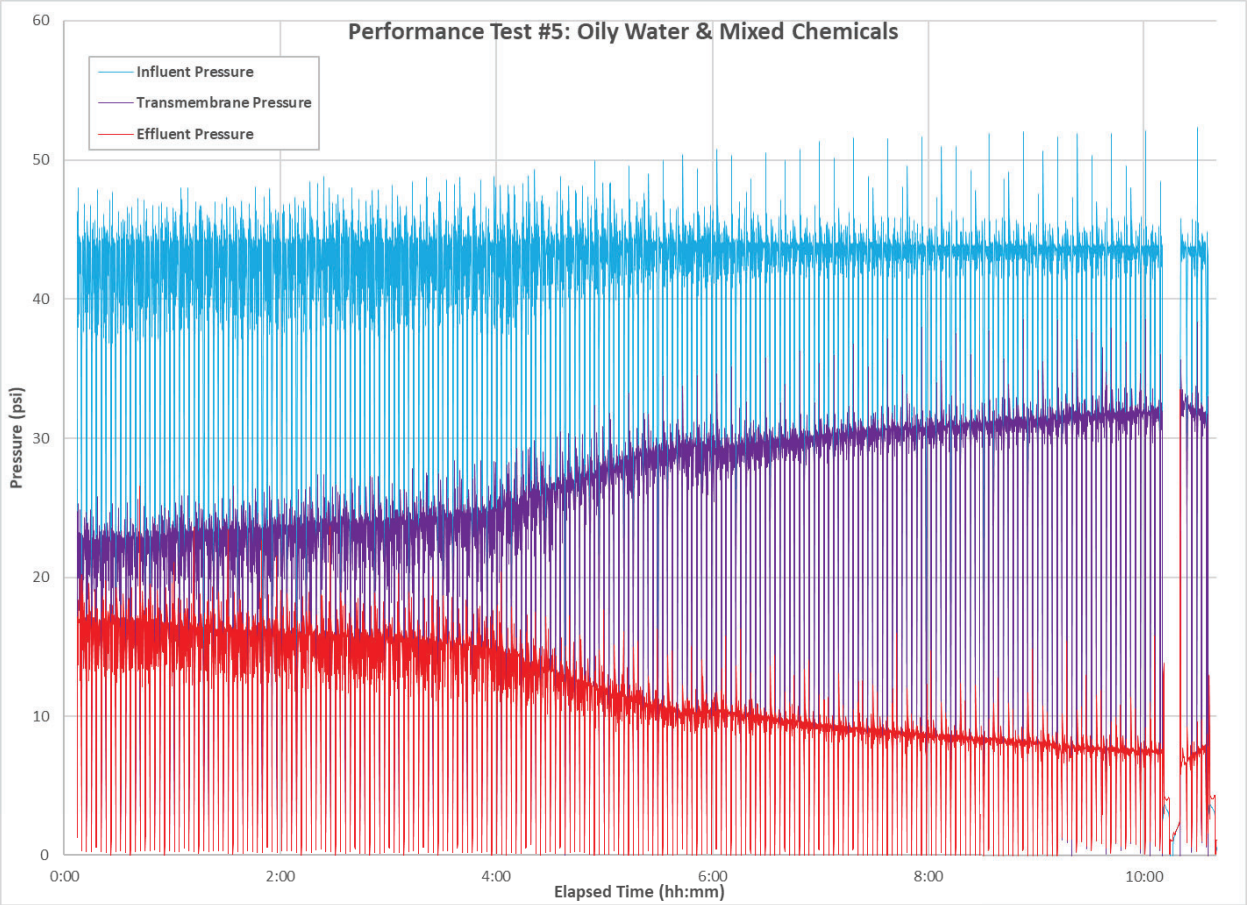


Figure 34. Performance Test #5 - Feed and Discharge Pressure

Test #15

Performance Test #15 was ended early after 8 hours due to the HSRMS experiencing the low effluent flow rate alarm "FIC-120 Alarm LL underrun" and entering standby mode. Restarting the system did not alleviate the low flow issue and resulted in the system returning to standby or operating at flowrates below 2.0 gpm. Despite the reduced flow rates and eventual stoppage, the HSRMS still continued to generate high quality permeate containing low oil content. The TD-107's internal logs indicated that the OCM made the decision to discharge fluid 100% of the time and did not trigger any high level alarms. Based on the manual logs (alarms from backpulse events not included), the ET-35N made the decision to discharge fluid 88% of the time due to an instance of Warning Light 3 triggering. The effective processing efficiency of the HSRMS over the course of the test was 74% based on the recorded totalizer data. The effluent flowmeter data indicated that the system produced an average overboard discharge rate of 3.2 gpm from the start of the test until the forced stop. The EPA Method 1664 SGT-HEM result returned "ND" for the single effluent sample.

Influent and effluent flow rates are presented in Figure 35. At the start of the test, the influent flow rate began at 6.0 gpm and the effluent flow rate at 5.0 gpm. The processing capacity of the system decreased and eventually caused the system to trigger a low flow rate alarm and end the operation. At this point, the membranes were fouled sufficiently to render backpulsing ineffective and restrict effluent from the system. A concentrate discharge with a

potable water flush was initiated by the operator in an attempt to clear the membranes, but the system was still unable to process any fluid. After a second attempt in flushing the system, the HSRMS was able to produce clean effluent again, albeit at a severely reduced flow rate. The system was unable to sustain the minimum processing capacity threshold of 2.19 gpm, and the resistance across the membranes had reached 1.83 psi/gfd (123% Resistance) just prior to the alarm. The membranes had fouled enough to warrant a complete regeneration. Although the HSRMS ended the test early and could no longer process the test mixture, the event was not considered a reliability failure since there was no oil breakthrough and the system was able to be restored with the cleaning procedure. The subsequent membrane regeneration was therefore classified as "routine maintenance" for the considerations of this report.

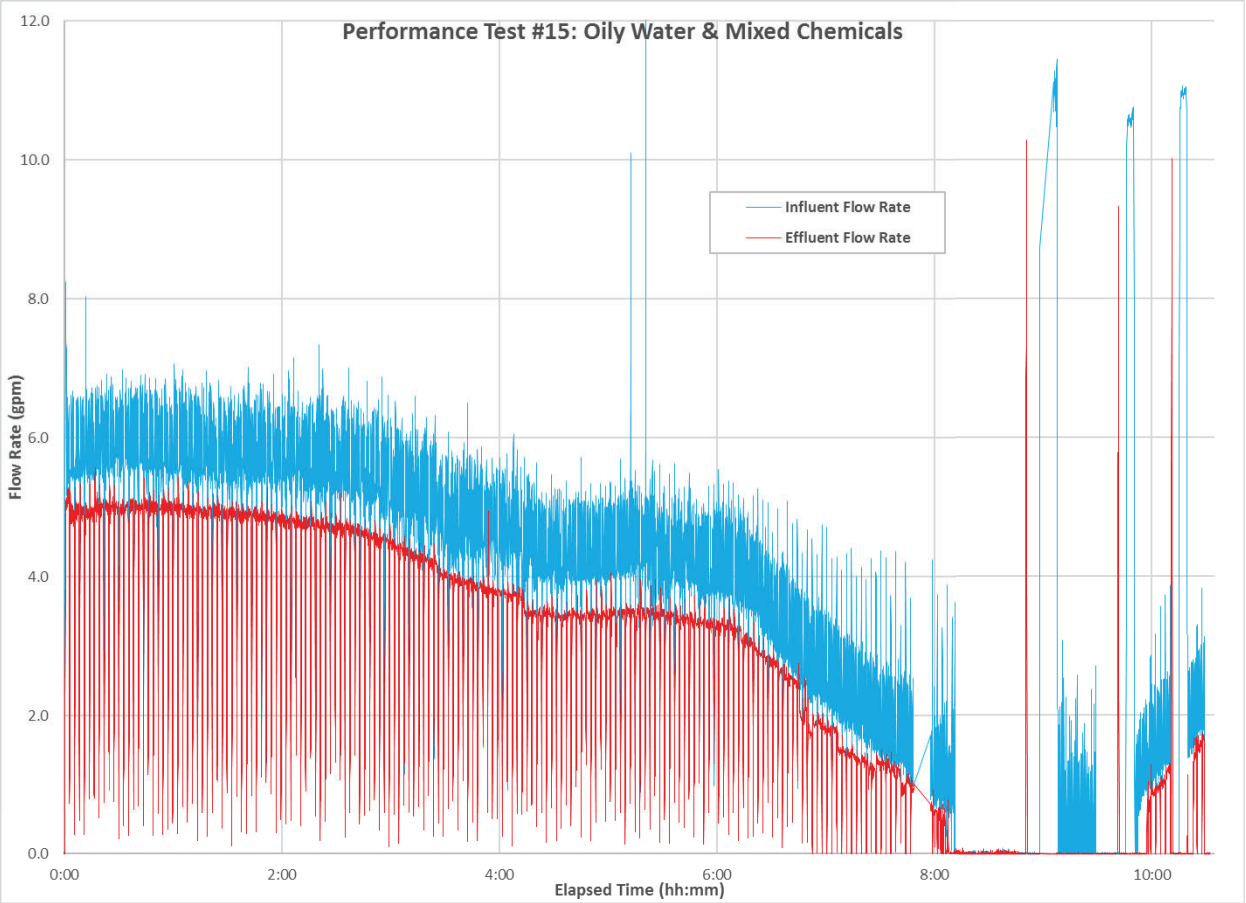


Figure 35. Performance Test #15 - Influent and Effluent Flow

The influent and effluent pressures are presented in Figure 36. The TMP was approximately 29.3 psi at the start of the test and reached 37.2 psi when the low-level alarm was triggered. The system demonstrated an overall decrease in TMP similarly to Performance Test #5, except there was a sudden increase in TMP at 7:40 elapsed time corresponding to the sharp drop in flow rates in Figure 36. As the membrane resistance exceeded 100%, the feed pump pressure was no longer able to push filtrate through the system. The average TMP during the 8.2-hour injection period was 29.8 psi.

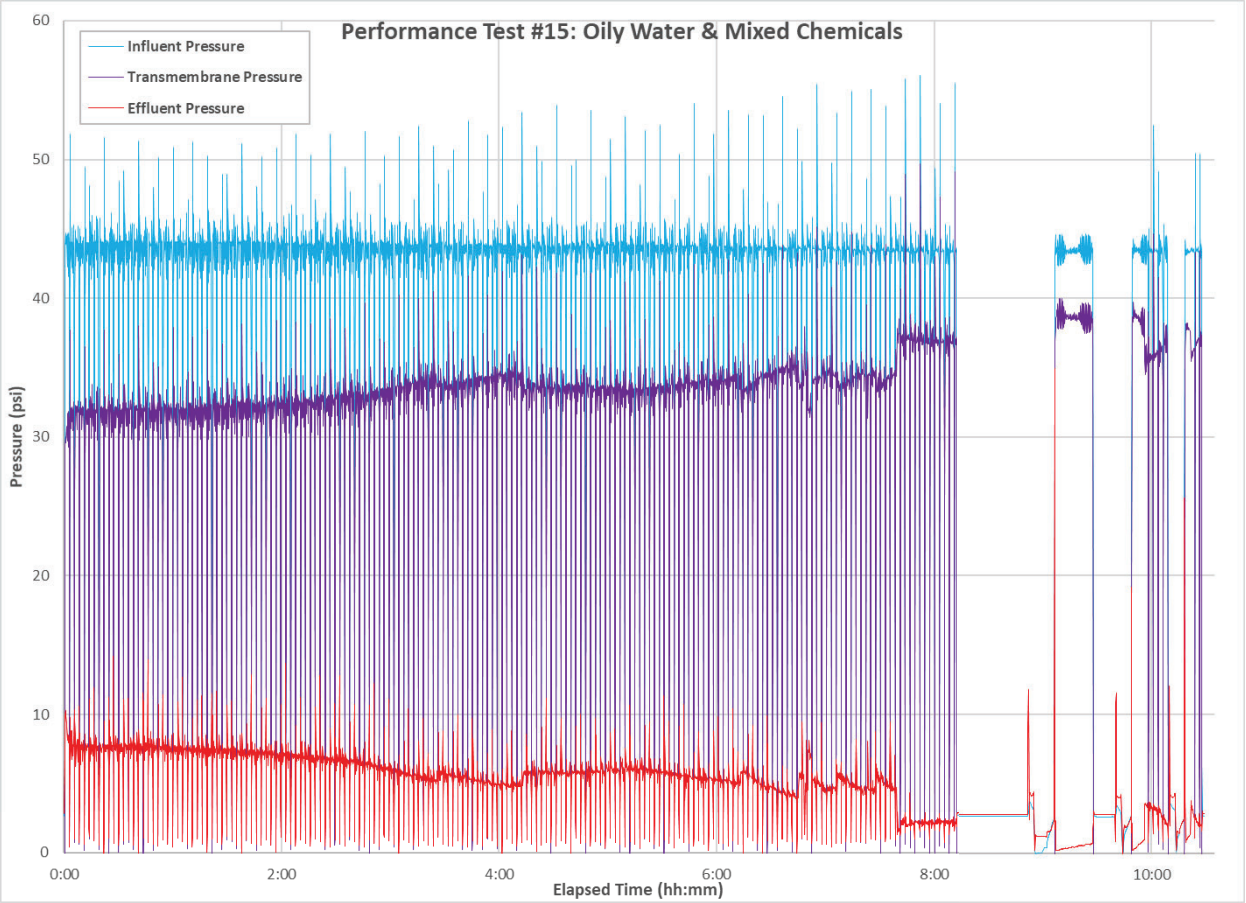


Figure 36. Performance Test #15 - Feed and Discharge Pressure

Performance Tests #6 and #16: Oily Water & AFFF

During these tests, the HSRMS processed 1,000-ppm NSBM #4 and 100-ppm AFFF in potable water.

Test #6

The TD-107's internal logs indicated that the OCM made the decision to discharge fluid 100% of the time and did not trigger any high level alarms over the course of the test. Based on the manual logs (alarms from backpulse events not included), the ET-35N also made the decision to discharge fluid 100% of the time. The effective processing efficiency of the HSRMS over the course of the test was 77% based on the recorded totalizer data. The effluent flowmeter data indicated that the system produced an average overboard discharge rate of 3.7 gpm. All EPA Method 1664 SGT-HEM results returned "ND" for the effluent samples.

Influent and effluent flow rates are presented in Figure 37. At the start of the test, the influent flow rate fluctuated at 6.5 gpm and the effluent flow rate fluctuated at 6.0 gpm. The processing capacity of the system then began to decrease as testing progressed. By the end of the test, the processing capacity had reduced to 3.0 gpm, and the potable water flush did not have any substantial effect on flow rate.

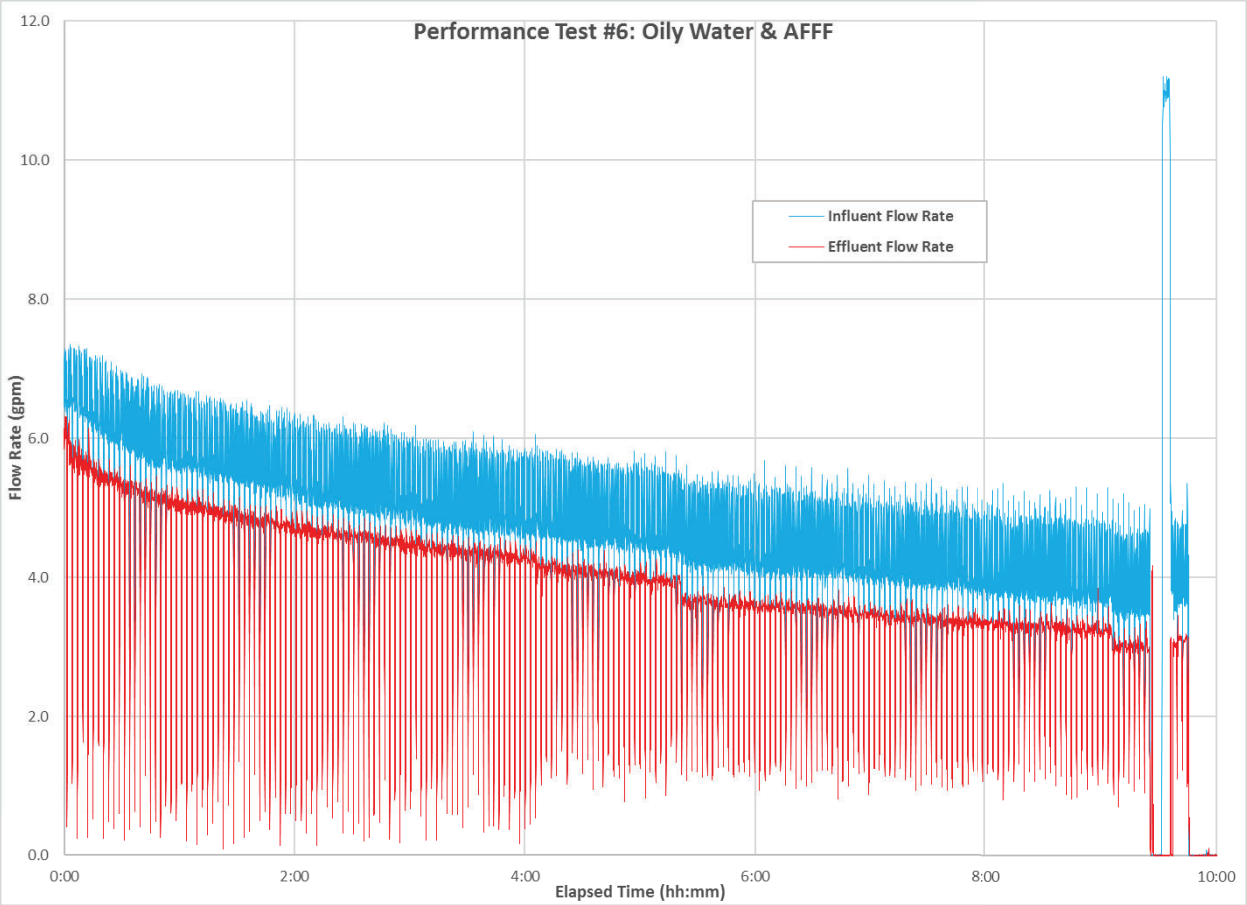


Figure 37. Performance Test #6 - Influent and Effluent Flow

The influent and effluent pressures are presented in Figure 38. The TMP was approximately 28 psi at the start of the test and increased to near 33 psi by the end of the test. The system experienced a gradual increase to TMP aside from the sudden increases at 5:20 and 9:07 elapsed time; these changes were due to the globe valve being throttled more closed to allow the ET-35N to receive the minimum operational flow. The average TMP throughout the 9.3-hour test was 29.1 psi.

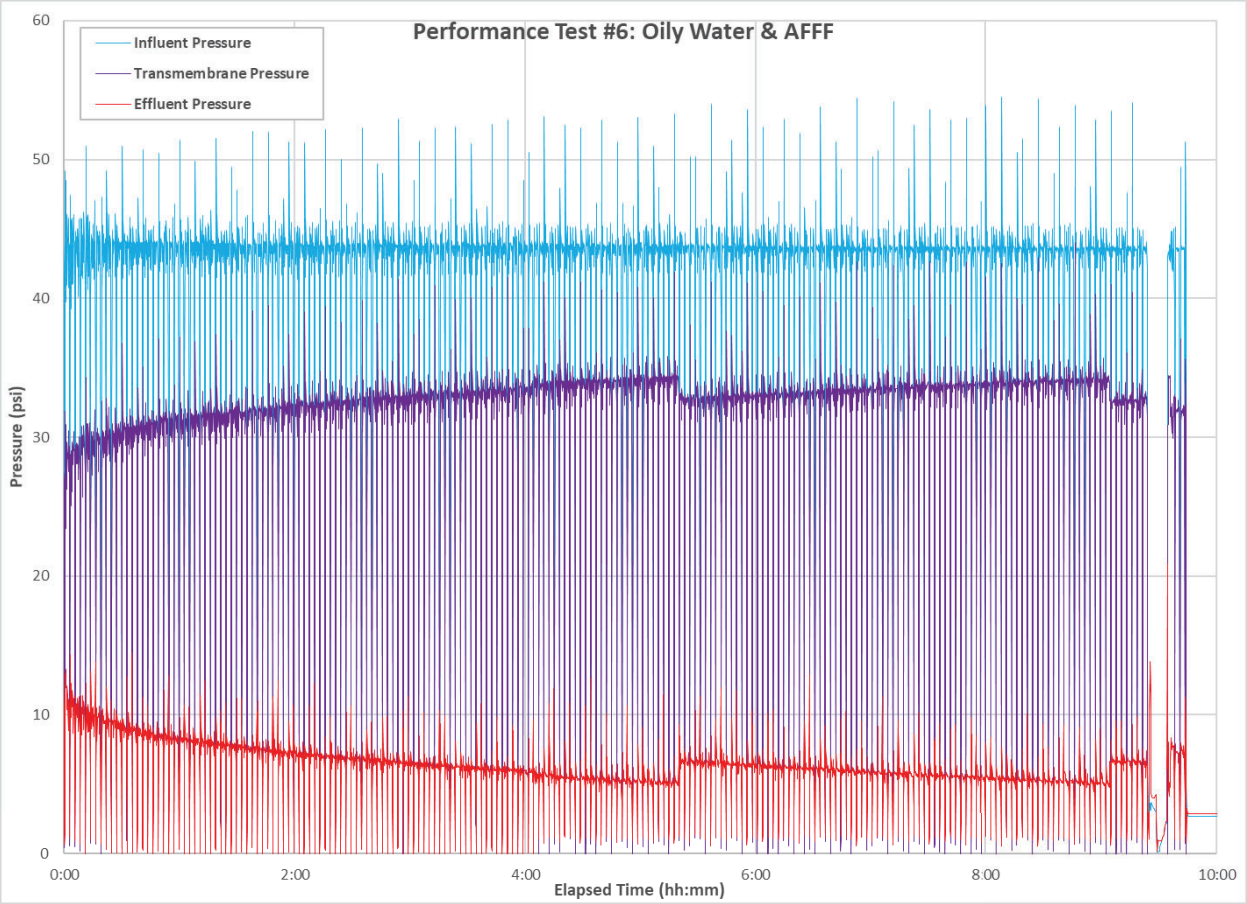


Figure 38. Performance Test #6 - Feed and Discharge Pressure

It should be noted that the AFFF mixture generated the greatest amount of foam of all the tests as seen in Figure 39, but this foam was only present in the mix tank and had dissipated during injection. The system, flowmeters, and OCMs were therefore not impacted by the AFFF foam, unlike the Type 1 Detergent foam that would persist within the system.



Figure 39. Performance Test #6 - Mix Tank AFFF Foam

Test #16

The TD-107's internal logs indicate that the OCM made the decision to discharge fluid 100% of the time and did not trigger any high level alarms. Based on the manual logs (alarms from backpulse events not included), the ET-35N made the decision to discharge fluid 82% of the time due to Warning Light 2 triggering at the initial hours of the test. The effective processing efficiency of the HSRMS over the course of the test was 75% based on the recorded totalizer data. The effluent flowmeter data indicated that the system produced an average overboard discharge rate of 4.2 gpm. All EPA Method 1664 SGT-HEM results returned "ND" for the effluent samples.

Influent and effluent flow rates are presented in Figure 40. Since this test was carried out the day following a membrane regeneration procedure, the initial flow rates were reflective of a clean system. The influent flow rate initially fluctuated over 10.0 gpm and the effluent rate at 8.5 gpm.

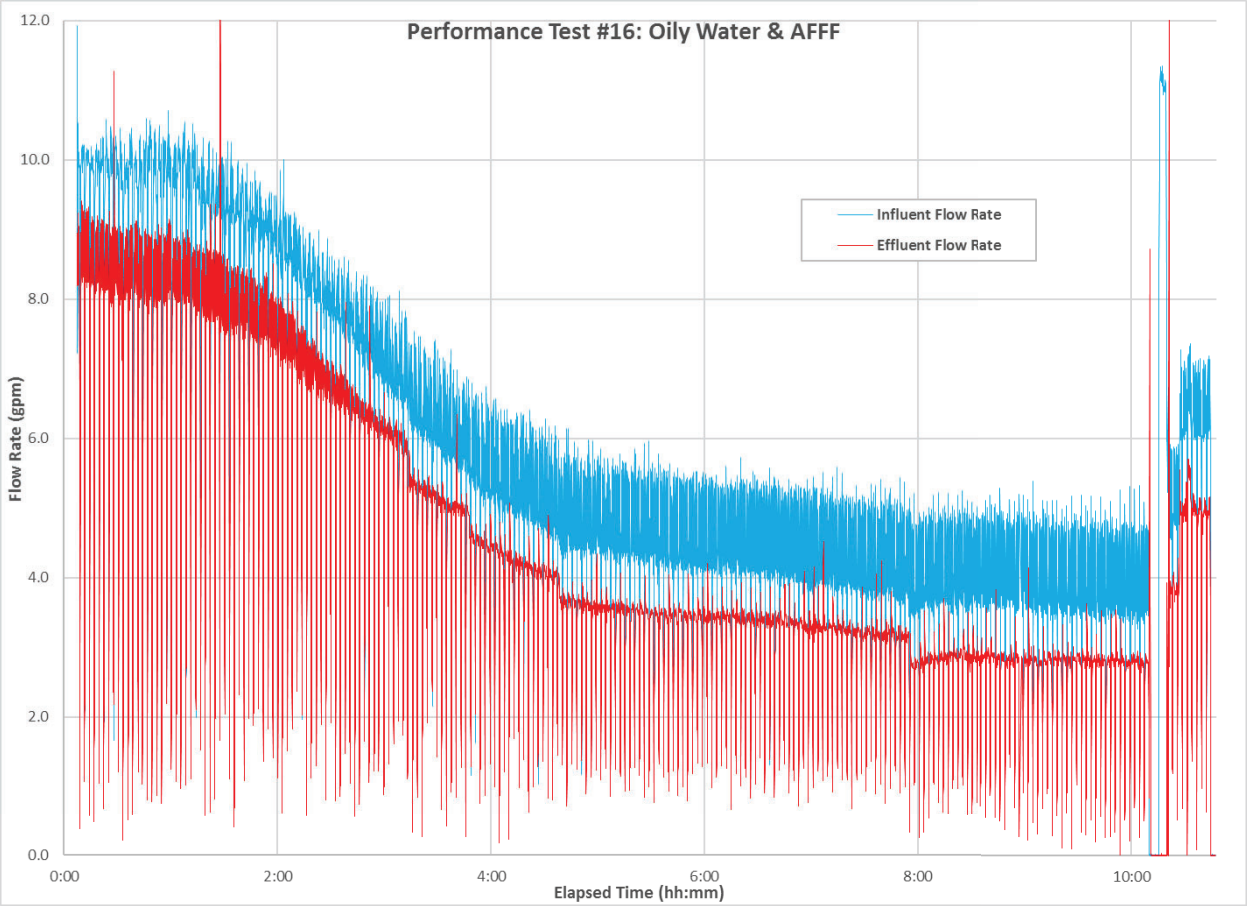


Figure 40. Performance Test #16 - Influent and Effluent Flow

The influent and effluent pressures are presented in Figure 41. The TMP was initially low at 18 psi due to the membrane regeneration conducted during the prior day, but by the conclusion of the 10-hour test, the TMP increased to near 31 psi. The HSRMS influent pressure continued to increase until the feed pump reached its maximum setting of 3.0 bar (43.5 psi) after 3:00 elapsed time where it remained consistent thereafter. Several sudden increases in effluent pressure at 3:13, 3:52, 4:38, and 7:55 elapsed time were due to the globe valve being more closed to prevent the ET-35N from shutting off. The missing data between 8:20 and 9:03 were due to the HSRMS's data logs becoming partially corrupted. The average TMP throughout the 10-hour test period was 27.7 psi.

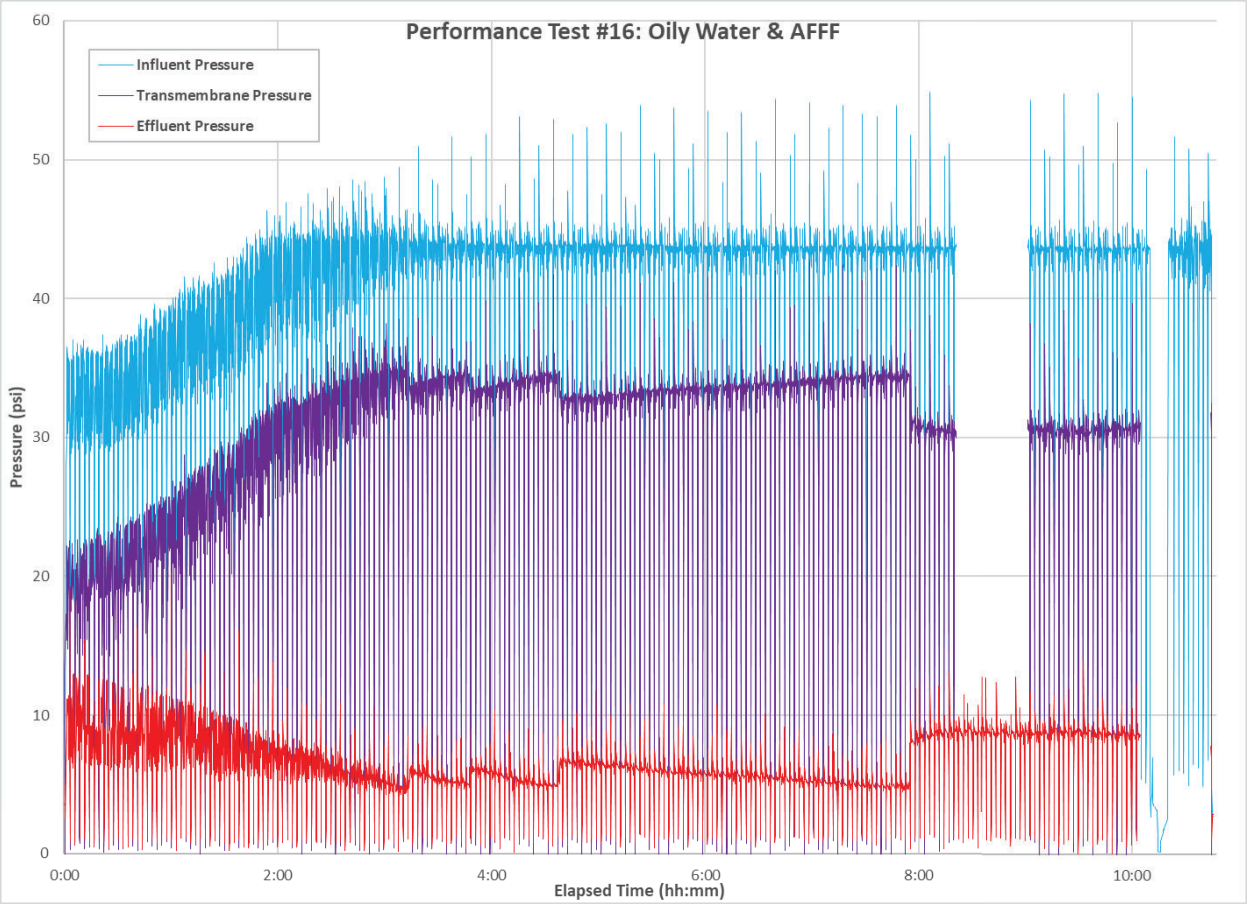


Figure 41. Performance Test #16 - Feed and Discharge Pressure

Performance Tests #7 and #17: Oily Water, Mixed Detergent, & Particles

During these tests, the HSRMS processed 1,000-ppm NSBM #4, 100-ppm Detergent Mix #4, 100-ppm Arizona test dust, and 0.70-ppm cloth fibers in potable water.

Test #7

The TD-107's internal logs indicated that the OCM made the decision to discharge fluid 100% of the time and did not trigger any high level alarms. Based on the manual logs (alarms from backpulse events not included), the ET-35N made the decision to discharge fluid 64% of the time due to high level alarms and Warning Light 2 events. The effective processing efficiency of the HSRMS over the course of the test was 79% based on the recorded totalizer data. The effluent flowmeter data indicated that the system produced an average overboard discharge rate of 4.4 gpm. All EPA Method 1664 SGT-HEM results returned "ND" for the effluent samples.

Influent and effluent flow rates are presented in Figure 42. The fouling caused by Performance Test #6 during the prior day created challenging starting conditions for the system. The influent flow rate initially fluctuated at 6.0 gpm and the effluent flow rate at 4.0 gpm. The flow rates decreased suddenly to 3.0 gpm and quickly approached low flow alarm conditions until the processing capacity began to recover a few minutes later. The processing capacity continued to increase before stabilizing near 5.5 gpm at the end of the test. The missing data

between 5:11 to 6:14 elapsed time was due to the data logger crashing and needing to be restarted.

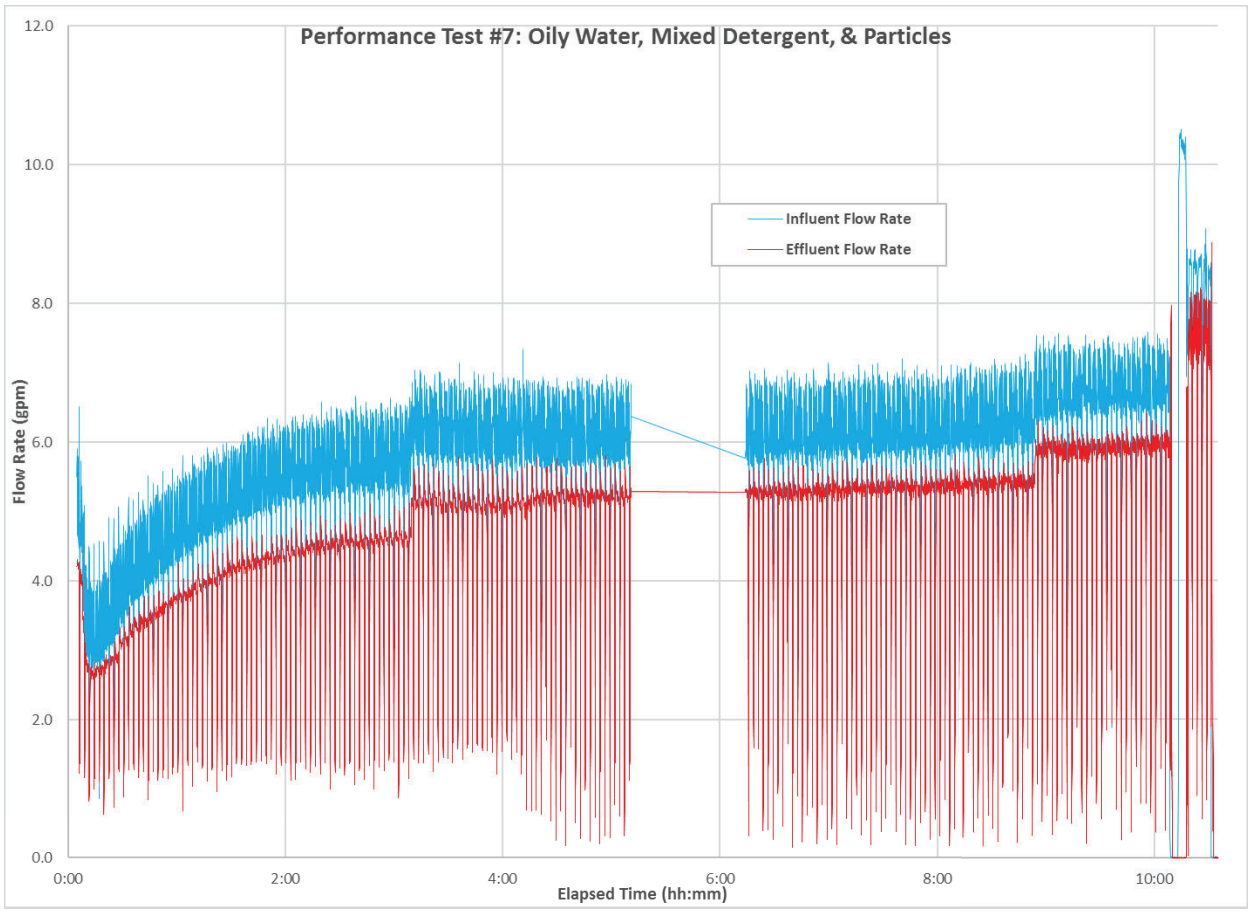


Figure 42. Performance Test #7 - Influent and Effluent Flow

The influent and effluent pressures are presented in Figure 43. The TMP was approximately 33.8 psi at the start of the test and decreased to approximately 33 psi by the end of the 10-hour test period. The system experienced a gradual decrease of TMP within the first 3 hours of the test, reaching as low as 27 psi. As the processing capacity increased, the globe valve was opened (e.g. 3:09 and 8:54) to reduce the back pressure that was previously needed to maintain ET-35N operation at lower flows. The average TMP throughout the 10-hour test period was 26.9 psi.

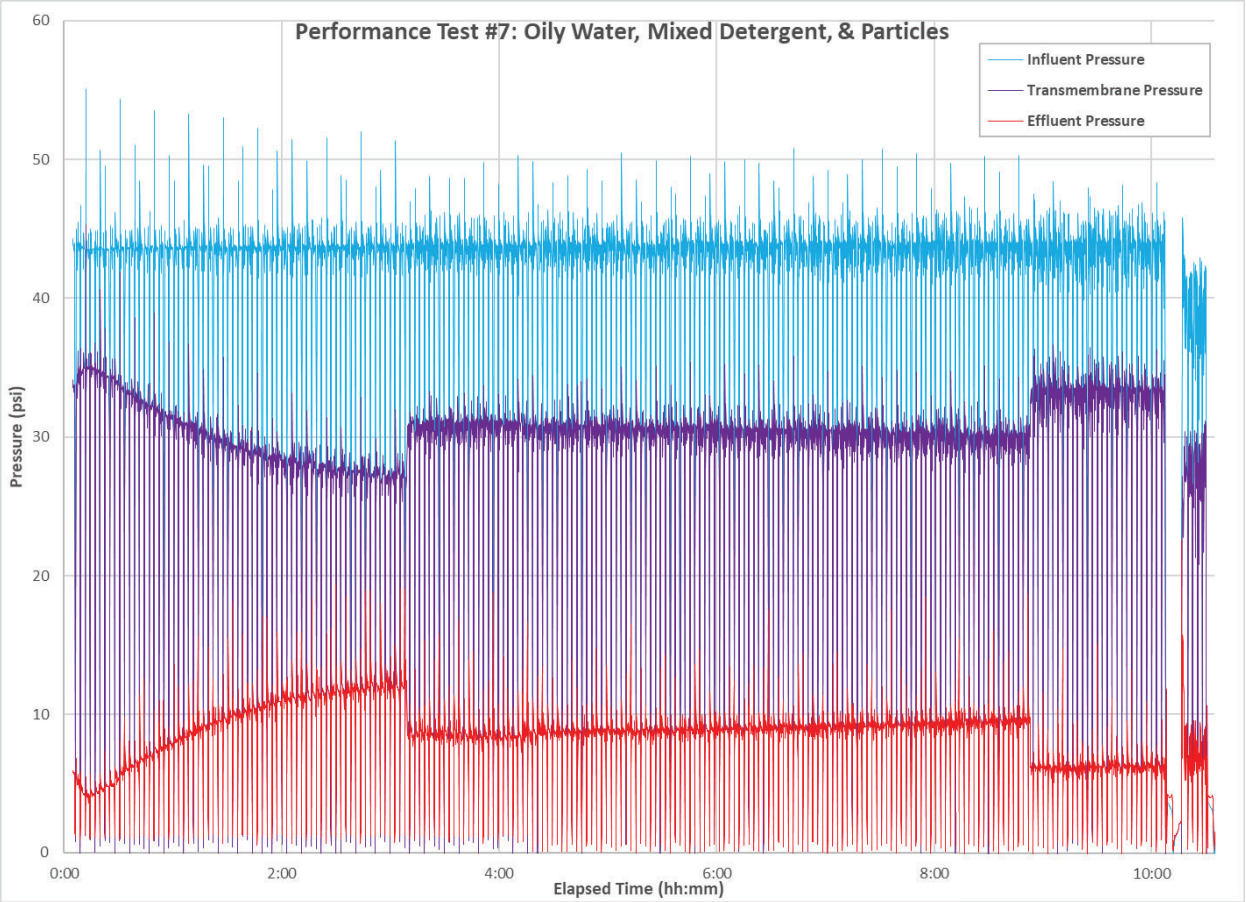


Figure 43. Performance Test #7 - Feed and Discharge Pressure

Test #17

The HSRMS data logs for Performance Test #17 could not be captured due to the system's logs becoming corrupted. However, partial test data was still appropriately recorded by the laboratory DAS, OCMs, and manual logs. The TD-107's internal logs indicated that the OCM made the decision to discharge fluid 100% of the time and did not trigger any high level alarms. Based on the manual logs (alarms from backpulse events not included), the ET-35N made the decision to discharge fluid 46% of the time due to Warning Light 2 triggering consistently during the first half of the test. The effective processing efficiency of the HSRMS over the course of the test was 79% based on the recorded totalizer data. The effluent flowmeter data indicated that the system produced an average overboard discharge rate of 5.6 gpm. All EPA Method 1664 SGT-HEM results returned "ND" for the effluent samples.

Influent and effluent flow rates are presented in Figure 44. At the start of the test, the influent flow rate fluctuated near 7.5 gpm and the effluent flow rate fluctuated near 6.0 gpm. Similar to Performance Test #7, the system's processing capacity gradually increased over time to 6.5 gpm. However, after 4:30 elapsed time, the flow rates decreased to 5.8 gpm over the remainder of the test. The potable water flush also restored the processing capacity to just under 7.0 gpm.

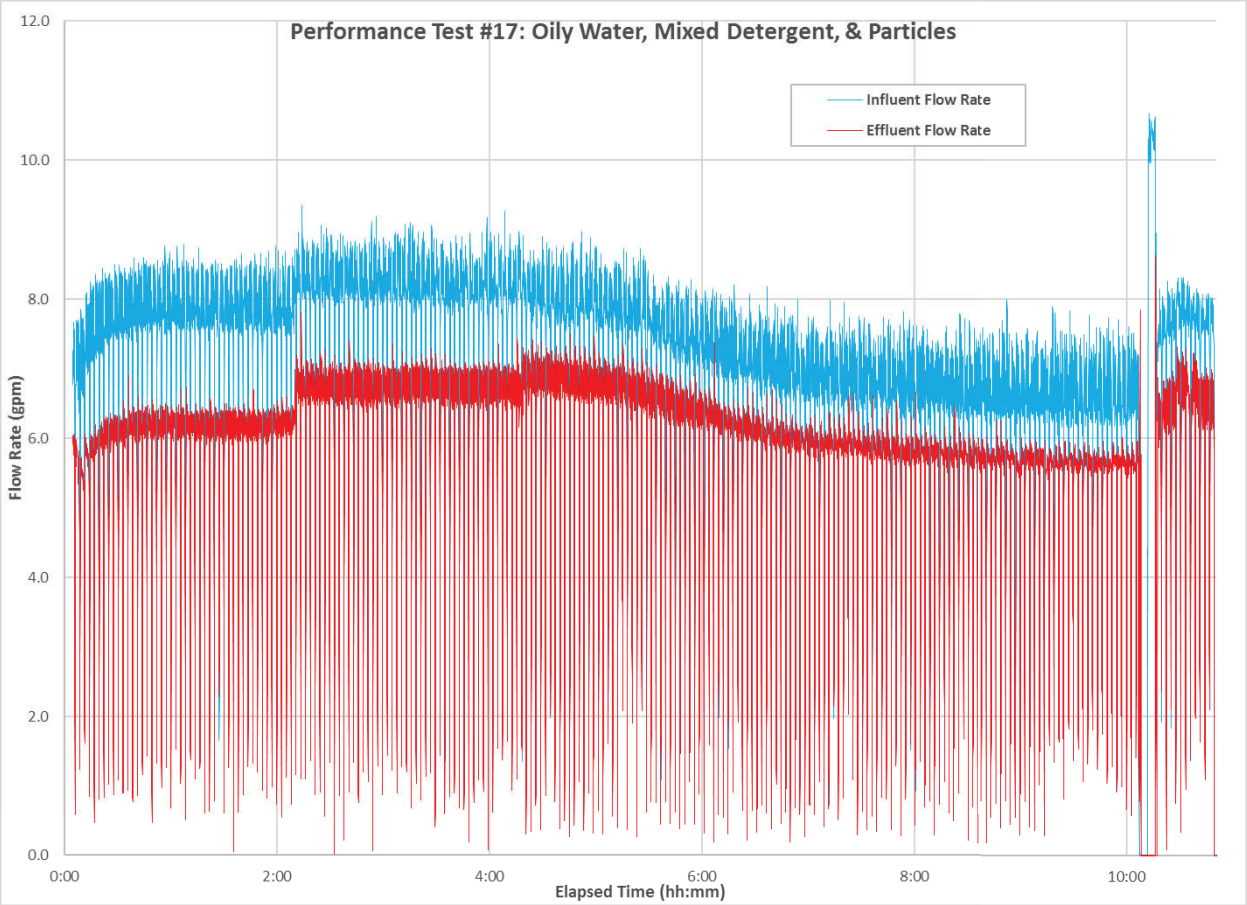


Figure 44. Performance Test #17 - Influent and Effluent Flow

Figure 45 shows samples collected from the influent and effluent sample ports. The influent sample was emulsified similar to other tests (Appendix P). However, like performance test #7 the effluent samples had a clear layer of foam formed at the surface from the detergents.

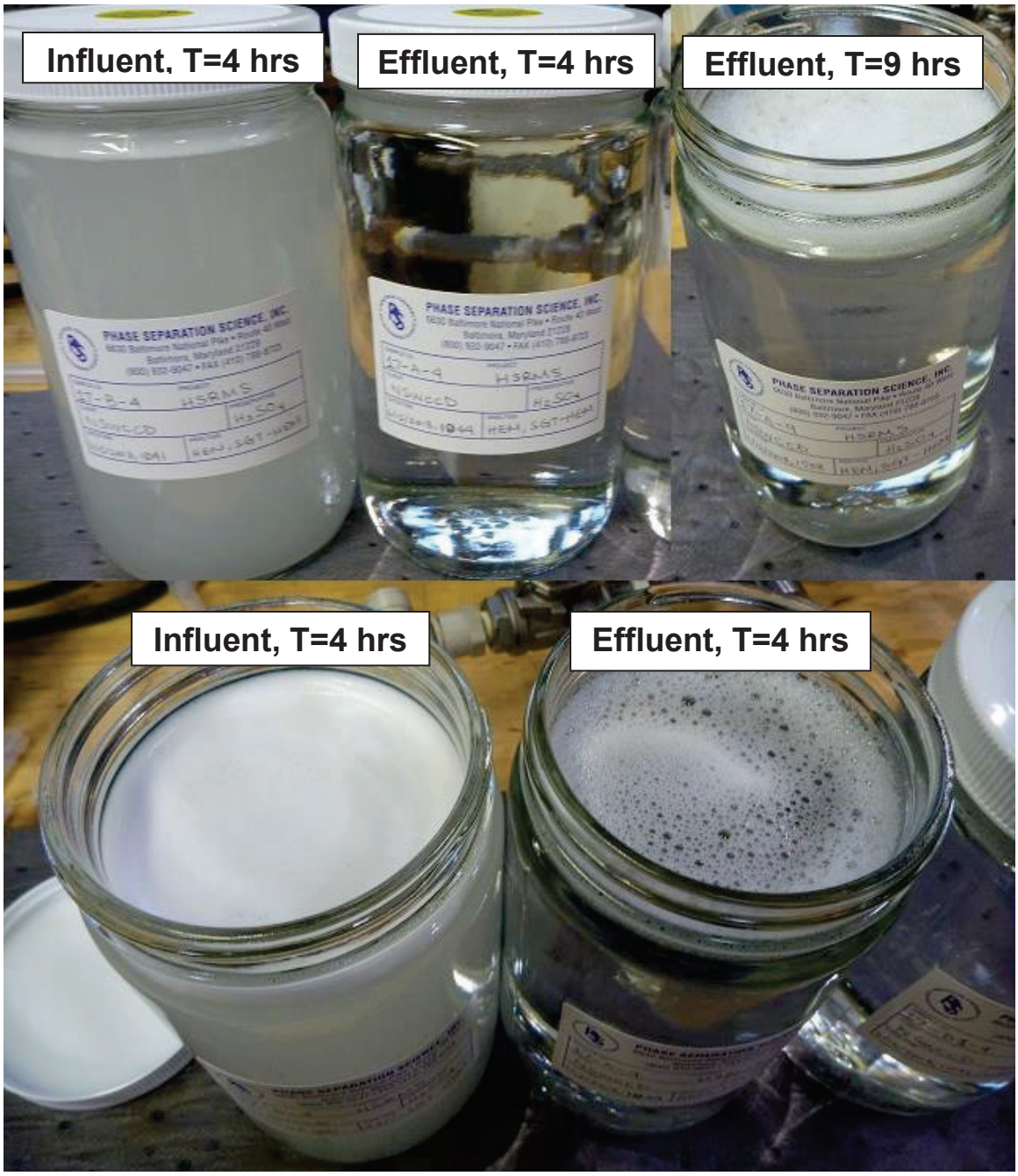


Figure 45. Performance Test #17 - Influent and Effluent Samples

Performance Tests #8 and #18: JP-5 Oily Water & Mixed Detergent

During these tests, the HSRMS processed 1,000-ppm NSBM #4 JP-5 Variant and 100-ppm Detergent Mix #4 in potable water.

Test #8

The TD-107's internal logs indicated that the OCM made the decision to discharge fluid 100% of the time and did not trigger any high level alarms. Based on the manual logs (alarms from backpulse events not included), the ET-35N also made the decision to discharge fluid 100%

of the time. The effective processing efficiency of the HSRMS over the course of the test was 77% based on the recorded totalizer data. The effluent flowmeter data indicated that the system produced an average overboard discharge rate of 3.6 gpm. All EPA Method 1664 SGT-HEM results returned "ND" for the effluent samples.

Influent and effluent flow rates are presented in Figure 46. At the start of the test, the influent flow rate fluctuated near 8.0 gpm and the effluent flow rate fluctuated near 7.0 gpm. The system experienced a sharp decline in flow rates within only a few minutes of injecting the JP-5 variant mixture, although there was a slight recovery to the membranes that followed for the next 3 hours. After 3:00 elapsed time, the flow rate continued to gradually decrease, eventually reaching 3.2 gpm by the end of the test. Flow rate increased to 4.8 gpm after the potable water flush.

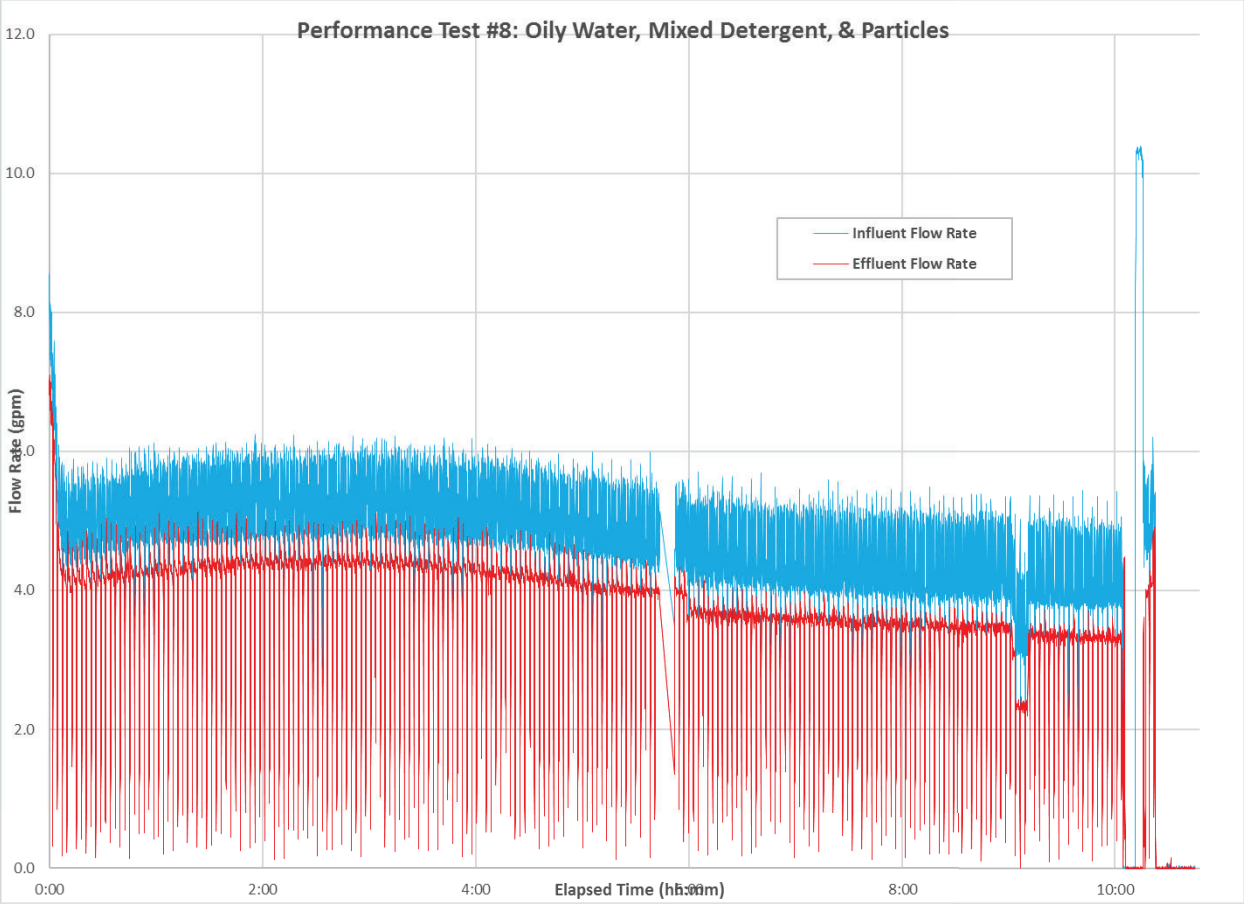


Figure 46. Performance Test #8 - Influent and Effluent Flow

The influent and effluent pressures are presented in Figure 47. The TMP was approximately 31 psi at the start of the test and increased to 32 psi by the end of the 10-hour test period. The JP-5 variant mixture immediately began to negatively affect the membranes within the first 20 minutes of the test, increasing the TMP by 3 psi but then slowing the rate of fouling for the remainder of the test. As the processing capacity of the system was reduced, the globe valve was closed at 6:00 elapsed time to maintain ET-35N operation. The average TMP throughout the 10-hour test period was 29.3 psi.

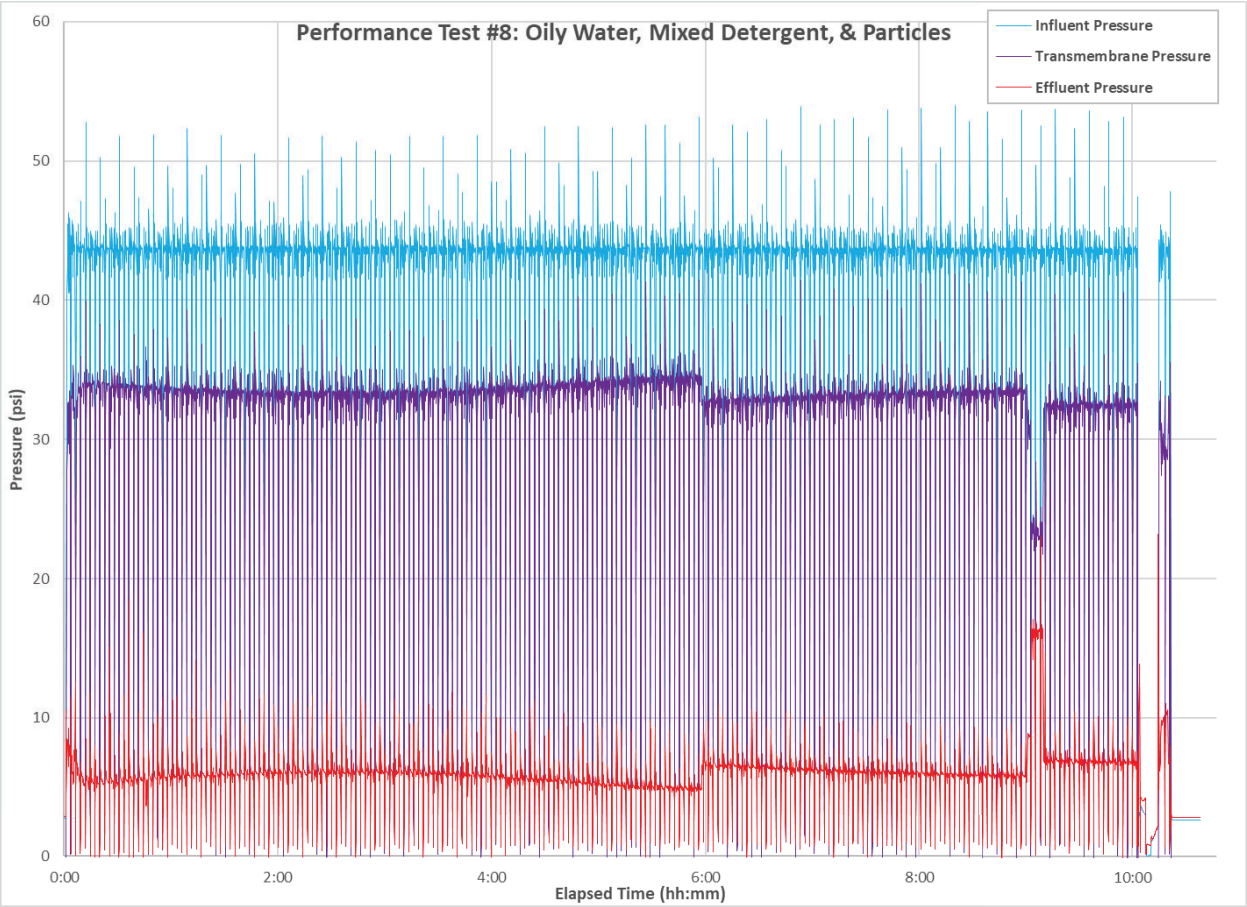


Figure 47. Performance Test #8 - Feed and Discharge Pressures

Test #18

The TD-107's internal logs indicated that the OCM made the decision to discharge fluid 100% of the time and did not trigger any high level alarms. Based on the manual logs (alarms from backpulse events not included), the ET-35N made the decision to discharge fluid only 36% of the time due the effluent triggering Warning Light 3, likely caused by foam. The effective processing efficiency of the HSRMS over the course of the test was 78% based on the recorded totalizer data. The effluent flowmeter data indicated that the system produced an average overboard discharge rate of 4.6 gpm. All EPA Method 1664 SGT-HEM results returned "ND" for the effluent samples.

Influent and effluent flow rates are presented in Figure 48. At the start of the test, the influent flow rate was 8.5 gpm and the effluent flow rate was 7.5 gpm. The effluent flow rate immediately decreased to 6.1 gpm once injection of the NSBM #4 JP-5 Variant and Detergent Mix #4 started. The effluent flow rate then continued to gradually decrease to 4.8 gpm by the end of the test. The data between 7:22 to 8:09 elapsed time were missing due to the data logger crashing.

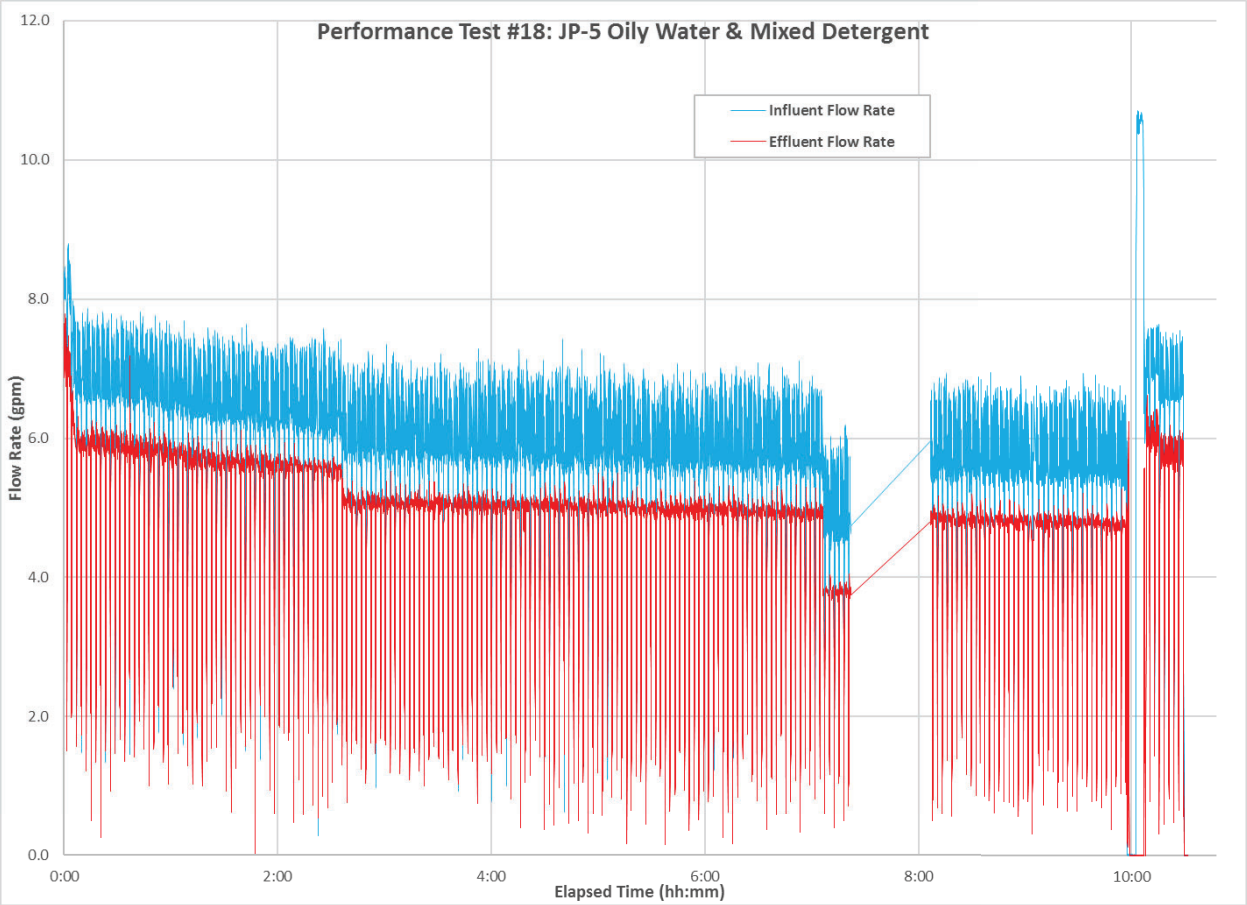


Figure 48. Performance Test #18 - Influent and Effluent Flow

The influent and effluent pressures are presented in Figure 49. The TMP was initially 33.5 psi at the start of the test and increased to 36.2 psi by the end of the 10-hour testing period. The JP-5 variant mixture immediately began to negatively affect the membranes within the first 15 minutes of the test, increasing the TMP by 3.9 psi but then leveling out for the remainder of the test. The average TMP throughout the 10-hour test was 32.2 psi.

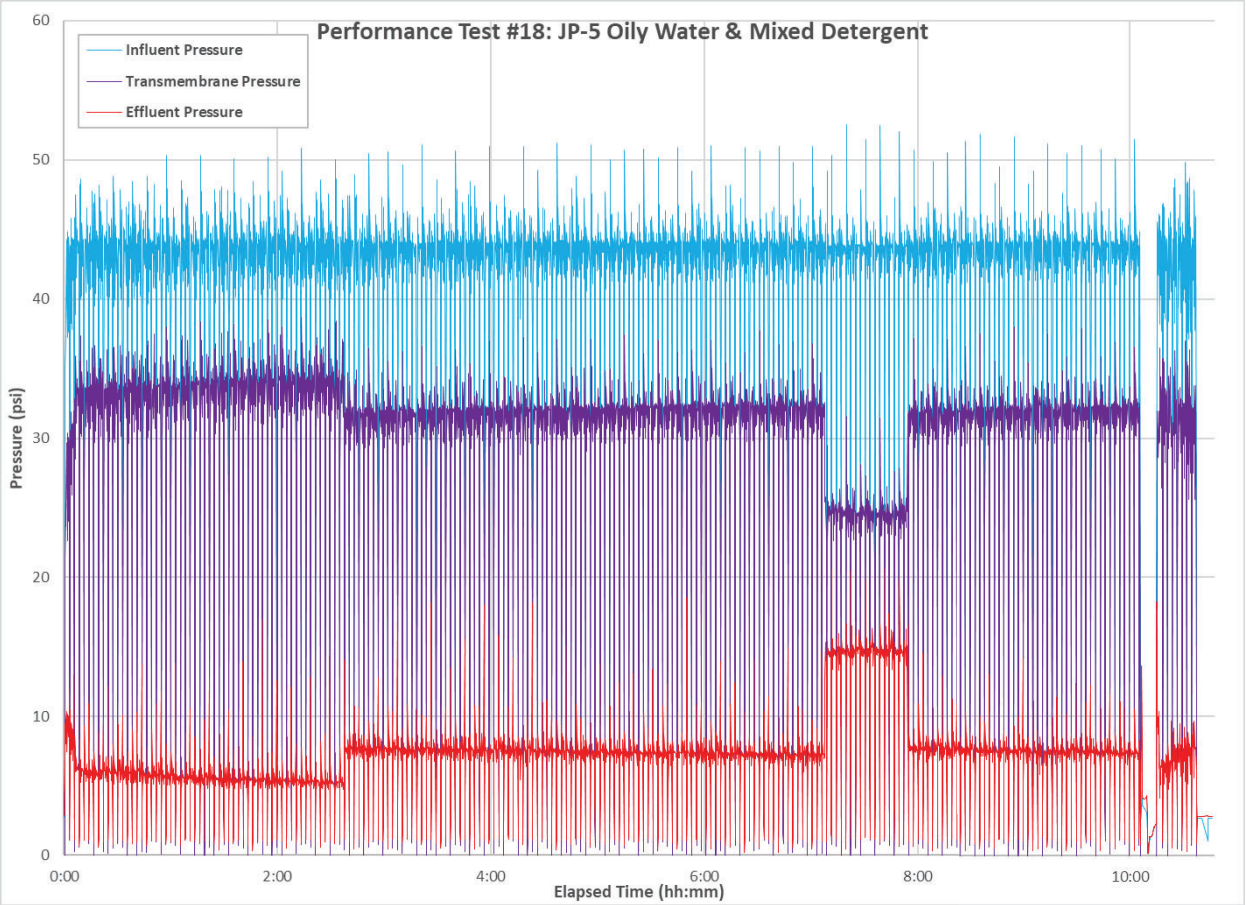


Figure 49. Performance Test #18 - Feed and Discharge Pressures

Performance Tests #9 and #19: Oily Water & Seawater

During these tests, the HSRMS processed 1,000-ppm NSBM #4 in synthetic seawater at 35,000-ppm salinity.

Test #9

The TD-107's internal logs indicated that the OCM made the decision to discharge fluid 100% of the time and did not trigger any high level alarms. Based on the manual logs (alarms from backpulse events not included), the ET-35N also made the decision to discharge fluid 100% of the time. The effective processing efficiency of the HSRMS over the course of the test was 68% based on the recorded totalizer data; this percentage was lower than other tests due to the decreased flow rate. The effluent flowmeter data indicated that the system produced an average overboard discharge rate of 2.3 gpm. All EPA Method 1664 SGT-HEM results returned "ND" for the effluent samples.

Influent and effluent flow rates are presented in Figure 50. At the start of the test, the influent flow rate started near 6.0 gpm and the effluent flow rate near 4.5 gpm. The effluent flow rate decreased to 2.2 gpm over the first 4 hours of the test. The flowrate remained at 2.2 gpm for the remainder of the test. No abnormal events occurred, and the HSRMS demonstrated its capability to process the synthetic seawater without any noticeable differences compared to when

potable water was processed. The potable water flushes conducted at the end of the test provided only a slight increase to the effluent flow rate.

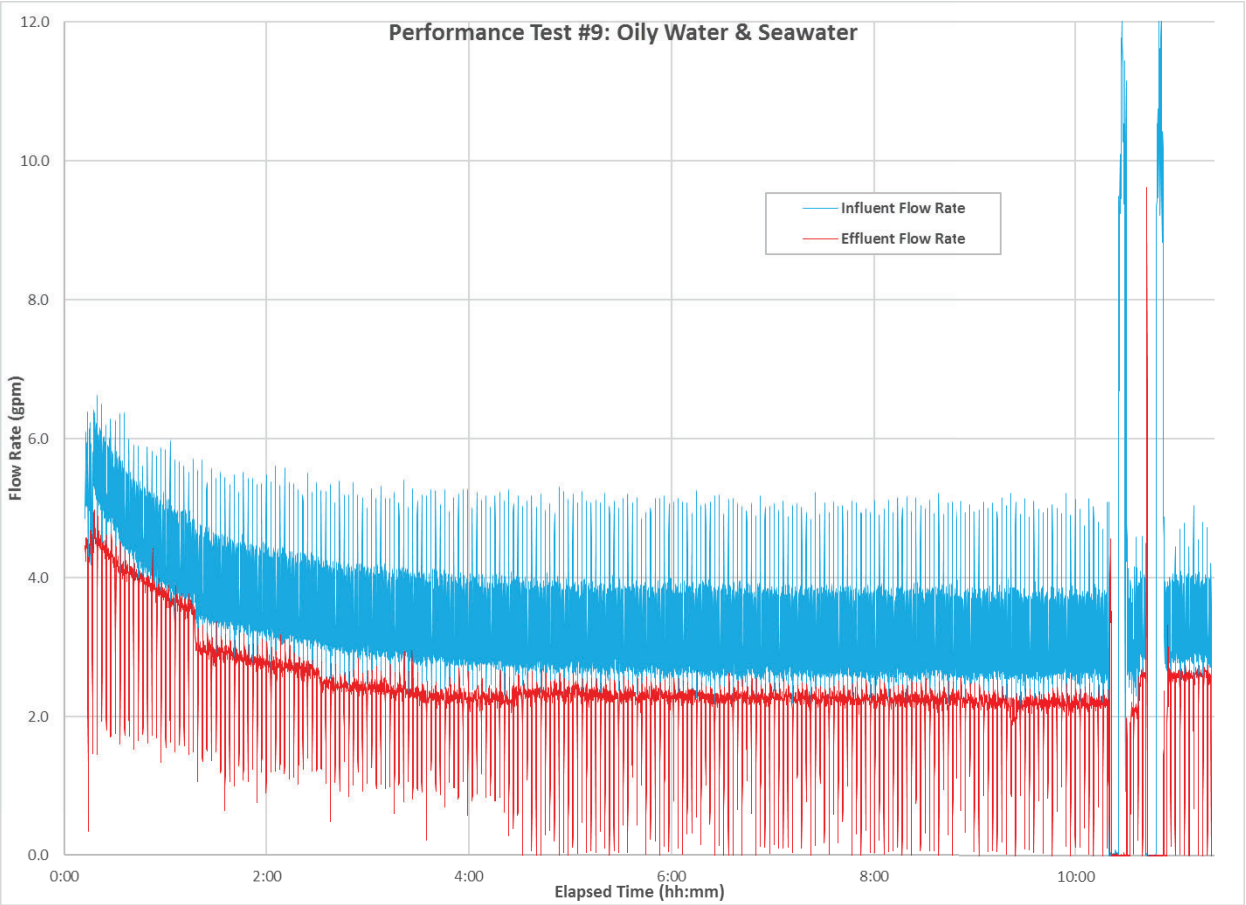


Figure 50. Performance Test #9 - Influent and Effluent Flow

The influent and effluent pressures are presented in Figure 51. The TMP was approximately 32 psi at the start of the test and increased to 34 psi by the end of the 10-hour test period. There was an increase in TMP within the first hour by 3 psi until the globe valve had to be throttled more closed to keep the ET-35N operational. The TMP then remained steady throughout the remainder of the test. The average TMP throughout the 10-hour test was 30.8 psi.



Figure 51. Performance Test #9 - Feed and Discharge Pressures

Test #19

The TD-107's internal logs indicate that the OCM made the decision to discharge fluid 100% of the time and did not trigger any high level alarms. Based on the manual logs (alarms from backpulse events not included), the ET-35N also made the decision to discharge fluid 100% of the time. The effective processing efficiency of the HSRMS over the course of the test was 75% based on the recorded totalizer data. The effluent flowmeter data indicated that the system produced an average overboard discharge rate of 3.8 gpm. All EPA Method 1664 SGT-HEM results returned "ND" for the effluent samples.

Influent and effluent flow rates are presented in Figure 52. It should be noted that the data collected up until 00:36 elapsed time was omitted due to the salt water feed becoming blocked due to an air pocket in the piping. The test was restarted and experienced no other issues for the remainder of the day. After restarting the test, the influent flow began at above 8.0 gpm and the effluent flow rate at 6.5 gpm. The effluent flowrate then began to gradually decrease, reaching a flow rate of 3.5 gpm by the end of the test. The results of Performance Test #19 were similar to that of Performance Test #9. The system was able to process a seawater mixture with no negative effects on the system components aside from fouling the membranes, and the rate of membrane fouling due to the mechanically emulsified oily seawater corresponded with the rates experienced with mechanically emulsified oily water. The potable water flush conducted at the end of the test did not provide any substantial recovery to the system's processing capacity.

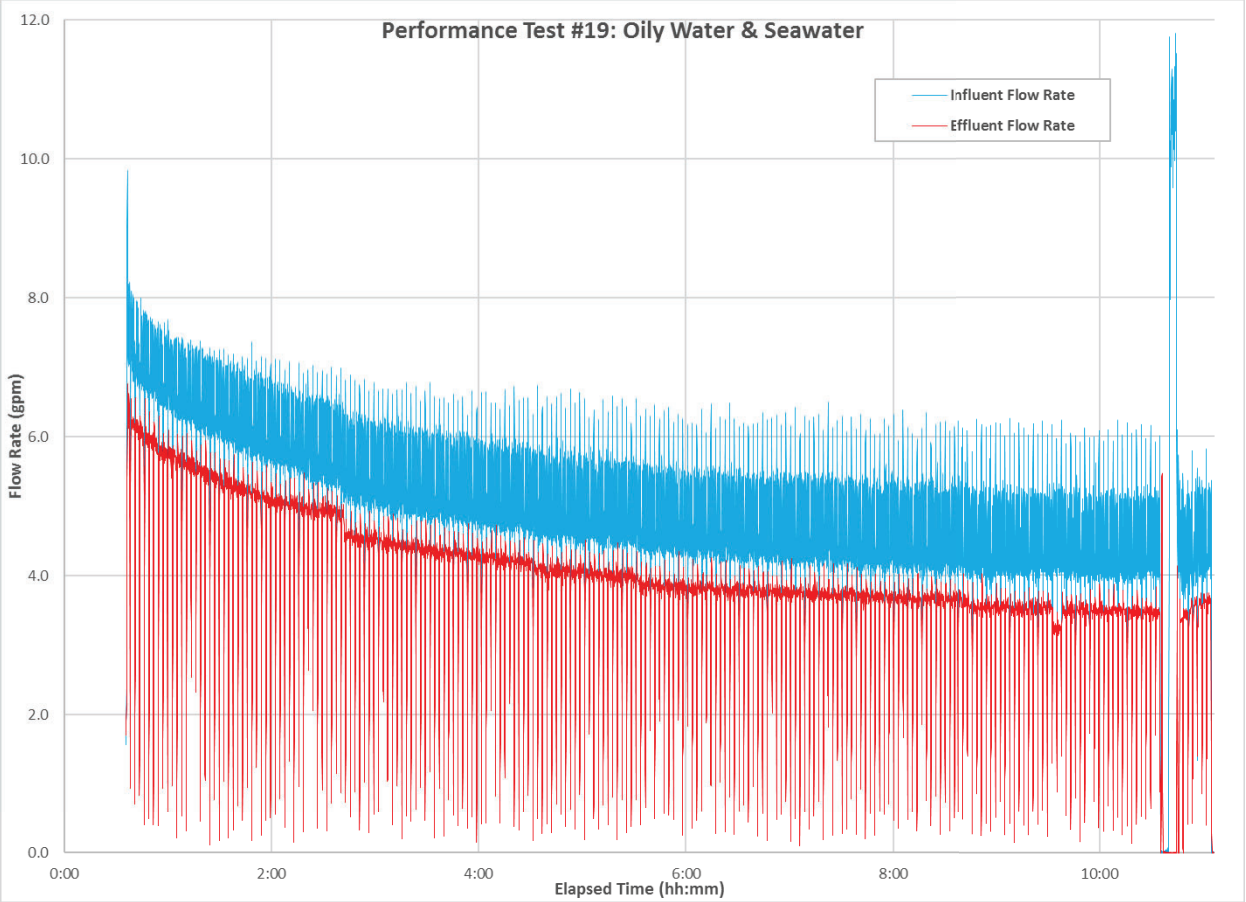


Figure 52. Performance Test #19 - Influent and Effluent Flow

The influent and effluent pressures are presented in Figure 53. The TMP was approximately 31 psi at the start of the test and increased to 34 psi by the end of the 10-hour test period. Similar to Performance Test #9, there was also an initial increase in TMP by 3 psi. The globe valve was used to increase backpressure at 2:45, 4:33, 5:34, and 8:45 elapsed time in order to maintain ET-35N operation, which resulted in the small, sudden TMP decreases of approximately 1.0 psi. The average TMP throughout the 10-hour injection period was 30.6 psi.

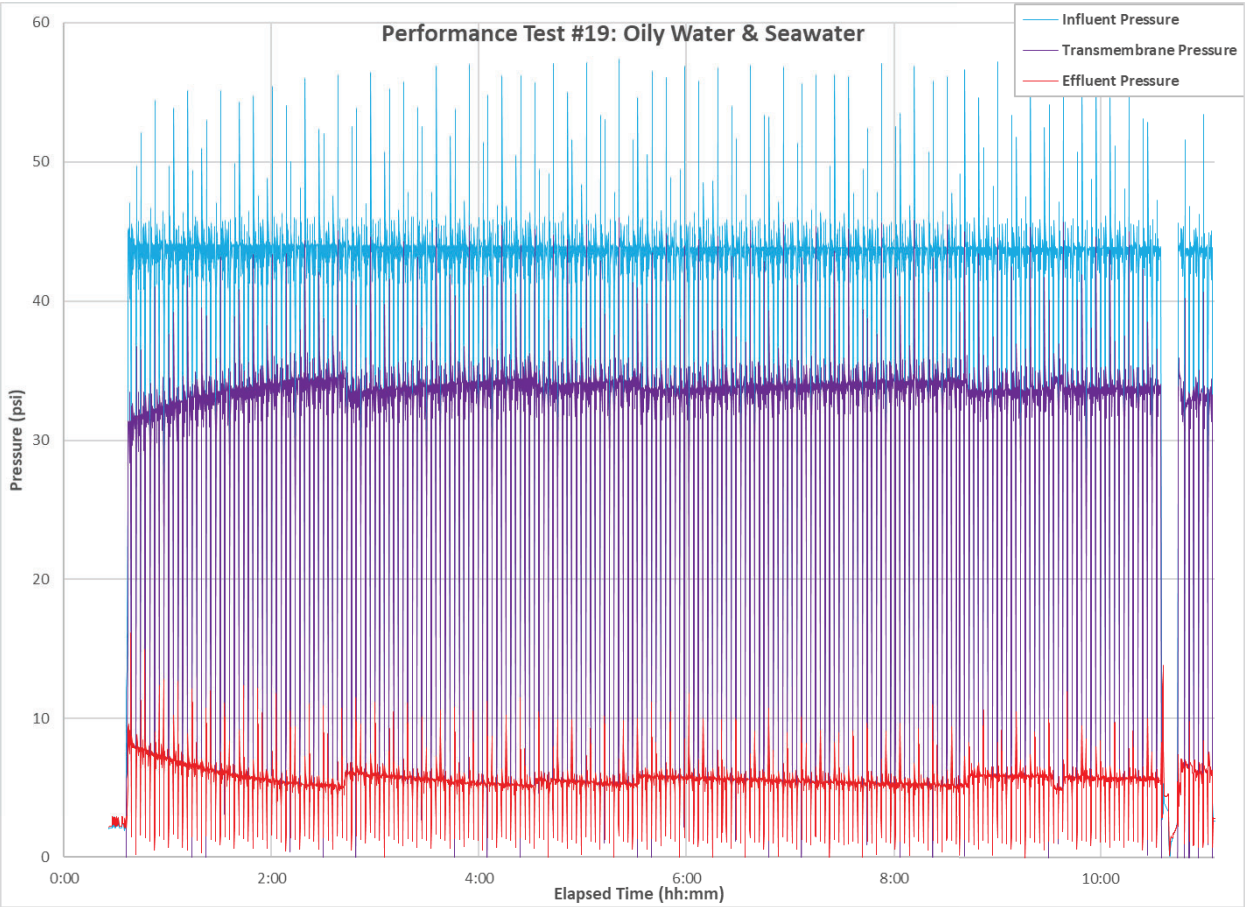


Figure 53. Performance Test #19 - Feed and Discharge Pressures

Performance Tests #10 and #20: OWHT Transition Test

During these tests, the HSRMS was intended to process 1% NSBM #4 for the first six hours, then 50% NSBM #4 for 10 minutes, and finally 100% NSBM #4, or bulk oil, for 30 minutes.

Test #10

The first attempt at conducting Performance Test #10 was interrupted due to the injection pump leak through its seal. The test was stopped after 3:54 elapsed time to attempt repairs, but testing could not be resumed since the pump needed to be completely replaced. The entirety of Performance Test #10 was therefore repeated the following day from the beginning using the gearhead pump for injection.

The TD-107's internal logs indicated that the OCM made the decision to discharge fluid 100% of the time and did not trigger any high level alarms. Based on the manual logs (alarms from backpulse events not included), the ET-35N also made the decision to discharge fluid 100% of the time. The effective processing efficiency of the HSRMS over the course of the test was 77% based on the recorded totalizer data. The effluent flowmeter data indicated that the system produced an average overboard discharge rate of 4.5 gpm. All EPA Method 1664 SGT-HEM results returned "ND" for the collected effluent samples. During the bulk oil section of the test,

the HSRMS automatically ended production within two minutes of introducing bulk oil due to a high torque alarm, “M-100 torque Alarm HH exceeded”.

Influent and effluent flow rates are presented in Figure 54. At the start of the test, the influent flow rate fluctuated at 6.3 gpm and the effluent flow rate at 5.2 gpm. The HSRMS was able to maintain the flow rates at consistent levels throughout the 6 hours of 1% oil injection. Unlike the tests with mechanically emulsified or chemically emulsified oil, Performance Test #10 injected the oil without the use of the disperser. Due to the absence of fine oil droplets or chemical emulsions in the injection mixture, the HSRMS was able to process the oil more successfully. The processing capacity of the system decreased very slightly once the influent was switched to 50% oil at 6:00 elapsed time and appeared to maintain steady when switching the feed to 100% oil until automatic shutdown.

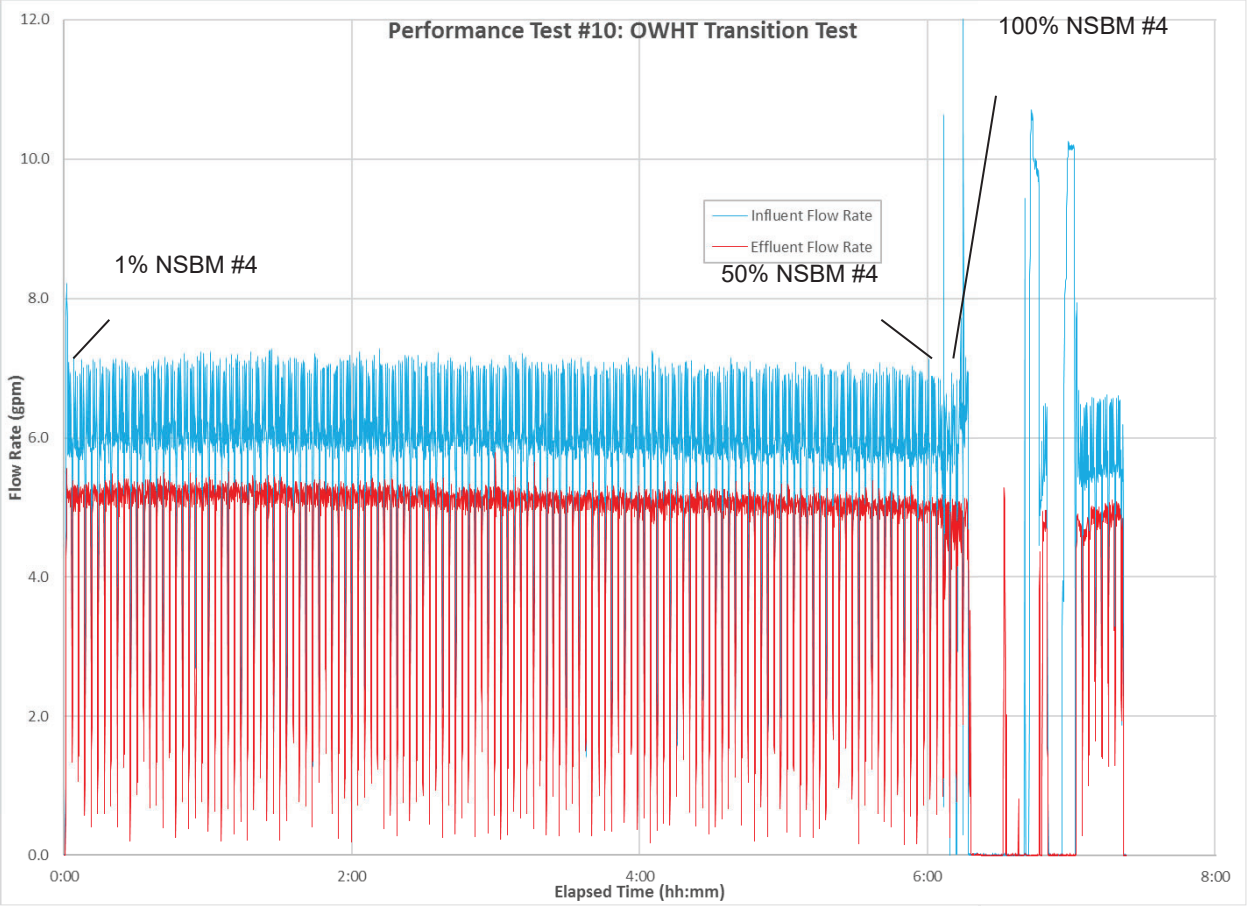


Figure 54. Performance Test #10 - Influent and Effluent Flow

The HSRMS filter torque and temperature data are presented in Figure 55. The initial measurements were reflective of all other tests with the torque starting above 100 N·m but falling quickly to a torque in the range of 70 to 80 N·m. Normally, this level of torque is maintained throughout the whole duration of testing due to the medium being almost entirely water, but with Performance Test #10, the system experienced a sharp increase in filter torque while transitioning to bulk oil. Initially, the system experienced a slight drop in torque while the influent was throttled to 50% oil, but the torque quickly began to increase past 87 N·m after 10 minutes. Once the feed was switched to 100% NSBM #4, the system reported a high torque

warning at 120 N·m after about 1.5 minutes of processing the influent. After only a few seconds of triggering this warning, the system triggered its high torque alarm at 130 N·m which initiated an automatic stop to operations; note that Figure 55 does not depict the torque exceeding the 130 N·m threshold due to the HSRMS data logging frequency of once every 10-seconds. This result was favorable since the system was able to automatically stop once it comes into contact with the oil layer, thereby preventing oil breakthrough and preventing damage to the system's components.

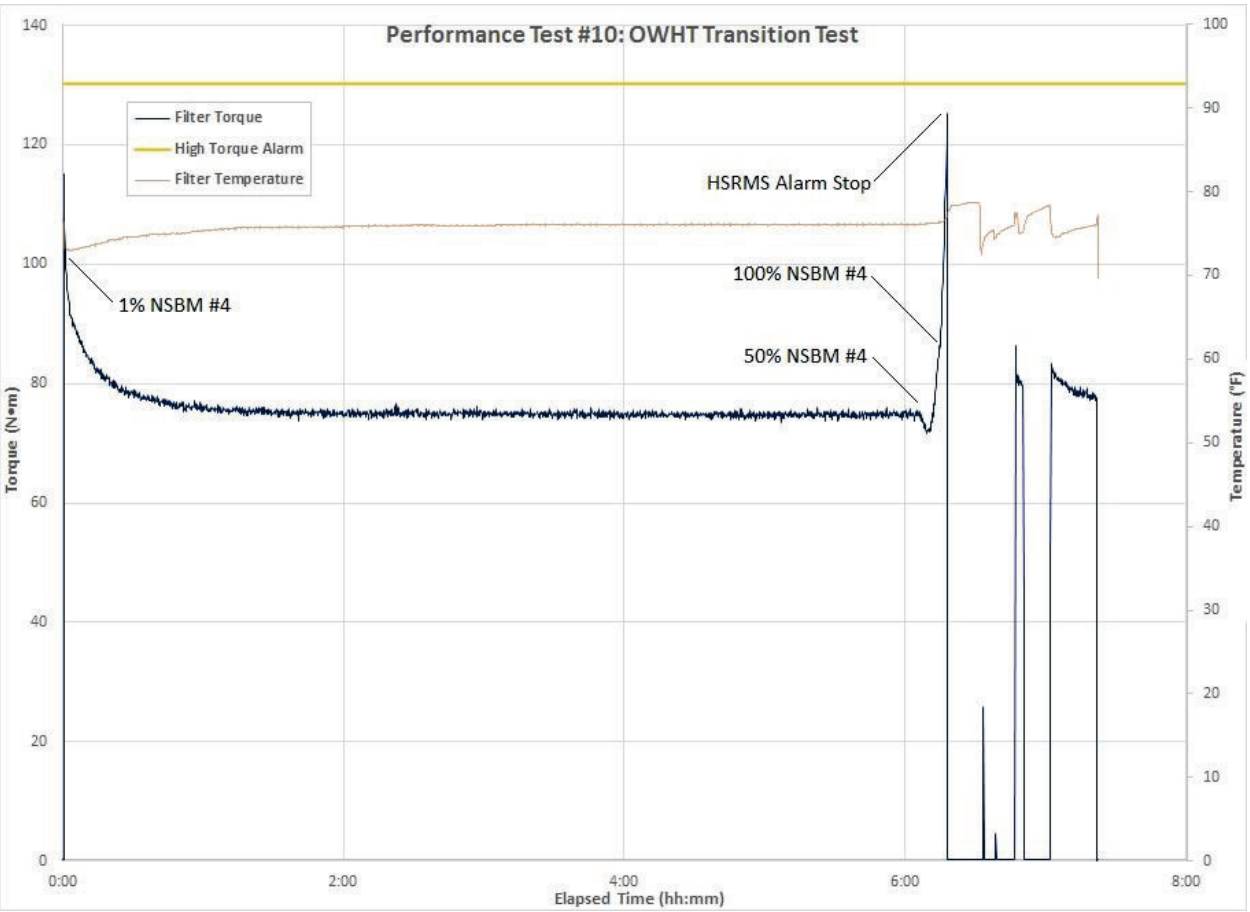


Figure 55. Performance Test #10 - Membrane Torque and Temperature

The influent and effluent pressures are presented in Figure 56. The TMP was approximately 33 psi at the start of the test and 21 psi just prior to the high torque alarm. Throughout the majority of the test, the TMP remained consistent, similar to the processing capacity. The exception occurred at 6:00 elapsed time when the TMP began to decline when the influent was switched to 50% oil. The feed pump could no longer maintain the discharge pressure at the 3.0 bar (44.5 psi) setting due to the viscosity of the oil and began to produce less flow. There was insufficient time to observe the feed pump pressure reaching a steady state since the alarm triggered within 1.5 minutes into bulk oil portion of the test. The average TMP throughout the 6-hour test period was 29.3 psi.

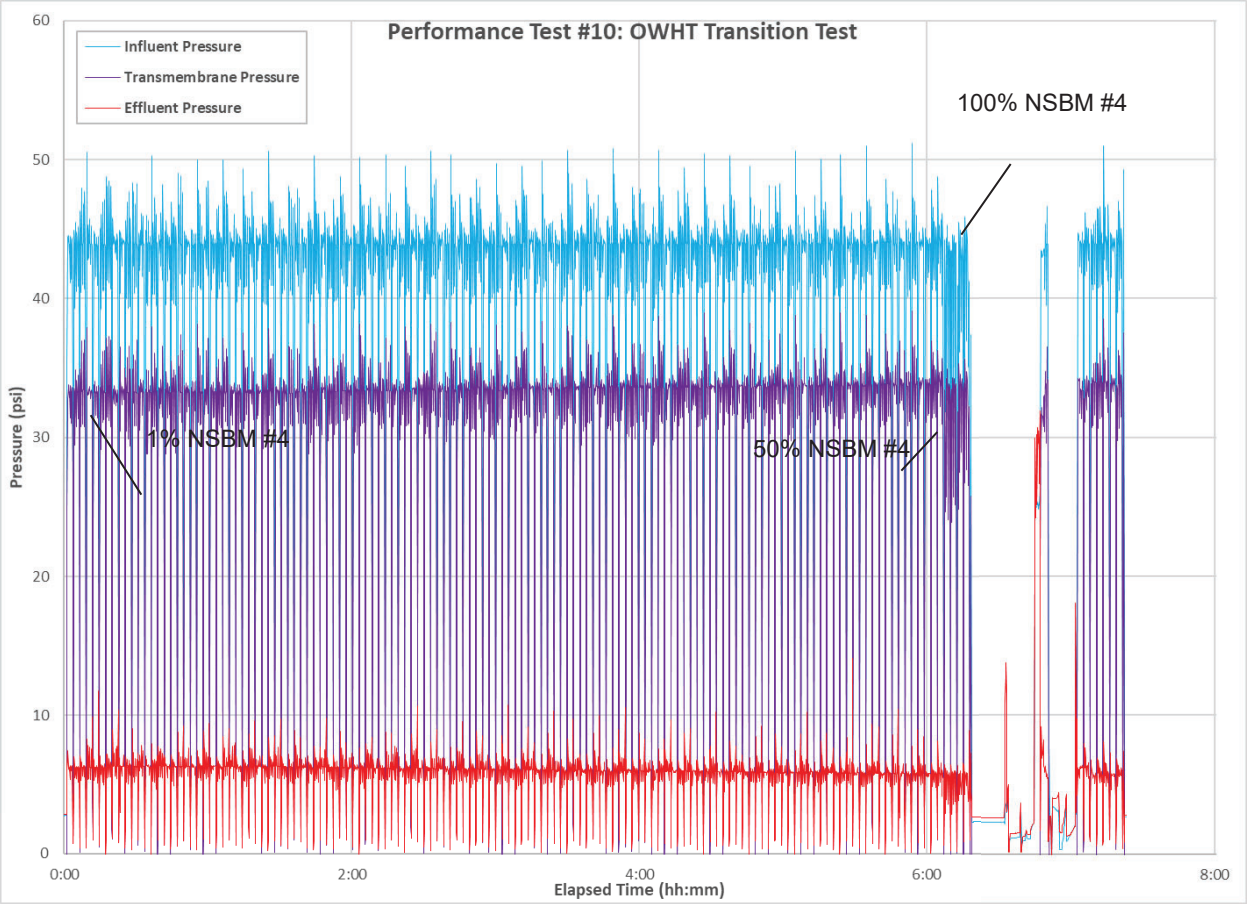


Figure 56. Performance Test #10 - Feed and Discharge Pressures

Figure 57 shows influent and effluent samples collected 4 hrs into Performance Test #10. The influent sample had a very thick, milky appearance with the entirety of the sample appearing emulsified. The effluent sample was clear and colorless with no apparent sheen.

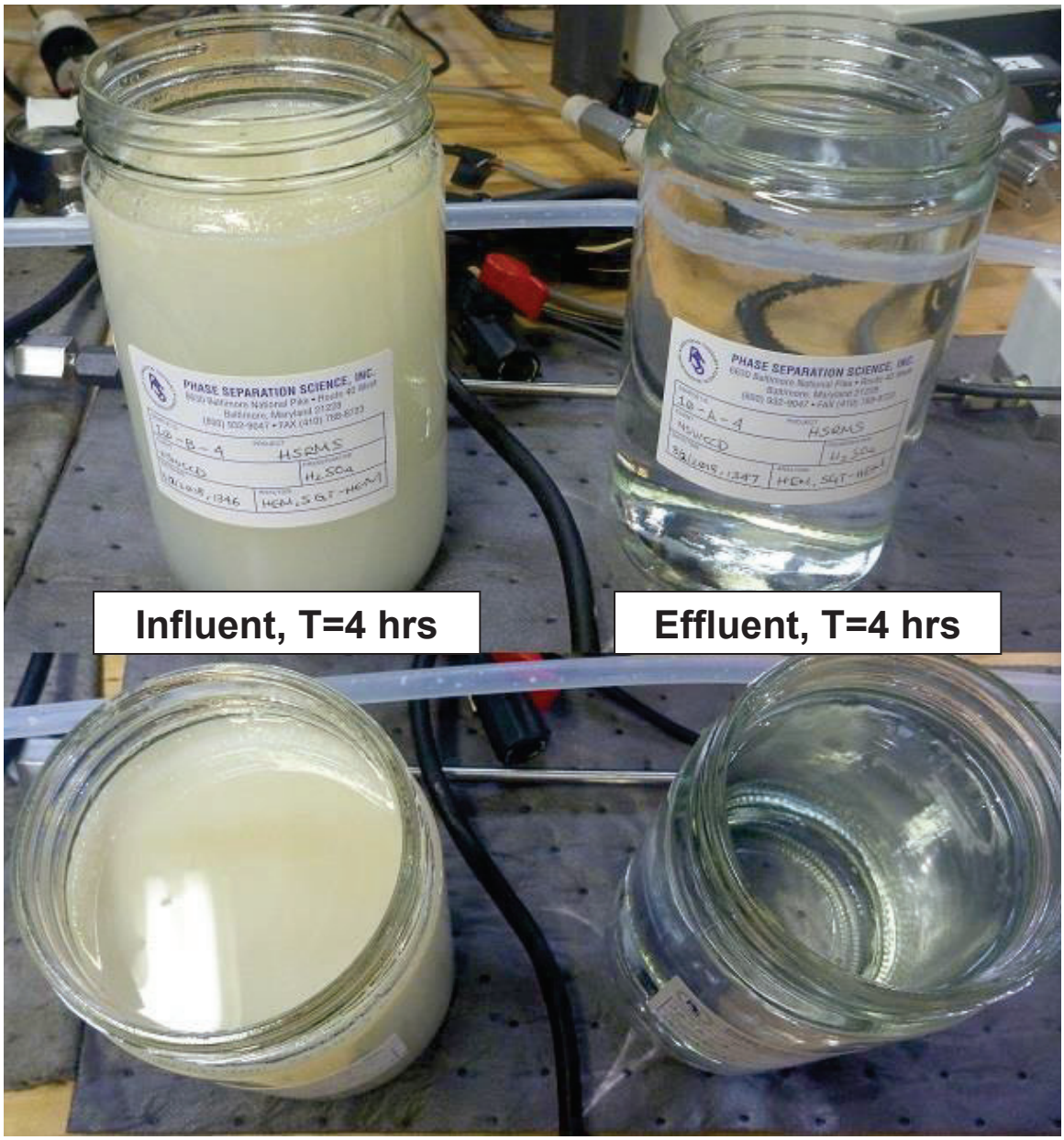


Figure 57. Performance Test #10 - Influent and Effluent Samples

Test #20

The TD-107's internal logs indicated that the OCM made the decision to discharge fluid 100% of the time and did not trigger any high level alarms. Based on the manual logs (alarms from backpulse events not included), the ET-35N also made the decision to discharge fluid 100% of the time. The effective processing efficiency of the HSRMS over the course of the test was 78% based on the recorded totalizer data. The effluent flowmeter data indicated that the system produced an average overboard discharge rate of 4.7 gpm. All EPA Method 1664 SGT-HEM results returned "ND" for the effluent samples that could be gathered.

Influent and effluent flow rates are presented in Figure 58. At the start of the test, the influent flow rate fluctuated at 6.5 gpm and the effluent flow rate at 5.2 gpm. Similar to

Performance Test #10, the HSRMS experienced no discernable degradation to its processing capacity for the 1% oil portion of the test. A gradual decrease in processing capacity was observed at 6:20 elapsed time when the influent was switched to 50% oil. After switching the influent to bulk oil, the system automatically stopped operations within 1.5 minutes due to the triggering of the high torque alarm, "M-100 torque Alarm HH exceeded". After the test, a potable water flush was conducted, and the processing capacity returned to 4.8 gpm, which was equal to the capacity just prior to the torque alarm. The sudden influent flow rate spike at 6:45 elapsed time was due to an unsuccessful attempt at a potable water flush; the membrane chamber's low level sensor was covered with oil and incorrectly registered the chamber as full. The CIP valve was opened to allow the chamber to fill with water, and the subsequent concentrate discharge cleared the sensor.

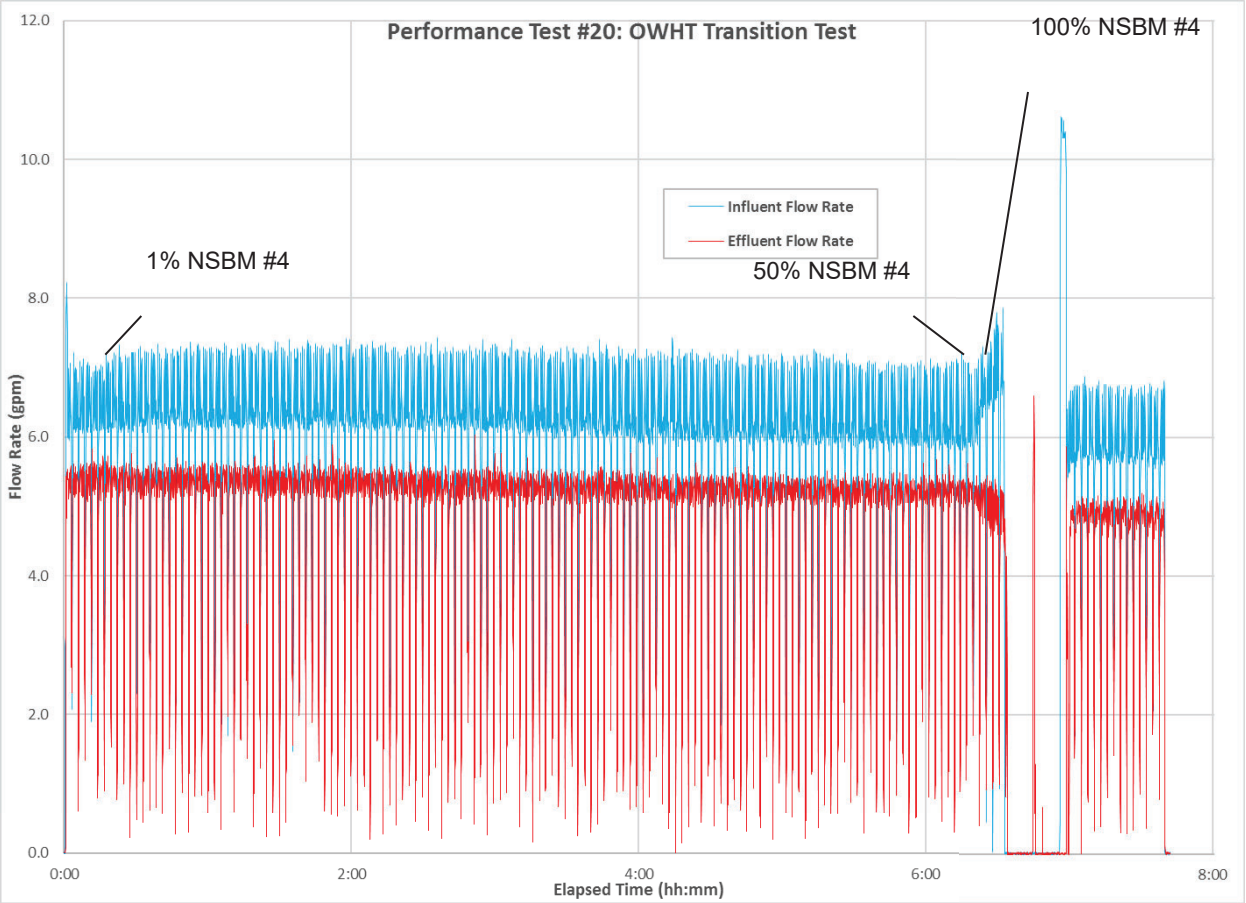


Figure 58. Performance Test #20 - Influent and Effluent Flow

The HSRMS membrane torque and temperature data are presented in Figure 59. The results were comparable to what was demonstrated in Performance Test #10 with the bulk oil causing a sharp spike in torque triggering the alarm. The 1% oil injection was delayed by 15 minutes due to difficulties starting the gearhead pump; the pump head needed to be replaced with a backup. While the system was just processing potable water, the reported torque was still consistent with every other test; the initial torque began at over 100 N·m but declined quickly within a few minutes of operations. Similar to Performance Test #10, the reported torque experienced a minor decrease once the 50% oil influent was supplied at 6:21 elapsed time.

However, the torque increased when more oil concentrated within the chamber. The 50% oil influent would have likely triggered the 130 N·m alarm eventually, but the influent was switched to 100% oil at 6:33 elapsed time which accelerated the time to triggering the alarm. The reported torque exceeded the 130 N·m threshold at 6:34 which was approximately 1.5 minutes of 100% oil influent.

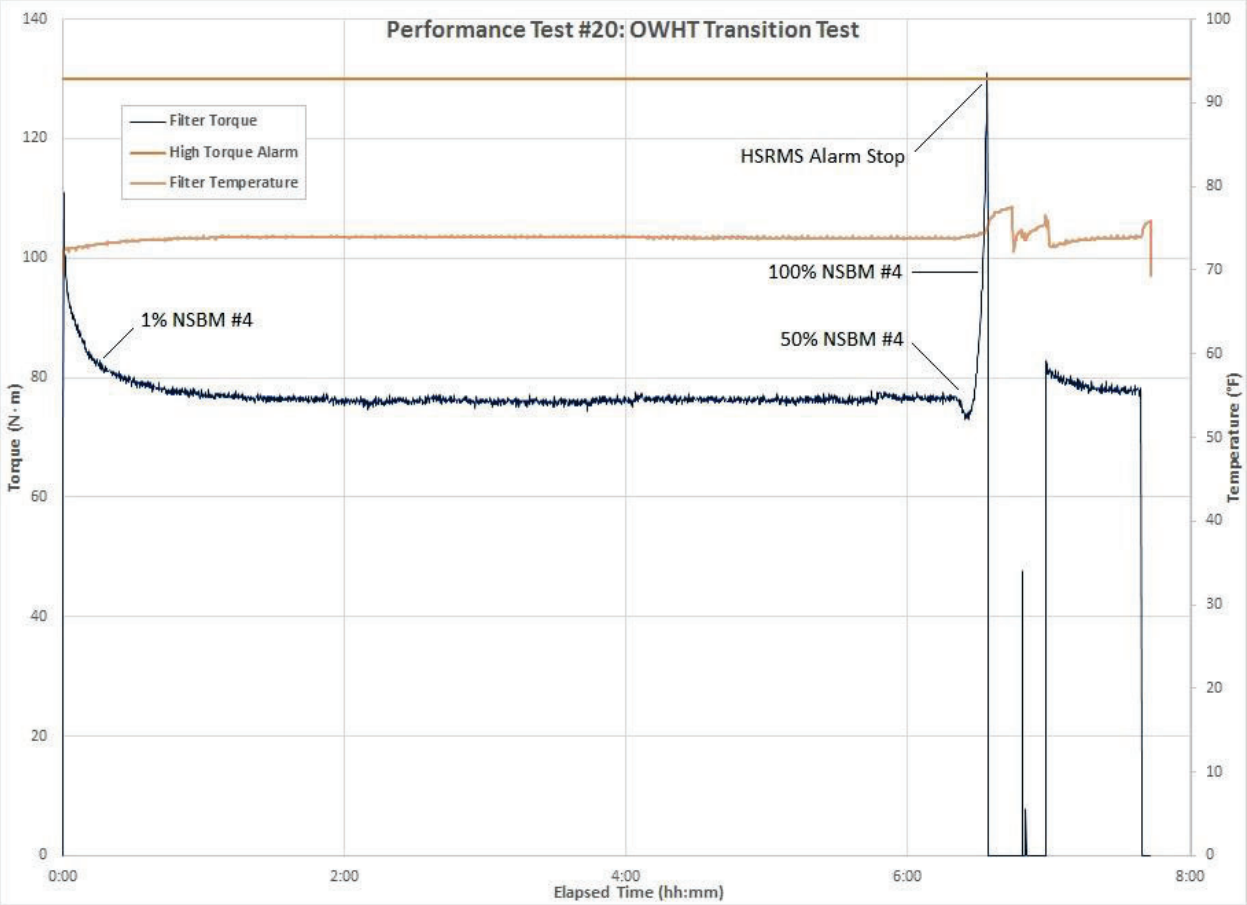


Figure 59. Performance Test #20 - Membrane Torque and Temperature

The influent and effluent pressures are presented in Figure 60. The TMP was approximately 30 psi at the start of the test and 29 psi just prior to the high torque alarm. Throughout the majority of the test, the TMP remained consistent, similar to the processing capacity. The TMP only began to decrease once the feed was switched to 50% oil. The feed pump pressure was also affected; however, the time to observe the feed pump pressure reaching a steady state was insufficient since the alarm triggered within 1.5 minutes of processing bulk oil. The average TMP throughout the test was 31.8 psi.

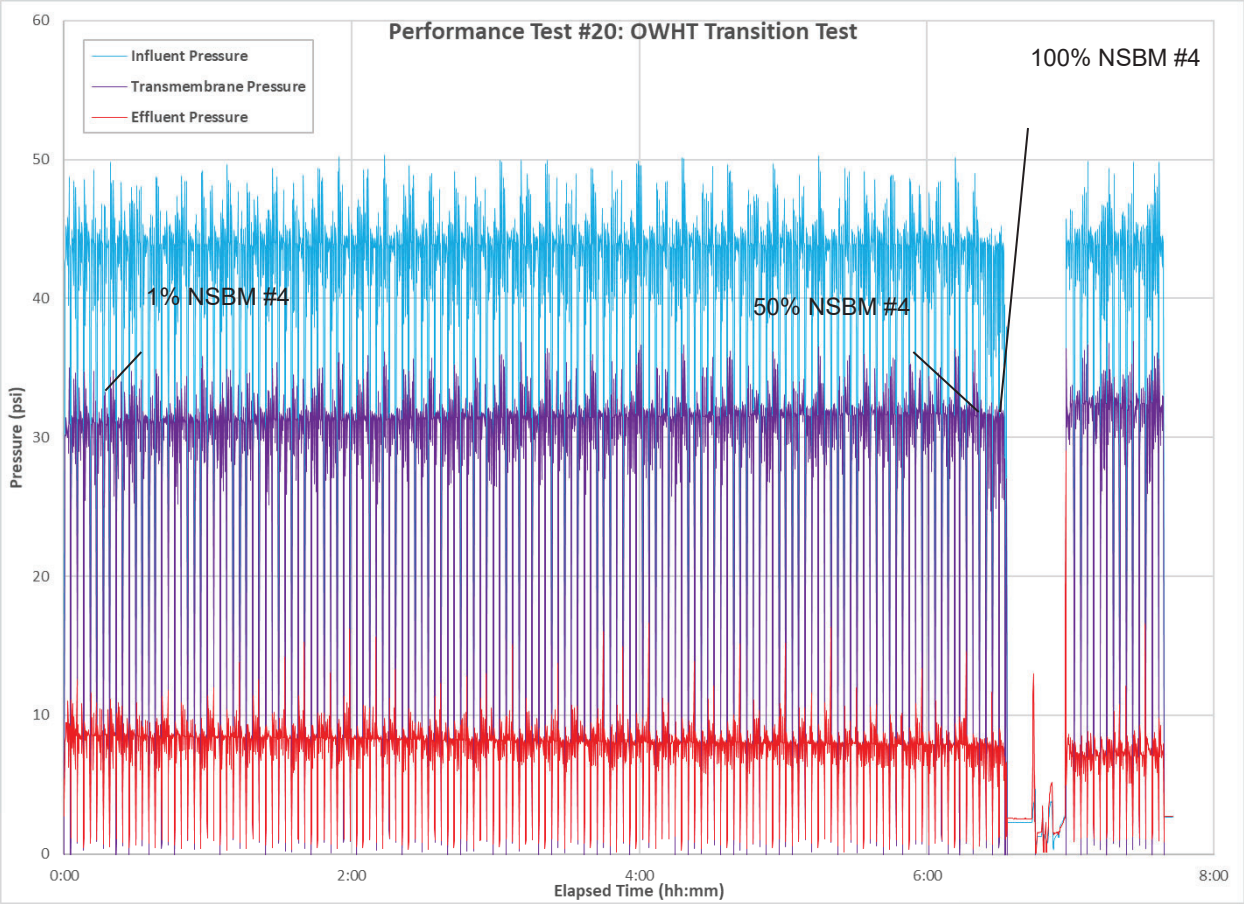


Figure 60. Performance Test #20 - Feed and Discharge Pressures

Figure 61 shows samples collected during Performance Test #20. The influent sample had a slightly cloudy appearance with a thick, milky layer forming at the surface of the sample. The effluent samples were clear and colorless with no apparent sheen. Haziness in photo was due to condensation on the outside of the sample jars.

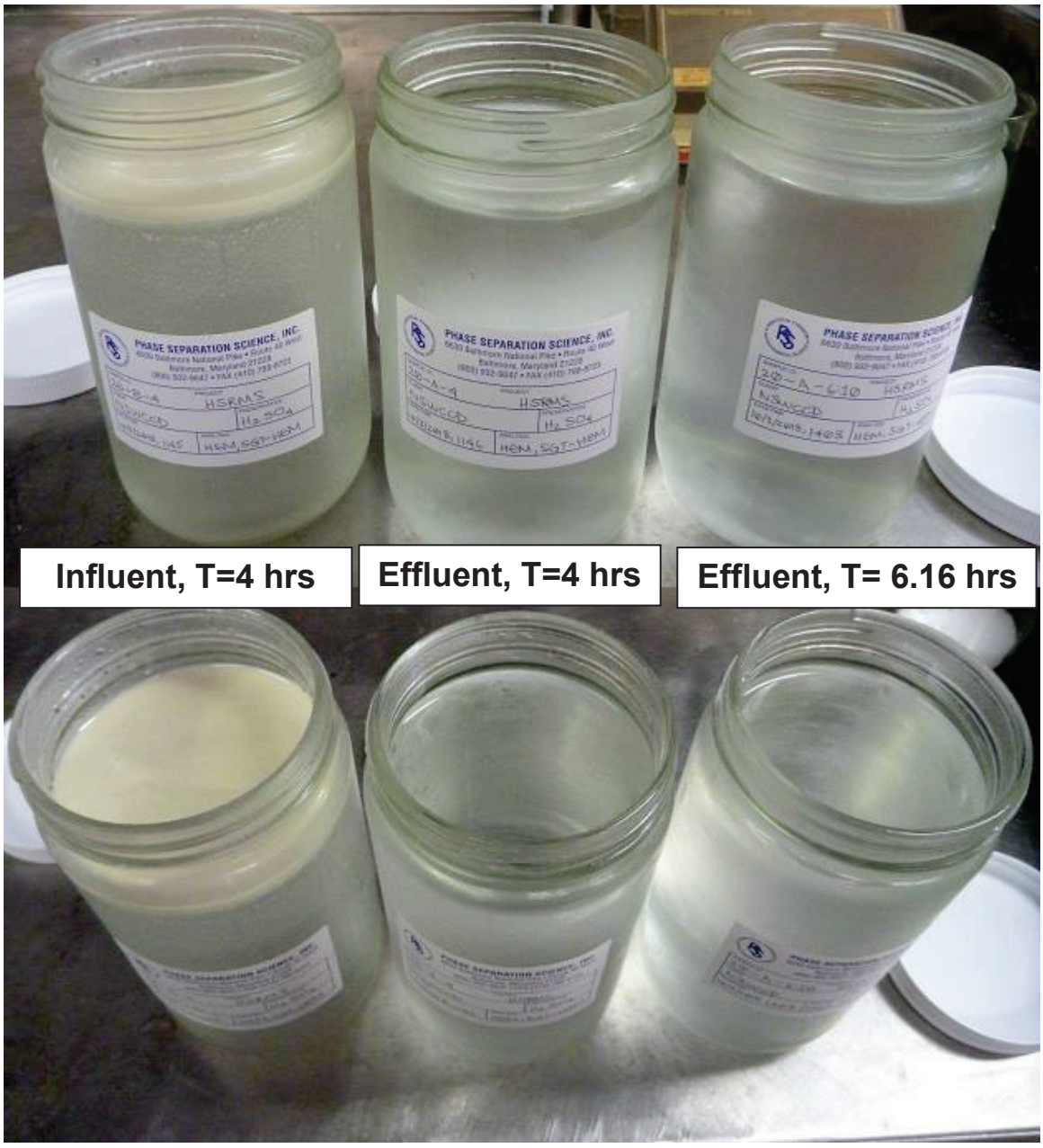


Figure 61. Performance Test #20 - Influent and Effluent Samples

Membrane Life

Membrane Regeneration Summary

The membranes were regenerated five times throughout the evaluation to determine life of the membranes and the effect of cleaning procedures on membrane recovery. The summary of the membrane regenerations and recoveries is listed in Table 11.

Table 11. Summary of Membrane Regenerations and Recoveries

Membrane Regeneration	Time between regeneration	Restored Flux**	Cleaning Efficiency***	Notes
Micro-dosing Regeneration #1 (Cleaning time= 2 hrs)	212 hrs (+140 hrs potable water)	46.3%	53.4%	Membrane regeneration required due to OCM alarm (likely due to foam in effluent)
Membrane Regeneration #1 (Cleaning time=11 hrs)	0 hrs*	70.9%	64.5%	Membrane Regeneration #1 occurred immediately following the micro-dosing experiment
Membrane Regeneration #2	147 hrs	66.9%	96.5%	Membrane regeneration required due to low flow alarm
Membrane Regeneration #3	145 hrs (+270 hrs potable water)	43.0%	73.4%	No heat was used during cleaning
Membrane Regeneration #4	0 hrs*	60.2%	50.1%	Membrane regeneration #4 occurred immediately following membrane regeneration #3 to observe the effect of heat on membrane flux

**Regeneration occurred immediately following the previous regeneration*

***Based on the recovery of specific flux,* $(1/R_r)/(1/R_i) \times 100$*, where* R_r *= regenerated membrane resistance, and* R_i *= new membrane resistance (0.12 psi/gfd).*

****Based on % Membrane Recovery =* $(R_f-R_r)/(R_f-R_i) \times 100$*, where* R_f *= fouled membrane resistance,* R_r *= regenerated membrane resistance, and* R_i *= initial membrane resistance*

Micro-Dosing Test

A micro-dosing test was performed to evaluate the effectiveness of a shorter cleaning cycle using less chemicals. Injection was accomplished through the use of the system-integrated CIP system, and the procedure was carried out according to the recommendations outlined in the Novoflow operating manual [9]. Per the instructions, a pre-cleaning/rinsing cycle of 10 minutes was performed with potable water followed by a complete drain. The HSRMS then pumped Micro 90 into the membrane chamber for 16 seconds. This specific time interval was used to supply the minimum 1% alkaline concentration in water recommended by Novoflow. During this step, 0.42 gallons of Micro-90 was injected into the membrane chamber, and the remaining

volume was then filled with approximately 43 gallons of potable water. The HSRMS subsequently performed a cleaning cycle with the membrane contents being circulated for 90 minutes and backflushes being conducted every 10 minutes; no additional water or chemicals were added during this step. Following the cleaning cycle, the system conducted a complete drain, a final rinse for 10 minutes using potable water, and then a final membrane discharge.

Prior to conducting the cleaning procedure, the HSRMS demonstrated a resistance of 0.42 psi/gfd. After the micro-dosing was completed, the system demonstrated a resistance of 0.26 psi/gfd. There was a partial improvement to effluent flow rate as a result of the cleaning, but the membranes were not restored to near-initial conditions. In comparison, Membrane Regeneration #1 resulted in the system being able to produce a membrane resistance of only 0.17 psi/gfd. The remainder of the laboratory evaluation was therefore conducted with full regeneration procedures in order to restore the membranes to the fullest extent practicable.

Full Scale Chemical Cleaning Tests

Overall, the chemical cleanings were considered effective for restoring membrane performance and extending system availability. Figure 62 includes photos of the system prior to the first micro-dosing membrane regeneration procedure. The membranes were discolored from processing the oily water mixtures (Figure 62a and 62b), but the fouling was not visibly severe and there was no gross contamination to the system. Most of the oil contamination was concentrated at the inner portion of the membranes where the shear forces were weakest. The clamping ring at the top of the shaft (Figure 62c) was tarnished by oil contamination, but there was no rust or any corrosion to the stainless steel components. In the Figure 62d, the lower spring seal was in good condition, and some of the dust from the non-degradation tests had settled at the bottom of the membrane chamber.

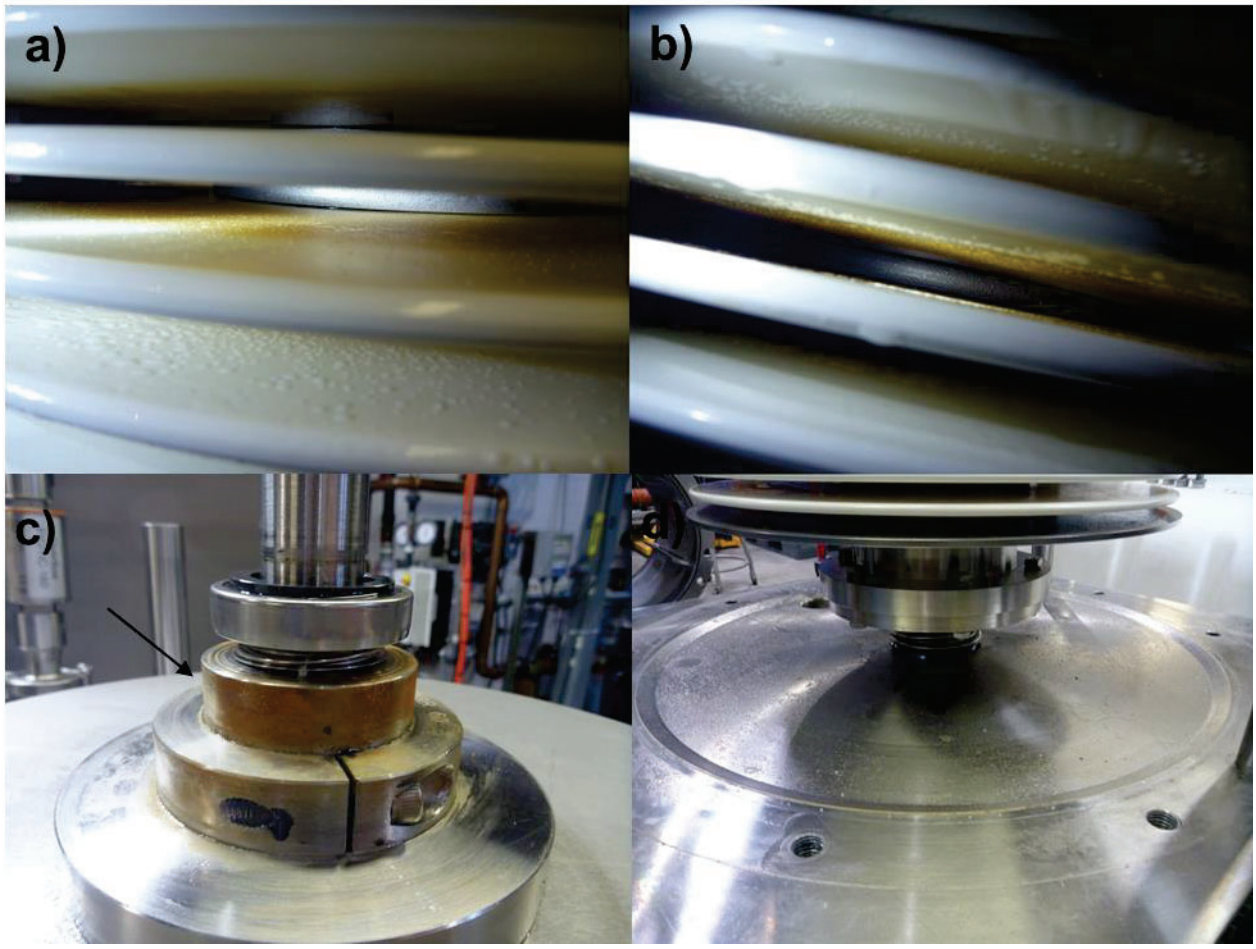


Figure 62. Membrane Inspection - Prior to Microdosing and Full Membrane Regeneration

Figure 63 includes photos of the system following the first full membrane regeneration procedure. While there was still a very slight tarnish at the inner portion of the membranes, the overall conditions of the membranes were greatly improved. The outer portions of the membranes were clear and free of contaminants, and rubbing cloth against the surface did not reveal any remaining oil or grime. Most of the dust particles that had settled at the bottom of the membrane chamber had been cleared away, and the remaining bits of dust were negligible.

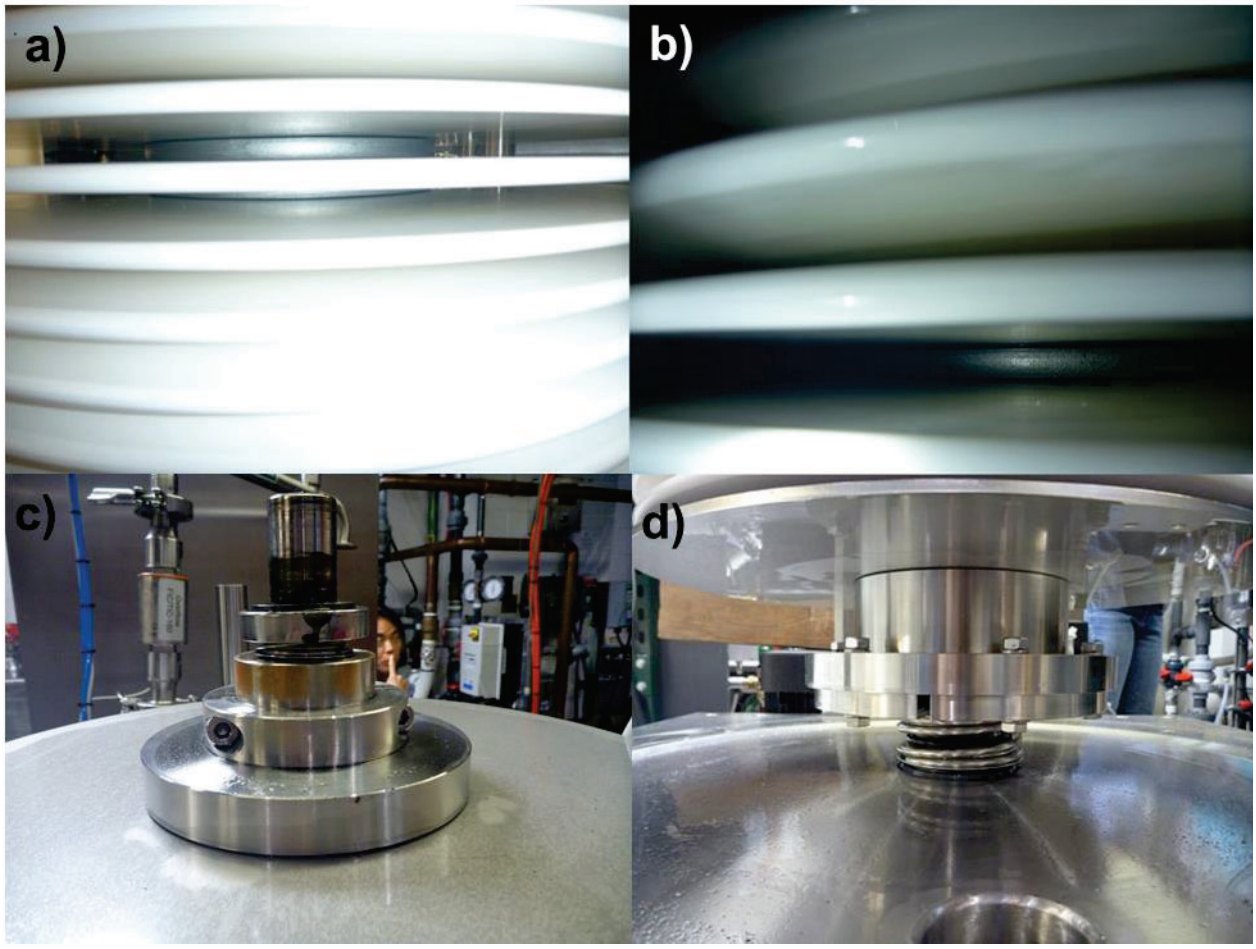


Figure 63. Membrane Inspection - Following Membrane Regeneration #1

The HSRMS required full membrane regenerations on two occasions throughout the entire evaluation. The test plan originally required a regeneration procedure once the system reached a TMP of 2.0 bar (29.0 psi), but this qualifier was modified once the manufacturer confirmed that the system automatically regulated system pressure and could be safely operated at 3.0 bar (43.5 psi); this being the maximum backflush pump pressure rather than any indication of membrane fouling. The first chemical cleaning was conducted following 212 hours of oil and detergent reliability testing after the TD-107 OCM consistently indicated high level alarms and recirculated the effluent. These high level alarms were later confirmed by the laboratory analyses to be erroneous since no oil content was detected, but the processing capacity of the system was also nearly low enough to warrant a cleaning procedure. The second full membrane regeneration was conducted following 147 hours of performance testing when the system indicated a low flow rate alarm and surpassed the 100% resistance parameter; the last reading taken indicated a resistance of 1.83 psi/gfd (123% resistance). Two additional, nonessential chemical cleanings were conducted at the end of the evaluation to compare the effectiveness of cleanings with or without heat added to the system.

The membrane regenerations were able to restore the processing capacity of the system to the initial flow rate of 8.5 gpm (inclusive of flow rate losses from the OCMs and the membrane overflow valve), but the TMP could not be fully restored to the lower levels observed at the start

of the evaluation. During the initial tests with potable water (prior to any oil or contaminant injection), the system was able to achieve a processing capacity of 8.5 gpm with a TMP of 13.34 psi or a resistance of 0.12 psi/gfd. However, following Full Membrane Regeneration #1, #2, #3 and #4, the system demonstrated resistances of 0.17 psi/gfd, 0.18 psi/gfd, 0.28 psi/gfd, and 0.20 psi/gfd, respectively. Resistance following Membrane Regeneration #3 was significantly higher than the other regenerations because it was performed without heat. The increasing membrane resistances following Membrane Regeneration #1, #2, and #4 indicates the buildup of nonreversible fouling. However, the cleanings were still sufficient in restoring the membranes to achieve an acceptable processing capacity, and there was not a need to replace the entire membrane stack as a result of the regeneration procedures.

Impact of Heat

Membrane Regenerations #1, 2 and 4 utilized heat and produced varying results with cleaning efficiency of 64.5%, 96.5%, and 50.1%; respectively. However, membrane regenerations #1 and 4 followed previous regeneration procedures which impacted the regeneration effectiveness. Therefore, only Membrane Regeneration #2 was used to determine the impact of heat on cleaning effectiveness. For Membrane Regeneration #3, a cleaning efficiency of 73.4% was observed. Thus, the data indicates the application of heat has a positive impact on membrane regeneration. Figure 64 shows the application of heat membrane regenerations #1-4. For Membrane Regenerations #3, the system temperature initially started at 74 °F but increased over time due to the kinetic energy imparted by the feed pump and rotating membranes. Despite the fluid being recirculated and the system retaining a portion of the heat generated, the system temperature remained well-below 120 °F (i.e. temperature during Membrane Regenerations #1, #2, and #4), achieving a maximum temperature of 104 °F. Membrane Regeneration #4 immediately followed Membrane Regeneration #3 and used heat. For Membrane Regeneration #4, the processing capacity was restored to 0.20 psi/gfd.

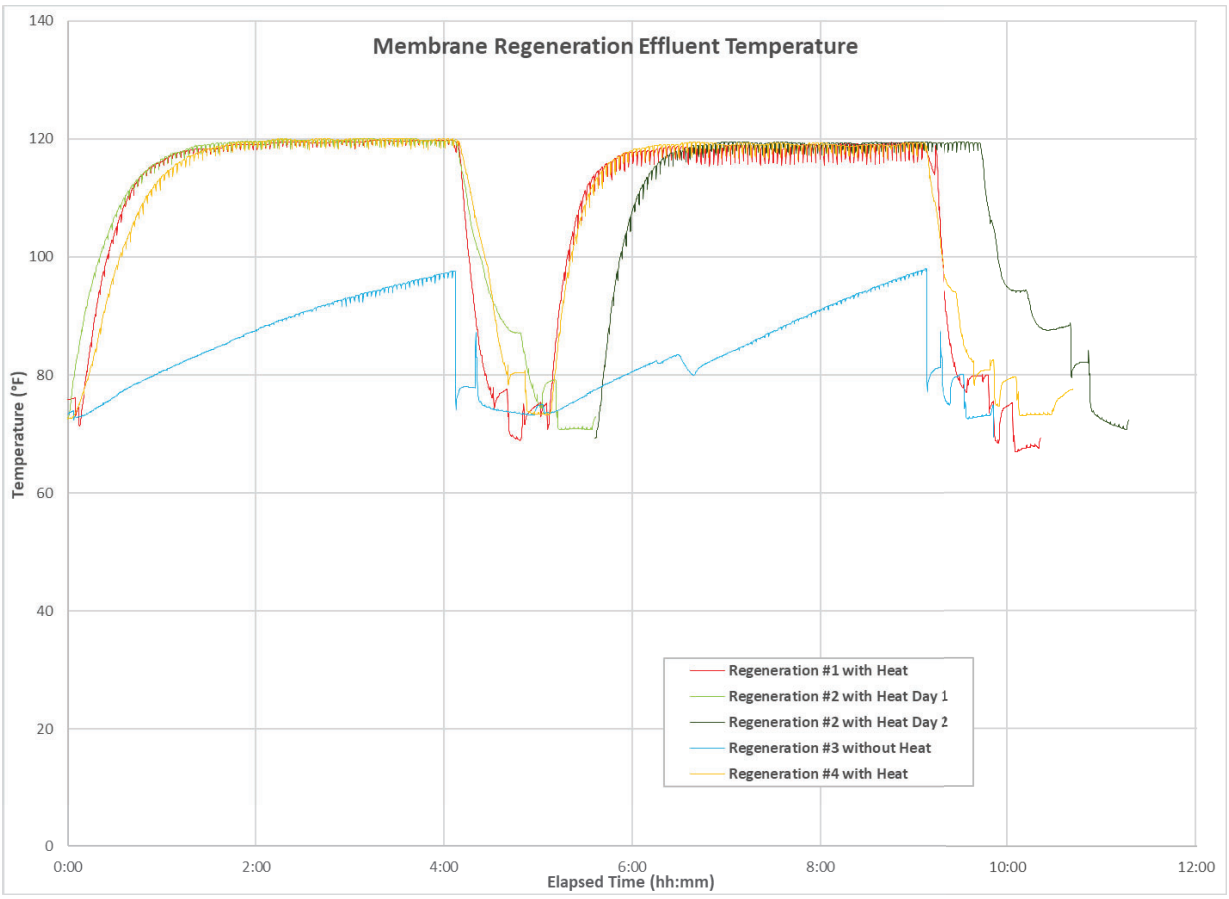


Figure 64. Membrane Regeneration Effluent Temperature

Membrane Regeneration Waste

The waste generated from the membrane regeneration procedures include the alkaline and acid solutions that were circulated through the system, the potable water used to flush the system, and any fouling that was removed from membranes. An amount of 80 gallons of alkaline solution and 80 gallons of acid solution was discharged to the USTs by the end of each procedure. 80 to 200 gallons of potable water was also used to flush the system after each cleaning phase and was sent to the USTs for disposal. The cleaning tank also needed to be rinsed before and after any solution was added, which accounted for an additional 40 to 100 gallons of waste. Altogether, each cleaning procedure produced a range of approximately 400 to 700 gallons of waste for disposal.

Waste disposal was not an issue for the laboratory configuration, but this becomes a potential drawback for shipboard configurations. The cleaning waste should not be discharged to an OWHT to avoid reintroducing the same contaminants back into the HSRMS and should not be directed to a WOT since the waste was composed of mostly water. Therefore, membrane regenerations would be limited to times that a ship is in port. Although the fact that the cleaning agents are non-hazardous is a benefit (i.e. environmentally-friendly, Micro-90 and citric acid, Mirco-A07), proper disposal should be investigated for future shipboard demonstration.

Reliability, Maintainability, and Availability

Reliability

System reliability was calculated in terms of the MTBF test metric. The success criteria for the reliability portion of this evaluation was to achieve a 400-hour MTBF with a 90% confidence level [6]. In order to achieve this level of confidence, the HSRMS must not experience a "relevant critical" or "relevant major" operational failure during 922 hours of operation. During the laboratory evaluation, the HSRMS operated for a total of 959 hours with zero "relevant critical failures" and zero "relevant major failures", thereby satisfying the MTBF acceptance criteria. The failures that did occur include the following:

- One "relevant minor failure" occurred after 50 hours of operation due to a manufacturing defect. The counter bearing bush was manufactured with insufficient clearance causing the mechanical seals to press too tightly together and erode. The system did not lose the capability to process oily waste, and the redesigned component addressed future concerns regarding this failure.
- One "non-relevant major failure" occurred after 874 hours of operation due to operator/procedural error. The mechanical seal was chipped and allowed the ball bearings in the counter bearing to corrode. The failure is suspected to have occurred during disassembly of the membrane which is not part of the manufacturer's scheduled maintenance.
- Two "non-relevant minor failures" resulted from damaged fittings. A metric bite-type fitting was damaged while disassembling the membrane and had to be replaced with an equivalent fitting. The leakage indicator port on the cover plate also cracked and was replaced with a redesigned port sent by the manufacturer. These events were readily addressed and did not impact system operations.
- Several "non-relevant minor failures" resulted from the HSRMS sensors returning false readings. Throughout the evaluation, sensor attachments and air supply tubing came loose by inadvertent contact, usually while disassembling the membrane. The system failed to detect these inconsistencies and operated without actually opening or closing the valves. There was also one instance of the level sensor being unable to detect a full membrane chamber due to oil obstruction from the OWHT transition test. These issues only caused a short pause in testing and were addressed by operators within seconds or minutes.

Maintainability

For maintainability portion of the evaluation, the HSRMS was able to meet most of the success criteria. MTTR was determined to be 1 hour which was well below the 3.5-hour limit defined by the success criteria. The maximum TTR was 1.5 hours, which was also below the 8-hour limit. In addition, the maximum preventative maintenance action was 11.3 hours, which was below the 16-hour requirement. However, the HSRMS failed to meet the maintenance ratio and weekly preventative maintenance requirements. This was due to system rinses performed at the end of each production cycle and unnecessary membrane regenerations for testing the impact of heat of membrane recovery. It is expected that the maintenance ratio and weekly preventative maintenance will meet the success criteria under shipboard operation where the membranes will only be regenerated when required.

The MLDT was not considered an OWS success criteria and was determined for informational purposes only. A total of 4 separate requests for parts were sent to Novoflow throughout the evaluation. On average, each part required 11.3 calendar days to arrive. The manufacturer was readily available for troubleshooting via e-mail or teleconference and had a very short response time for inquiries. All requests were quickly approved and coordinated by the manufacturer, but the lead-times for parts were lengthy due to the need for overseas shipping from Germany.

Preventative Maintenance

Most of the manufacturer's recommended maintenance activities involved periodic inspections for leaks, correct operation, and proper pressures and temperatures; these minor tasks were accomplished in tandem with testing and were inherently addressed when operating the system. Significant maintenance tasks such as membrane cleaning procedures, membrane vessel disassembly, and component repairs were documented in the "Maintenance Log Sheets" included in Appendix F.

The most time-consuming preventative maintenance activity was the regeneration of the membranes. Of the 959 operating hours, 43 hours were dedicated to membrane regeneration procedures. The longest membrane regeneration required 11.3 hours to complete, but the procedures were not labor-intensive. Operators were only required to prepare the cleaning mixtures, operate the HSRMS production cycle as usual, and gradually raise and lower the system temperature within the recommended rate ($\leq$ 5.2 °F/minute) using the heat exchanger; no disassembly or manual cleaning of the internal components was necessary. The manufacturer recommended refraining from temperature changes of more than 5.2 °F/min to avoid cracking the ceramic membranes. The HSRMS manufacturer stated that if the unit was filled with building potable water, adding 120°F water for cleaning should not exceed a temperature change of more than 5.2 °F/min; however, preliminary testing showed change of temperature change of 4.0 °F/min when even adding 70-100°F water directly to the system under normal operating conditions. As a precaution, the water was slowly heated as it was added to the HSRMS at 2.9 °F/min. The HSRMS accommodated the use of non-hazardous, non-corrosive cleaners (i.e. Micro-90 and Micro-A07) which were effective in restoring the system's processing capacity and partially restoring the TMP. There were no significant safety hazards posed to operators, and the only major concern was potentially shocking the membranes with a dramatic temperature change (e.g. flowing cold potable water into an empty system still at 120 °F).

The second most time-consuming preventative maintenance activity was the potable water flushes following each contaminant test. At the end of a 10-hour test, the injection pump was stopped, a concentrate discharge was initiated, and then a new production cycle with potable water was initiated. Once the OCMs displayed 0-ppm, the production cycle was stopped and the system was shut down. On average, these flushing procedures required 33 minutes to complete, accounting for a total of 28 hours of the system's 959 operating hours. Note that "rinsing" can be potentially substituted for a potable water flush; this is a preset command on the system that fills the membrane chamber with potable water, spins the membranes for 10 minutes without producing filtrate, then discharges the contents. This option could be considered as an alternative for reducing water consumption and man-hours but needs to be explored further.

The system was also disassembled on five occasions to visually inspect the membranes. These membrane inspections were not part of the manufacturer's recommended maintenance

schedule and were conducted at NSWCCD's own discretion for the purpose of analysis. The inspections were therefore omitted from the RMA calculations. Inspections required two operators to lower and raise the 80 kg (180 lb) membrane housing; although a single operator could potentially accomplish this with appropriate weight handling equipment (e.g. chain fall, crane, pulley, etc.). Each inspection required 2.2 hours (4.4 man-hours) on average. The operating manual contained sufficient instructions for disassembling and reassembling the membrane, although instructions to remove the air supply piping was omitted, but would have been useful.

The pumps, motors, bearings, mechanical seals, and the gear drive only require inspection for wear and damage every 12 months which was outside the time frame of the laboratory evaluation. Novoflow mentioned that the gear drive would need to have the oil replaced after 3,000 hours of operations or within 2 years, whichever occurs first. The mechanical seals also need to be serviced once a year.

As specified in the OPA Design and Installation Requirements, the maintenance ratio should not exceed 0.03 to satisfy the evaluation metric [5]. A total of 71 hours of preventative maintenance and 2 hours of corrective maintenance was performed over the 959 hours of operation. This equates to a maintenance ratio of 0.08 which fails to satisfy the evaluation metric. If the non-essential membrane regenerations are omitted from the equation (i.e. the two cleanings at the end of the evaluation), then the maintenance ratio calculates to 0.05, which is still unsatisfactory.

The preventative maintenance actions should not have exceeded 3.5 hours per week to satisfy the evaluation metric. With a total of 71 hours of preventative maintenance performed over 98 days of tests, the average preventative maintenance equates to 5.1 hours per week (if operating 7 days a week). Omitting the non-essential membrane regenerations reduces the weekly average to 3.6 hours, which still fails to satisfy the evaluation metric.

The maximum time to perform a preventative maintenance action should not have exceeded 16 man-hours to satisfy the evaluation metric. The longest preventative maintenance action performed during the evaluation was a chemical cleaning procedure lasting 11.3 hours. Only a single operator was required to prepare the cleaning mixtures and monitor the system at any given time. The time required to perform the maintenance action therefore equates to 11.3 man-hours, which satisfies the evaluation metric.

Corrective Maintenance

There were two corrective repairs performed during the evaluation, both of which involved the upper counter bearing and its corresponding mechanical seal. As a brief overview of the components, the membrane shaft is held in place by the upper counter bearing which houses the hardened steel ball bearings. These ball bearings are covered by a silicon-carbide seal that prevents the contaminants from coming into contact with the bearings. The seal is set against a matching spring-loaded silicon-carbide seal mounted on the shaft. This mechanical seal interface prevents contaminants from seeping into the bearing chamber and allows the seals to spin freely once they are lubricated with the working fluids. Figure 65 includes photos of an unused counter bearing (left) with its mechanical seal inserted (right), and Figure 66 includes photo of the matching spring-loaded seal (left) mounted on the shaft (right). The silicon-carbide seals have a smooth, uniform surface with no scoring or scuff marks.



Figure 65. Upper Counter Bearing (left) and installed silicon-carbide seal (right)



Figure 66. Matching Spring-Loaded Silicon-Carbide Seal (left) and Mounted Seal (right)

Corrective Action #1

After 50 hours of potable water tests, the plastic tubing attached to the top of the system began to trickle grease. This tubing is the counter bearing leakage indicator (Figure 67) which indicates when the seal is compromised. No warnings or alarms were issued by the PLC, and system performance did not appear to be negatively impacted at the time. This issue was discussed with Novoflow engineers during the system commissioning and were informed that this was a sign of damage to the component. Novoflow engineers then disassembled and removed the counter bearing cover to determine the source of the leakage. Upon inspection, the upper seal was found to be visibly scored across the surface and the lower seal was greatly deformed; see Figure 68. The damaged seals allowed water to enter the ball bearing chamber and

subsequently pushed the bearing grease out through the leakage indicator. The engineers later determined that the counter bearing bush was manufactured with insufficient clearance causing the seals to press too tightly against each other. With the bearing bush being manufactured 2 mm too long, the spring tension in the lower seal became too high. The increased pressure between the seals then led to them eroding one another during system operations.



Figure 67. Counter bearing leakage indicator

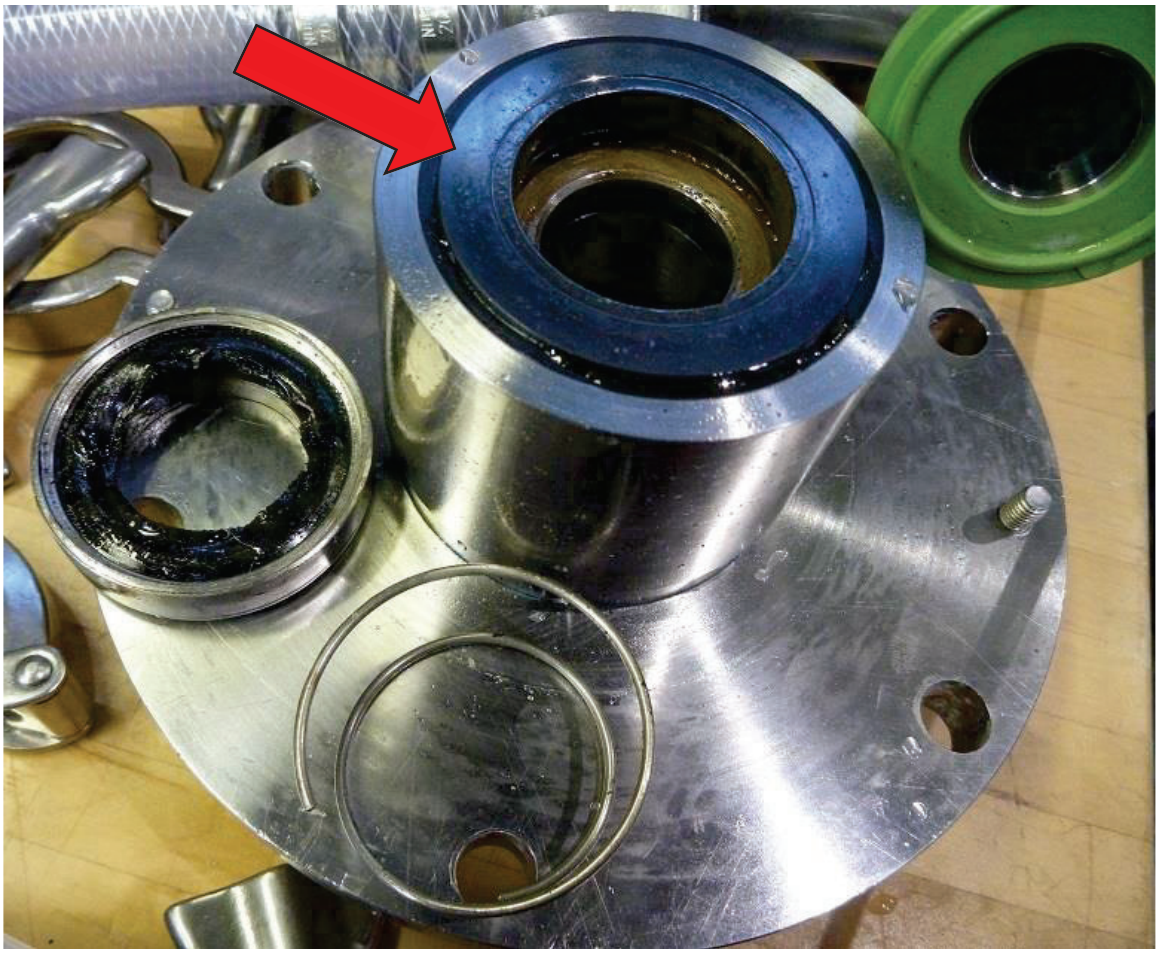


Figure 68. Damaged Counter Bearing Seals

The Novoflow engineers indicated they would redesign and manufacture a new counter bearing to replace the defective component. The system could still be operated with water or oil while waiting for the new component, but the mechanical seal would have to be removed to avoid breaking apart in the membrane, and neither solids nor detergents could be allowed into the system. Testing was therefore continued with potable water in the interim, and the failure was classified as a "relevant minor failure". Once the new counter bearing was received 10 calendar days later, only 30 minutes was needed to unbolt the defective counter bearing and install the replacement. The installation was expedited due to the manufacturer sending an entirely new assembly attached to a new cover plate; the ball bearings arrived pre-greased, and the mechanical seal was preinstalled. The installation was uncomplicated and the manufacturer offered sufficient instructions through their correspondences. However, there were no instructions in the operating manual or other documents for how to deal with a damaged seal. Furthermore, the documents did not cover the purpose of the leakage indicator; the operators had to contact the manufacturer directly to inquire why grease was leaking from the tubing.

Corrective Action #2

After operating the system for 874 hours without experiencing any notable failures, a visual inspection of the membranes was conducted as a follow-up to the OWHT transition test. During the inspection, it was discovered that a piece of the upper mechanical seal had chipped

off; see Figure 69. The leakage indicator did not discharge any grease during testing, so the damage was determined to have occurred during disassembly of the membrane when the operator mistakenly unbolted the counter bearing cover while the membrane stack was in the horizontal position. The weight of the membrane stack prevented the cover from being removed, so the operator returned the membrane stack to the upright position to remove the cover. The seal likely chipped as a result of the cover being unbolted horizontally, or the seal may have been dropped a short distance while the membrane was returned to the upright position. The manufacturer mentioned that the silicon-carbide material is brittle and prone to damage from shock impact.

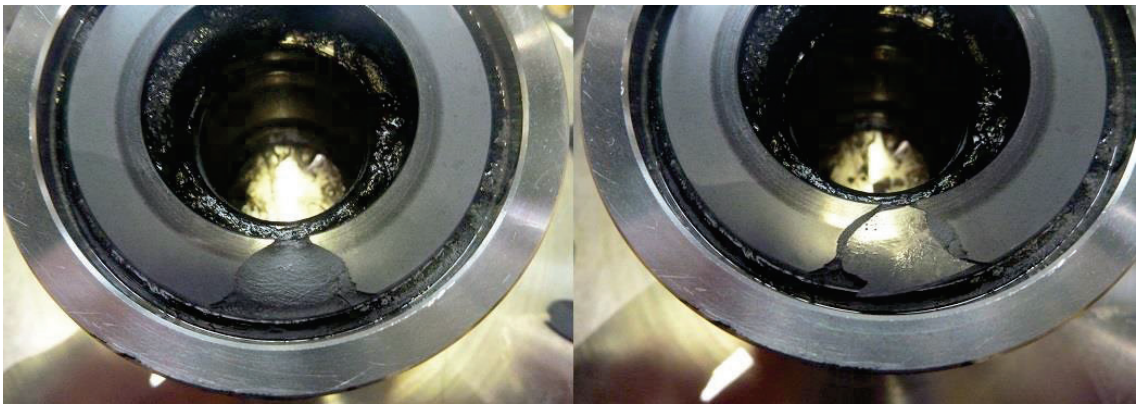


Figure 69. Chipped Counter Bearing Seal

The manufacturer was contacted, and a new mechanical seal arrived 9 calendar days later. However, when the damaged seal was removed to install the replacement, the operator discovered that the ball bearings had become corroded and seized in place; see Figure 70. The bearings are prone to rust due to being hardened steel (i.e. not stainless). The direct source of the corrosion could not be identified; however, this corrosion was attributed to the previously cracked mechanical seal. Water which seeped through the cracked seal or exposure to ambient air could during disassembly could have both led to the formation of rust on the ball bearing. The manufacturer recommended power-washing the bearings and replacing the grease. The cleaned bearings revealed that they were thoroughly rusted and unsalvageable; see Figure 70.



Figure 70. Corroded Ball Bearings before (left) and after (right) Cleaning

Novoflow then manufactured a replacement bearing which was received 13 calendar days later. The operator spent 90 minutes installing the new counter bearing and the corresponding seals. The longer repair duration was attributed to the labor needed to install the new bush, apply grease to the components, and mount the seals onto the counter bearing and shaft. Due to the failure being attributed to operator/procedural error and causing the system to become inoperable, the failure was classified as a "non-relevant major failure".

Potential Repairs

Other potential repair procedures were presented by the manufacturer but were not experienced during the evaluation. Novoflow gave specific instructions for how to disassemble the membrane stack to replace damaged disks or to access the gear drive for repairs. Membrane stack removal/replacement was not performed since the initial set of membranes did not require replacement throughout the entire evaluation.

The MTTR did not exceed 3.5 hours to satisfy the evaluation metric. A total of 2 hours of corrective maintenance was performed for 2 major repair procedures equating to a satisfactory MTTR of 1 hour. Note that any minor repairs requiring only a few minutes to address (e.g. reattaching a sensor or replacing a non-critical fitting) were omitted from the MTTR calculation.

The Max TTR did not exceed 8 hours for any single corrective maintenance procedure. The longest repair activity took 1.5 hours to perform, thereby satisfying the Max TTR requirement.

Availability

The availability of the system was required to meet or exceed 95% to satisfy the evaluation metric. There was a lengthy downtime due to the "non-relevant major failure" involving the chipped mechanical seal caused by operator/procedural error. If this downtime is omitted from the calculation, then the system had an uptime of 158 calendar days and a downtime of 5 calendar days equating to a satisfactory availability of 97%. If the downtime caused by the failure is instead included, then the system had a downtime of 61 days equating to an unsatisfactory availability of 72%. Given the circumstances of the non-relevant failure, 97% is the more appropriate metric to assign to the HSRMS.

Operability

Training time, operating time, and operator skill level were used to evaluate operability of the system. During the laboratory evaluation, operators had no issues learning the operation of the system. They were able to follow operation instructions and maintenance guidance from the technical manual provided by the OEM. In addition, the operators found the HMI intuitive and easy to use. Operators reported the complexity of system as "similar to other oil water separators". However, it is important to note that laboratory operators were dedicated and vested interest in the operation of the system, ships force may have a different comfort level with the operability.

Shipboard Testing Results

System Performance

The Novoflow HSRMS was installed and operated as the primary OWS on the USNS Matthew Perry (T-AKE-9) from July 2021 to March 2022. The system was powered for a total

of 112 hours during the evaluation with 35 total hours in production mode, of which 33 hours while underway. The system treated a total of 7,963 gallons while underway giving an average processing rate of 4.0 gpm; similar to the processing rate observed during the laboratory investigation. The effluent oil concentration was below regulatory limits (15 ppm) for the full shipboard evaluation. The MEPC.107(49) approved commercial-off-the-shelf (COTS) oil content monitor (OCM), Turner TD-107 OCM, had no high alarms and made the decision to discharge 100% of the time. Alarms from the US Navy approved OCM, ET-35N, were not recorded during the evaluation due to issues with the shipboard data logger; however, the oil concentration never exceeded 3 ppm. Overall, the system was able to process machinery space bilgewater under shipboard conditions and produce high quality effluent.

Processing rate

The average processing rate for the shipboard evaluation was 4.0 gpm. Changes in influent, effluent, and overflow flowrates are shown in Figure 71. The first two hours of operation were used to prime the influent line and troubleshoot integration issues and are not shown in the data. A full data set can be found in Appendix L. From 2.0 to 3.1 hours, the system was operated in port during commissioning and ABS approval. All other hours on the system were operated while underway. Figure 71 shows the system was operated for 8 productions cycles while underway, each between 2 and 6 hours in duration. Processing rate was highest at the beginning of each production cycle then decreased until it reached an equilibrium, typically around 4 gpm. This initial loss of processing rate was attributed to oil concentrating in the membrane housing rather than permanent membrane fouling.

After 26 hours of operation, the overflow rate decreased to 0 gpm. Based on data from the HSRMS and correspondence from ship's force, this was believed to be due to a closed valve between the overflow line and the Machinery Oily Waste Tank (MOWT). There were two valves on the overflow line that could have been closed and were never reopened, one near the cleaning tank and one near the MOWT. The obstructed overflow after 26 hours indicates the system would concentrate oil and other containments in the membrane housing, rather than recirculating it back to the MOWT; thus leading to more rapid membrane fouling.

In addition, the influent flow, effluent flow, and overflow does not balance after 26 hours. This coincides with ship's force attempting to redirect the discharge from the OCMs back to the cleaning tank to be processed by the HSRMS. If ship's force used the rinse feed to redirect the OCMs' discharge, then the OCM discharge would not be recorded by the influent flow meter. A faulty influent sensor could also explain the difference between the influent and effluent flows but this seems unlikely considering the data. For example, the influent flow follows the same trend as the effluent flow. Also, the strainer between the influent flow meter and the HSRMS was cleaned after 32 hours, which explains the increase in influent flowrate.

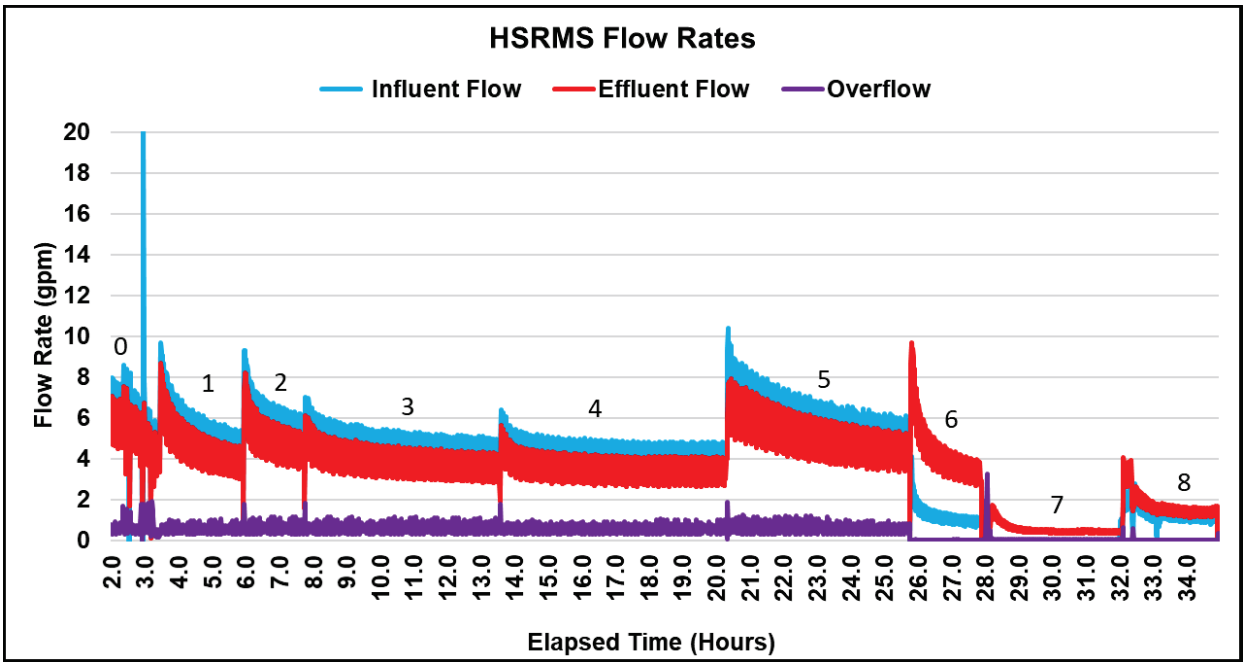


Figure 71. HSRMS Flow Rates over Elapsed Time in Production Mode during the Shipboard Demonstration

Effluent quality

Performance success criteria was defined as more than 95% of the OWS effluent samples having less than or equal to 15 ppm oil in water and all OWS effluent samples containing concentrations of less than or equal to 100 ppm oil in water. Two OCMs (Turner Designs Model TD-107 and Admartec Model ET-35N) were used to continuously monitor effluent when the HSRMS was in operation. The TD-107 OCM is MEPC.107(49)-certified and was used to control overboard discharge. The Admartec ET-35N was installed as a secondary OCM because of its use aboard Armed Forces vessels.

Figure 72 shows the oil content measurements from the Turner TD-107 and Admartec ET-35N over the shipboard evaluation. The Turner TD-107 OCM had no high alarms and made the decision to discharge 100% of the time. The Turner TD-107 recorded regular zero alarms during the HSRMS commissioning; however, the zero alarm does not influence the OCM's decision to discharge. There were no zero alarms during the underway operation of the HSRMS. Alarms from the Admartec ET-35N were not recorded due to issues with the data logger; however, the oil concentration never exceeded 3 ppm.

The ET-35N had no signal during Production Cycle #5 (i.e. at 21-25 hours). It is possible that ship's force turned off the ET-35N since it was not used to control overboard discharge and its discharge contributed to the bilge pockets needing to be emptied. However, this was not mentioned during correspondence with ship's force during the evaluation.

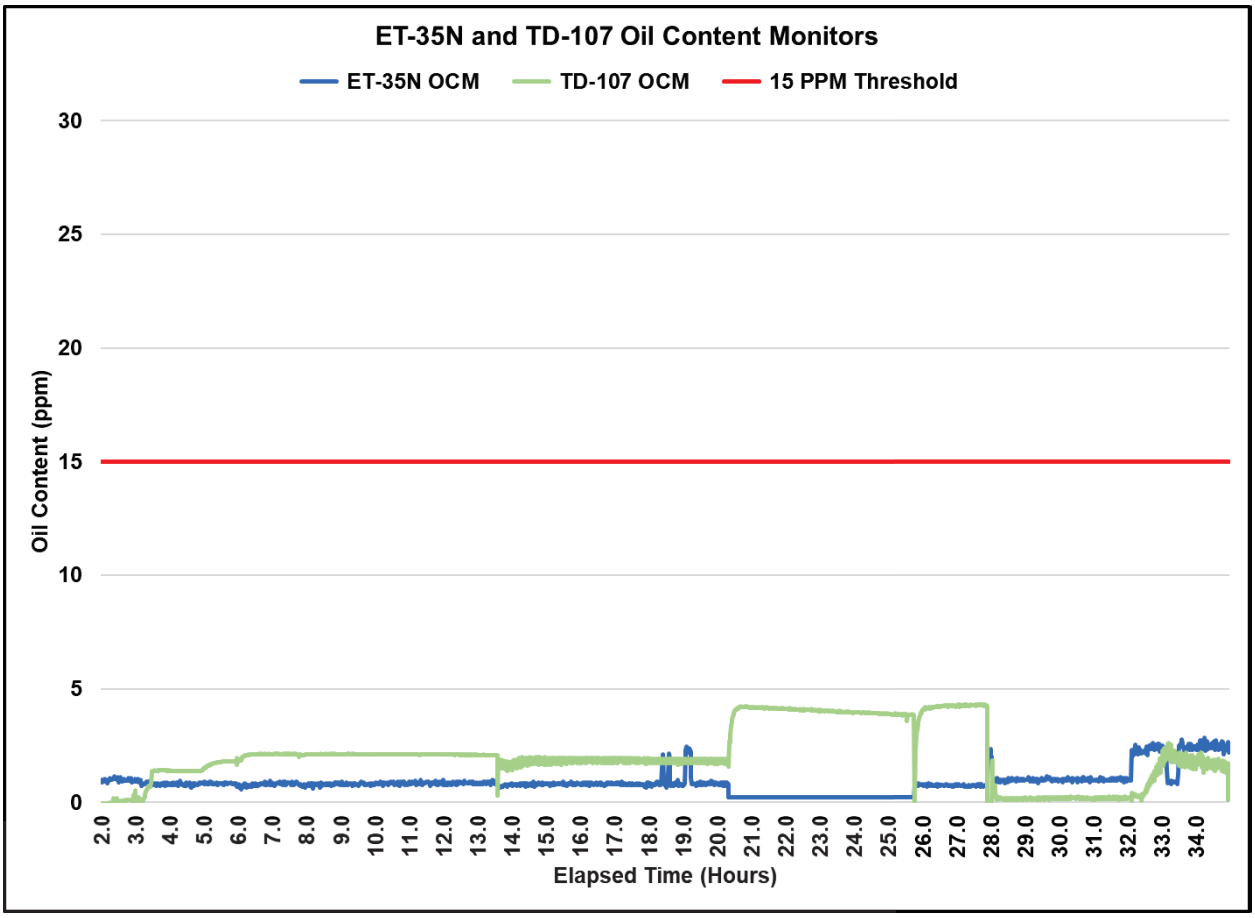


Figure 72. Oil Content Measurements from ET-35N and TD-107 Oil Content Monitors over Elapsed Time in Production Mode during the Shipboard Demonstration

Sensors and alarms

Part of the performance success criteria was that all of the system alarms, indicators, and sensors should function as designed in all operating modes. During the shipboard evaluation, three alarms were recorded. The first alarm was reported by ship's force on 13 August 2021 when the error 'P-110 VFD faulty' and 'P-110 locked' during system start up. The 'P-110 VFD faulty' error was attributed to ship's supply voltage to the HSRMS and function properly. When ship's supply voltage returned to normal, the ship's force was able to start the system. The second was reported by ship's force on 20 October 2021 when the HSRMS failed to start due to a level sensor that was fouled by oil. After the sensor was cleaned, ship's force was able to start the system. The final alarm was reported by ship's force on 04 November 2021, when 'feed pump dry run' alarmed several times, preventing system start up. This alarm was contributed to the LS-L-110 and LS-HH-100 level sensors.

Overall, it was clear that the level sensors used in the Novoflow HSRMS were not designed for oily wastewater. The level sensors prevented the start-up of the system on several occasions during the evaluation. If the HSRMS was to be considered for shipboard oil/water separation, a new level sensor type or level sensor location would need to be considered.

Membrane Life

Per the evaluation's success criteria, the ceramic membranes were expected to reach at least 300 hours of operation prior to cleaning. New membranes were installed before the shipboard evaluation. The transmembrane pressure (TMP) and membrane resistance were recorded to determine the failure mechanism and fouling rate. This was also used to better estimate total life cycle cost, including membrane replacement and maintenance costs.

Figure 73 shows the TMP over the shipboard evaluation. The HSRMS was operated with a max influent pressure of 43.5 psig (3 bar) for the full shipboard evaluation, as recommended by the OEM to prevent pore clogging. The effluent pressure decreased from 10 psig to 9 psig after 26 hours of operation. Likewise, the TMP increased after 26 hours of operation.

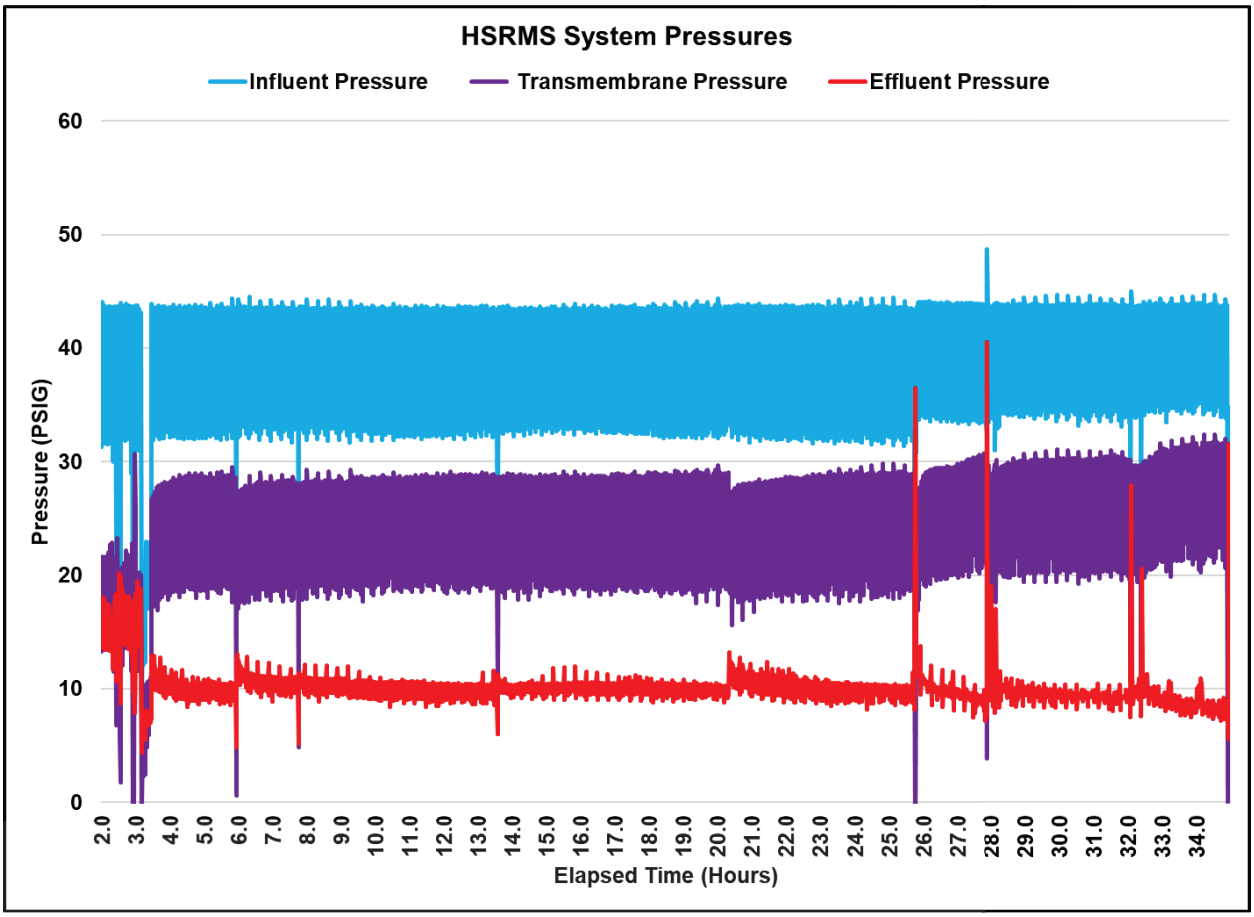


Figure 73. Influent Pressure, Effluent Pressure, and TMP over Elapsed Time in Production Mode during the Shipboard Evaluation

Figure 74 shows the membrane resistance over the shipboard evaluation. Per the test protocol, a membrane regeneration procedure is required once the membranes reach 100% resistance defined at 1.49 psi/gfd @ 68°F. For the first 26 hours of operation, the membrane resistance did not change significantly, remaining below 0.55 psi/gfd @ 68°F. Then during the production cycle following 26 hours, the resistance increased to 0.66 psi/gfd. After 28 hours the membrane resistance exceeded the maximum threshold (1.49 psi/gfd @ 68°F), indicating the need for membrane regeneration or replacement. After 32 hours of operation, the strainer was

cleaned and membrane resistance decreased below the maximum threshold; however, after two more hours of operation, the resistance again exceeded the threshold, indicating the need for regeneration.

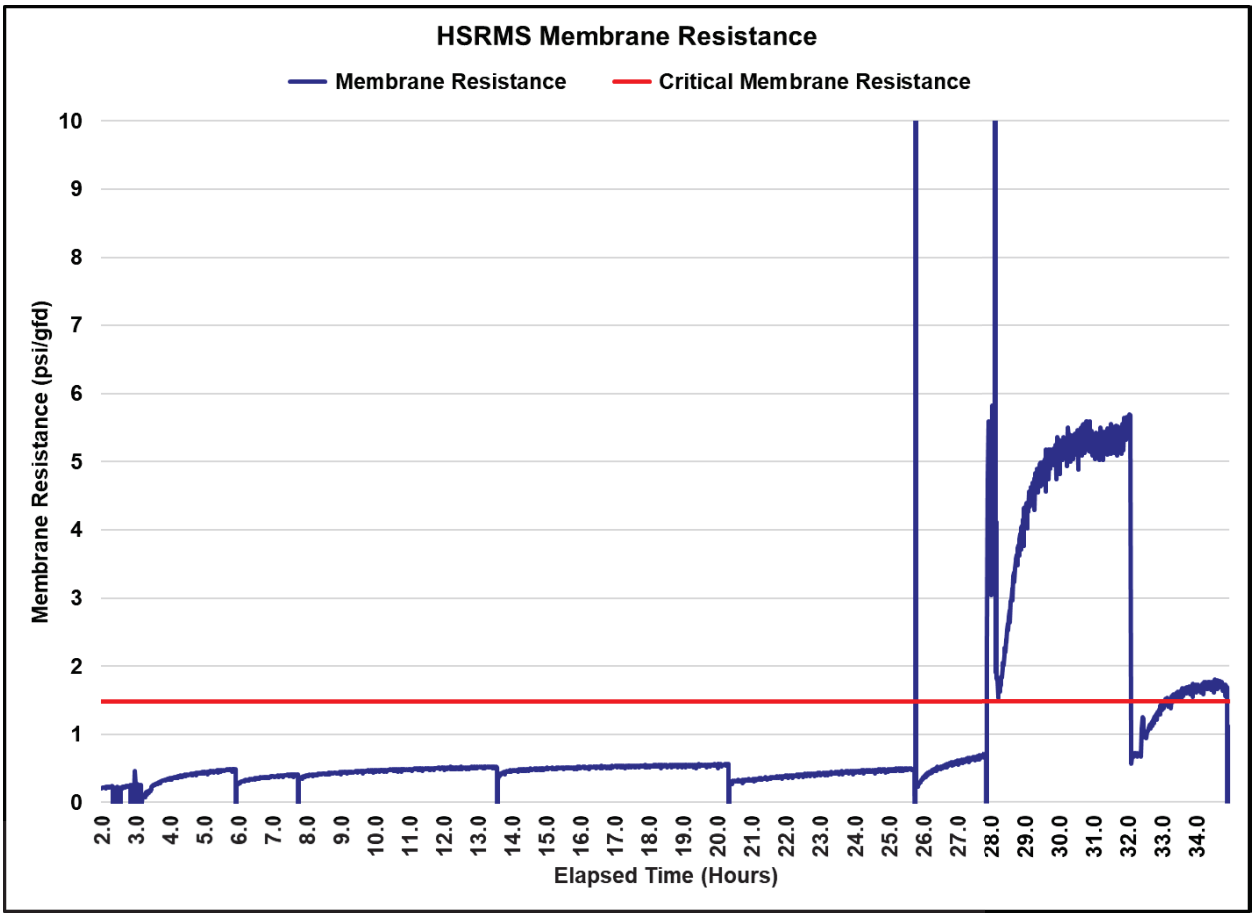


Figure 74. Membrane Resistance over Elapsed Time in Production Mode during the Shipboard Demonstration

While the membrane life did not meet the performance criteria of exceeding 300 hours of operation before requiring a membrane regeneration, the technology did demonstrate a potential improvement over the current Navy membrane system over the first 26 hours. This is significant because, as indicated by Figure 71, the system was being operated as a dead end filtration process which is prone to accelerated fouling. Therefore, only membrane resistance before 26 hours of operation should be considered when evaluating how the system was intended to be operated.

Due to the dead end operation of the system after 26 hours, it is unclear if the HSRMS technology improves the membrane life and performance over the Navy's currently used ceramic membrane systems. However, extrapolating the fouling rate data before 26 hours can give a useful indication of the systems expected performance. Figure 75 shows the upper and lower fouling rates based on Navy ship data of current ceramic oily waste membrane systems [21, 22]. Based on this data, the expected membrane life would be similar to current membrane technologies used by the Navy. Extrapolating to membrane failure, the HSRMS membranes are

expected to last 350 hours, which would meet the evaluation criteria (>300 hours between membrane regenerations).

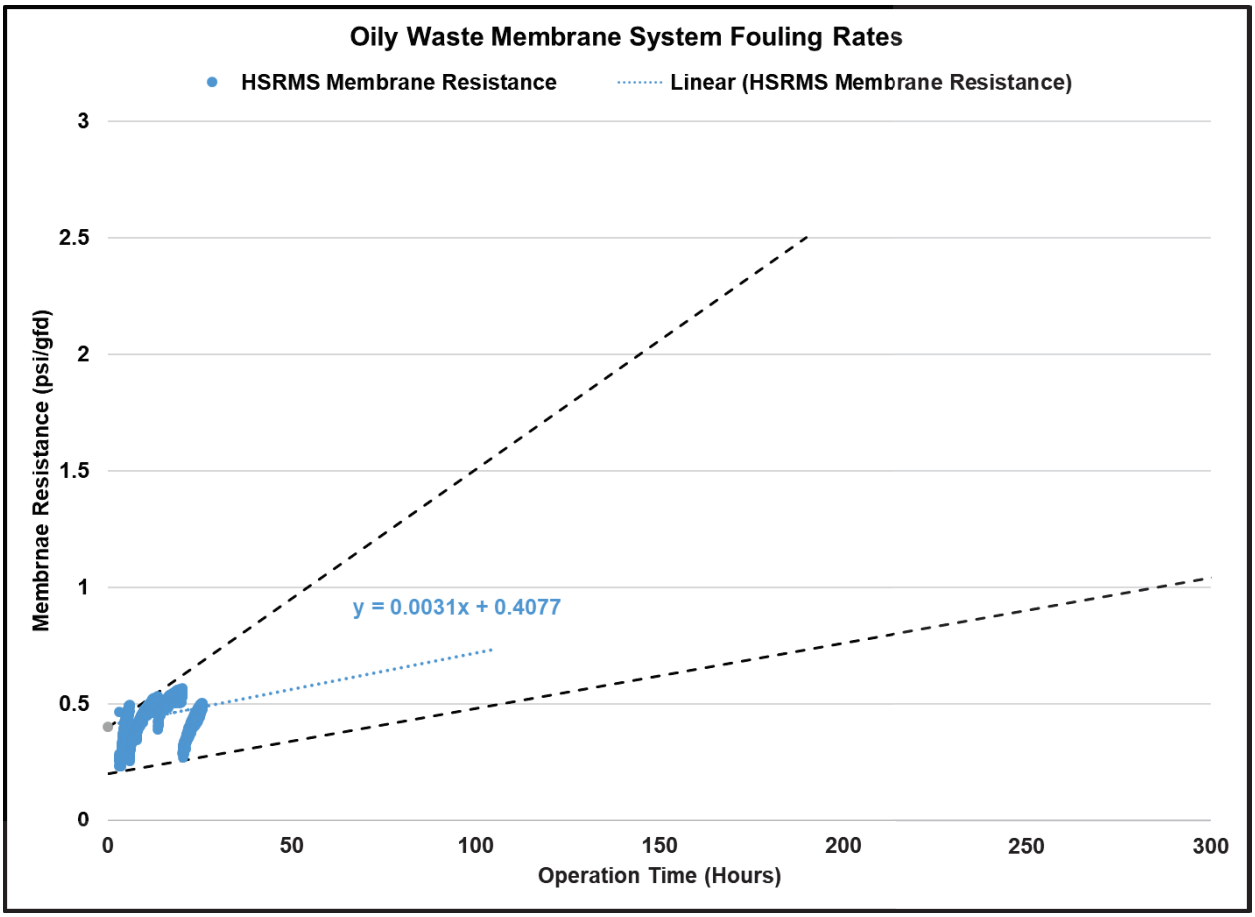


Figure 75. Membrane resistance of Navy shipboard membranes [21, 22] and the HSRMS membranes aboard T-AKE 9

Reliability, Maintainability, and Availability

Reliability

The Novoflow HSRMS was not specifically designed as an oil/water separator or for use on ships; therefore, many of the reliability failures were associated with system design rather than failure of the core HSRMS technology. Likewise, the failures during the shipboard evaluation were different from the laboratory investigation indicating further design is required for integration on ships. Although failures were categorized based on the Novoflow system design, additional discussion on the feasibility for HSRMS technology to be integrated on ships was also evaluated.

Over the shipboard evaluation period, there were one relevant minor failure, one non-relevant major failure, and two non-relevant minor failures.

Relevant minor failure

- On 13 August 2021, ship's force reported the error "P-110 VFD faulty" and "P-110 locked". After consulting with the OEM, it was confirmed the error was due to the ship's

supply voltage outside the tolerance range of the VFD. NSWCCD Code 633 worked with the OEM to provide ship's force with instructions on how to increase the voltage tolerance to prevent future failures. Ship's force reported they were able to "tighten wire connections" to solve the issue. This was classified as a relevant minor failure since the failure prevented the operation of the system but was quickly repaired by ship's force.

Non-relevant major failure

- On 20 October 2021, ship's force reported issues setting the system to production mode. Ship's force was able to confirm the feed pump was filling the membrane housing but the level sensor (LS-HH-100) could not detect the liquid. This was believed to be due to oil fouling the conductivity sensor. Ship's force was able to disassemble and clean the sensor with instructions from NSWCCD Code 633. However, ship's force still needed to open a manual valve on the overflow line to get the level sensor to detect liquid. This indicated the sensor may have not been the problem. On 04 November 2021, ship's force again reported issues getting the system into production mode. They confirmed the level sensor was clean but again needed to manually open the overflow valve to get the level sensor to detect liquid and start production.

  After reviewing the HSRMS data, it is likely that the failure to start production was due to a blockage in the overflow/recirculation line downstream of the HSRMS, possibly a closed valve. After 26 hours of operation, the system overflow decreased from 0.5 gpm to 0.0 gpm. This blockage would not allow the membrane housing to fill properly and enter production mode. Therefore, this was classified as a non-relevant major failure since it prevented the system from being used to process oily wastewater for more than 5 hours, but was attributed to operator or procedural error.

Non-relevant minor failures

- On 27 July 2021, ship's force reported the remote indicator light on the system control panel stopped illuminating, shown in Figure 76, and failed to send a signal to the remote alarm in machinery plant centralized control system (MCCS). The indicator light was used as the relay for the remote alarm; therefore, the remote alarm was no longer functional after the indicator light failed. Ship's force confirmed that the overboard discharge and recirculation valves were properly operating even though the indicator lights were not illuminated. This was classified as a minor non-relevant minor failure since the remote indicator light was not part of the HSRMS and the MCCS alarm was not a requirement, however, useful for observation. Ship's force attempted to use electrical installation drawings to resolve the issue but were unable to correct the problem.

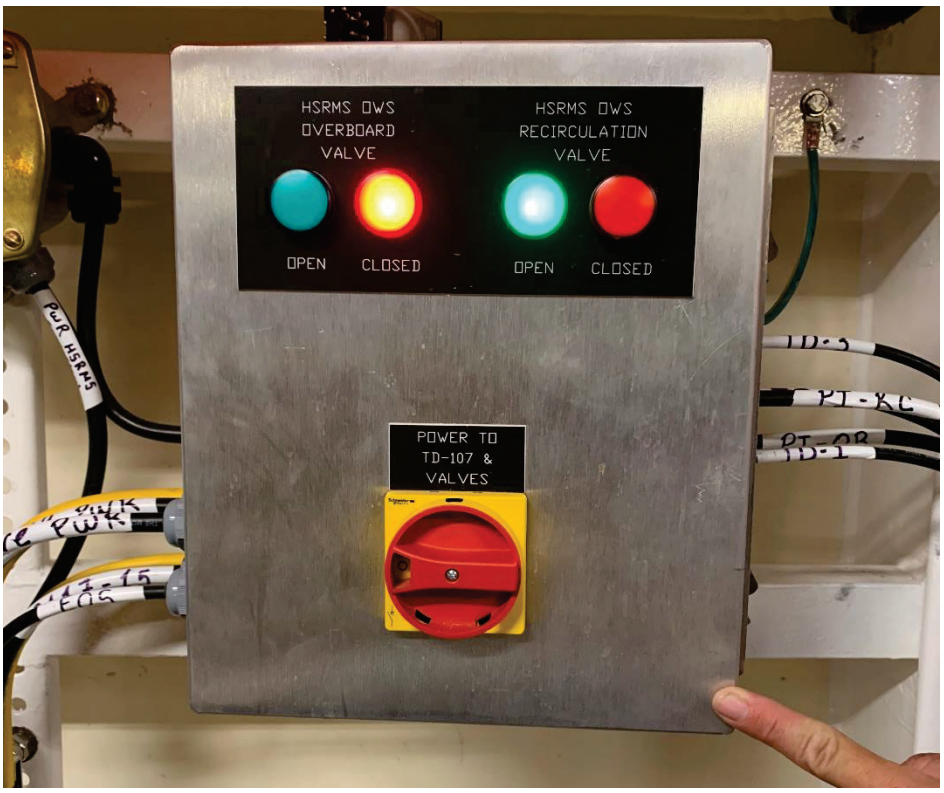


Figure 76. Remote Indicator Lights during installation for the HSRMS Overboard and Recirculation Valves

- On 18 September 2021, ship's force reported "SITOP UPS1600 (-3K1)" module error. This is the uniform power supply for the data logger that was used to back up data in the event of a sudden loss of power. This was classified as a non-relevant minor failure since it did not impact the ability of the HSRMS to operate.

Maintainability

Preventative Maintenance

Ship's force was trained on preventative maintenance requirements prior to the shipboard evaluation of the HSRMS aboard USNS Matthew Perry (T-AKE 9). This included OEM recommended maintenance activities; routine checks for leaks, operation of motors, and checking the mechanical seal leakage indicator. Ship's force was also asked to perform maintenance activities related to the OCMs and emptying the strainer every 30 hours of operation. In addition, ship's force was asked to perform a 1-minute rinse with potable water during every shutdown event. This differed from the laboratory evaluation where the concentrate was discharged and potable water was used to rinse the membranes for 30 minutes during every shutdown.

As specified in the OPA Design and Installation Requirements, the maintenance ratio should not exceed 0.03 to satisfy the evaluation metric [5]. After reviewing HSRMS data and correspondence with ship's force, it was clear that very little time was spent on preventative maintenance. The 1-minute rinses at the end of each production cycle were not performed. The only preventative maintenance action that was conducted by ship's force was cleaning the

strainer after 32 hours of operation. Assuming the strainer cleaning required less than 1 hour, the preventative maintenance ratio was 0.02, which satisfies the maintenance metric. If ship's force rinsed the membrane at the end of each cycle and cleaned the strainer every 30 hours of operation, per instruction, the preventative maintenance ratio would have still been satisfied (0.025). Likewise, criteria for preventative maintenance actions to not exceeded 3.5 hours per week was also met. However, the system was only operated for 35 hours; therefore, it is difficult to determine confidence in meeting the preventative maintenance criteria. Because, the HSRMS was not designed for shipboard applications, maintenance actions with this HSRMS may differ from a ruggedized HSRMS designed for ship use. Therefore, the shipboard preventative maintenance criteria were listed as inconclusive; and it is recommended to evaluate further with a ruggedized shipboard suitable HSRMS system.

Corrective Maintenance

There were two corrective repairs performed during the evaluation. The first was addressing issues related to the VFD. NSWCCD Code 633 worked with the OEM to provide ship's force with instructions on how to increase the voltage tolerance to prevent future failures. Based on the instructions the corrective maintenance time was estimated to be 1 hour. The other corrective maintenance action was cleaning the level sensor (LS-HH-100) after 26 hours of operation. A pre-programmed clean-in-place procedure was implemented to try to clean the sensor, which required approximately 20 minutes to complete. After the clean-in-place failed to clean the sensor, ship's force was asked to clean the sensor manually. This involved disassembling the sensor, cleaning with a rag, then replacing the sensor. This action was estimated to require 2 hours.

There were several success criteria for corrective maintenance. First, the MTTR should not exceed 3.5 hours to satisfy the evaluation metric. A total of 3.25 hours of corrective maintenance was performed for 2 major repair procedures equating to a satisfactory MTTR of 1.6 hours. Second, the Max TTR should not exceed 8 hours for any single corrective maintenance procedure. The longest repair activity required approximately 2 hours to perform, thereby satisfying the Max TTR requirement.

When considering both preventative and corrective maintenance, the maintenance ratio should not exceed 0.03 as specified in the OPA Design and Installation Requirements [5]. Assuming the strainer cleaning required less than 1 hour, and corrective maintenance required 3.25 hours, the preventative maintenance ratio is 0.12, which does not satisfy the maintenance metric.

Operability

Training time and ship's force feedback was used to evaluate operability of the system. During the shipboard evaluation, ship's force was trained by NSWCCD Code 633 during the system installation and had no issues learning the operation of the system. Initial feedback on the system indicated the complexity of the operation was similar to other oil water separators. 1AE Figueroa stated:

> "Operating the system is straight forward. The instructions are clear and also we have trained everyone to be able to use it with no problems in lightoff/shut down. Unattended operation - there is no issue here. If anything.. the only monitoring we have to do is with

> the amount it [OCM discharge] fills up the bilges but that has already been addressed." – 10 August 2021 Email

However, after encountering issues with system start up, which was determined to be caused by a closed valve upstream of the overflow, ship's force was not satisfied with the operation of the system. CHENG Corey wrote:

> "Basically they were not happy with the operation of the HSRMS. It had a very low capacity of production and used a lot of water doing flushes. We have not operated it since I arrived on the ship in November." – 3 March 2022 Email

Since the operability of the system was impacted by a valve that was non-relevant to the system, issues with system start up and water flushes were not considered as part of the operability evaluation. Overall, the system met the operability success criteria of "displays skill level required to operate and maintain equipment".

COST ASSESSMENT

Cost Model

The HSRMS is an effective and efficient shipboard OPA system that satisfies discharge regulations and could significantly reduce operational and maintenance costs. However, many of these costs are unknown and will vary with each mission. Likewise, the costs of installing OPA systems can vary drastically for each platform. Consequently, a formal cost/benefit analysis could not be performed. However, a cost/benefit analysis focused on the cost savings associated with capital, operational, maintenance, and in-port waste oil disposal costs was completed by NSWCCD Code 633 (Table 12). All assumptions and calculations used for the cost assessment are detailed in Appendix L. NSWCCD Code 633 has performed cost analyses in the past, and can provide a more detailed analysis if a ship platform is selected and additional system data is collected throughout the shipboard demonstration.

During the shipboard demonstration, maintenance data was tracked along with installation costs including drawing development, parts procurement, and installation labor and system certification. This enabled a more informed cost estimate for installations aboard non-combatant vessels.

Table 12. Direct and Indirect Costs Used for the Cost Assessment of the Novoflow NCDF-10

Direct Costs		Indirect costs
Start-up	**Operation & Maintenance**	
-System Purchase	-Operation (Labor)	-Wastewater Disposal
-System Design	-Utilities	
-Training	-Maintenance & Parts	

The time period for the cost study was 30 years with a system maximum service life assumed to be 15 years. The baseline technology for comparison is the 10NP oil/water separator (OWS) with the AAE Model 740956 oily waste membrane system (OWMS). The OWS and OWMS are currently deployed on Armed Forces ships, and system, operation, and maintenance costs have been previously documented [23]. The Novoflow system, operation, and maintenance costs were determined from information received from vendors, current labors rates, and results from the laboratory evaluation [23, 24]. Wastewater disposal costs were determined assuming daily bilge generation rates documented by UNDS efforts [26]. Additional assumptions for generation rates incurred in-port versus underway were derived from a previous cost analysis comparing existing to upgraded OWSs [27]. Table 13 shows the assumptions used for bilgewater generation and disposal costs based on platforms requiring systems less than 10 gpm processing rate (FFG-56).

Table 13. Average Bilgewater Generation and Disposal

Bilgewater Generation Parameter	Value

In-port (gal/day)	63
Underway (gal/day)	250
% in-port	45%
% underway	55%
Disposal Cost per gal	$ 0.24
[+]Annual Bilgewater Generation (Underway) (gals)	50,188
[+]Annual Bilgewater Generation (In-port) (gals)	10,266

[+]Based on daily bilgewater generation rate for FFG-56 of 250 gal/day

The start-up cost was calculated for the baseline and alternative. This incorporates costs associated with the system purchase, design, and training. Platform dependent initial costs, like integrated logistics support (ILS) were not compared. Operating costs including training of operators, the labor to operate equipment, and utilities cost were assumed to be equivalent between the baseline and alternative technology (i.e. HSRMS). The cost of labor was based on a previous study and includes 2% yearly compounding inflation to present [23] Cost associated with membrane regeneration and replacement were based on results from a previous study, estimated life of existing ceramic membranes [23], and the HSRMS laboratory evaluation for comparison, where a membrane regeneration is estimated to be required for every 300 hours of operation, or one regeneration per year. Replacement of parts, and consumables were estimated based on parts manufacturer's recommended life. Table 14 shows the estimated cost and frequency of each various parts for the Novoflow NCDF-10.

Table 14. Parts and Maintenance Cost for HSRMS

Item Name	Specification /Part NO.	Vendor	Frequency in 30 Year Lifecycle	Total per Event	Item Cost (Each)	Hours/ Event	Labor Cost/Event
OWMS	NCDF-10	Novoflow	2	1	$ 116,361.00		
Gear Drive		SEW Eurodrive	2	1	$ 2,995.17	20	$ 1,392.60
Oil seal	13262378	SEW Eurodrive	10	1	$10.12	8	$ 557.04
Oil seal	13261819	SEW Eurodrive	10	1	$17.17	8	$ 557.04
Bearing Grease	Renolit CX-TOM 15	Fuchs	10	1	$10.00	2	$ 139.26
Lubricant	S4WE 220	Shell	10	1	$200.00	2	$ 139.26
Control Valve	550 10D 1AC2 511 G1	Gemü	2	2	$1025.00	8	$ 557.04
Control Valve	550 25D 1AC2 511 G1	Gemü	2	4	$1025.00	8	$ 557.04
Control Valve	550 8D 137 510 G1	Gemü	2	6	$185.00	8	$ 557.04
Level Sensor	FTW23 AA4MWVJ	E+H	2	5	$206.00	8	$ 557.04
Flow meter	SM 8004	IFM	2	2	$778.00	8	$ 557.04
Pressure gauge	Cerebar PMP23 AA1M1PB3CJ	E+H	2	2	$366.00	8	$ 557.04
Pump	CRN 1-4 A-FGJ-G1-V-HQQV	Grundfos	2	1	$947.16	25	$ 1,740.75
Pump	CRN 3-5 A-FGJ-GI-V-HQQV	Grundfos	2	1	$1,696.72	25	$ 1,740.75
Pump	CXM 25 FTT-V	Almatec	2	1		25	$ 1,740.75
Ceramic Filters	SSDF 2-15-374	Kerafol	6	100	$ 121.68	16	$ 1,114.08
Spare Parts		Novoflow	30	1	$ 5,110.63	8	$ 557.04
Membrane Cleaners	Micro 90; A07	International Products Corp	30	1	$ 2,566.76	10	$ 696.30

Cost Analysis

Direct Cost-Start up

The costs of ruggedization and integrated logistics support were not compared between the Novoflow NDCF-10 and the 10NP OWS with a 5-gpm OWMS. This is because these costs are platform dependent and could vary significantly based on the platform selected. Therefore, start-up cost should be re-evaluated once a target platform is selected. The total system cost for the Novoflow NDCF-10 is $232,722.00, which includes a 2x cost increase as compared to the commercially available system. This assumption is based on the ruggedization of both the ET-35N OCM and Alfa Laval OWS. The baseline technology has an upfront cost of $399K based on a previous report [23].

Training ship's force was assumed to be $11K for both systems. Training cost was based on training 3 people for 2-8 hour days and $3K of travel cost. While estimated training costs are reported here, they are not included within the 30 year cost calculations because of the platform-based training requirement variability. Combatant Navy vessels have high turnover rate and would require more frequent training intervals as compared to non-combatant Navy vessels that are typically manned by contractors and therefore experience lower turnover rates.

Direct Cost-Operation & Maintenance

System operation and maintenance account for the majority of costs included in the analysis. The cost of operation was assumed to be the same for the Novoflow NDCF-10 and the baseline system. It is assumed that the systems will be operated one hour per operation cycle and will require two operation cycles per month to treat according to a daily bilgewater generation rate of 250 gal/day as noted in the UNDS bilgewater generation rate study.

It was also assumed that the difference in utilities between the two systems would be negligible. The three utilities of concern for the Novoflow NDCF-10 and 10NP/OWMS were power consumption, compressed air, and potable water.

As mentioned previously, system life is assumed to be 15 years for both systems; therefore, both systems will be replaced once within the 30 year cost study in year 15. Yearly maintenance costs for the comparison system were derived from a previous study [23]. For the Novoflow NDCF-10, primary system components were identified through the manufacturer's parts list. The maintenance manuals were then consulted to determine worn part replacement frequency and to estimate labor associated with part maintenance. In the absence of replacement data from the technical manuals, vendor recommendations, or the laboratory evaluation, it was assumed the primary parts would need to be replaced at half the system life (e.g. in years 7 and 21). Part cost was determined through existing procurement contracts, quote requests, or vendor searches.

A primary driver of the maintenance cost is the membrane regeneration and recommended spare parts replacement for the Novoflow system. Based on the laboratory evaluation, membrane regenerations are expected to occur every 300 hours of operation or approximately once per year. Based on previous membrane regenerations, 10 hrs of labor and $2.6K in supplies will be required for each membrane regeneration event. In addition, replacement of various components like seals, lubricants, and grease are anticipated to be replaced every three years.

Over the 30 year cost analysis, the total estimated HSRMS maintenance was calculated to be $818K. The baseline technology 30-year maintenance cost was found to be $1,724K. Thus, a significant cost savings is contributed to the maintenance cost, primarily because the system replacement cost at year 15 is included under the maintenance cost.

Indirect Cost-Waste Disposal

Waste disposal costs were found to be similar between the Novoflow NDCF-10 and the 10NP OWS and Model 740956 OWMS. Daily bilgewater generation rates were determined to be 250 gal/day based on the UNDS daily bilgewater generation study for the FFG-56, which has an OWS rate for < 10 gpm. This generation rate is assumed to be for underway generation. Based on a previous study investigating the cost of wastewater disposal, 25% of the underway generation is assumed for the in-port generation (62.5 gal/day). The system is expected to operate 45% in-port and 55% underway. The cost of disposal is $0.25/gal based on a previous study and including inflation [23]. These assumptions are summarized in Table 13. 100% of the in-port generated wastewater will undergo pierside disposal, while underway generation is treatment system dependent. Based on a previous study, the combined 10NP OWS with Model 740956 OWMS membranes was able to process 95% of the wastewater generated [23]. Alternately, the Novoflow system is able to process 90% of the wastewater generated based on the laboratory evaluation. This translates to a wastewater disposal cost of $130K for the baseline technology and $155K for the Novoflow NDCF-10.

Estimated 30 Year Cost Benefit

Overall, the cost benefit showed a positive 30 year cost savings of $1,066K. As shown in Table 15, all of the cost savings were attributed to start-up and maintenance costs; however, this estimate can vary significantly depending on the target platform. For example, the cost of ruggedization for shock and vibration testing for a Navy ship can total over $200K for qualification and could require a sacrificial system. Likewise, many factors affect the cost of ILS for new Navy shipboard equipment. The fact that the Novoflow NCDF is complex will likely increase the ILS cost. In particular, the cost of converting a commercial technical manual into a Navy manual, developing and revising the Coordinated Shipboard Allowance List, Ship Drawings, and ILS certification will all need to be taken into account for a more accurate cost benefit. Army or MSC ships will likely have different costs associated with operation and maintenance documentation as compared to combatant Navy vessels.

Table 15. Estimated 30 Year Cost Benefit

	Baseline Technology	Alternative Technology	Cost Benefit
Direct Costs			
Start-up Cost	$ 399K	$ 233K	$166K
Operation Cost	$ 68K	$ 68K	$0K
Maintenance Cost	$ 1,724K	$ 818K	$906K
Indirect Cost			
Wastewater Disposal	$ 130K	$ 155K	(-$25K)
		30 year ROI	$ 1,066K

CONCLUSIONS

Overall, the shipboard results indicate HSRMS as a promising technology for bilgewater treatment; however, its current design would need to be repackaged for DoD shipboard applications. The Novoflow HSRMS, in its current configuration, did not meet the reliability criteria for maintenance ratio. This was due to corrective maintenance needed to clean a level sensor and correct tolerances with the feed pump variable frequency drive (VFD). Reliability criteria could be met with the following considerations, 1) an automatic rinse function during shut down to prevent oil fouling sensors, 2) relocating sensors to avoid fouling from oil, 3) redesign to avoid the use of VFDs, and 4) redesign production capacity using full scale evaluation results. Further considerations would be needed for militarized ships, including redesign for shock, vibration, EMI and other requirements (e.g. cyber security). A reliability study of the redesigned system would also need to be performed to ensure design changes meet the OWS requirements for DoD ship platforms.

Based on the results of the shipboard evaluation, a redesigned HSRMS could be a candidate for new Army, MSC, Navy, and USCG ship acquisition programs that are seeking a small, compact and complete OWS system.

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APPENDIX A: JOINT TEST PROTOCOL

JOINT TEST PROTOCOL (JTP)

Demonstration of High Shear Rotary Membrane System (HSRMS) for Shipboard Bilgewater Treatment (WP-201708)

January 2018

Draft

Revision 1

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ACRONYMS

AFFF	Aqueous Film Forming Foam
A_O	Operational Availability
COTS	Commercial-off-the-shelf
DAS	Data Acquisition System
DCMR	District of Columbia Pretreatment Regulations
ESTCP	Environmental Security Technology Certification Program
gpm	gallons per minute
HEM	Hexane Extractible Material
HSRMS	High Shear Rotary Membrane System
JTP	Joint Test Protocol
MDT	Mean Down Time
MEPC	Marine Environmental Protection Committee
MLDT	Mean Logistic Delay Time
MTBF	Mean Time Between Failure
MTTR	Mean Time To Repair
NAVFAC	Naval Facilities Engineering Command
NAVSEA	Naval Sea Systems Command
NSBM	Navy Standard Bilge Mix
NSWCCD	Naval Surface Warfare Center, Carderock Division
OCM	Oil Content Monitor
OPA	Oil Pollution Abatement
OPNAVINST	Chief of Naval Operations Instruction
OWHT	Oily Waste Holding Tank
OWMS	Oily Waste Membrane System
OWS	Oil/Water Separator
ppm	parts per million (volume)
rpm	revolutions per minute
SGT-HEM	Silica Gel Treated Hexane Extractible Material
STW	Ships Technical Warrant
TTR	Time To Repair
UST	Underground Storage Tank
WOT	Waste Oil Tank
WP	Weapon Systems and Platforms

POINT OF CONTACT

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1.0 INTRODUCTION

1.1 Objectives

The objective of this laboratory evaluation is to determine the high shear rotary membrane system's (HSRMS's) ability to reliably and efficiently process the highly variable bilgewater found on Navy ships and produce an effluent that meets the discharge requirement of having an oil concentration of less than 15 ppm. Table 1 lists the targeted hazardous material, bilge oil, and other material information associated with investigating the commercial off-the-shelf (COTS) HSRMS. By completing a series of system tests and recording passive data obtained through reliability, maintainability, availability (RMA) and operability, this protocol will enable the determination of system oil removal, performance in the presence of bilge contaminants, effective processing rate, operation and labor requirements and shipboard integration needs.

Table 1. Target HazMat Summary

Target HazMat	Current Process	Applications	Current Specifications	Potentially Affected Programs	Candidate Parts and Substrates
Bilgewater	Gravity coalescence; Filtration	Armed Forces Vessels	DoD Instruction 4715.6 OPNAVINST 5090.1 Army Technical Bulletin TB-55-1900-206-14	Military Sealift Command N75 NAVSEA 05P5 Future Fleet Office for Product Director Army Watercraft Systems	Oil/Water Separator via High Shear Rotary Membrane System (HSRMS)

1.2 Stakeholders

Primary stakeholders identified for this project include the Environmental Security Technology Certification Program (ESTCP) Weapon Systems and Platforms (WP) Program Manager, who manages the program which selected this project for funding, and Naval Sea Systems Command (NAVSEA) Wet Environmental Systems and Discharges Technical Warrant Holder (05P5), who is the Navy's technical authority for oil pollution abatement (OPA) systems. Prior to joint test protocol (JTP) submission to ESTCP, NAVSEA 05P5 was consulted and concurred on the submitted test design and protocol.

1.3 Meeting Information

The Naval Surface Warfare Center, Carderock Division (NSWCCD) regularly communicates with the NAVSEA 05P5 and Oily and Non-Oily Wastewater Engineering Manager to determine appropriate paths forward for testing based on current research findings. A quarterly meeting is held to discuss research pursuits, best practices and standards. Outside of these regular meetings, lines of communication are open, and NAVSEA Technical Authority expertise is requested when developing any test plans. The information contained in this test plan has been reviewed by NAVSEA 05P5 and recommended edits have been incorporated where feasible.

2.0 PERFORMANCE AND TESTING REQUIREMENTS

The HSRMS laboratory evaluation is generally broken out into four different tests:

1. System Processing Performance
2. Membrane Life
3. Membrane Regeneration
4. RMA

Table 2 describes the common performance and testing requirements for this project as determined by NAVSEA 05P5 and ESTCP WP Program Manager. These tests are consistent with typical oil/water separator (OWS) testing protocols previously developed by NSWCCD with NAVSEA concurrence. There are no additional extended tests.

Table 2. Common Performance and Testing Requirements

Engineering Requirement	Test	JTP Section	Acceptance Criteria	References
Oil removal, system performance, and processing rate	**System Processing Performance**	3.3	95% of effluent samples ≤ 15 ppm oil 100% of effluent samples ≤ 100 ppm oil All of system alarms, indicators, and sensors function as designed in all operating modes	1
Material requirements, system performance and processing rate	**Membrane Life**	3.4	Run time of 300 hrs without reaching 100% resistance	2
Material maintenance	**Membrane Regeneration**	3.5	Regeneration observed	3
Failure frequency	**Reliability**	3.6	MTBF ≥ 922 Hours with No Failures (Relevant Critical or Relevant Major)	4,5
System availability	**Availability**	3.6	$A_O \geq 95\%$	4,5

Maintenance burden; operation burden	**Maintainability & Operability**	3.6	MTTR ≤ 3 Hours Max TTR ≤ 8 Hours Maintenance Ratio ≤ .03 Preventative Maintenance ≤ 3.5 Hrs per Week Operator displays skill level required to operate and maintain equipment	4,5

Table 3 and Table 4 provide additional information on the tests described in Table 2 including data requirements for system evaluation based on the listed success criteria and calculation definitions for RMA determinations.

Table 3. Full Scale Laboratory Demonstration Performance Objectives

Performance Objective	Data Requirements	Success Criteria
Quantitative Performance Objectives		
System Processing Performance	Oil concentration (ppm)	[+]95% of effluent samples ≤ 15 ppm oil
		[+]100% of effluent samples ≤ 100 ppm oil
	Measured alarms, indicators and sensors	[+]All of system alarms, indicators, and sensors function as designed in all operating modes
Membrane Life	TMP and effluent flow rate	Run time of 300 hrs without reaching 100% resistance[2]
Reliability, Maintainability, and Availability	See Table 4	
Qualitative Performance Objectives		
Membrane Regeneration	TMP and effluent flow rate[3]	Regeneration observed

[+]OWS Evaluation Protocol Metric [1]

Table 4. RMA Performance Objectives

Performance Objective	Metric Definition	Metric	Success Criteria
Reliability	$\text{MTBF} = \frac{\text{Total Number of Operating Hours}}{\text{Total Number of Failures}}$	Logged Operation Data	[+]MTBF ≥ 922 Hours with No Failures (Relevant Critical or Relevant Major)
	$K' = \frac{\text{Total Calendar Time} - \text{Downtime}}{\text{Total Number of Operating Hours}}$		

	$= \frac{K'(MTBF)}{\text{Total Calendar Time} - \text{Downtime}}$ $\text{Total Number of Failures}$		
Availability	$A_O = \frac{\text{Uptime}}{\text{Total Time}}$ $= \frac{\text{Uptime}}{(\text{Uptime} + \text{Downtime})}$ $A_O = \frac{(\text{Total Time} - \text{Downtime})}{\text{Total Time}}$ $A_O = \frac{K'(MTBF) - MDT}{K'(MTBF)}$ $= \frac{1 - [MTTR + MLDT]}{K'(MTBF)}$	Logged Operation Data	$^{+}A_O \geq 95\%$
Maintainability	$MLDT = \frac{\text{Total Logistic Time Delay}}{\text{Total Number of Failures}}$ MTTR $= \frac{\text{Total Corrective Maintenance Time}}{\text{Total Number of Failures}}$ $MDT = \frac{\text{Total Downtime}}{\text{Total Number of Failures}}$ $MDT = (MTTR + MLDT)$ Maintenance Ratio $= \frac{\text{Total Active Maintenance Man Hrs}}{\text{Total Operating Time}}$	Logged Operation Data	$^{+}$MTTR ≤ 3 Hours $^{+}$Max TTR ≤ 8 Hours $^{+}$Maintenance Ratio ≤ .03 $^{+}$Preventative Maintenance ≤ 3.5 Hrs per Week $^{+}$No Preventative Maintenance Action Shall Take > 16 Man hrs
Operability	Training time Operating time Maintenance time (Corrective and Preventative)	Logged Operation Data	
	Operator skill level	Logged Operation Data	Displays skill level required to operate and maintain equipment

$^{+}$ OWS Evaluation Metric [4,5]

Tests in this joint test protocol (JTP) may involve the use of hazardous materials, operations, and equipment. This JTP does not address all safety issues associated with its use. It is the responsibility of each user of this JTP to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to its use. Refer to the Carderock Health and Safety Plans developed for specific processes and equipment for additional information. A copy of these documents is available through the Wastewater Management Branch as well as the Carderock Safety Office.

3.0 TEST DESCRIPTIONS

3.1 Overview

In support of the listed objectives, the laboratory evaluation will analyze the system's:

- Ability to separate oil, including oil-in-water emulsions,
- Performance in the presence of expected bilge contaminants (Aqueous Film Forming Foam (AFFF), cleaning solvents, detergents, solids, etc.),
- Effective processing rate,
- System reliability, maintainability, availability, and operability labor requirements, and
- Shipboard integration.

The system's ability to separate oil and performance in the presence of bilgewater contaminants will determine the system's performance under a wide variety of conditions that may be present shipboard. This information will also determine other information such as chemical resiliency, system processing reliability and treatment effectiveness.

The effective processing rate will analyze the flowrate of the influent compared to the flowrate of the effluent with an oil content of less than or equal to 15 ppm for each test. This comparison will quantify throughput efficiency of the system. Ideally, the difference between influent and effluent flowrates while processing non-bulk oil fluid should only be due to oil content monitor (OCM) usage (approximately 1 gpm/OCM), regular backpulsing and concentrate bleeds.

The cost of ownership shall also be documented. This will be calculated from use of consumables (membrane discs, gaskets, etc.), time spent operating and maintaining system (labor), time spent training to use the system, time spent repairing the system, and cost of replacement parts. This information will be logged to determine number of replacement parts and additional maintenance burden for the future shipboard evaluation.

For shipboard integration, the laboratory evaluation will evaluate several attributes of the HSRMS and analyze how they may affect installation and use. The primary drivers for shipboard integration will be if the HSRMS requires special services that are not readily available shipboard, and actual maintenance envelope.

This laboratory evaluation will be conducted in accordance with the testing guidelines outlined in the Uniform Test Plan for Oily Water Separators (Updated 2013) [1].

3.2 Laboratory Setup

3.2.1 System Setup

The laboratory setup applies to the System Processing Performance, Membrane Life, and Membrane Regeneration tests. The setup consists of the HSRMS, which will be fed by either the laboratory's fresh water supply via a 500-gallon buffer tank or saltwater via a 10,000-gallon above ground storage tank as shown in Figure 1. The test mix will be fed into the HSRMS supply line from a 200-gallon mix tank or a 500-gallon oil tank. Fresh water will be supplied from the building's potable water system. The 500-gallon buffer tank will be used to supply influent at near atmospheric pressure and temperature. The 10,000-gallon above ground storage tank will be used to store and supply simulated seawater.

The 200-gallon mix tank shall be used to create a test mixture with an oil concentration of one percent for the 200 ppm oily water tests and five percent for all other tests except the

transition test. The 500-gallon oil tank shall be used to supply Navy Standard Bilge Mix (NSBM) #4 during the transition test. The 200 and 500-gallon tanks are located on the mezzanine level of the oily wastewater laboratory. Effluent (fresh and saltwater) with an oil concentration less than 15 ppm will be discharged to the laboratory floor drain. Effluent with an oil concentration greater than or equal to 15 ppm and waste oil discharges shall be diverted to one of the two 20,000-gallon laboratory underground storage tanks (UST) for reprocessing by a laboratory OWS.

The following laboratory support equipment is required:

- 200-gallon mix tank (Tank #7) and recirculation loop;
- 500-gallon oil tank (Tank #5);
- 10,000-gallon above ground storage tank;
- 500-gallon buffer tank (Tank #10);
- Two 20,000-gallon underground oily waste storage tanks (UST-60-1 and UST- 60-2);
- One 2,500-gallon underground oily waste storage tank (UST-60-4)
- Data acquisition system;
- Digital camera;
- Disperser (high shear mixer) at injection line;
- Flow meters:
    - Magnetic for influent;
    - Magnetic for effluent discharge flow $\leq$ 15 ppm
    - Magnetic for effluent recirculation flow > 15 ppm
    - Magnetic for injection line (for all tests except oily waste holding tank (OWHT) transition test);
    - Turbine for injection line (for OWHT transition test only);
    - Magnetic for backflush water;
- Pressure gauges;
- Thermometer;
- Laboratory centrifuge;
- Log sheets/book;
- Stopwatch;
- Salinity probe;
- Static (low shear) mixer at influent;
- Seepex progressive cavity pump;
- Gearhead injection pump with PTFE gears and seals;
- Associated nylon tubing for oil and contaminant injection;
- ET-35N OCM to monitor effluent;
- COTS OCM to monitor effluent;
- Sample bottles;
- Sample collection nozzles or pitot tubes for non-waste oil samples; and
- Plexiglas tank (40-50 gallons capacity) with one gallon marking to collect waste oil tank discharges.

All laboratory flow meters and pressure gauges used for data collection will either have a valid factory calibration or calibrated in accordance with NSWCCD's Uniform Test Plan for Oily Water Separators (Updated – 2013) [1].

3.2.2 Simulated Bilgewater Generation

a) Mix Tank Preparation

For each test condition listed in Table 7, a concentrated influent mixture shall be made in the influent test mix tank (Tank #7 in Figure 1). A sufficient amount of the mix shall be made for the entire day's test, approximately 120% of the calculated amount required plus 30 gallons to account for the volume of the recirculation loop and the tank volume below the recirculation pump intake. The concentrated influent mix shall contain one percent by volume NSBM #4 for the 200-ppm test and five percent by volume NSBM #4 for all other tests except the transition test to ensure injection flow rates are within a stable flow range of the injection pump. Except for solids, the other contaminants required for a specific test run shall be added to the mix tank prior to starting the recirculation pump. Solids will be added to the mix tank after the recirculation pump is started on the day of the test.

After each test, the mix tank and recirculation line shall be cleaned with potable water. At the conclusion of a test, the mix tank shall be drained and then sprayed down with a garden hose. Fifty gallons of potable water shall be added to the mix tank and recirculated for five minutes. After draining the fluid to UST-60-1 or UST-60-2, the recirculation/flushing procedure shall be completed three times. The bottom of the mix tank should be visible with the final 50 gallons of flush water in it.

b) Simulated Seawater Calculation

The formula used to calculate the minimum required volume ($Vol_{Required}$) of simulated seawater for each simulated seawater test is as follows:

$$Vol_{Required} = (\text{Test System Capacity (gpm)} \times \text{Duration of Test (minutes)} + 1{,}000 \text{ Gallons}) \times 1.2$$

This formula accounts for the approximate 1,000 gallons of space from the bottom of the 10,000 gallon outdoor tank to the suction pipe and a 20% safety factor. The calculated value should be multiplied by two for the total volume of simulated seawater procurement/generation for both tests.

For the HRMS arrangement, the minimum required saltwater for the evaluation is as follows:

(10 gpm x 600 minutes + 1000) x 1.2 = 8,400 gallons of saltwater per test
8,400 gallons x 2 = 16,800 gallons of saltwater for the evaluation

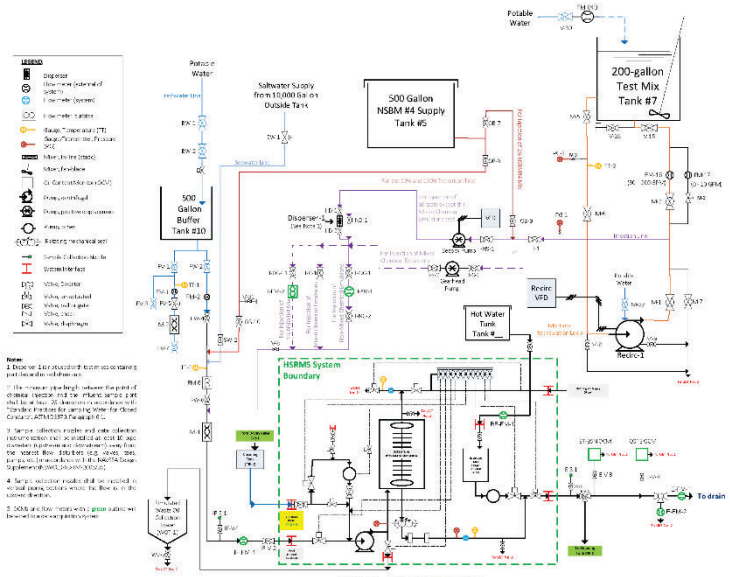


Figure 1. Laboratory Setup

c) Recirculation Pump

The centrifugal pump installed on the mix tank recirculation loop operates at 3,450 rpm, meeting the minimum MEPC.107(49) requirement that the recirculation pump operates no less than 3,000 revolutions per minute (rpm). The target flow rate of the recirculation pump shall be approximately 160 gpm. This flow rate will provide a minimum of approximately one mix tank change-out per minute over the duration of the test. The recirculation pump shall be operated for sufficient time to achieve at least 10 change-outs (approximately 10 minutes) prior to the start of a test (not including the transition test).

d) Injection Line Configuration

The mixture of oil and water or the combination of oil, water, and contaminants shall be injected to a water stream supplied by the building potable water system at the rate necessary to achieve the required inlet concentration. A disperser shall be placed after the injection pump to aid in generating the desired oil droplet sizes. The disperser shall be set to 8,000 rpm [1]. The disperser will be taken offline for the detergents, mixed chemicals, and solids tests, as the fluids used for these tests are expected to contain stable emulsions, are not compatible with the disperser. The disperser will not be used during the transition tests as the fluid injection will be single phase. A low shear/static inline mixer installed prior to the OWS shall be used to ensure that the injected mixture is uniformly mixed with the balance of water entering the OWS.

For the transition test, 100% NSBM #4 shall be transferred to the 500-gallon influent source tank. The transition test is designed to test the ability of the HSRMS to treat the contents of the OWHT when the water layer transitions to the bulk oil layer. The one percent NSBM #4 test will use the seepex pump to inject NSBM #4 into the inlet stream. For the 50% NSBM #4 test, the seepex pump will be secured, and potable water and NSBM #4 flow rates will be adjusted using throttle valves to balance the flow rates to the OWS. For the bulk oil test, the potable water source will be secured and only NSBM #4 will flow to the OWS. Details the influent mix amounts and injection rates for each test for the OWS are provided within each test section.

The system operator shall document the amount of water and contaminants added to the mix tank, the time the recirculation pump is started, and the time the pump's speed is reduced (if needed), see Figure 2.

Date	Test Seq. #	Total Water Added (gal)	NSBM #4 Added (gal)	Contaminants Added/ Quantity	Time Recirc Pump Started	Time Recirc Pump Stopped	Initials

Figure 2. Test Mixture Generation Log

3.2.3 Data Recording and Analysis

A data acquisition system (DAS) will automatically record various parameters during the laboratory evaluation. The model DAS to be used will be the Personal Daq 3001 Series. The DAS measures the output signal produced from a transducer (i.e. flow meter, OCM, etc.). When the measured parameter of the transducer changes, a corresponding change in the transducer's output will occur. The output is calibrated to the parameter being measured. After calibration, the DAS's display automatically converts the transducer's output to a useful engineering measurement such as ml/min or ppm. The DAS will be set up to record a measurement every five seconds for the duration of the test run. If a transducer outputs a milliamp signal, then a precision resistor (e.g. 100 ohm, dependent on equipment) will need to be placed between the contacts of the transducer and DAS to convert the signal to voltage. If a transducer already outputs a voltage, such as the ET-35N OCM, then no resistor shall be used for that transducer. The averaging parameter of the DAS shall be set to 50. The averaging parameter defines the number of readings the DAS will average into a set of recorded measurements. By setting the number of scans to 50, the noise to signal ratio of the measurements will be reduced. The following parameters are to be recorded by the DAS:

- Influent flow rate
- Effluent flow rates with an oil content less than 15 ppm
- Effluent flow rate with an oil content greater than or equal to 15 ppm
- Backflush flow rate
- Test mix injection flow rate
- Oil concentration (ppm) readings from the ET-35N OCM
- Oil concentration (ppm) readings from the COTS OCM

During the performance evaluation and the non-degradation portions of the reliability evaluation, the system operator will record the system's flow rates, total flows, backpulse/concentrate bleed volume, backwash volume, pressures, temperature, and oil content of the effluent, and UST levels hourly on a daily log sheet, see Figure 3. The operator shall also record any alarm or error codes.

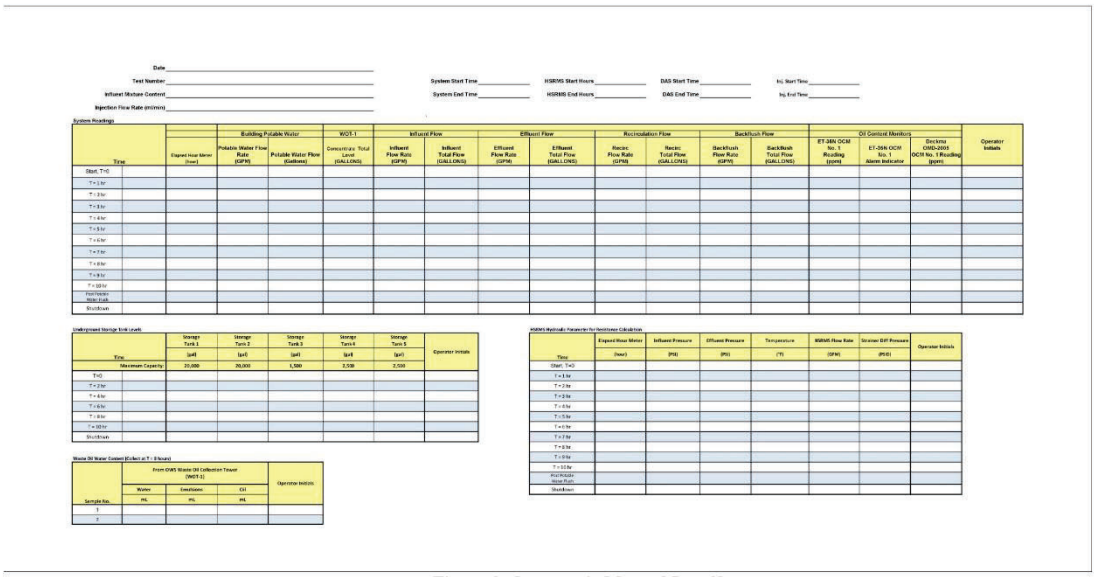
During the 100% water portions of the reliability evaluation, the system operator will record the system's flow rates, total flows, backpulse/concentrate bleed volume, backwash volume, pressure, temperature, oil content of the effluent, and UST levels on a daily log sheet every other hour.

The average water content of the fluid discharged to the simulated waste oil tank (WOT) will be measured during this laboratory evaluation to verify if the fluid contains less than 20% water by volume. The total volume of fluid sent to the simulated WOT over the course of a test for which bulk oil is not processed (i.e. not a transition test) will be measured. By analyzing the total fluid volume sent to the simulated WOT, calculations can be made to estimate the amount of fluid to be sent to a shipboard WOT by the HSRMS during a 60-day mission.

Four magnetic flow meters shall be used to measure flow rates and total flows of the influent, effluent and backflush water. Of the two magnetic flow meters for the effluent, one flow meter shall measure effluent flow less than 15 parts per million (ppm) and the other flow meter shall measure effluent flow greater than or equal to 15 ppm.

Discharges from the waste oil outlet shall be collected in a Plexiglas waste oil collection tower (except for the 50% and 100% portions of the transition tests where waste oil will be diverted to the UST system) where total volume discharged will be manually recorded. All flow rates and total flows will be recorded hourly on the system operator's daily log, see Figure 4.

Any maintenance operations that are required during the evaluation will be recorded. The total time required to perform the maintenance will be documented; see Figure 5 and Figure 4. The data collected throughout this evaluation will be calculated using the definitions and success criteria listed in the Performance and Testing Requirements section.



Date_____

Test Number:_____ System Start Time_____ HSRMS Start Hours_____ DAS Start Time_____ Inj. Start Time_____

Influent Mixture Content_____ System End Time_____ HSRMS End Hours_____ DAS End Time_____ Inj. End Time_____

Injection Flow Rate (ml/min)_____

System Readings

Time		Building Potable Water		WOT-1	Influent Flow		Effluent Flow		Recirculation Flow		Backflush Flow		Oil Content Monitors			Operator Initials
		Elapsed Hour Meter (hour)	Potable Water Flow Rate (GPM)	Potable Water Flow (Gallons)	Consolidated Tank Level (GALLONS)	Influent Flow Rate (GPM)	Influent Total Flow (GALLONS)	Effluent Flow Rate (GPM)	Effluent Total Flow (GALLONS)	Recirc Flow Rate (GPM)	Recirc Total Flow (GALLONS)	Backflush Flow Rate (GPM)	Backflush Total Flow (GALLONS)	ET-38N OCM No. 1 Reading (ppm)	ET-38N OCM No. 1 Alarm Indicator	Deckma CMS-2015 OCM No. 1 Reading (ppm)	
Start, T=0																	
T + 1 hr																	
T + 2 hr																	
T + 3 hr																	
T + 4 hr																	
T + 5 hr																	
T + 6 hr																	
T + 7 hr																	
T + 8 hr																	
T + 9 hr																	
T + 10 hr																	
Post Potable Water Flush																	
Shutdown																	

Underground Storage Tank Levels

Time		Storage Tank 1 (gal)	Storage Tank 2 (gal)	Storage Tank 3 (gal)	Storage Tank 4 (gal)	Storage Tank 5 (gal)	Operator Initials
Maximum Capacity		20,000	20,000	1,500	2,500	2,500	
T=0							
T + 2 hr							
T + 4 hr							
T + 6 hr							
T + 8 hr							
T + 10 hr							
Shutdown							

Waste Oil Water Content (Collect at T - 0 hours)

Sample No.	From OWS Waste Oil Collection Tower (WOT-1)			Operator Initials
	Water	Emulsions	Oil	
	mL	mL	mL	
1				
2				

HSRMS Hydraulic Parameter for Resistance Calculation

Time	Elapsed Hour Meter (hour)	Influent Pressure (PSI)	Effluent Pressure (PSI)	Temperature (°F)	HSRMS Flow Rate (GPM)	Strainer Diff Pressure (PSID)	Operator Initials
Start, T=0							
T + 1 hr							
T + 2 hr							
T + 3 hr							
T + 4 hr							
T + 5 hr							
T + 6 hr							
T + 7 hr							
T + 8 hr							
T + 9 hr							
T + 10 hr							
Post Potable Water Flush							
Shutdown							

Figure 3. Operator's Manual Log Sheet

Test #	Date	Time	Comments	Initials

Figure 4. Operators Daily Log

Date	Test Seq. #	Time	Duration	Operator Initials	Maintenance Event

Figure 5. Maintenance Log Sheet

3.2.4 Fluid Sampling

Visual samples of the influent and effluent will be taken throughout the evaluation. This will provide quick qualitative feedback of system performance, relative burden on the HSRMS, and a rough check on oil content monitor performance (i.e. a cloudy sample should yield a high oil content reading and a clear sample should yield a low oil content reading).

The HSRMS influent, effluent and waste oil reject will be sampled during the performance evaluation and the reliability non-degradation test runs. Two influent and effluent samples shall be collected during each performance and non-degradation test. For tests planned for 10 hours, samples shall be collected at t = 4 and 9 hours. For tests that are stopped early due to oil breakthrough, samples shall be collected at t = 2 and 4 hours. For the transition test, effluent samples shall be collected at t = 4 and 6 hours (10 minutes into the 50% oil test). At least 10% of all samples shall be quality control standards [7]. Quality control standards shall be prepared with concentrations of 15-ppm or 100-ppm NSBM #4. Per batch of samples (expected to be 10-15 bottles) sent to the analytical laboratory, a set of triplicate samples (three times the normal sample volume) shall be collected. These samples will be collected to allow for analytical laboratory-generated quality control spikes. The triplicate samples will be collected in three sample bottles and labeled as triplicates, see Data collection will follow the data collection plan described in Data Recording and Fluid Sampling sections of this report. Data collection specific to this test is described in the below sections.

Sampling Plan. A second set of triplicate samples will also be collected and provided to the analytical laboratory for their internal use.

Waste oil samples shall be collected at t = 8 hours for all tests except the transition test. A waste oil sample shall be collected at t = 6 hours for the transition test. For tests that are stopped early due to oil breakthrough, a waste oil sample shall be taken an hour prior to the end of the test. Samples shall be taken by collecting 150 ml of oil reject at the inlet of the Plexiglas WOT. After collection, the sample shall immediately be transferred to two volumetric centrifugal bottles (50 ml of sample per bottle). Samples shall be processed using a laboratory centrifuge to

determine the percentage of water in the waste oil. Samples shall be centrifuged for 10 minutes at a gravity setting of 420 g (3/4 speed on the centrifuge). Results will be recorded on the Waste Oil Content section of the system operator's daily log, see Figure 3. There is a possibility that the primary separator may not be able to treat the influent test mix. If this is the case, there will be no oil reject sample to collect. If this condition arises, it will be noted on the log sheet.

Effluent samples shall be collected for each test. Effluent samples shall be collected at t = 4 and 9 hours for each test. A corresponding influent sample shall be drawn for effluent samples collected at t = 4 and 9 hours for each test [1]. Influent samples shall be collected in 1,000 ml sample collection bottles. This influent and effluent testing schedule will quantify the ability of the HSRMS on treating mechanical emulsions (oily water), weak chemical emulsions (oily water with AFFF), and strong chemical emulsions (oily water with mixed detergent).

Non-waste oil samples shall be collected isokinetically using a sample collection nozzle or pitot tube design, as depicted in Figure 6. Samples shall be collected in clean, solvent-rinsed glass bottles with clean, solvent-rinsed Teflon-lined caps provided by Phase Separation Science (analytical laboratory). Samples will be preserved with 10 normal sulfuric acid (10N H_2SO_4) to a pH of less than 2, and refrigerated at 4°C. Effluent samples shall be measured for oil concentration using the regulatory EPA Method 1664, Hexane Extractable Material (HEM) and Silica Gel Hexane Extractable Material (SGT-HEM) [7]. OCM readings shall be noted during each sampling event.

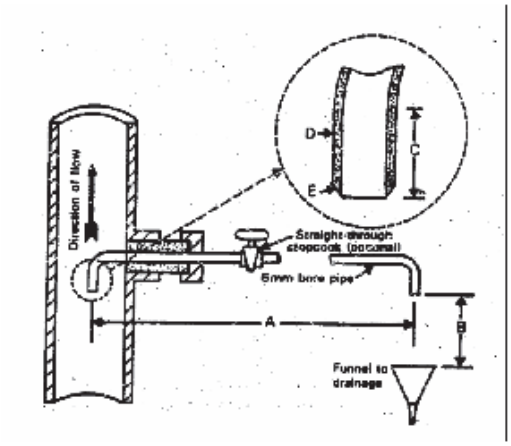


Figure 6. Diagram on Sample Port Arrangement

All sample bottles shall be identified with adhesive labels displaying the date and time the sample was taken, the operator's initials, and a unique sample designator. The following format shall be used to identify the samples:

Sample Designation Format: Test Number – Sample Type – Time of Sample – Laboratory Triplicate (if applicable)

Test Number:

Test number as defined in Appendix A – Test Sequence

Sample Type

A = Effluent Discharge

B = Influent
C = Quality Control
D1 or D2 = Effluent Spikes

Time of Sample:
Time (in hours) sample taken from initiation of test

Laboratory Triplicate (if applicable)
T1, T2, and T3 = Triplicates

Sample label information shall be recorded on a chain-of-custody sheet and forwarded with the samples to the laboratory. No information that would bias the laboratory analysis, such as which samples are quality control samples, shall be contained on this sheet.

3.2.5 Pre-Tests

a) System Physical Size

The HSRMS footprint, maintenance envelope, and weight shall be documented. The HSRMS's footprint will be measured and maintenance envelope estimated. The HSRMS weight shall be based on the manufacture's drawings and label plate.

b) Initial Startup

After installation, the unit shall process potable water for at least one hour. During processing, all transducers and gauges, such as flow meters and pressure gauges, shall be checked for proper functioning. The amount of time the HSRMS requires to meet processing conditions shall be noted. Alarms intrinsic to the HSRMS shall also be verified for proper function unless performing the alarm check risks a significant potential to damage the system. If testing indicates unsafe conditions while operating the system (e.g. excessive temperatures or vibration) the manufacturer will be consulted to remediate the condition. Testing will proceed once operating conditions are deemed safe.

c) Metering Pumps

A seepex positive displacement, progressive cavity oil metering pump Viton gears and seals shall be used to inject the desired amount of oil and contaminant from the test mix tank into the influent wastewater feed mixture. The influent oil concentration can be changed by varying the injection rate. The seepex progressive cavity pump with Viton gears and seals can be used for all tests except the mixed chemicals test. The gearhead pump with polytetrafluoroethylene (PTFE, also known as Teflon®) seals shall be used for the mixed chemicals test.
The injection rate is adjusted by varying the pump's rotational speed, revolutions per minute (rpm). The influent oil and contaminant concentration can be changed or fine-tuned by varying the injection rate via the pumps' drives.

d) Injection Flow Meter and DAS Calibration

A magnetic-style flow meter shall be used to monitor the injection flow during all tests except the transition test and mixed chemicals test. A turbine-style flow meter shall be used during the 1% oil portion of the transition test. The DAS shall be calibrated to convert the output of the injection flow meters to the correct injection flow rates (except for the 50% and 100% NSBM #4 portions of the transition tests and the mixed chemicals tests). For the mixed chemicals test, the DAS calibration of the injection flow meter output will be checked before the mixed chemicals test is performed. After checking the DAS calibration, the required metering

pump rpm setting corresponding to the target injection flow rate will be set prior to bypassing the injection flow meter. Except during the transition tests, the volume of test mix in Test Mix Tank #7 will be checked on an hourly basis as a secondary check to ensure proper injection of the test mix. During the transition tests, NSBM #4 Supply Tank #5 will be checked hourly for fluid draw down.

DAS calibration curves will be generated for the magnetic and turbine injection flow meters. Each calibration curve will be in the range of ± 12.5% of the target injection rate. Each calibration curve will have at least five calibration points [1]. Two-minute bucket tests shall be conducted to calibrate the DAS to the output of the flow meter. The DAS shall convert the output signal (voltage or milliamp) of the flow meter to a calculated flow rate. The calculation to convert the signal to a flow rate shall be based off of the results from the bucket test. Potable water is an acceptable fluid to use during calibration. Bucket tests will be performed with a small discharge pressure head. This prevents significant fluctuations in the flow rate for a given rpm setting. A high variance in the flow rate can lead to unacceptable calibration curves.

To ensure that the flow meter reads accurately over the duration of the evaluation, DAS calibration checks shall be performed. Checks shall be performed every three tests that require the injection of contaminants or once per week. A two minute bucket test shall be performed in the same manner as previously described. Only a single point near the target injection rate needs to be checked. If the check produces a DAS value within five percent of the bucket test value, then the DAS calibration curve will be deemed acceptable. If the DAS values are outside of five percent of the bucket test value, then a new five-point DAS calibration curve shall be generated.

3.2.6 Maintenance

During the evaluation, all required routine maintenance shall be conducted on the system. Table 5 lists some of the routine maintenance that may be required during the evaluation that is specific to the HSRMS or to laboratory transducers. The HSRMS technical manuals shall be consulted when performing any maintenance operations.

3.2.7 Test Duration Protocol

Test durations for each test type are listed in the test approach of each of the appropriate tests: performance and membrane life. These test durations may be shortened if an oil breakthrough condition occurs where the COTS OCM indicates an oil concentration above its upper detection limit, and the ET-35N OCM displays its upper detection limit (determined by actuating the OCM test switch) and/or if a warning light signals or if the maximum operational pressure of 2 bar is reached. This will reduce the burden on the laboratory UST system. The amount of time to shorten a test will be dependent on the visual quality of the effluent. If the effluent is cloudy with the OCM conditions stated above met, the test may be stopped after 4 hours. If the remaining time is less than 4 hours, then the test is to continue until the test duration is complete. The shortened test duration will alleviate burden on the UST system and laboratory OWS, but allow for additional observation of the system in recirculation mode [1].

3.2.8 Environmental Safety

Effluent discharges to the drain are covered under the wastewater discharge permit, which authorizes discharges to the Blue Plains Wastewater Treatment Plant from NSWCCD. The permit is issued in accordance with the District of Columbia Pretreatment Regulations (DCMR Title 21 Chapter 15). The Naval Facilities Engineering Command (NAVFAC) at

Carderock manages the permit. The permit limits the oil and grease content in the disposed effluent to less than 100 ppm. The ET-35N OCM will measure the effluent oil content.

Effluent with oil content less than 15 ppm will be discharged to the sanitary drain. The contents of UST-60-1 or UST-60-2 will be reprocessed using a laboratory OWS. Waste oil separated by all systems will be discharged to UST-60-4, which will act as the WOT.

Table 5. Routine Maintenance Intervals

Unit	Interval	Action	Required Material
COTS OCM	As required	As required	-As required
Magnetic Flow Meter (Injection)	Every 2 tests requiring contaminant injection	Confirm injection flow meter reading with a 2 minute bucket test	-Stopwatch -Graduated cylinder
Turbine Flow Meter (Injection)	Prior to transition tests	Confirm injection flow meter reading with a 2 minute bucket test	-Stopwatch -Graduated cylinder
Metering Pump(s)	Every 2 tests	Confirm injection flow meter reading with a 2 minute bucket test	-Stopwatch -Graduated cylinder
HSRMS	As required	Clean and inspect filter	N/A
	As required	Clean and inspect influent pump	N/A
	As required	Tighten screws	N/A
	System resistance is 1.5 bar	Perform regeneration	Micro A07 and Micro 90 Detergents
	As required	Inspect membrane discs for wear and corrosion	N/A
	At system start-up	Gear box oil level	Motoroil SAE 10W30

3.3 System Processing Performance

3.3.1 Rationale

The purpose of the System Processing Performance testing is to determine the performance of the system based on a series of challenge solutions. The system's performance is determined through processing rate, effluent quality and reliability throughout these tests.

3.3.2 Test Approach

A series of tests will be conducted to determine the performance and reliability of the HSRMS. Table 6 lists the contaminants used in all of the tests; Table 7 and Table 8 provide specific tests that will be conducted. Prior to initiating these tests, Code 633 will inspect and document the material condition of the HSRMS.

For the performance portion of the evaluation, a sequence of test runs will be conducted using various concentrations of NSBM #4, detergent mix #4, and other contaminants to simulate the variable conditions found aboard Navy ships. These tests will determine the HSRMS's performance when encountering various potential contaminants. Table 6 lists the contaminant

constituents that will be used during these tests. The reliability portion of the evaluation will determine if the system can achieve a mean time between failure (MTBF) of 400 hours with a confidence of 90%. The reliability tests will extend the system's total operating time beyond the performance test's operating time to achieve a total system run time of 922 hours. No operational failures are acceptable during the 922 hours [1].

Table 6. Constituents of Influent Additives

Oil	NSBM #4	50% by volume Diesel Fuel Marine, MIL-DTL-16884 25% by volume 2190 TEP Steam Lube Oil, MIL-PRF-17331 25% by volume 9250 Diesel Lube Oil, MIL-PRF-9000
	NSBM #4 JP-5 Variant	50% by volume Marine Aviation Fuel, MIL-DTL-5624 25% by volume 2190 TEP Steam Lube Oil, MIL-PRF-17331 25% by volume 9250 Diesel Lube Oil, MIL-PRF-9000
Contaminants	Detergent Mix #4	50% Type 1 General Purpose Non-Ionic Detergent, MIL-D-16791 25% Commercial Detergent 2X "Ultra Tide" Original Scent (liquid) 25% Degreasing Solvent, MIL-PRF-680, Type III
	Other	AFFF, 6%, MIL-F-24385 Arizona Test Dust, ISO-12103-1, A4 Coarse "Clorox" Bleach, 260 mg/L NaOCl Cloth Fibers, lint mostly 25-150 microns in length Acetone, "Barr Klean Strip" Product NO. GAC18 Degreasing Solvent, MIL-PRF-680, Type III Simulated Seawater: Salinity - 35,000 –ppm(m) +/- 5% (Solar Salt, Medium Size)

a) Performance Evaluation

The performance evaluation consists of a series of tests using different influent oil concentrations and contaminant levels to determine the performance of the HSRMS in the highly variable conditions aboard Navy ships. Table 7 lists the influent conditions and test durations and order in which the tests will be carried out

Table 7. Performance Evaluation Test Conditions and Sampling Frequency

Test #	Test		Influent Mixture	# of Tests	Test Duration[1]	Sampling Frequency[2]
1,11	Oily Water		200-ppm NSBM #4	2	10 hours	Effluent – Two samples (t = 4,9) Influent – One samples (t = 4) Waste Oil – One sample (t=8) Quality Assurance – One Sample (100 ppm)
2, 12	Oily Water		1,000-ppm NSBM #4	2	10 hours	Effluent – Four samples (t = 4,9+ triplicates) Influent – One sample (t = 4) Waste Oil – One sample (t=8) Quality Assurance – One Sample (15 ppm)
3a, 13a	OWHT Transition Test	1% Oil	1% NSBM #4	2	6 hours	Effluent (1% test) – One samples (t = 4) Influent (1% test) – One sample (t = 4) Effluent (50% Test) – One sample (t=10 min) Effluent (100% Test) – One sample (t = 30 min) Waste Oil – One sample (t=6.5) Quality Assurance – One Sample (100 ppm)
3b, 13b		Interface	50% NSBM #4 50% Water		10 min	
3c, 13c		Bulk Oil	100% NSBM #4		30 min	
4, 14	Oily Water & Mixed Detergent		1,000-ppm NSBM #4 100-ppm Detergent Mix #4	2	10 hours	Effluent – Four samples (t = 4,9+ triplicates) Influent – One sample (t = 4) Waste Oil – One sample (t=8) Quality Assurance – One Sample (100 ppm)
5,15	JP-5 Oily Water & Mixed Detergent		1,000-ppm NSBM #4 JP-5 Variant 100-ppm Detergent Mix #4	2	10 hours	Effluent – Four samples (t = 4,9+ triplicates) Influent – One sample (t = 4) Waste Oil – One sample (t=8) Quality Assurance – One Sample (100 ppm)
6,16	Oily Water & Detergent		1,000-ppm NSBM #4 100-ppm Type 1 Detergent	2	10 hours	Effluent – Two samples (t = 4,9) Influent – One sample (t = 4) Waste Oil – One sample (t=8) Quality Assurance – One Sample (15 ppm)
7,17	Oily Water & Seawater		1,000-ppm NSBM #4 35,000-ppm(m) Synthetic Seawater	2	10 hours	Effluent – Two samples (t = 4,9) Influent – One sample (t = 4) Waste Oil – One sample (t=8) Quality Assurance – One Sample (15 ppm)
8,18	Oily Water & AFFF		1,000-ppm NSBM #4, 100-ppm AFFF	2	10 hours	Effluent – Four samples (t = 4,9+ triplicates) Influent – One sample (t = 4) Waste Oil – One sample (t=8) Quality Assurance – One Sample (100 ppm)
9,19	Oily Water & Mixed Chemicals		1,000-ppm NSBM #4 0.17% "Clorox" bleach (260 mg/L NaOCl) 0.17% Acetone 0.17% Paint Thinner	2	10 hours	Effluent – Two samples (t = 4,9) Influent – One sample (t = 4) Waste Oil – One sample (t=8) Quality Assurance – One Sample (15 ppm)
10,20	Oily Water, Mixed Detergent, & Particles		1,000-ppm NSBM #4 100-ppm Detergent Mix #4 100-ppm (m) Arizona Test Dust (coarse) 0.70-ppm (m) Cloth Fibers (lint mostly 25-150 microns in length)	2	10 hours	Effluent – Four samples (t = 4,9 + triplicates) Influent – One sample (t = 4) Waste Oil – One sample (t=8) Quality Assurance – One Sample (100 ppm)

[2] Samples are planned to be collected in the first test round only. Samples will be collected in following test rounds if test or sample results from the first test round indicate a need to collect additional samples.

b) Reliability Testing

The uniform test plan requires a reliability evaluation that demonstrates a 400-hour MTBF with a 90% confidence level[1]. In order to achieve this level of confidence, no operational failures (critical or major) can occur during 922 hours of operation. The reliability tests extend the system's run-time from the end of the performance evaluation to a total operating time of at least 922 hours. For every 100 hours of reliability testing, the HSRMS will process a mixture of NSBM #4, solids, and fibers for 10 hours to demonstrate non-degraded performance. For the remaining 90 hours, the HSRMS will process a mixture of NSBM#4 and detergent mix no. 4 until the membranes are fouled. When the membranes are fouled (100% resistance or 2 bar), the membranes will be regenerated[6]. The HSRMS will then process potable water for subsequent reliability tests when not demonstrating non-degraded performance.

Table 8 summarizes the influent conditions and test durations for the reliability evaluation.

Table 8. Reliability Evaluation Test Conditions

Test	Influent Mixture	Duration (hours)	Sampling
Reliability: Oily Water and Detergent Mix No. 4[3]	Potable (building) Water 1,000-ppm NSBM#4 100-ppm Detergent Mix No.4	90 out of every 100 hours	N/A
Reliability: Water[3]	Potable (building) Water	90 out of every 100 hours	N/A
Reliability Non-Degradation: Oily Water & Particles	1,000-ppm NSBM #4 100-ppm (m) Arizona Test Dust (coarse) 0.70-ppm (m) Cloth Fibers (lint mostly 25-150 microns in length)	10 out of every 100 hours	Effluent – Two samples (t=4, 9) Waste Oil – One sample (t=8)

3.3.3 Data Collection

Data collection will follow the data collection plan described in Data Recording and Fluid Sampling sections of this report. Data collection specific to this test is described in the below sections.

a) Sampling Plan

Table 9. Performance Evaluation

Test #	Test	Time				Quality Control
		T=4	T=6	T=8	T=9	
1, 11	Oily Water	Effluent Influent		WO	Effluent	Standard (100 ppm)

[2] Samples are planned to be collected in the first test round only. Samples will be collected in following test rounds if test or sample results from the first test round indicate a need to collect additional samples.

[3] The HSRMS will process 1,000-ppm NSBM#4 and 100-ppm detergent mix no. 4 for 90 out of every 100 hours until the membranes are fouled. When the membranes are fouled, the membranes will be regenerated per "Protocols for the Regeneration and Integrity Verification of Aircraft Appliances & Equipment (AAE) Oily Waste Membrane System" (NSWCCD-63-TM-2017/33) [6]. The HSRMS will subsequently process building potable water.

Test #	Test		Time				Quality Control
			T=4	T=6	T=8	T=9	
2, 12	Oily Water		Effluent Influent		WO	Effluent Laboratory Triplicates (+2)	Standard (15 ppm)
3a, 13a	OWHT Transition Test	1% NSBM #4	Effluent Influent	WO			Standard (100 ppm)
3b, 13b		50% NSBM #4 50% fresh water		Effluent (at T=10 min)			
3c, 13c		100% NSBM #4		Effluent WO (at T = 30 min)			
4, 14	Oily Water & Mixed Detergent		Effluent Influent		WO	Effluent Laboratory Triplicates (+2)	Standard (100 ppm)
5,15	JP-5 Oily Water & Mixed Detergent		Effluent Influent		WO	Effluent	Standard (100 ppm)
6, 16	Oily Water & Type 1 Detergent		Effluent Influent		WO	Effluent	Standard (15 ppm)
7, 17	Oily Water & Seawater		Effluent Influent		WO	Effluent	Standard (15 ppm)
8, 18	Oily Water & AFFF		Effluent Influent		WO	Effluent Laboratory Triplicates (+2)	Standard (100 ppm)
9, 19	Oily Water & Chemicals		Effluent Influent		WO	Effluent	Standard (15 ppm)
10, 20	Oily Water, Mixed Detergent, & Particles		Effluent Influent		WO	Effluent Laboratory Triplicates (+2)	Standard (100 ppm)

Table 10. Reliability Evaluation (Non-Degradation)

Test #	Test	Time			Quality Control
		T=4	T=8	T=9	
31, Non-Degradation 1	Oily Water and particles	Effluent	WO	Effluent	
41, Non-Degradation 2		Effluent Laboratory Triplicate (+2 Bottles)	WO	Effluent	
51, Non-Degradation 3		Effluent	WO	Effluent	
61, Non-Degradation 4		Effluent	WO	Effluent	Standard (15 ppm)
71, Non-Degradation 5		Effluent Laboratory Triplicate (+2 Bottles)	WO	Effluent	
81, Non-Degradation 6		Effluent	WO	Effluent	
91, Non-Degradation 7		Effluent	WO	Effluent	Standard (100 ppm)

3.4 Membrane Life

3.4.1 Rationale

The membrane life portion of testing will determine the life span of the membranes prior to requiring cleaning. Per the evaluation's success criteria, the ceramic membranes are expected to reach at least 300 hours of operation prior to cleaning. By collecting this data, the failure mechanism, rate and frequency can be determined to provide a better estimation of total life cycle cost, including membrane replacement and maintenance.

3.4.2 Test Approach

The system will be operated as mentioned in the Laboratory Setup portion of this report. The membrane life test is incorporated into the reliability portion of the testing described in the System Processing Performance section of this report. Typically during reliability testing, water is run through the system for 90 out of every 100 hours until the total run time of 922 hours is reached. Since the membrane life test will be incorporated into the reliability testing, instead of processing water through the system during this test, oily water and detergents will be processed. The test duration will be determined by when the system reaches 100% resistance or 2 bar. At this point the membranes will be regenerated[6] and will continue processing water 90 out of every 100 hours for the remaining 922 hours. For specifics on the components of the test mixture and duration, reference Table 8.

3.4.3 Data Collection

Data collection will follow the data collection plan described in Data Recording and Fluid Sampling sections of this report. Effluent samples will not be collected and evaluated for EPA 1664 results during the membrane life test. Finer data resolution is possible to determine membrane failure via recordings of the OCM during these tests and will therefore be used as the basis for calculating membrane life.

3.5 Membrane Regeneration

3.5.1 Rationale

Previous ceramic membrane research conducted at NSWCCD has found chemical cleanings of ceramic membranes to greatly improve membrane performance once 100% resistance has been reached. As a part of this study, a chemical cleaning procedure developed for stationary ceramic membranes will be modified and employed to determine the cleaning benefit to the HSRMS and quantify regeneration. The purpose of this test is only to quantify the amount of regeneration achieved through the cleaning process. Any level of regeneration will be considered "successful" according to the success criteria; however this information coupled with the membrane failure rate will assist in determining maintenance and life cycle costs.

3.5.2 Test Approach

Once the membranes reach 100% resistance, the membranes will be regenerated. The 5 GPM Oily Waste Membrane System (OWMS) Regeneration Procedure[6] will be modified for the HSRMS. These modifications will include operating the HSRMS in the cleaning sub-process with the permeate loop configured in recirculation mode since the system must operate with the permeate valve open to avoid dead-heading the system. As in the listed regeneration protocol, hot water flushes and a dual detergent approach will be used, first regenerating with the basic cleaner, Micro-90, for 4 hours then regenerating with the acid counterpart, Micro A07, for 4 hours. The water used during recirculation will be heated and maintained at 120 °F. After the first 30 minutes of cleaning with Micro-90, all recirculated water will be directed to the UST for removal of gross contamination. Fresh Micro-90 solution will be prepared for system feed and used for the remaining 3.5 hours. The 4 hour cleaning cycle will be repeated with Micro A07 excluding the discharge of the cleaning solution after the first 30 minutes.

3.5.3 Data Collection

Data recorded will include the amount of consumables used during the procedure and total fluid requirements. To determine the regeneration quality, performance data will be recorded as mentioned in Section 3.2.3: Data Recording and Analysis for comparison of performance before and after system cleaning.

3.6 RMA Testing

3.6.1 Rationale

The primary purpose for collecting RMA data is to better understand shipboard needs and sailor burden prior to the shipboard demonstration. The information collected via RMA calculations will enable a better estimation of NSWCCD support required throughout the evaluation, operator training prior to the shipboard demonstration, and spare part procurements.

3.6.2 Test Approach

Reliability, maintainability, and availability objectives and success criteria are listed in Table 4 and is a passive process recorded throughout the performance, membrane life, and membrane regeneration testing. Reliability and maintainability of the HSRMS will be measured using the concept of operational availability (A_o). A_o, which also addresses supportability factors, will yield an estimate of what portion of time the HSRMS is operational and available for processing. A_o will be measured via MTBF, mean time to repair (MTTR), and mean logistic delay time (MLDT). MTBF quantitatively measures system reliability. MTTR quantitatively measures system maintainability. MLDT quantitatively measures HSRMS supportability.

Maximum time to repair (Max TTR) is the total allowed time for a single repair event to occur. The maintenance ratio is the ratio of total active maintenance man hours (scheduled and unscheduled) to the total operating time. Failures are categorized as follows:

- Critical – any failure that prevents attainment of a key performance parameter (e.g. effluent oil concentration greater than 15 ppm)
- Major – any failure that causes the system to lose capability to process oily waste, or a malfunction that requires more than five hours of corrective maintenance action to remedy (e.g. repeated plugging of membrane discs, OCM malfunction).
- Relevant – includes failure attributed to equipment design defects or equipment manufacturing defects.
- Non-relevant – includes failure attributed to operator or procedural error, or accident, mishandling, and improper storage or installation.

Definitions for how each of the RMA metrics will be calculated are provided below in Table 11.

Table 11. RMA Definitions

Performance Objective	Metric Definition
Reliability	$\text{MTBF} = \frac{\text{Total Number of Operating Hours}}{\text{Total Number of Failures}}$
	$K' = \frac{\text{Total Calendar Time} - \text{Downtime}}{\text{Total Number of Operating Hours}}$ $K'(\text{MTBF}) = \frac{\text{Total Calendar Time} - \text{Downtime}}{\text{Total Number of Failures}}$
Availability	$A_O = \frac{\text{Uptime}}{\text{Total Time}}$ $= \frac{\text{Uptime}}{(\text{Uptime} + \text{Downtime})}$ $A_O = \frac{(\text{Total Time} - \text{Downtime})}{\text{Total Time}}$ $A_O = \frac{K'(\text{MTBF}) - \text{MDT}}{K'(\text{MTBF})}$ $= \frac{1 - [\text{MTTR} + \text{MLDT}]}{K'(\text{MTBF})}$
Maintainability	$\text{MLDT} = \frac{\text{Total Logistic Time Delay}}{\text{Total Number of Failures}}$

Performance Objective	Metric Definition
	$\text{MTTR} = \frac{\text{Total Corrective Maintenance Time}}{\text{Total Number of Failures}}$
	$\text{MDT} = \frac{\text{Total Downtime}}{\text{Total Number of Failures}}$ $\text{MDT} = (\text{MTTR} + \text{MLDT})$
	$\text{Maintenance Ratio} = \frac{\text{Total Active Maintenance Man Hrs}}{\text{Total Operating Time}}$
Operability	Training time
	Operating time
	Maintenance time (Corrective and Preventative)
	Operator skill level

3.6.3 Data Collection

Data will be collected as required throughout the evaluation. This process is passive, meaning that there are no additional tests required to collect this data. Maintenance, operational down-time, part procurement and lead time, and other data pertinent to calculating RMA will be recorded during the evaluation and documented in the final report.

4.0 REFERENCE DOCUMENTS

Table 12. Reference Documents.

Reference Document	Title	Date	Applicable Sections of Reference Document	JTP Test	JTP Section
1	Uniform Test Plan for Oily Water Separators (Updated-2013), NSWCCD-63-TM-2013/26	11/ 2013	Entire Document	System Processing Performance	0
2	Military Performance Standard (MIL-PRF)-32097A, "Filtration Module, Oily Waste Membrane Type"	3/2005	Section 3.6.5: Operating Life	Membrane Life	3.4
3	Military Performance Standard (MIL-PRF)-32098A, Ultrafiltration System, 10-Gallon per Minute Oily Waste Membrane (OWMS-10)	9/2004	Section 3.6.3.2.3: Membrane Regeneration	Membrane Regeneration	3.5
4	"Shipboard Evaluation Test Plan for the Mahle-Norddeutsche Filter Vertriebs Deoiler 2000 PPT-BWS/MESB aboard USS FREEDOM (LCS-1)", NSWCCD-63-TM-2012/69	8/2012	RMA Section	RMA	3.6
5	"Demonstration Plan for a Prototype Oily Water Separator (OWS), NAG OPUS 6.6/22 RWO Modified 1.5 m^3/hr, Aboard USS SIMPSON (FFG 56)", NSWCCD-63-TM-2013/94	4/2014	RMA Section	RMA	3.6

6	"Protocols for the Regeneration and Integrity Verification of Aircraft Appliances & Equipment (AAE) Oily Waste Membrane System" (NSWCCD-63-TM-2017/33)	Draft	Entire Document	Membrane Regeneration	3.5
7	EPA 1664, Method 1664 - N-Hexane Extractable Material (HEM; Oil and Grease) and Silica Gel Treated N- Hexane Extractable Material (SGT-HEM; Non-polar Material) by Extraction and Gravimetry	2/1999	Entire Document	System Processing Performance	3.2.4 0

APPENDIX B: POINTS OF CONTACT

POINT OF CONTACT Name	ORGANIZATION Name Address	Phone Fax E-mail	Role in Project
Ms. Danielle M. Paynter	NSWC-Carderock Division	(301) 227-5089 Danielle.paynter@navy.mil	Principal Investigator
Dr. Jared Church	NSWC-Carderock Division	(301) 227-4950 Jared.k.church.ctr@navy.mil	Co-PI
Ms. Tracy Carole	NSWC-Carderock Division	(301) 227-4893 Tracy.carole@navy.mil	Co-PI
Mr. Sang Lee	NSWC-Carderock Division	(301) 227-5262 Sang.m.lee@navy.mil	Administrative
Ms. Deborah Russell	NSWC-Carderock Division	(301) 227-2718 Deborah.h.russell.ctr@navy.mil	Financial
Mr. Donny Campbell	Military Sealift Command (MSC)	(757) 443-0882 Donald.g.campell2@navy.mil	Co-Performer
Ms. Lorraine Greene	Military Sealift Command (MSC)	(757) 443-0948 Lorraine.greene@navy.mil	Financial

APPENDIX C: HEALTH AND SAFETY PLAN

NSWCCD has a Health and Safety Plan (HASP) for their laboratories. The Bethesda Site Chemical Hygiene Plan addresses responsibilities, rules and procedures, chemical handling protocol, maintenance and inspections, medical surveillance, protective apparel, and training. In addition, NSWCCD personnel are required to take an annual shipboard training (TWMS-631353). This includes training on health and safety requirements. During the shipboard demonstration, NSWCCD personnel and MSC ship's force will be subject to health and safety guidance defined in the NAVOSH Afloat Safety and Occupational Heath Manual and OPNAVINST 5100.19F.

Furthermore, bilgewater is to be treated as a regulated waste. There will be no discharge of bilgewater with more than 15 ppm oil; as directed in DoD Instruction 4715.6 [1], Navy Instruction OPNAVINST 5090.1 [7], and Army Technical Bulletin TB55-1900-206-14 [8]. Oil found in bilgewater has possible health and fire hazards. Protocols defined in OPNAVINST 5100.19F should be followed with handling bilgewater and proper PPE should be worn. There is also a potential for hydrogen sulfide accumulation within the bilgewater tank. Therefore, confined spaces protocols should be followed. No personnel shall enter a confined space without proper authorization.

APPENDIX F: MANUAL DATA COLLECTION LOG SHEETS

Manual Log Sheet 1 of 3
Oily Water Separator (OWS) Readings

DATE _____

Operator Name _____

Pierside or Underway _____

System Readings

Time (displayed on HSRMS)	M100 Total Hours (hour)	Influent Flow		Effluent Flow		System Conditions		Oil Content Monitors				Operator Initials
		Influent Flow Rate / E-FM-1 (gpm)	Influent Total Flow (gal)	Effluent Flow Rate / E-FM-3 (gpm)	Effluent Total Flow (gal)	Overflow Valve Position / RV1600 (%)	Filter Torque (Nm)	ET-35N OCM No. 1 Reading (ppm)	ET-35N OCM No. 1 Alarm Indicator (Y/N)	Turner Designs TD -107 OCM No. 2 Reading (ppm)	Turner Designs TD-107 OCM No. 2 Alarm Indicator (Y/N)	

Storage Tanks

Time (displayed on HSRMS)	OWHT Level	WOT Level	Diverter Valve Position
	(gal)	(gal)	(Overboard/ Recirculation)

HSRMS Hydraulic Parameter for Resistance Calculation

Time (displayed on HSRMS)	Influent Pressure PIC1100	Effluent Pressure PIC1200	Effluent Flow Rate FIC1200	Effluent Temperature TIC1200	Overflow Flow Rate FIC1600	Overflow Temperature TIC1600
	(bar)	(bar)	(lph)	(°C)	(lph)	(°C)

Page_____ of _____

Manual Log Sheet 2 of 3
Comments Sheet

Date	Time (displayed on HSRMS)	Alarm (Y/N)	Comments	Initials

Page_____ of _____

Manual Log Sheet 3 of 3
Maintenance and Repair Log Sheet

Action (Maintenance /Repair)	Description	Start Date and Time*	End Date and Time*	Number and Rating of Personnel Involved	Total Man-Hours Required to Execute Operation	Problems Encountered and Actions Taken

* Record Date and Time displayed on HSRMS

Examples:
Problem: Lack of supplies (tools, parts, lubricants)
Action Taken: Supplies ordered and received MM/DD/YYYY

Page_____ of _____

APPENDIX G: SAMPLING AND ANALYSIS PLAN

INTRODUCTION

This Sampling and Analysis Plan (SAP) describes activities necessary to collect and analyze samples of oily waste for the evaluation of the Novoflow HSRMS. Samples will be taken by representatives of the Environmental and Energy Division, Code 63, NSWCCD during visits to the ship over a six-month evaluation period. The results of sample analytical testing will be used to document the performance of the OWS system during the evaluation.

SAMPLING APPROACH

Close coordination with ship's force will be executed by NSWCCD in order to schedule ship visits and sampling episodes at times that are convenient for the ship and when sufficient oily waste is accumulated to ensure that representative samples can be acquired from the Novoflow HSRMS. Samples may be taken from the Novoflow HSRMS while the ship is in-port and while it is underway, depending on the ship's schedule, in order to characterize Novoflow HSRMS's performance under a wide range of generation rates and variable oily waste characteristics. Samples may be taken while the Novoflow HSRMS is recirculating treated oily waste or while treating oily waste for overboard discharge. Ship status, Novoflow HSRMS operating variables, and other pertinent information regarding the conditions under which oily waste is treated will be recorded in detail during each sampling episode.

Ship visits that occur while in-port will be attempted to be scheduled to precede the offload evolution so that a sufficient volume of oily waste can be processed through the Novoflow HSRMS while samples are being taken. If the homeport maintains a zero discharge limit, the bulk stripping pump will be utilized to draw down the OWHT and transfer fluid to the WOT. At predetermined OWHT levels, samples shall be drawn for analysis. After the sampling episode has occurred, the transferred fluid in the WOT can then be offloaded via pier connection.

If possible, certain ship visits may be scheduled to occur several days prior to the ship getting underway so that both in-port and at-sea sampling can occur. If scheduled this way, NSWCCD will request that ship's force retain oily waste two to three days in advance of getting underway. Upon arrival NSWCCD personnel will sample oily waste that is processed through the OWS system prior to offload. If possible, NSWCCD personnel will then ride with the ship while underway and collect OWS system samples at-sea. If it is not possible to ride with the ship, NSWCCD personnel will attempt to collect OWS system samples after the propulsion system is started, but before it has left the pier. Finally, certain ship visits may be conducted while the ship is underway and Novoflow HSRMS samples will be collected at-sea.

The overall goal of the Novoflow HSRMS sampling effort will be to collect and analyze matched sets (OWS influent and effluent) taken during a six-month evaluation period. Samples will be analyzed for O&G and TPH measured by using U.S. Environmental Protection Agency Method 1664. EPA 1664 method uses n-hexane as an extraction solvent and gravimetry to measure O&G (total hydrocarbon content). A silica gel treatment technique is applied to the same sample for total petroleum hydrocarbon analysis. The minimum level of quantitation is 5 mg/l.

The following paragraphs present details of the sampling approach, including: sampling locations, sample collection methods, field sampling measurements, sample preservation, field documentation, field quality assurance/quality control (QA/QC) samples, and laboratory QA/QC samples.

Sampling Location, Type, Number, and Timing

All samples will be drawn from existing system sampling ports. OWS influent will be sampled from the sample port immediately downstream of the OWS basket strainer. OWS effluent samples will be drawn from the sample port located along the system's effluent line. To draw an effluent sample, the effluent will be accessible via the TD-107 OCM discharge as shown in Figure 1.

After an influent sample is drawn, the corresponding effluent sample will be drawn following a 10-minute waiting period. Allowing a 10-minute wait period between samples will allow for a better assessment of the treatment effectiveness.

Influent samples will not be sent out for analysis if the sample appears to contain a high percentage of oil. Samples with high percentages of oil will be collected in a 100 ml plastic graduated cylinder. After a 1-hour settling time, the volumes of the oil and water layers will be recorded and the oil content of the sample calculated.

Table G-1. Summary of Sampling Locations

Sampling Point Designation	Sampling Point Description	Sampling Location
SP-1	OWS Influent	Sample port immediately downstream of system basket strainer.
SP-2	OWS Effluent	Sample port on system effluent line.

Sample Collection Methods

Grab sampling shall be the sample collection method used during the OWS system evaluation. Three grab samples each of OWS influent and effluent will be collected during a sampling run at approximately 20, 50, and 80 percent of the OWHT to obtain a representative distribution of samples. If system recirculates without overboard discharge for more than 10 minutes, then a sample will be taken and the system will be shut down. OCM readings will be manually recorded on the sample collection sheet and automatically (by the DAS) recorded simultaneous to sampling events and compared to corresponding analytical results. The OCM decision regarding either overboard discharge or recirculation of treated oily waste back to the OWHT at the time of sampling will also be recorded. The number and type of samples and sample timing are summarized in Table D-2. Grab samples taken for quality assurance and quality control (QA/QC) are discussed in the laboratory QA/QC Samples section.

Table G-2. Sample Type and Number per OWS System Sampling Run

Sampling Point	Number of Grab Samples per Sampling Run	Sample Timing (one each at % of total run volume)	Field Duplicate	Matrix Spike	Matrix Spike Duplicate	Total Number of Samples
1st Bi-monthly Sampling						
SP-1	3	20, 50, 80	1 (50%)	N/A	N/A	4
SP-2 Effluent	3	20, 50, 80	N/A	1 (20%)	1 (20%)	5
15 ppm Standard	1	N/A	N/A	N/A	N/A	1
2nd Bi-monthly Sampling						
SP-1	3	20, 50, 80	N/A	1 (80%)	N/A	4
SP-2 Effluent	3	20, 50, 80	1 (20%)	N/A	N/A	4
15 ppm Standard	1	N/A	N/A	N/A	N/A	1

Quality Assurance/Quality Control (QA/QC) Samples

Field QA/QC Samples

Field duplicate samples consist of two successive samples collected from the same sampling point. Results of the field duplicate analyses are used to evaluate overall precision, and account for all sources of data variability, including sample collection, handling, preparation, and analysis. Field duplicate samples are typically collected at a frequency of 10 percent of the total number of field samples collected during the sampling episode. The number of field duplicate samples to be collected is summarized in Table D-2.

Laboratory QA/QC Samples

Matrix spike (MS) and matrix spike duplicate (MSD) samples collected during sampling episodes serve as laboratory QA/QC samples used to assess laboratory analytical quality control. The number and types of samples to be collected on the ship are presented in Table D-2. MS and MSD samples should be taken successively in the same grab. MS and MSD samples are collected at the frequency of approximately 10 percent of the field samples. These quality control analyses measure the accuracy of the laboratory analyses by spiking the sample with a hexadecane and steric acid spiking solution.

A 15 ppm standard sample can also be used to assess laboratory analytical quality control. This quality control analyses measures the accuracy of the laboratory analyses by spiking potable water with a known quantity of analyte and analyzing the spiked sample. The number and types of samples to be collected on the ship are presented in Table D-2. One 15 ppm standard sample will be pre-mixed in a laboratory and sent with each sampling episode for analysis.

Sample Preservation, Packaging, and Shipping

All sample containers will be labeled with standard sample labels. All samples will be tracked using a chain of custody (COC) form. The sample COC will begin at the time of sample collection and will be maintained by the sampling team until samples are relinquished for shipment to an analytical laboratory.

Preservation

All samples will be preserved on site according to EPA protocols, which in the case of Method 1664, requires the addition of a small quantity of hydrochloric acid or sulfuric acid to achieve a pH of 2. Sample bottles procured shall be preloaded by the analytical lab with a few milliliters sulfuric acid. The appropriate environmental, occupational health, and safety precautions that apply ashore and afloat shall be followed when handling the sample bottles with sulfuric acid. The samples are then packed in ice chests with a sufficient quantity of ice to maintain a temperature of 4°C until the samples arrive at the designated analytical laboratory. The ice chests shall be the type that is not equipped with a drain spout to prevent the release of water from melted ice.

Packaging

The sampling team will follow these general packaging and labeling procedures:

1. Double-bag ice in sealable one-gallon bags.
2. Place each properly labeled, preserved (if required), and capped glass sample bottle inside a bubble bag and seal with pull tab tape. Place this bag inside another bubble bag and seal. Place the bottle into a sealable one-gallon bag. Prior to bubble wrapping, write identifying information about the sample on the outside of the plastic bag with a permanent marker to facilitate information for COC and packing and shipping the samples.
3. Place two 30-gallon garbage bags (one inside the other) in the bottom of the cooler (Coolers and all cooler packing and identification materials shall be purchased and delivered to the ship before the sampling episode occurs).

4. Place sample bottles inside the inner garbage bag in the cooler and close the inner bag, removing as much excess air as possible. Fill the second garbage bag with the ice bags so that the cooler is completely filled. Close the outer garbage bag.
5. Place COC forms in a sealable one-gallon plastic bag and tape securely to the inside of the cooler lid. Place a "Return to" label on the inside cooler lid. Close the cooler.
6. Make several wraps with strapping tape around the cooler perpendicular to the seal to assure that the lid will remain closed.
7. Tape the cooler drain plug (if applicable) with strapping or duct tape so it will not open.
8. Remove labels from the cooler from previous shipping.
9. Place a completed address label on the lid of the cooler including name, address, and telephone number of the receiving laboratory and the return address and telephone number of the shipper. Cover the label with clear tape.

Shipping

All sample fractions are to be shipped via Federal Express Overnight (Priority One) from the local Federal Express office to the laboratory and personnel performing the analyses. Members of the sampling team will deliver the properly labeled sample packages to the local Federal Express Office or have Federal Express pick-up the packages on-site. If samples are collected while underway, ensure the samples are kept properly chilled and preserved until they can be shipped. For OCONUS samples, sample analysis feasibility will be determined based on international shipping regulations. If unable to ship internationally without ensuring the sample shipping quality, onsite measurement techniques will be investigated.

Field Documentation

The sampling team shall document information related to OWS system samples and operational parameters during sampling episodes. The information shall be recorded on Manual Data Collection Log Sheets. In general, the information shall include the following:

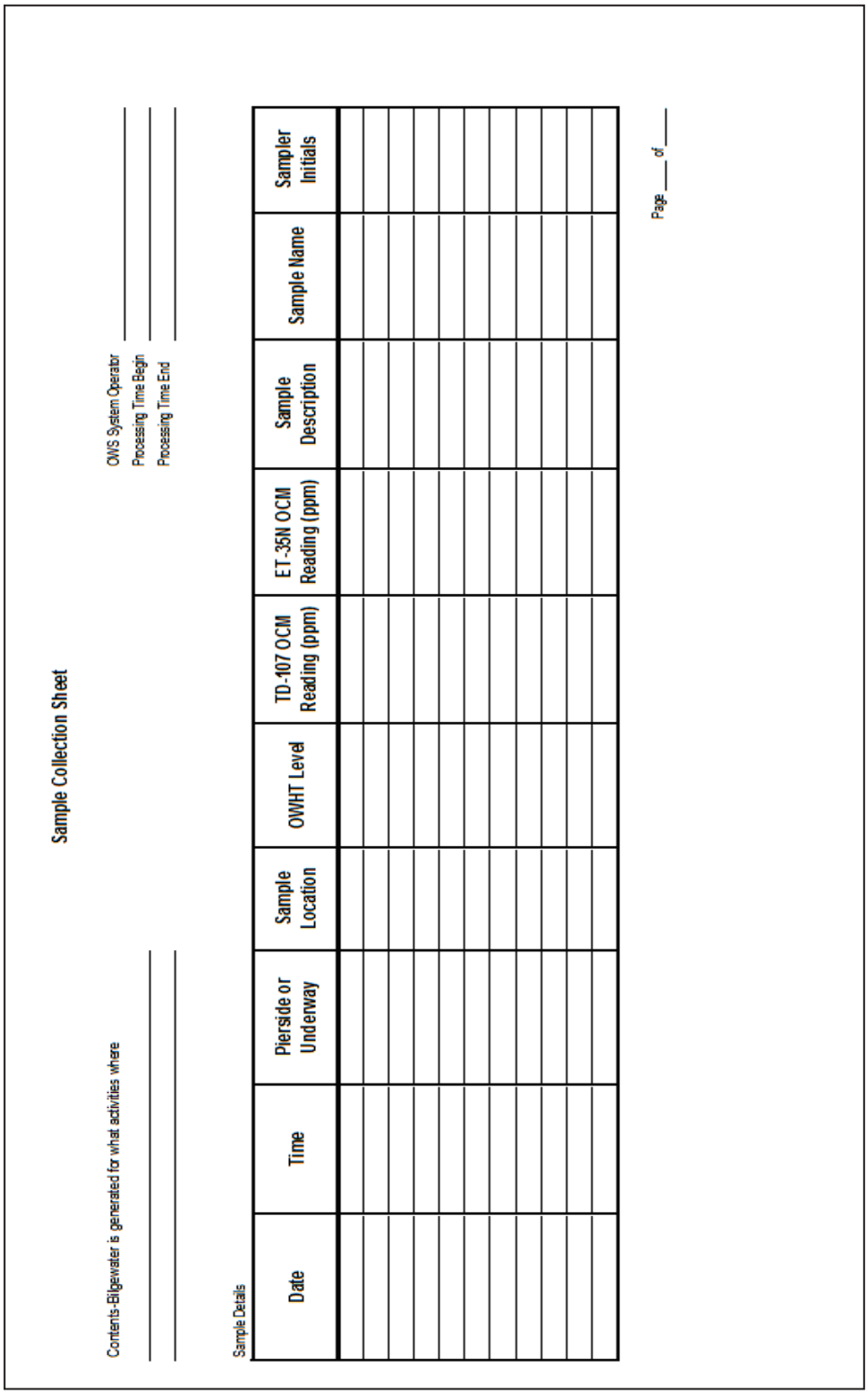
1. Information regarding OCM operating parameters,
2. Information regarding OWS operating parameters,
3. Additional notes and observations,
4. Sample COC form
5. Information regarding the sample and sampling circumstances

When the samples are shipped to the analytical laboratory, a COC form for each cooler will be completed. Two copies will be transmitted with the samples to the analytical laboratory and another copy will be kept by the samplers. When samples are received by the analytical laboratory, a copy of the COC form will then be returned to NSWCCD to acknowledge the receipt and condition of the samples.

All samples will be identified with a sample label in addition to an entry on a COC form. The sample labels will be completed with indelible ink, attached to the sample bottle, and

covered with clear plastic waterproof tape. Information on the sample labels will include the sample number, sample type, parameters to be analyzed, date of collection, time of collection, and preservation technique employed.

Sample Collection Data Sheets



Sample Collection Sheet

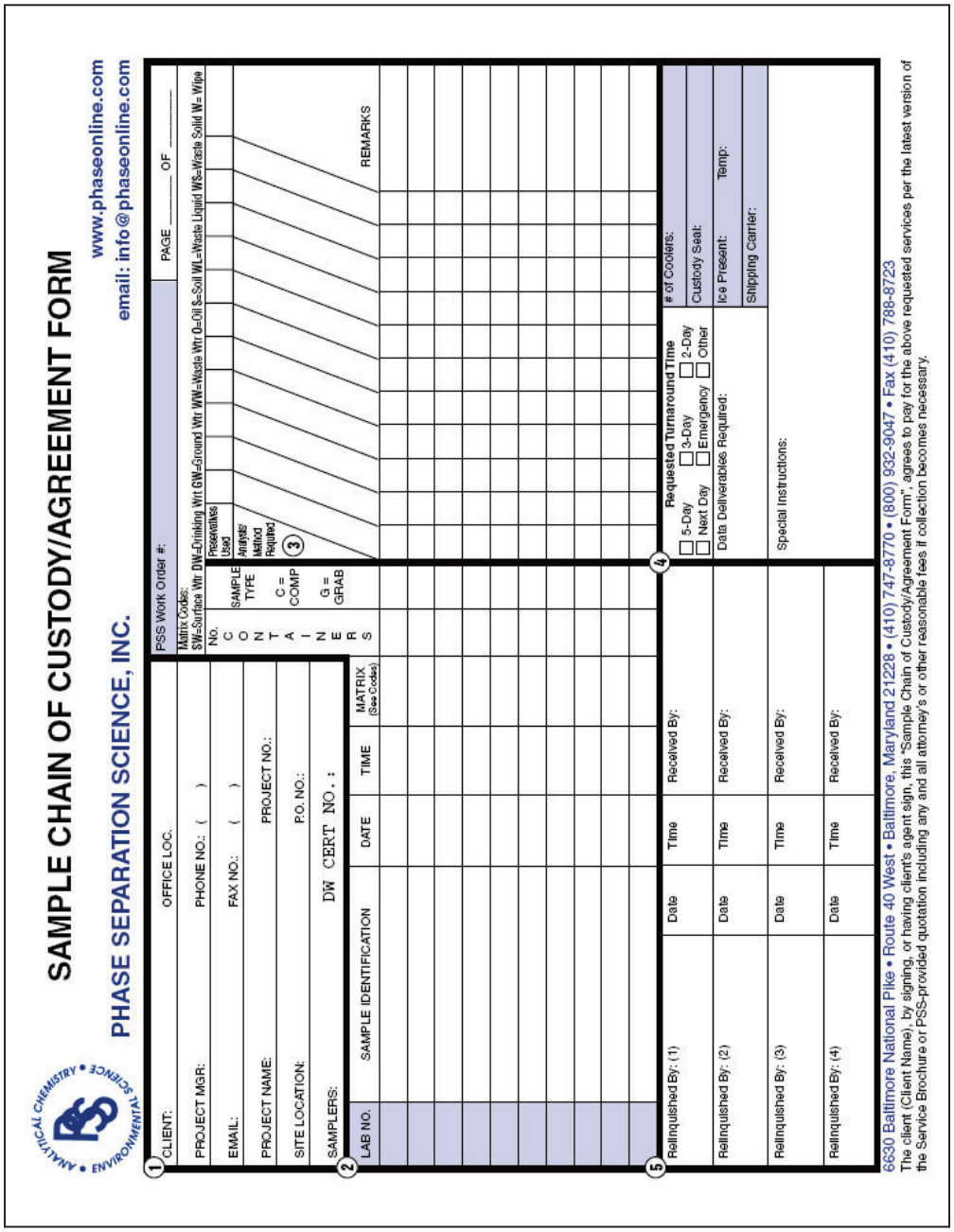
Contents-Bilgewater is generated for what activities where

OWS System Operator
Processing Time Begin
Processing Time End

Sample Details

Date	Time	Pierside or Underway	Sample Location	OWHT Level	TD-107 OCM Reading (ppm)	ET-35N OCM Reading (ppm)	Sample Description	Sample Name	Sampler Initials

Page ____ of ____



SAMPLE CHAIN OF CUSTODY/AGREEMENT FORM

PHASE SEPARATION SCIENCE, INC.

www.phaseonline.com
email: info@phaseonline.com

1 CLIENT: OFFICE LOC: PSS Work Order #: PAGE ____ OF ____

PROJECT MGR: PHONE NO.: ( ) Matrix Codes: SW=Surface Wtr DW=Drinking Wtr GW=Ground Wtr WW=Waste Wtr O=Oil S=Soil WL=Waste Liquid WS=Waste Solid W= Wipe

EMAIL: FAX NO.: ( ) CONTAINERS No. | SAMPLE TYPE C = COMP G = GRAB | Preservatives Used | Analysis/ Method Required (3) | REMARKS

PROJECT NAME: PROJECT NO.:

SITE LOCATION: P.O. NO.:

SAMPLERS: DW CERT NO.:

2 LAB NO. | SAMPLE IDENTIFICATION | DATE | TIME | MATRIX (See Codes)

5 Relinquished By: (1) Date Time Received By:
Relinquished By: (2) Date Time Received By:
Relinquished By: (3) Date Time Received By:
Relinquished By: (4) Date Time Received By:

4 Requested Turnaround Time
☐ 5-Day ☐ 3-Day ☐ 2-Day
☐ Next Day ☐ Emergency ☐ Other
Data Deliverables Required:
Special Instructions:

# of Coolers:
Custody Seal:
Ice Present: Temp:
Shipping Carrier:

6630 Baltimore National Pike • Route 40 West • Baltimore, Maryland 21228 • (410) 747-8770 • (800) 932-9047 • Fax (410) 788-8723
The client (Client Name), by signing, or having client's agent sign, this "Sample Chain of Custody/Agreement Form", agrees to pay for the above requested services per the latest version of the Service Brochure or PSS-provided quotation including any and all attorney's or other reasonable fees if collection becomes necessary.

SAMPLING PROCEDURE

The following subsections present specific information pertaining to this sampling episode. An onboard sampling team will perform sampling preparation work a few days prior to sampling.

Sample Team Organization

The sampling team will consist of representatives from NSWCCD who will arrange and coordinate all administrative and logistical aspects of the sampling effort. NSWCCD representatives will schedule the ship sampling periods and obtain the necessary concurrence of

the ship. The NSWCCD representative will also execute the following: provide in-briefs and out-briefs, arrange necessary ship and system operating conditions with the ship's crew, and document sample collection through photography and crew interviews. The NSWCCD representative will execute sample and operational data collection, preservation, and shipping activities performed on site. After completion of the visit, the analytical results from a contracted analytical laboratory will be collated and summarized in a sampling episode report as an appendix to the technical report documenting the OWS evaluation.

Detailed Procedure

Sample fractions collected will be labeled, sealed, and placed in coolers on ice for shipment to the analytical laboratories. The Sample Collection Sheet shall be completed as a sample is being drawn. The COC forms will be completed and placed in plastic bags inside the coolers after the day's samples are drawn. The sampling schedule should accommodate the ship's schedule and the availability of bilgewater for processing. At the conclusion, the sampling equipment will be removed and returned to its source.

Sample Nomenclature

All sample bottles will be identified with adhesive labels containing the date the sample was taken and a unique sample designator. The following format will be used to identify the samples:

Sample Designation Format: Sample Date – Sample Type – Sample Location (if applicable) – OWHT Level – Sample Duplicate (if applicable)

Sample Date:

In the format of ddmmyyyy (Time displayed on HSRMS)

Sample Type:

A = Normal Sample Draw

B = Quality Control

C1 or C2 = Effluent Spikes

Sample Location:

1 = Influent

2 = Effluent

OWHT Level:

Percent volume from tank level indicator (e.g. 80 = 80% of OWHT volume)

Duplicate:

D1 and D2 = Duplicates (if applicable)

Preparation for Sample Collection Procedure

Prior to sample collection, the following equipment should be set up at each oily waste sampling point:

- A sampling valve with the ability to collect a grab sample directly into a sample container or through Teflon or Nylon tubing;
- A sump or other container (e.g., a bucket under the sampling valve) in which to dispose of sample that is purged from the valve prior to sample collection;
- Properly labeled containers to collect a grab sample set (e.g., 1-L glass jars for EPA 1664 Analysis) containing the appropriate quantity of sulfuric acid
- 100 mL plastic graduated cylinder for influent samples that have a high percentage oil concentration

Sample Collection Procedure

The following sample collection procedure shall be followed:

1. Ensure that the sample bottle sets are complete, labeled, and readily accessible.
2. Ensure that the OPA system equipment is operating normally with all parameters within normal operating ranges.
3. Obtain grab samples as follows:
    a. For all samples, fully open the sample valve and allow the sample port to purge into a bucket for ten seconds.
    b. Fill the grab sample 1-L bottles. Fill each one without letting the sample spill over the rim of the jar. Allow for approximately a half inch of headspace to remain for each sample bottle. Record the time and date for each sample on the comments sheet and the COC form. For effluent samples collected, record the OCM reading at the time of the sample draw.
    c. After collecting influent or midpoint samples, wait ten minutes before taking the next downstream sample.
    d. Store the samples on ice.
    e. For influent samples with high oil concentration (approximately 5% or greater), collect the sample in the 100 mL plastic graduated cylinder. Fill the graduated cylinder to the 100 mL mark. Allow the sample to settle for one hour and record the water and oil volumes. If conditions such as high sea state prevent settling of the high oil sample, collect the sample in a sealable bottle. After conditions calm, thoroughly shake the sample and perform the settling in the graduated cylinder.

Post Sample Collection Procedure

After collection, store the sample fractions on ice until they can be packaged and shipped to the analytical laboratory. The samples should be packed in ice chests with a sufficient

quantity of ice to maintain a temperature of 4°C until the samples arrive at the designated analytical laboratory. The collected sample fractions will be sent to an analytical laboratory for EPA 1664 analysis.

CONTACT INFORMATION

This section summarizes contact information for the Navy, analytical laboratories, and the shipping company.

APPENDIX H: CHECKLIST FOR DATA LOGGER CONNECTIONS FOR INITIAL OPERATION

#	Connection	OK
	Flow Meters	
1	Influent Flow	
2	Effluent Flow	
	OCMs	
3	TD-107 OCM PPM Output	
4	TD-107 OCM High Alarm	
5	TD-107 OCM Cell Fouling Alarm	
6	TD-107 OCM Zero Alarm	
7	ET-35N OCM PPM Output	
8	ET-35N Alarm	
	Novoflow Control Panel	
9	Overflow Valve	
10	Backflush Water Valve	
11	Feed Pump Conductivity Probe	
12	Concentrate Discharge Valve	
13	Overflow Rate	
14	Effluent Flow Rate	
15	Torque	
16	Influent Pressure	
17	Effluent Pressure	
18	Effluent Temperature	
19	Overflow Temperature	
20	Novoflow On/Off	
	Valves	
21	3-Way Diverter Valve	

APPENDIX J: TAKE-9 COMPONENT PROCEDURE: ALIGNING AND OPERATING NOVOFLOW HSRMS OIL WATER SEPARATOR

DESCRIPTION:

The document includes the valve alignment and guidance for normal operation, concentrate discharge, and rinse cycle functions of the Novoflow HSRMS. For more detailed instructions on the use and maintenance of the Novoflow HSRMS, please refer to the "Novoflow HSRMS Operation Manual".

PROCEDURE

NOTE: Numbers refer to valves as numbered on drawing – APPENDIX A: HSRMS INSTALL DRAWING.
Final valve labels will be updated after the installation is complete.

WARNING!

Danger of injury due to improper operation!

Improper operation can cause serious injury or property damage.

a) NORMAL OPERATION

1. Verify system valve alignment

Ensure the following valves are **CLOSED**

Valve Description	Valve Label
Overflow to cleaning tank	HSRMS-V-03
HSRMS drain to cleaning tank	HSRMS-V-18
3-way valve (close to cleaning tank connection)	HSRMS-V-05
Cleaning tank system feed	HSRMS-V-04
Cleaning tank to recirculation	HSRMS-V-22
Potable water	HSRMS-V-15
Distilled Water	HSRMS-V-19
HSRMS drain to waste oil tank	HSRMS-V-06
Waste oil tank	OW-V-114

Ensure the following valves are **OPEN**

Valve Description	Valve Label
Machinery oily waste tank	OW-V-25
Machinery oily waste feed	HSRMS-V-01
Overflow recirculation	HSRMS-V-02
OWS recirculation	OW-V-71
Overboard discharge	OW-V-40
Filtrate	HSRMS-V-09
3-way valve (open to overboard)	HSRMS-V-05
HSRMS drain to recirculation valve	HSRMS-V-12
Distilled Water	HSRMS-V-07

	HSRMS-V-08

2. Turn on the Novoflow HSRMS via the “Main” switch located on the system control panel (Turn to red “On”). The touch panel HMI will take approximately 2-3 minutes to fully boot. Ensure “Control” switch is in the “On” position to allow control of the Touch Panel HMI. Locations of the Main Switch, Control Switch, and Touch Panel HMI are shown in Figure 1.

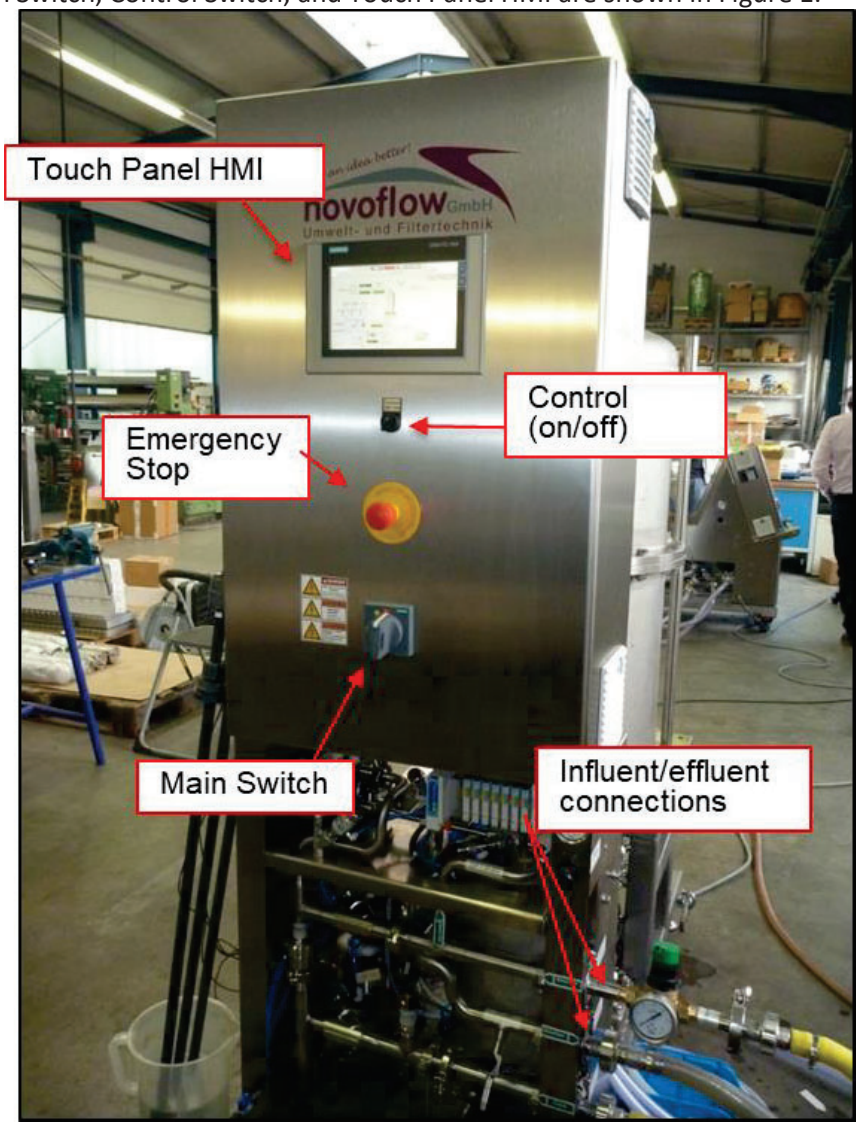


Figure J-1. Front view of Novoflow HSRMS

3. Check and clear all alarms. Refer to HSRMS operation manual for guidance on alarm trouble shooting.
   a. Open alarms menu on the top of the touch panel HMI (Fig. 2).
   b. Select alarm and select “ACK”.
   c. The password in 200.
4. Verify that the HSRMS is supplied with pressurized air by checking if the pressurized air indicator is green on the touch screen control panel (Fig. 2).

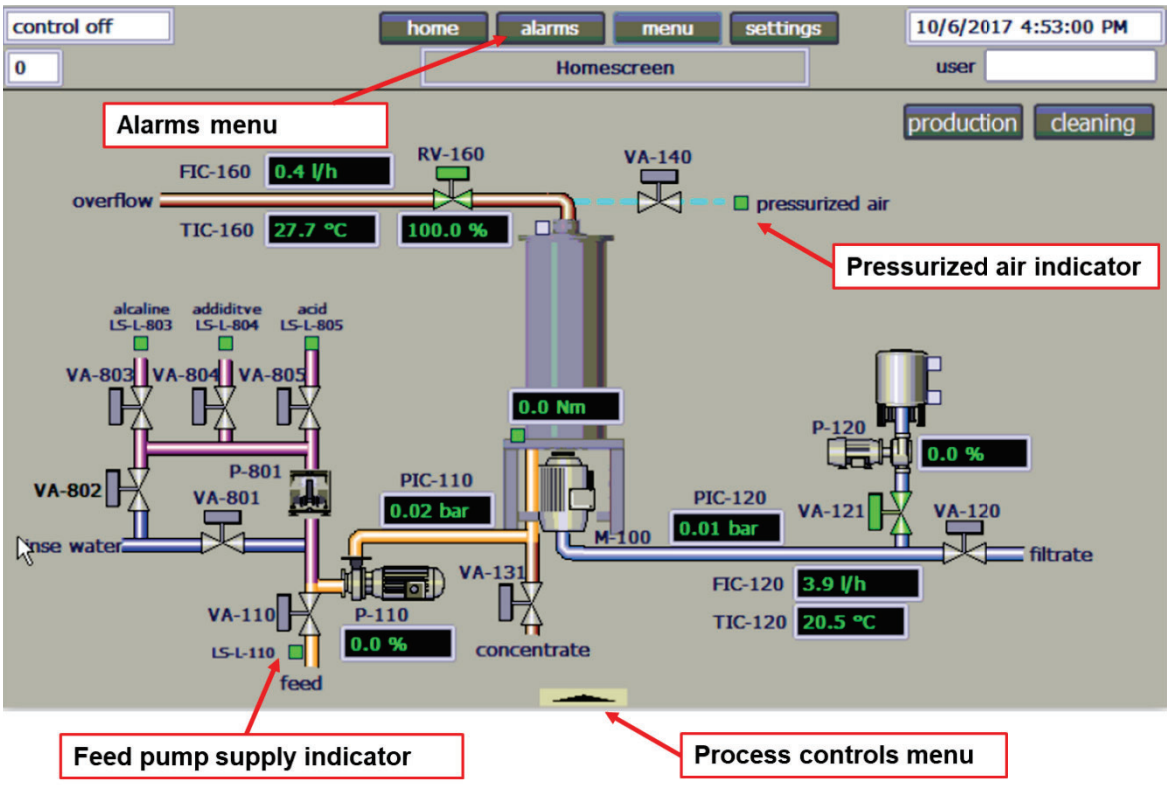


Figure J-2. Home screen of the Touch Panel HMI

5. Verify that the HSRMS feed pump is primed by checking if the LS-L-110 sensor indicator is green on the touch screen control panel (Fig. 2).
    a. If the feed pump is primed, continue to step 6.
6. Prime feed line as follows:

NOTE: Machinery oily waste tank is located slightly higher than the HSRMS. Therefore, gravity can be used to prime the influent line.

a. Ensure machinery oily waste tank contains at least 2 feet of liquid.
b. Ensure feed from machinery oily waste tank is **OPEN** HSRMS-V-01
c. Ensure feed from cleaning tank is **CLOSED** HSRMS-V-04
d. Open strainer (Figure 3) and wait until liquid is flowing out of the top of the strainer
e. Close strainer

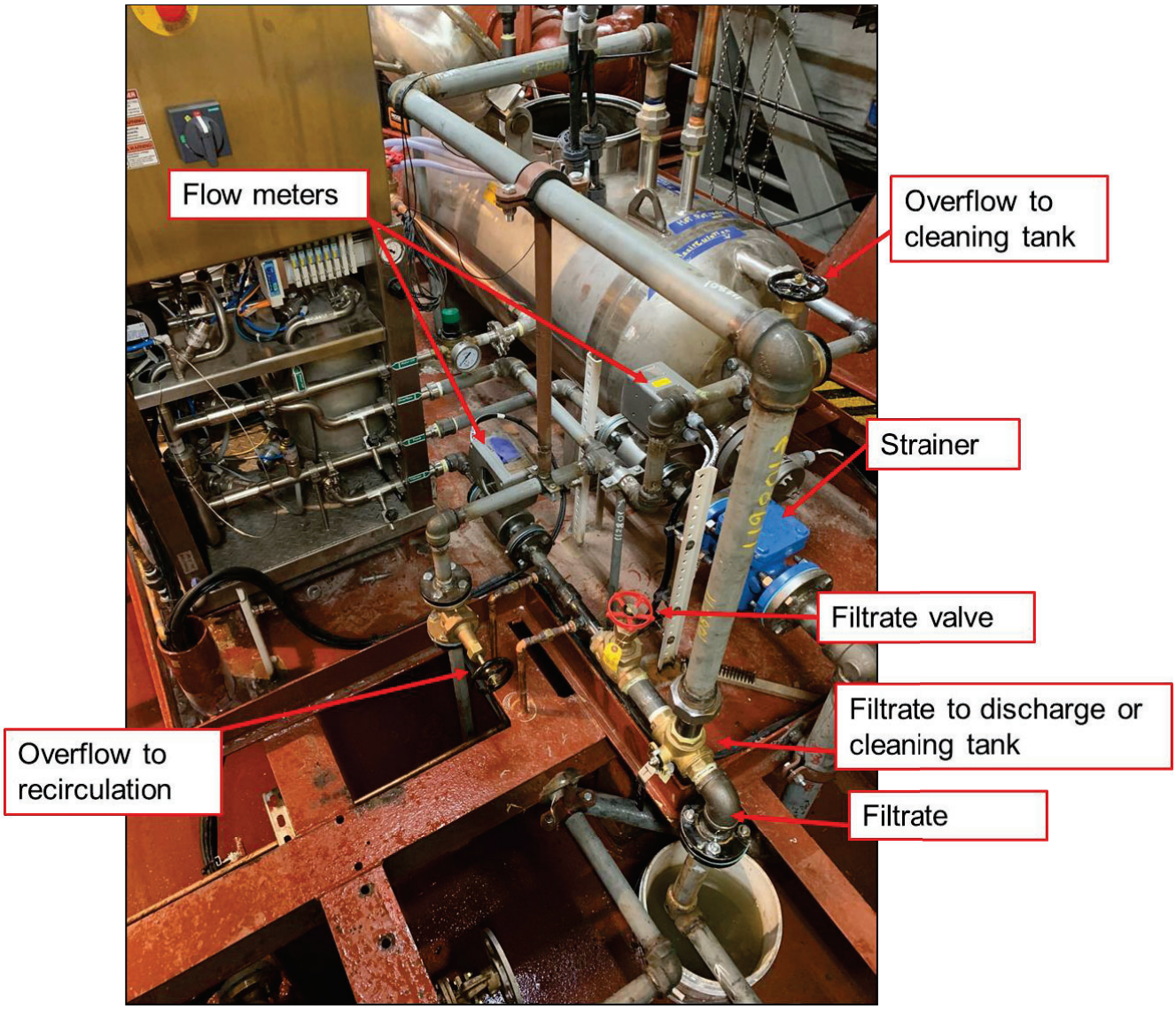


Figure J-3. Strainer and valve locations

7. Ensure OCMs are powered on and operational (refer to provided operation manuals for further guidance).
   a. Power on Turner TD-107 and ET-35N. Power supply switches are shown in Figure 4.
   b. Ensure potable supply valve to the ET-35N OCM is **CLOSED** (HSRMS-V-19).
   c. Ensure solenoid diverter valves are not locked in the overboard position (indicator lights on TD-107 control panel).

   NOTE: the Turner TD-107 OCM will automatically control OWS discharge via two solenoid valves (HSRMS-V-xx and HSRMS-V-xx). The ET-35N OCM will be used for data recording purposes only.

   NOTE: Per OPNAVINST 5090.1C, the OCM alarm limit (PPM) must be set to 15 ppm at all times

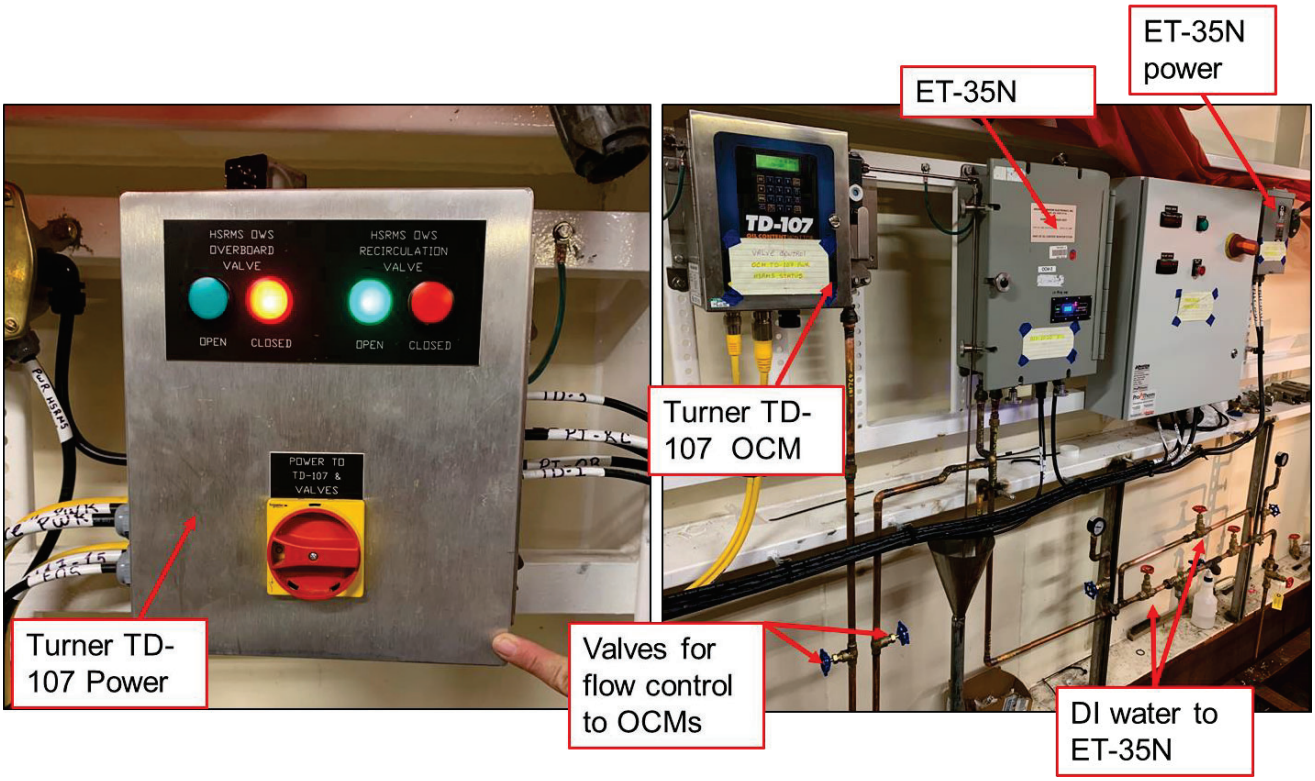


Figure J-4. OCM and OCM power locations

8. Open process controls (Figure 2) to start production. Select production “on” in the process controls menu (Figure 5).

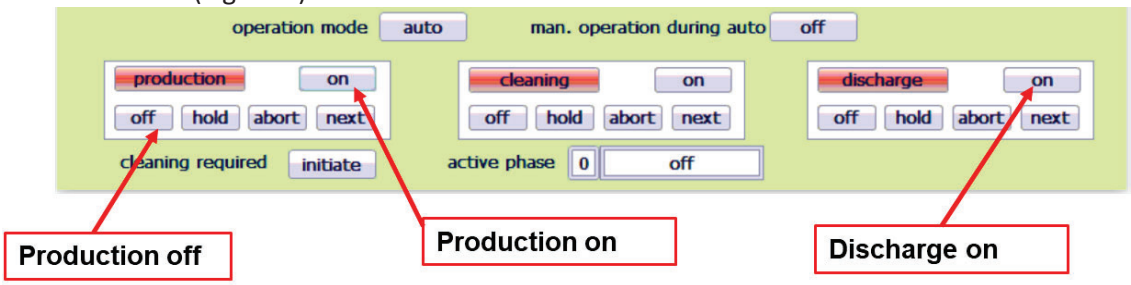


Figure J-4. Process Controls Menu

9. HMI will prompt several questions. Select “yes” to all.
10. Monitor the home screen to ensure there are no alarms. The membrane housing will fill with feed water. Once the upper level sensor indicates that the membrane housing is full, the HSRMS will automatically start rotating. Most alarms will occur before the membranes start rotating. Refer to and the NSWCCD guidance for trouble shooting alarms.

Note: If the feed line was not fully primed or if air gets into the feed line, the feed pump will lose pressure. An air vent is located on the back of the feed pump to vent any air in the feed line.

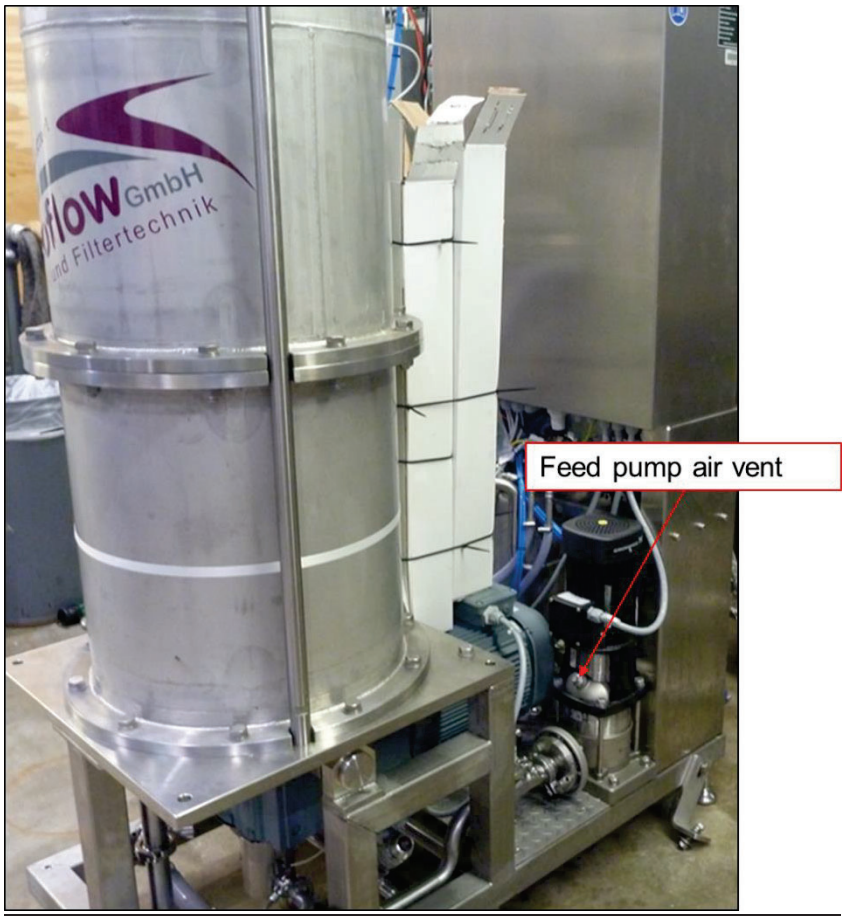


Figure J-5. Location of feed pump air vent

11. Check for leaks or abnormal operation (e.g., leaking seals, pooling beneath the system, loud noises, excessive vibrations, etc). If abnormal operation is detected, use the emergency stop button located on the front of the control panel to immediately stop operation. Report to NSWCCD is emergency stop is used.
12. Check filtrate is flowing to both OCMs and into drain funnel. Use valves to control flow so that flow is as low as possible without creating a stutter in the sample discharge lines.
13. Operate for one 8-hour shift or stop before bulk oil is reached. If bulk oil is reached, a concentrate discharge will need to be performed.
    NOTE: HSRMS will backflush automatically every 2 minutes
14. To shut down the HSRMS, open the process control menu on the touch screen and select production “off” (Fig. 5).
15. Perform concentrate discharge (See Section B (HSRMS CONCENTRATE DISCHARGE)) **only if bulk oil is reached** (i.e. torque alarm above 130 N • m or flow rate drops below 0.4 gpm). If bulk oil is was not reached during production, continue to step 16.
16. Rinse for 1 minute with potable water (See Section C (HSRMS RINSE)).
17. Shut down HSRMS via the main power switch (Fig. 1).
18. Shut down power to TD-107 OCM and ET-35N OCM.

b) HSRMS CONCENTRATE DISCHARGE

1. Verify system alignment.
   Ensure the following valves are **CLOSED**

Valve Description	Valve Label
Overflow to cleaning tank	HSRMS-V-03
HSRMS drain to cleaning tank	HSRMS-V-18
3-way valve (close to cleaning tank connection)	HSRMS-V-05
Cleaning tank system feed	HSRMS-V-04
Cleaning tank to recirculation	HSRMS-V-22
Potable water	HSRMS-V-15
Distilled Water	HSRMS-V-19
HSRMS drain to waste oil tank	HSRMS-V-06
Waste oil tank	OW-V-114

   Ensure the following valves are **OPEN**

Valve Description	Valve Label
Machinery oily waste tank	OW-V-25
Machinery oily waste feed	HSRMS-V-01
Overflow recirculation	HSRMS-V-02
OWS recirculation	OW-V-71
Overboard discharge	OW-V-40
Filtrate	HSRMS-V-09
3-way valve (open to overboard)	HSRMS-V-05
HSRMS drain to recirculation valve	HSRMS-V-12
Distilled Water	HSRMS-V-07 HSRMS-V-08

2. Open process controls to start concentrate discharge process. Select discharge “on” in the process control menu. Figures 2 & 5 shows where the process controls menu is located within the touch panel HMI.
3. System will automatically return to standby mode when concentrate discharge is complete. Concentrate discharge takes about 10 minutes.

c) HSRMS RINSE

NOTE: A rinse will be performed before every shutdown to prevent fouling the level sensor. If there is a level sensor alarm or if the filtrate flow rate drops below 2 gpm a rinse should also be performed.

1. Ensure Cleaning Tank is half full with room temperature potable water.
2. Verify system alignment
   Ensure the following valves are **CLOSED**

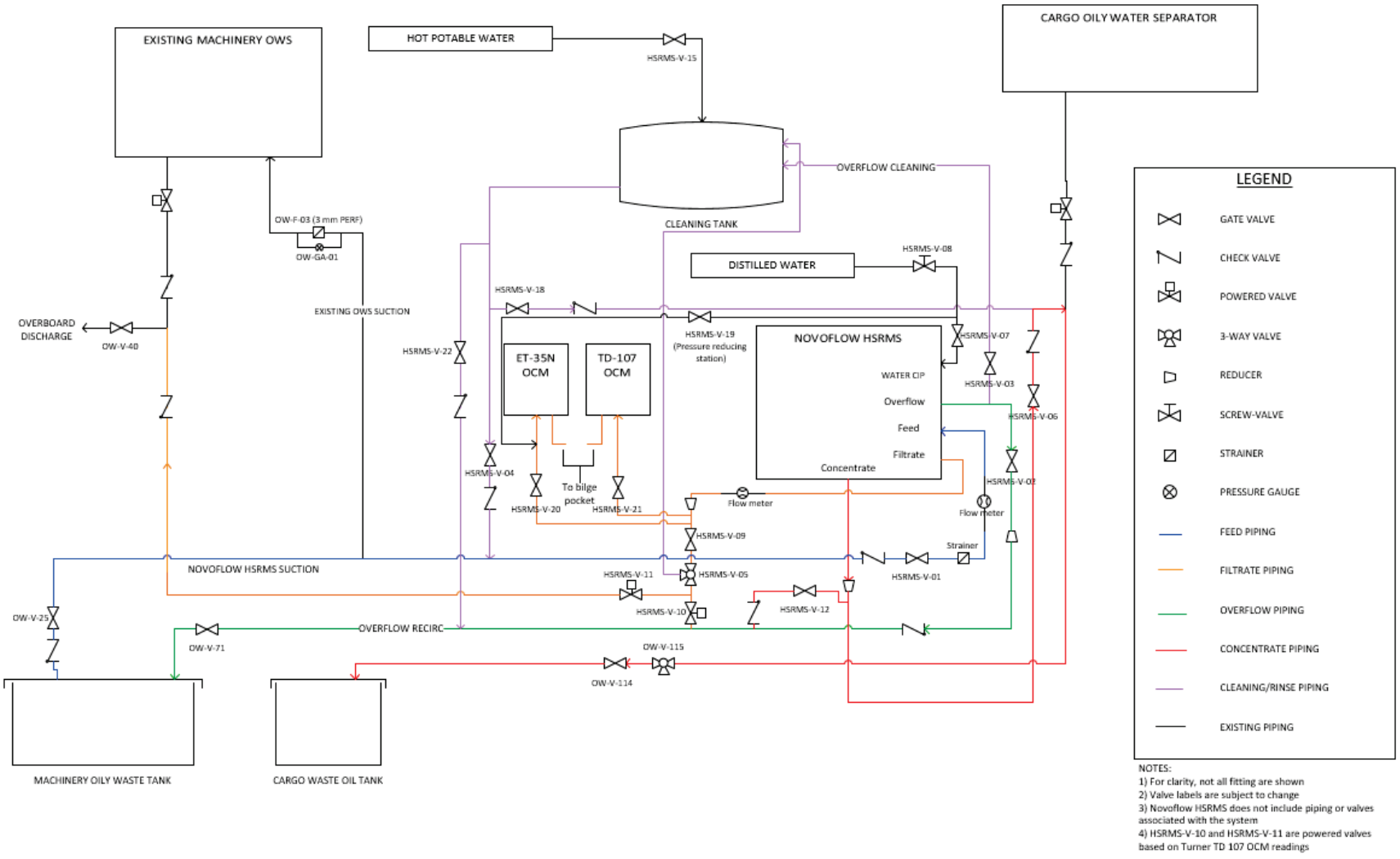
Valve Description	Valve Label
Overflow to cleaning tank	HSRMS-V-03

HSRMS drain to cleaning tank	HSRMS-V-18
3-way valve (close to cleaning tank connection)	HSRMS-V-05
Machinery oily waste feed	HSRMS-V-01
Cleaning tank to recirculation	HSRMS-V-22
Potable water	HSRMS-V-15
Distilled Water	HSRMS-V-19
HSRMS drain to waste oil tank	HSRMS-V-06
Waste oil tank	OW-V-114

Ensure the following valves are **OPEN**

Valve Description	**Valve Label**
Machinery oily waste tank	OW-V-25
Cleaning tank system feed	HSRMS-V-04
Overflow recirculation	HSRMS-V-02
OWS recirculation	OW-V-71
Overboard discharge	OW-V-40
Filtrate	HSRMS-V-09
3-way valve (open to overboard)	HSRMS-V-05
HSRMS drain to recirculation valve	HSRMS-V-12
Distilled Water	HSRMS-V-07 HSRMS-V-08

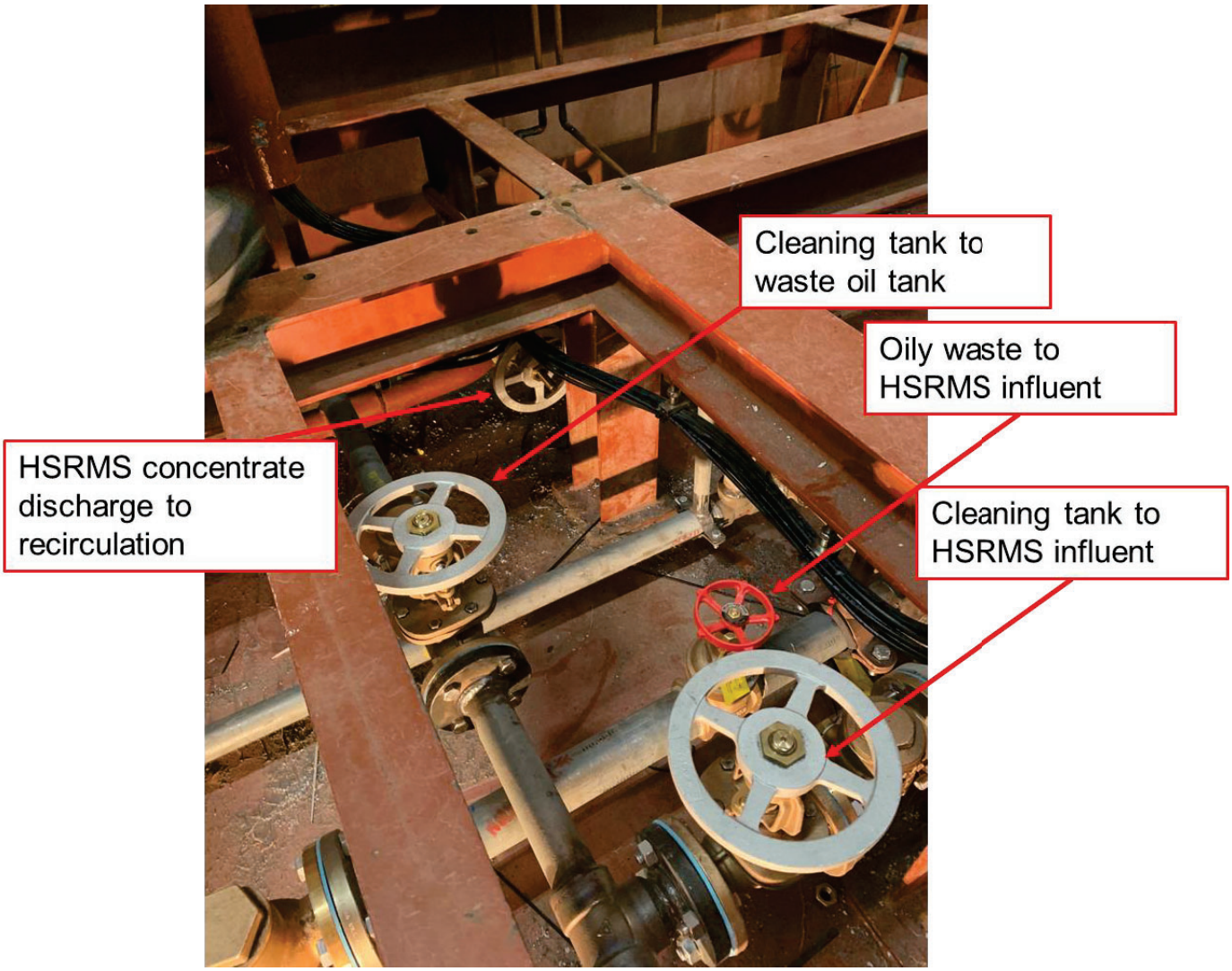
3. Open process controls to start production. Select production “on” in the process controls menu (Figure 3.).
4. Operate for 1 minute to allow the rinse water to clear the filtrate line. If LL-L-100 is not green after the first rinse, a second 1 minute rinse should be performed. If the LL-L-100, is still not green after the second rinse, contact NSWCCD.
5. Shut down system by selecting production “off” in process controls menu. Refer to the NSWCCD guidance and operation manual (pg. 23).

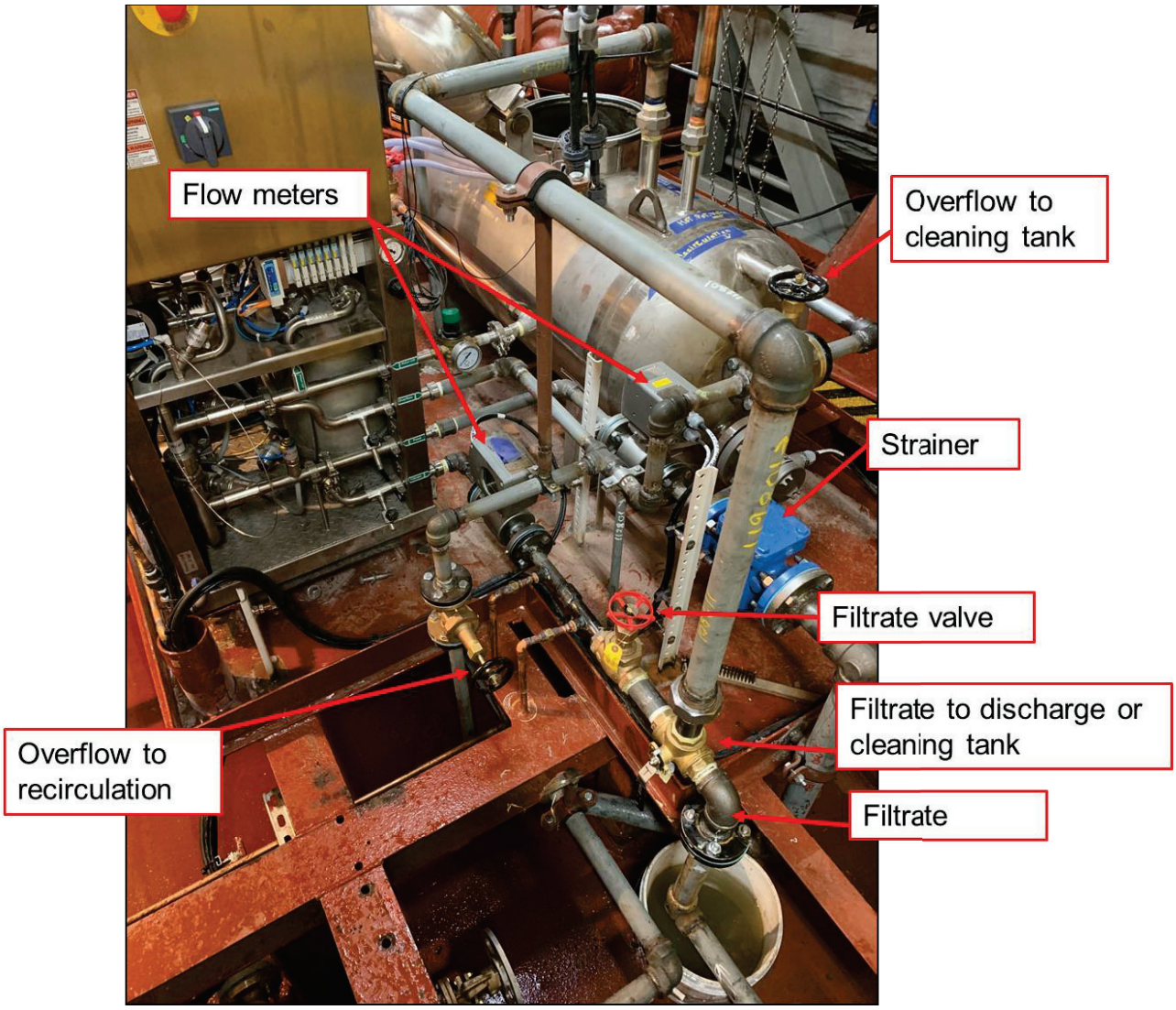


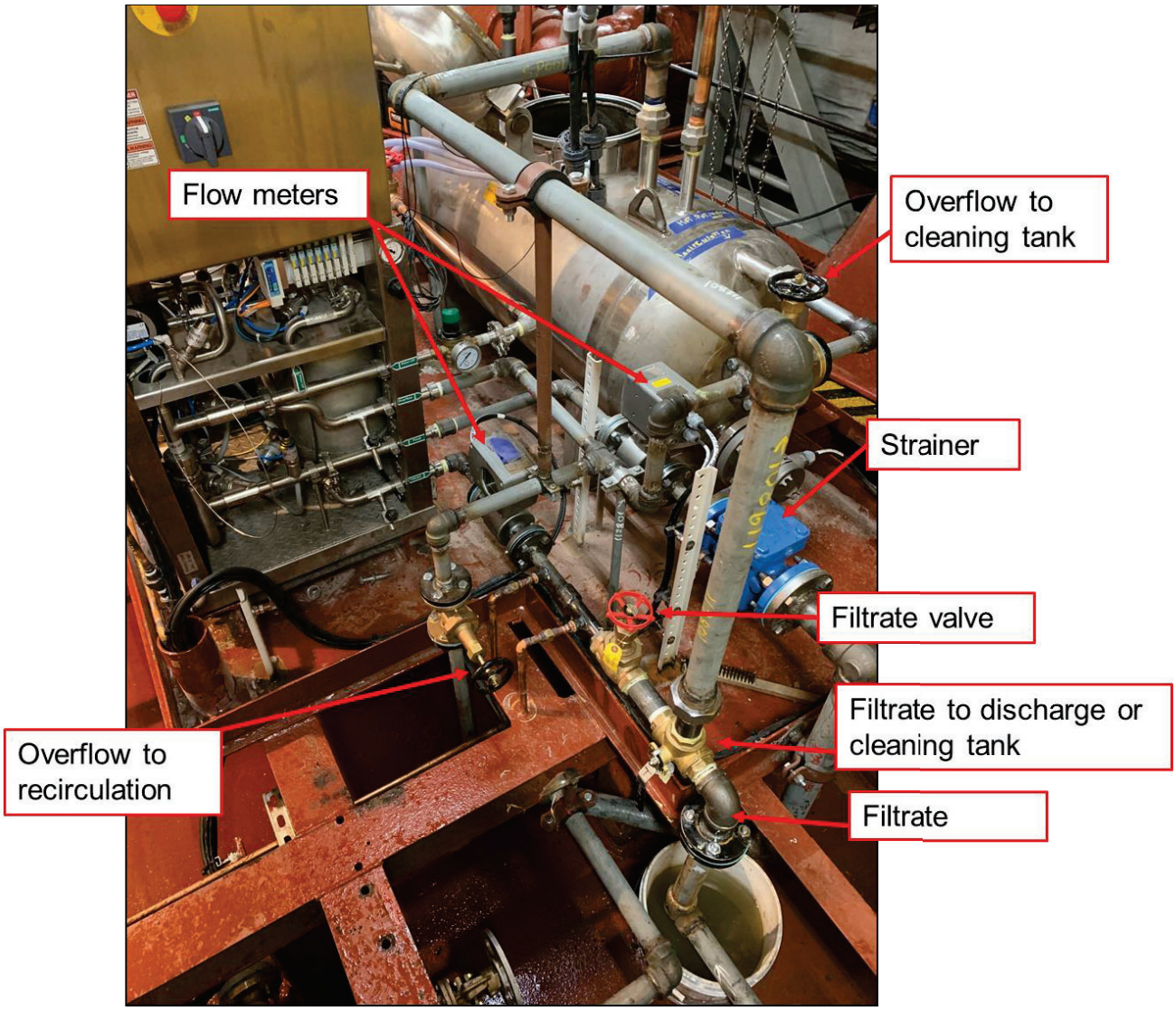
NOTES:
1) For clarity, not all fitting are shown
2) Valve labels are subject to change
3) Novoflow HSRMS does not include piping or valves associated with the system
4) HSRMS-V-10 and HSRMS-V-11 are powered valves based on Turner TD 107 OCM readings

Condition #	Alarm Condition	Description	Fix
1	Emergency Shutdown	The system's emergency stop was engaged. The system is equipped with a stand-alone emergency-stop button and a main switch that is configured as emergency-stop switch. If the emergency stop button is pushed, the "e-stop" alarm will appear.	Pull the emergency stop button back to disengage. Acknowledge the alarm in the "alarms" menu of the HMI.
2	Compressed Air Supply Loss	There is no compressed air supply to the system.	Check if the air supply has pressure by reading the regulator at the lower right of the system. Check the HMI for a green box by the pressurized air. Acknowledge the alarm in the "alarms" menu of the HMI.
3	Pump Dry Run (dry run P-110)	A capacitive level switch is installed upstream of the feed pump to protect the pump from running dry. If the sensor is dry or becomes fouled, the "dry run P-110" will alarm and shut down production in 15 seconds.	Check the valve alignment from the MOWT to the HSRMS. If a valve is closed the HSRMS will run dry. If the valve alignment is correct, check the sensor connection is not loose. The sensor should have a green or yellow LED is it is connected properly. Acknowledge the alarm in the "alarms" menu of the HMI and run a "rinse cycle" to try to clear the fouled sensor. If sensor is still fouls after "rinse cycle" contact NSWCCD.
4	Low Filtrate Flow (FIC-120 Alarm L underrun)	Filtrate flow is less than 100 lph (0.4 gpm).	Acknowledge the alarm in the "alarms" menu of the HMI. Run a rinse cycle to try to clean membrane surface. If low filtrate flow continues to alarm, the membranes may be irreversibly fouled. Contact NSWCCD.

5	High Feed Pressure	The pressure transducer installed downstream of the feed pump exceeded 4.5 bar (65.3 psi).	Acknowledge the alarm in the “alarms” menu of the HMI. Run a rinse cycle to try to clean membrane surface. If the high feed pressure continues to alarm, the membranes may be irreversibly fouled. Contact NSWCCD.
6	High Torque Alarm	The gear drive, which rotates the filter stack, exceeded the high torque alarm threshold set at 130 N • m (95.9 lb • ft). This indicates the bulk oil layer was reached.	Acknowledge the alarm in the “alarms” menu of the HMI. Run a rinse cycle to try to clear the oil from the membrane housing.
7	High Temperature Alarms	The flow meters on the HSRMS are equipped with temperature sensors. If a temperature above 70 °C (158 °F), is detected the system will alarm.	Determine the cause of the high temperature alarm. Acknowledge the alarm in the “alarms” menu of the HMI.
8	Loss of Power to Pumps/Motors	The HSRMS does not allow any procedures to occur until both pumps are detected. During system start up, the pumps take a few seconds to power on which causes several alarms; “P-110 VFD faulty”, “P-110 locked”, “P-120 VFD faulty”, and “P-120 locked”.	If the alarms are triggered during start up, acknowledge the alarms in the “alarms” menu of the HMI and continue operation. If the alarms are triggered during normal operation, shut down the HSRMS and contact NSWCCD.
9	Loss of Power to the Gear Drive	The HSRMS does not allow any procedures to occur until the gear drive is detected. During system start up, the gear drive takes a few seconds to power on which causes several alarms; “M-100 VFD faulty” and “M-100 locked” .	If the alarms are triggered during start up, acknowledge the alarms in the “alarms” menu of the HMI and continue operation. If the alarms are triggered during normal operation, shut down the HSRMS and contact NSWCCD.
10	Low CIP Fluid Levels	The CIP feature utilizes 3 suctions lances with integrated float switches. Trigger warnings for “LS-L-803 alkaline empty”, “LS-L-804 additive empty”, and “LS-L-805 acid empty”.	The CIP function will not be used during the evaluation. Verify that suction lances are in the upward position, acknowledge the alarms in the “alarms” menu of the HMI, and continue operation.


Cleaning tank to waste oil tank
Oily waste to HSRMS influent
HSRMS concentrate discharge to recirculation
Cleaning tank to HSRMS influent


Flow meters
Overflow to cleaning tank
Strainer
Filtrate valve
Filtrate to discharge or cleaning tank
Overflow to recirculation
Filtrate


Flow meters
Overflow to cleaning tank
Strainer
Filtrate valve
Filtrate to discharge or cleaning tank
Overflow to recirculation
Filtrate

APPENDIX K: SUMMARY OF DATA ACQUISITION SYSTEM FOR SHIPBOARD EVALUATION

Description	Event to be Logged	Justification	Frequency of Measurement
OWS System Status Indication: On off	Logs system status (on or off), change of state of the OWS	Will indicate that the system is on or off	**Event Based-** Records state (on/off)
OWS System Status Indication: Warning	Logs system status (warning) change of state of the OWS	Will indicate that the system is warning	**Event Based-** Records state (on/off)
OWS System Status Indication: Alarm	Logs system status (alarmed) change of state of the OWS	Will indicate that the system is alarmed	**Event Based-** Records state (on/off)
Influent Flow Meter	Logs (units of gpm) discharge flow rate	Will indicate the amount of influent entering the HSRMS	**Timed**- Every 5 seconds
Effluent Flow Meter	Logs (units of gpm) discharge flow rate	Will indicate the amount of effluent	**Timed**- Every 5 seconds
TD-107 OCM PPM Output	Logs (units of ppm) the value of contaminant measurement of samples drawn from the OWS effluent	Will indicate the condition of the OWS effluent	**Timed**- Every 5 seconds
TD-107 OCM High Alarm	Logs (on or off) a change of state of the High Alarm	Indicates ppm reading exceeds preset limit, for display purposes	**Event Based-** Records state (on/off)
TD-107 OCM Cell Fouling Alarm	Logs (on or off) a change of state of the Cell Fouling Alarm	Indicates cell readings may potentially be inaccurate and cell needs to be cleaned; if on, system will not perform overboard discharge	**Event Based-** Records state (on/off)
TD-107 OCM Zero Alarm	Logs (on or off) a change of state of the Zero Alarm	Indicates the oil content reads 0.0 ppm. This signal is logged for information purposes and has no effect on OCM operation	**Event Based-** Records state (on/off
ET-35N OCM PPM Output	Logs (units of ppm) the value of contaminant measurement of samples drawn from the OWS effluent	Will indicate that the system is on or off. Will also indicate if system has alarmed or in supervisory automatic mode	**Timed**- Every 5 seconds

ET-35N Alarm 1,2,3	Logs (on or off) a change of a blown fuse alarm	1) Indicates OCM fuse is blown, indicates dirt or bubbles in sample 2) Indicates dirt or foam in sample or no flow 3) Maintenance is required	**Event Based**- Records state (on/off) *Not recorded during evaluation due to relay failure.
Feed Pump Conductivity Probe	Logs conductivity reading	Will indicate dry run or bulk oil condition	**Timed**- Every 5 seconds
HSRMS System Status Indication	Logs system status (on or off, alarmed, supervisory automatic) change of state of the HSRMS	Will indicate that the system is on or off. Will also indicate if system has alarmed or in supervisory automatic mode	**Timed**- Every 5 seconds
Overflow Flow Meter	Logs (units of lph) recirculation flow rate	Will indicate the amount of fluid recirculated to OWHT	**Timed**- Every 5 seconds
Effluent Flow Meter	Logs (units of lph) recirculation flow rate	Will indicate the amount of HSRMS effluent before OCM	**Timed**- Every 5 seconds
Influent Pressure	Logs (units of bar) pressure of liquid entering the HSRMS	Will indicate degree of solids/sludge accumulation or membrane integrity	**Timed**- Every 5 seconds
Effluent Pressure	Logs (units of bar) pressure of filtrate leaving the HSRMS	Will indicate degree of solids/sludge accumulation or membrane integrity	**Timed**- Every 5 seconds
Overflow Temperature	Logs (units of °C) temperature of the overflow	Will indicate if membranes are exposed to thermal shock	**Timed**- Every 5 seconds
Effluent Temperature	Logs (units of °C) temperature of the Effluent	Will indicate if membranes are exposed to thermal shock	**Timed**- Every 5 seconds
Torque	Logs (units of N·m) the Torque of the rotating filter disk stack	Will indicate if the HSRMS is processing bulk oil	**Timed**- Every 5 seconds
Overflow Valve	Logs percent open of overflow valve	Will indicate volume recirculated to OWHT	**Timed**- Every 5 seconds

Backflush Water Valve	Logs when backflush water valve opens	Will indicate when system pressure is high or when system is in backflush mode	**Event Based**- Records change of state
Concentrate Discharge Valve	Logs when Concentrate Discharge valve opens	Will indicate when the system has completed a production cycle and discharges oil concentration to WOT	**Event Based**- Records change of state

APPENDIX L: OWS SYSTEM EVALUATION DATA COLLECTION REQUIREMENTS

OWS System Function/Criteria	Acceptance/Goal	Means of Data Collection	Category
Achieve acceptable duration of operation with no failures.	MTBF ≥ 922 Hours with No Failures (Relevant Critical or Relevant Major)	● DAS: -OWS System Status Indication (On/Off/Alarms) ● Ship's Force Log Sheets ● Crew Interview ● Manual Sample Collection	Reliability
Achieve operational availability (A_o) requirements.	$A_o \geq 95\%$	●DAS: -OWS System Status Indication (On/Off/Alarms) ● Ship's Force Log Sheets ● Crew Interview ● Manual Sample Collection	Reliability Maintainability Operability
Achieve maintenance requirements.	MTTR ≤ 3 Hours Max TTR ≤ 8 Hours Maintenance Ratio ≤ .03 Preventative Maintenance ≤ 3.5 Hrs per Week No Preventative Maintenance Action Shall Take > 16 Man Hrs	● Ship's Force Log Sheets ● Crew Interview Questionnaire ● Manual Sample Collection	Maintainability Operability
Achieve effluent requirements.	95% of OWS ≤ 15ppm Oil in Water Effluent Samples 100% of OWS ≤ 100ppm Oil in Water Effluent Samples	● DAS: -OWS System Status Indication (On/Off/Alarms) -TD-107/ET-35N OCM PPM Output -Effluent Flow Meter Readings ● Ship's Force Log Sheets ● Manual Sample Collection	Performance
Achieve acceptable water for transfer to WOT.	100% of Oil Discharge < 20% Water Samples to WOT	● Manual Sample Collection	Performance

Achieve a processing rate that exceeds bilge generation rate.	OWS must be sized to process the daily oily waste generation without accumulation in the OWHT within a 10 hour workday.	● DAS: -OWS Discharge Flow Rate -OWS Overflow Flow Rate -OWS System Status Indication (On/Off/Alarms) -TD-107/ET-35N OCM PPM Output -OWHT Level ● Ship's Force Log Sheets ● Manual Sample Collection	Performance
Determine operational and maintenance time requirements.	When should membranes be replaced? When should the OCMs be serviced? When should membranes need to be cleaned? When should basket strainer be cleaned?	● DAS: -OWS System Status Indication (On/Off/Alarms) -TD-107/ET-35N OCM PPM Output -OWS General Alarm -DP of OWS Basket Strainer -DP of Membrane Vessel ● Ship's Force Log Sheets ● Crew Interview Questionnaire ● Manual Sample Collection	Maintainability Operability
Determine if TD-107 OCM and EPA 1664 make congruent decisions. Also, determine degree of variation in oil concentration readings.	The OCM and chemical analysis should make the same decisions as to where to direct OWS effluent.	● DAS: -OWS System Status Indication (On/Off/Alarms) -TD-107/ET-35N OCM PPM Output -ET-35N OCM Alarms -TD-107 OCM Alarms -OWS Discharge Flow Rate ● Ship's Force Log Sheets ● Manual Sample Collection	Performance Operability Reliability
Determine if oil is being extracted from the OWS.	Once a significant amount of oil has accumulated in the membrane vessel, it should be discharged and directed to the WOT.	● DAS: -OWS System Status Indication (On/Off/Alarms) -OWS Concentrate Discharge -WOT Level	Operability Reliability

APPENDIX M: SHIP'S FORCE CORRESPONDENCE

From: Corey, William CIV (CHENG T-AKE 9)

To: Church, Jared K CIV (USA); McCarthy, James T. CIV (1ST A/E T-AKE 9); Mique, Jianna K. CIV; Landis, Lawrence L CIV (USA)

Cc: Lee, Sang M CIV USN NSWC CRD BDA MD (USA); Paynter, Danielle M CIV USN NSWC CRD BDA MD (USA); timothy.m.kelly3@navy.mil; Leroy, Dwight A CIV USN (USA)

Subject: RE: OWS Follow-up

Date: Thursday, March 3, 2022 2:25:03 PM

Jared,

I hope you received the previous emails we sent. Basically they were not happy with the operation of the HSRMS. It had a very low capacity of production and used a lot of water doing flushes.

We have not operated it since I arrived on the ship in November.

Regards,

William C. Corey Chief
Engineer

USNS Matthew Perry T-AKE 9
Unit 100479

FPO AP 96675-4108

NIPR: William.Corey.civ@ake9.navy.mil SIPR:
William.Corey.civ@ake9.navy.smil.mil Office:
850-549-0182

Cell: 757-927-6458

-----Original Message-----

From: Church, Jared K CIV (USA) [mailto:jared.k.church.civ@us.navy.mil]
Sent: Thursday, March 03, 2022 12:30 PM

To: Corey, William CIV (CHENG T-AKE 9); McCarthy, James T. CIV (1ST A/E T-AKE 9); Mique, Jianna K. CIV; Landis, Lawrence L. CIV 2 A/E

Cc: Lee, Sang M CIV USN NSWC CRD BDA MD (USA); Paynter, Danielle M CIV USN NSWC CRD BDA MD

(USA); timothy.m.kelly3@navy.mil; Leroy, Dwight A CIV USN (USA) Subject:
RE: OWS Follow-up

All,

As mentioned previously, the HSRMS will be removed during this upcoming MTA. I am still trying to get a handle on if the system has been operated since November 2021. We would like to be able to update our sponsors on its operation and pull the data if there has been additional hrs put on the system.

Thanks, Jared
Church

-----Original Message-----

From: Church, Jared K CIV (USA)

Sent: Thursday, February 3, 2022 3:49 PM

To: Corey, William CIV (CHENG T-AKE 9) <William.Corey.civ@ake9.navy.mil>; McCarthy, James T. CIV (1ST A/E T-AKE 9) <James.T.McCarthey.civ@ake9.navy.mil>; Mique, Jianna K. CIV

<Jianna.K.Mique.civ@ake9.navy.mil>; Landis, Lawrence L CIV (USA) <lawrence.l.landis.civ@ake9.navy.mil>
Cc: Lee, Sang M CIV USN NSWC CRD BDA MD (USA) <sang.m.lee@navy.mil>; Paynter, Danielle M CIV USN NSWC CRD BDA MD (USA) <danielle.paynter@navy.mil>; timothy.m.kelly3@navy.mil; Leroy, Dwight A CIV USN (USA) <dwight.a.leroy.civ@us.navy.mil>

Subject: RE: OWS Follow-up

CHENG,

Thanks for the info. We really appreciate your support on this. Our main objective is to determine the performance of the membranes in the new OWS, so we are really interested in the flowrate data and number of hours put on the system. The last update we received was on 09 November 2021 and there was some issues with start-up that seemed to be resolved. I am trying to figure out if the system has been operated since then so we can update our sponsors. I will stand by for input from 1AE and 3AE.

Thanks, Jared
Church

-----Original Message-----

From: Corey, William CIV (CHENG T-AKE 9) <William.Corey.civ@ake9.navy.mil> Sent:
Wednesday, February 2, 2022 5:27 PM

To: Church, Jared K CIV (USA) <jared.k.church.civ@us.navy.mil>; McCarthy, James T. CIV (1ST A/E T-AKE 9)

<James.T.McCarthey.civ@ake9.navy.mil>; Mique, Jianna K. CIV <Jianna.K.Mique.civ@ake9.navy.mil>; Landis, Lawrence L CIV (USA) <lawrence.l.landis.civ@ake9.navy.mil>

Cc: Lee, Sang M CIV USN NSWC CRD BDA MD (USA) <sang.m.lee@navy.mil>; Paynter, Danielle M CIV USN NSWC CRD BDA MD (USA) <danielle.paynter@navy.mil>; timothy.m.kelly3@navy.mil; Leroy, Dwight A CIV USN (USA) <dwight.a.leroy.civ@us.navy.mil>

Subject: RE: OWS Follow-up

Jared,

We have been very busy on the ship the past couple of months. My take on the new OWS is that it did NOT out-perform the existing OWS units that were originally installed. I am hoping the 1AE and 3AE on this email so they can provide more input.

Regards,

William C. Corey Chief
Engineer

USNS Matthew Perry T-AKE 9
Unit 100479

FPO AP 96675-4108

NIPR: William.Corey.civ@ake9.navy.mil SIPR:
William.Corey.civ@ake9.navy.smil.mil Office:
850-549-0182

Cell: 757-927-6458

-----Original Message-----

From: Church, Jared K CIV (USA) [mailto:jared.k.church.civ@us.navy.mil]
Sent: Wednesday, February 02, 2022 6:53 PM

To: Corey, William CIV (CHENG T-AKE 9); McCarthy, James T. CIV (1ST A/E T-AKE 9); Mique, Jianna K. CIV; Landis, Lawrence L. CIV 2 A/E

Cc: Lee, Sang M CIV USN NSWC CRD BDA MD (USA); CHENG; Paynter, Danielle M CIV USN NSWC CRD BDA MD (USA); timothy.m.kelly3@navy.mil; Leroy, Dwight A CIV USN (USA) Subject:
RE: OWS Follow-up

All,

Checking in to see if there are any updates with the HSRMS operation. Kirsten used to send data about once a month. Has the system been operated since she was relieved? If so, are you able to send the data? If you need any instruction on the operation or data offload, please let me know.

The system is supposed to be removed during this upcoming March MTA, so any information you have on the system as we close out the evaluation will be very useful.

Thanks, Jared
Church

-----Original Message-----

From: Corey, William CIV (CHENG T-AKE 9) <William.Corey.civ@ake9.navy.mil> Sent:
Monday, January 10, 2022 12:45 AM

To: Church, Jared K CIV (USA) <jared.k.church.civ@us.navy.mil>; McCarthy, James T. CIV (1ST A/E T-AKE 9)

<James.T.McCarthey.civ@ake9.navy.mil>; Mique, Jianna K. CIV <Jianna.K.Mique.civ@ake9.navy.mil>; Landis, Lawrence L CIV (USA) <lawrence.l.landis.civ@ake9.navy.mil>; Corey, William CIV (CHENG T-AKE 9)

<William.Corey.civ@ake9.navy.mil>

Cc: Lee, Sang M CIV USN NSWC CRD BDA MD (USA) <sang.m.lee@navy.mil>; melissa.a.gooch@navy.mil; CHENG <CHENG@ake9.navy.mil>; Paynter, Danielle M CIV USN NSWC CRD BDA MD (USA)

<danielle.paynter@navy.mil>; timothy.m.kelly3@navy.mil Subject:
RE: OWS Follow-up

Larry and Jianna,

Do you remember running this new OWS unit, and how did it do? Please provide any information you can.

Regards,

William C. Corey Chief
Engineer

USNS Matthew Perry T-AKE 9
Unit 100479

FPO AP 96675-4108

NIPR: William.Corey.civ@ake9.navy.mil SIPR:
William.Corey.civ@ake9.navy.smil.mil Office:
850-549-0182

Cell: 757-927-6458

-----Original Message-----

From: Church, Jared K CIV (USA) [mailto:jared.k.church.civ@us.navy.mil]
Sent: Friday, January 07, 2022 11:57 AM

To: McCarthy, James T. CIV (1ST A/E T-AKE 9)

Cc: Lee, Sang M CIV USN NSWC CRD BDA MD (USA); melissa.a.gooch@navy.mil; CHENG; Paynter, Danielle M CIV USN NSWC CRD BDA MD (USA); timothy.m.kelly3@navy.mil

Subject: RE: OWS Follow-up Hi

James,

Just wanted to check in to see if there are updates with the Novoflow OWS. Have you been able to run the system?

Thanks, Jared
Church

-----Original Message-----

From: Church, Jared K CIV (USA)

Sent: Wednesday, December 15, 2021 1:34 PM

To: McCarthy, James T. CIV (1ST A/E T-AKE 9) <James.T.McCarthey.civ@ake9.navy.mil>

Cc: Lee, Sang M CIV USN NSWC CRD BDA MD (USA) <sang.m.lee@navy.mil>; melissa.a.gooch@navy.mil; CHENG <CHENG@ake9.navy.mil>; Paynter, Danielle M CIV USN NSWC CRD BDA MD (USA)

<danielle.paynter@navy.mil>; timothy.m.kelly3@navy.mil Subject:
RE: OWS Follow-up

James,

I wanted to check in to see if you have been able to operate the Novoflow OWS. Please let me know if you have any

issues. An important component of this evaluation is your feedback on system operation; if the system works well or doesn't or you have design/operation suggestions, we want to hear about it.

We appreciate your support during the evaluation, and if you have any questions or if issue arise, don't hesitate to contact us.

Thanks, Jared
Church

-----Original Message-----

From: Church, Jared K CIV (USA)

Sent: Monday, November 29, 2021 2:55 PM

To: Figueroa, Kirsten R. CIV (1ST A/E T-AKE 9) <Kirsten.R.Figueroa.civ@ake9.navy.mil>; McCarthy, James T. CIV (1ST A/E T-AKE 9) <James.T.McCarthey.civ@ake9.navy.mil>

Cc: Lee, Sang M CIV USN NSWC CRD BDA MD (USA) <sang.m.lee@navy.mil>; melissa.a.gooch@navy.mil; CHENG <CHENG@ake9.navy.mil>; Paynter, Danielle M CIV USN NSWC CRD BDA MD (USA)

<danielle.paynter@navy.mil>; timothy.m.kelly3@navy.mil Subject:
RE: OWS Follow-up

Kirsten,

It was really great working with you over these last few months. I am sure it hasn't been easy dealing with the HSRMS while also maintaining your other responsibilities. We really appreciate your help with this project. I think we all learned a lot about how the system operates on a ship and the data collected during this evaluation will play a key role in decisions regarding future OWS technologies. We look forward to working with 1AE McCarthy moving forward.

Thanks, Jared
Church

-----Original Message-----

From: Figueroa, Kirsten R. CIV (1ST A/E T-AKE 9) <Kirsten.R.Figueroa.civ@ake9.navy.mil>
Sent: Sunday, November 28, 2021 8:12 PM

To: Church, Jared K CIV (USA) <jared.k.church.civ@us.navy.mil>; McCarthy, James T. CIV (1ST A/E T-AKE 9)

<James.T.McCarthey.civ@ake9.navy.mil>

Cc: Lee, Sang M CIV USN NSWC CRD BDA MD (USA) <sang.m.lee@navy.mil>; melissa.a.gooch@navy.mil; CHENG <CHENG@ake9.navy.mil>; Paynter, Danielle M CIV USN NSWC CRD BDA MD (USA)

<danielle.paynter@navy.mil>; timothy.m.kelly3@navy.mil Subject:
RE: OWS Follow-up

Jared,

I am currently doing turnover with my relief. Please for further contact regarding the OWS, contact 1AE James McCarthy who is cc'd in the email. Also the Chief engineer has been turned over to William Corey, but is CC'd with the generic 'CHENG' email. It has been an interesting experience and I hope you successfully get all the data you need for this project.

v/r

Kirsten Figueroa

1st Assistant Engineer

USNS Matthew Perry (T-AKE 9)

-----Original Message-----

From: Church, Jared K CIV (USA) [mailto:jared.k.church.civ@us.navy.mil]

Sent: Friday, November 05, 2021 2:39 PM

To: Figueroa, Kirsten R. CIV (1ST A/E T-AKE 9); Cruz, Edwin A. CIV (CHENG T-AKE 9)

Cc: Lee, Sang M CIV USN NSWC CRD BDA MD (USA); melissa.a.gooch@navy.mil; CHENG; Paynter, Danielle M CIV USN NSWC CRD BDA MD (USA); timothy.m.kelly3@navy.mil

Subject: RE: OWS Follow-up

Kirsten,

Thanks again for the update. Really appreciate you working through all these issues to get hours on the system. Glad you were able to redirect the OCM effluent to the cleaning tank. From your description, I think you might be right about something restricting flow on the recirculation line. That would explain why the system didn't discharge properly when you were cleaning the level sensor. Can you send the latest data? That would help us determine what is happening.

It sounds like the 'feed pump dry run' alarm was an issue with the lower level sensor (LS-L-110), since you saw flow through the pump vent and 4 bars of pressure. If LS-L-110 is fouled with oil, it thinks there is no fluid going to the pump and trips the dry run alarm. If you have issues again, you can try acknowledging the alarm and running again a few times to try to "rinse" the sensor. Just make sure there is actually fluid going to the pump. Processing the OCM effluent from the cleaning tank before each shutdown should help prevent this issue in the future.

I will relay the issues with system startup back to OEM to see if they have any suggestions. Thanks,

Jared Church

-----Original Message-----

From: Figueroa, Kirsten R. CIV (1ST A/E T-AKE 9) <Kirsten.R.Figueroa.civ@ake9.navy.mil>
Sent: Thursday, November 4, 2021 1:50 AM

To: Church, Jared K CIV (USA) <jared.k.church.civ@us.navy.mil>; Cruz, Edwin A CIV CPMS (USA)

<edwin.a.cruz.civ@ake9.navy.mil>

Cc: Lee, Sang M CIV USN NSWC CRD BDA MD (USA) <sang.m.lee@navy.mil>; melissa.a.gooch@navy.mil; CHENG <CHENG@ake9.navy.mil>; Paynter, Danielle M CIV USN NSWC CRD BDA MD (USA)

<danielle.paynter@navy.mil>; timothy.m.kelly3@navy.mil Subject:
RE: OWS Follow-up

Follow up to the previous.. I was able to get it back online again. Didn't do anything different other than power cycle, it just didn't trip on dry run. I primed the system with the MOWT and switched it over to process the cleaning tank and ran it for a bit with no other issues. I did wait a while when initially starting it for the high level sensor to illuminate. The overflow flow meter wasn't reading much, so I used the manual petcock until the level sensor was on long enough to start processing. It seems there may be a restriction on the overflow recirculation line somehow (after the ows skid). The feed/discharge flow rate did increase from the previous 1gpm to a whopping 3gpm after cleaning the strainer. This was with either MOWT or cleaning tank. We are pulling in soon, will continue after departure again.

v/r

Kirsten Figueroa

1st Assistant Engineer

USNS Matthew Perry (T-AKE 9)

-----Original Message-----

From: Figueroa, Kirsten R. CIV (1ST A/E T-AKE 9) Sent:
Thursday, November 04, 2021 3:44 AM

To: 'Church, Jared K CIV (USA)'; Cruz, Edwin A. CIV (CHENG T-AKE 9)

Cc: Lee, Sang M CIV USN NSWC CRD BDA MD (USA); melissa.a.gooch@navy.mil; CHENG; Paynter, Danielle M CIV USN NSWC CRD BDA MD (USA); timothy.m.kelly3@navy.mil; Figueroa, Kirsten R. CIV (1ST A/E T-AKE 9)

Subject: RE: OWS Follow-up Jared,

We got the tank hooked back up, the backflow preventer hasn't given any more problems since reseating the plunger. The sensor was cleaned, I managed to do a discharge back to the OWHT as per instructions. However, it would not shut off on its own after ~15 min, so I aborted it and depressurized using the overflow petcock. I reverted everything back to normal operation and had the same problem as before (idling), and yes the solenoid valve was showing open. I did another discharge to check the sensor, it was clean. Tried it again but this time venting at the overflow petcock until the filter filled and a solid stream came out. It began to run after that, the LS-HH-100 lit up for just a second and the M-100 started.

Shortly after this first time running, it tripped on something I did not get a picture of the alarms. It was something along the lines of the flow meters over run/under run. The overflow was a really high number if I recall. At this point we had improved our OCM dump diversion and filled up the cleaning tank and switched suctions to process the clean water tank. I started it like that and it stayed on after I switched back to MOWT suction (I had overflow manual petcock open until full stream to get it to run again). It ran like that for about 5 hours, every hour I would switch over the suction to the cleaning tank because it was getting full from the OCM dump. The whole time running I noticed the feed/ovbd discharge was pretty low (1gal/min) but I didn't want to shut it off until it ran for a while. I had the strainer pulled and cleaned after shutdown last night.

I wanted to see if cleaning would increase the flow and started it again this morning. Prior to start up, I made sure to vent the strainer housing and vent the feed pump. After a minute or so of it online and pressurizing system to ~4bar and clear flow through the pump vent, it trips on 'feed pump dry run'. I did this several times checking for flow and there was, also the pump was not getting hot. While the feed pump was running I checked for the following: overflow petcock open until solid stream, solid stream coming out of pump vent, solid stream at feed strainer, 4bar system pressure. After that I have not gotten it to run successfully, I will try again later to see if power cycling would have done anything.

v/r

Kirsten Figueroa

1st Assistant Engineer

USNS Matthew Perry (T-AKE 9)

-----Original Message-----

From: Church, Jared K CIV (USA) [mailto:jared.k.church.civ@us.navy.mil]
Sent: Monday, November 01, 2021 11:00 AM

To: Figueroa, Kirsten R. CIV (1ST A/E T-AKE 9); Cruz, Edwin A. CIV (CHENG T-AKE 9)

Cc: Lee, Sang M CIV USN NSWC CRD BDA MD (USA); melissa.a.gooch@navy.mil; CHENG; Paynter, Danielle M CIV USN NSWC CRD BDA MD (USA); timothy.m.kelly3@navy.mil

Subject: RE: OWS Follow-up

Kirsten,

Thanks for the update. Glad you were able to get the sensor cleaned. Looking forward to seeing if the system will operate correctly now.

Thanks, Jared
Church

-----Original Message-----

From: Figueroa, Kirsten R. CIV (1ST A/E T-AKE 9) <Kirsten.R.Figueroa.civ@ake9.navy.mil>
Sent: Saturday, October 30, 2021 10:05 PM

To: Church, Jared K CIV (USA) <jared.k.church.civ@us.navy.mil>; Cruz, Edwin A CIV CPMS (USA)

<edwin.a.cruz.civ@ake9.navy.mil>

Cc: Lee, Sang M CIV USN NSWC CRD BDA MD (USA) <sang.m.lee@navy.mil>; melissa.a.gooch@navy.mil; CHENG <CHENG@ake9.navy.mil>; Paynter, Danielle M CIV USN NSWC CRD BDA MD (USA)

<danielle.paynter@navy.mil>; timothy.m.kelly3@navy.mil Subject:
RE: OWS Follow-up

Jared,

Just to keep you updated, we had recently emptied all of our slops during our last port visit. In the meantime the sensor has been cleaned and we are currently reattaching the tank piping. Once that is done we'll flush and the unit and fill up MOWT water side to try again.

v/r

Kirsten Figueroa

1st Assistant Engineer

USNS Matthew Perry (T-AKE 9)

-----Original Message-----

From: Church, Jared K CIV (USA) [mailto:jared.k.church.civ@us.navy.mil]
Sent: Monday, October 25, 2021 12:08 PM

To: Figueroa, Kirsten R. CIV (1ST A/E T-AKE 9); Cruz, Edwin A. CIV (CHENG T-AKE 9)

Cc: Lee, Sang M CIV USN NSWC CRD BDA MD (USA); melissa.a.gooch@navy.mil; CHENG; Paynter, Danielle M CIV USN NSWC CRD BDA MD (USA); timothy.m.kelly3@navy.mil

Subject: RE: OWS Follow-up Hi

Kirsten,

Thanks for the update. I am surprised to hear the cleaning tank is not connected to the system. We used it during the installation to run the system. It must have not been put back online after hydro tesing, which is pretty frustrating. Would it be difficult to get reconnected?

From your description, it sounds like the level sensor is fouled with oil. This is something we came across during our testing and we were able to clear it by rinsing the system with potable water. However, it doesn't look like the rinse worked for you. I spoke with the OEM and they recommend removing the sensor and cleaning with it a rag. This

should be pretty straight forward. The sensor is easy to access. I have sent over a guidance document via dod safe with photos showing where the sensor is located and instructions on how to clean it.

Let us know how it goes. If the level sensor isn't the problem, we can look at the data to try to determine what the issue could be.

Thanks, Jared
Church

-----Original Message-----

From: Figueroa, Kirsten R. CIV (1ST A/E T-AKE 9) <Kirsten.R.Figueroa.civ@ake9.navy.mil>
Sent: Wednesday, October 20, 2021 3:44 AM

To: Church, Jared K CIV (USA) <jared.k.church.civ@us.navy.mil>; Cruz, Edwin A CIV CPMS (USA)

<edwin.a.cruz.civ@ake9.navy.mil>

Cc: Lee, Sang M CIV USN NSWC CRD BDA MD (USA) <sang.m.lee@navy.mil>; melissa.a.gooch@navy.mil;

CHENG <CHENG@ake9.navy.mil>; Paynter, Danielle M CIV USN NSWC CRD BDA MD (USA)

<danielle.paynter@navy.mil>; timothy.m.kelly3@navy.mil Subject:
RE: OWS Follow-up

Jared,

The DI leak is something that we can manage, it wasn't a matter of anything being loose. My original plan was to redirect the OCM dump to the clean water tank that is on the skid and recirc it back to either the feed pump suction or divert to COWT/MOWT. That backfired because the tank isn't piped into the system, The bottom of the tank is open and the pipe underneath leading up to it is capped off just before the tank. It wasn't obvious after the initial installation, but when water was dumping it was easier to trace.. I do have a backup location to divert the OCM to though. But that brings me to the next item..

Since we left the VR we have tried operating it and have run into some troubles. When trying to go into production mode, the feed pump kicks on and there is good pressure on the discharge. Venting it shows its getting oily waste. But after sitting there for 5 minutes... 10 minutes.. 15 minutes.. Nothing else happens. Usually the filter motor (M-100) would kick on and it would start processing. But it just sits with the feed and overflow valves open. I can see the feed pump running at 100% and charging the system to 4bar.

We originally thought that the MOWT level was too low so I had the watch engineer fill it and run again on his own. He eventually got an alarm saying to clean it. That is also how we discovered the washing tank was not connected to the system. I did do the CIP with the distilled water line and the cleaning function. It did the same thing, feed/overflow valves on and feed pump running but this time with the rinse water valve VA-801 open. It showed 0.2 L/H on the over flow and when I opened the petcock the flow jumped up to 10-12L/h. Anyways, the CIP didn't do much and when attempting to run after that the OWS performed the same as described above.

Also, I should mention that I did go into the cabinet and make sure all connections were tight. When it was running I had the cabinet open to monitor the VFD controllers. Nothing obvious to point out. Any guidance would be appreciated in the matter. I can upload the data from our failed starts if that would help?

v/r

Kirsten Figueroa

1st Assistant Engineer

USNS Matthew Perry (T-AKE 9)

-----Original Message-----

From: Church, Jared K CIV (USA) [mailto:jared.k.church.civ@us.navy.mil]
Sent: Tuesday, October 19, 2021 11:49 AM

To: Figueroa, Kirsten R. CIV (1ST A/E T-AKE 9); Cruz, Edwin A. CIV (CHENG T-AKE 9)

Cc: Lee, Sang M CIV USN NSWC CRD BDA MD (USA); melissa.a.gooch@navy.mil; CHENG; Paynter, Danielle M CIV USN NSWC CRD BDA MD (USA); timothy.m.kelly3@navy.mil

Subject: RE: OWS Follow-up Hi

Kirsten,

Just wanted to check in to see if there were any updates regarding the Novoflow OWS. Were you able to redirect the OCM effluent and fix the issue with the DI leak? Have you been able to operate the system since the VR period?

Thanks, Jared
Church

-----Original Message-----

From: Figueroa, Kirsten R. CIV (1ST A/E T-AKE 9) <Kirsten.R.Figueroa.civ@ake9.navy.mil>
Sent: Tuesday, September 21, 2021 1:17 AM

To: Church, Jared K CIV (USA) <jared.k.church.civ@us.navy.mil>; Cruz, Edwin A CIV CPMS (USA)

<edwin.a.cruz.civ@ake9.navy.mil>

Cc: Lee, Sang M CIV USN NSWC CRD BDA MD (USA) <sang.m.lee@navy.mil>; melissa.a.gooch@navy.mil; CHENG <CHENG@ake9.navy.mil>; Paynter, Danielle M CIV USN NSWC CRD BDA MD (USA)

<danielle.paynter@navy.mil>; timothy.m.kelly3@navy.mil Subject:
RE: OWS Follow-up

Jared,

Thank you for the drawings, I was able to retrieve them. We will be offloading slops before our departure, but when the opportunity arises again we will continue with data collection for the HSRMS and update with any new findings.

v/r

Kirsten Figueroa

1st Assistant Engineer

USNS Matthew Perry (T-AKE 9)

-----Original Message-----

From: Church, Jared K CIV (USA) [mailto:jared.k.church.civ@us.navy.mil]
Sent: Monday, September 20, 2021 3:10 PM

To: Figueroa, Kirsten R. CIV (1ST A/E T-AKE 9); Cruz, Edwin A. CIV (CHENG T-AKE 9)

Cc: Lee, Sang M CIV USN NSWC CRD BDA MD (USA); melissa.a.gooch@navy.mil; CHENG; Paynter, Danielle M CIV USN NSWC CRD BDA MD (USA); timothy.m.kelly3@navy.mil

Subject: RE: OWS Follow-up Hi

Kirsten,

Great to hear the system is running again! I just sent you our most current redline drawings via dod safe for future reference. Hopefully there won't be any more VFD issues moving forward.

Thanks for letting us know about the data logger. We anticipated there may be issues with UPS since the system sat in our lab without power for close to a year. I think we have the data being backed up every 5 mins, so worst case scenario is we lose 5 mins of data if there is a unexpected loss of power. I am double checking with the OEM that this shouldn't be an issue moving forward.

Just picked up the data you sent over DoD safe. We really appreciate you working around issues with the DI backflow preventer, OCM dump, and remote indicator to keep the system operational. Looking forward to updates after the VR period. Please reach out if you have any questions or concerns.

Thanks, Jared
Church

-----Original Message-----

From: Figueroa, Kirsten R. CIV (1ST A/E T-AKE 9) <Kirsten.R.Figueroa.civ@ake9.navy.mil>
Sent: Saturday, September 18, 2021 1:33 AM

To: Church, Jared K CIV (USA) <jared.k.church.civ@us.navy.mil>; Cruz, Edwin A CIV CPMS (USA)

<edwin.a.cruz.civ@ake9.navy.mil>

Cc: Lee, Sang M CIV USN NSWC CRD BDA MD (USA) <sang.m.lee@navy.mil>; melissa.a.gooch@navy.mil; CHENG <CHENG@ake9.navy.mil>; Paynter, Danielle M CIV USN NSWC CRD BDA MD (USA)

<danielle.paynter@navy.mil>; timothy.m.kelly3@navy.mil Subject:
RE: OWS Follow-up

Jared,

We were able to get the HSRMS running again, a rough redline drawing would have been helpful. But I went through and traced the cable and removed and reseated the associated wires and tightened up connections at for good measure. The vfd had no further issues.

One of the new things that came up is the backflow preventer installed in the distilled water supply line leaks. At one point it caused a significant loss in our Ship's distilled water tank because its tucked underneath deck plates and wasn't the first place we thought to look.. because the area is always wet from the OCM dump. It still leaks a bit when the unit is online, but not a big issue - we just cut off the main supply valve when not in use.

Another thing is in the data logger cabinet. The SITOP UPS1100 (-3C1) was not displaying an illuminated green 'OK' light. I took a meter to it and verified that there was no voltage. This in turn causes an alarm condition and battery fault on the adjacent SITOP UPS1600 (-3K1) module. The HSRMS was still able to run and the data logger is functional.

We just ran the unit for a couple of hours, it started off with ~6 gal/min discharge, then settled out to around 1-2gpm for the duration of its runtime. It still has a steady dump of ~2gpm via the OCM. We have come up with a plan to divert that OCM dump to a more suitable location. The ship is pulling in for a short VR period, during this time we will have the diversion in place and hopefully in the coming months we will be able to give more extensive data sets. At that time I will have someone see if the backflow preventer can be tightened up. When we pull in I will get the data uploaded to DODsafe.

v/r

Kirsten Figueroa

1st Assistant Engineer

USNS Matthew Perry (T-AKE 9)

-----Original Message-----

From: Church, Jared K CIV (USA) [mailto:jared.k.church.civ@us.navy.mil]
Sent: Wednesday, September 15, 2021 2:18 PM

To: Figueroa, Kirsten R. CIV (1ST A/E T-AKE 9); Cruz, Edwin A. CIV (CHENG T-AKE 9)

Cc: Lee, Sang M CIV USN NSWC CRD BDA MD (USA); melissa.a.gooch@navy.mil; CHENG; Paynter, Danielle M CIV USN NSWC CRD BDA MD (USA); timothy.m.kelly3@navy.mil

Subject: RE: OWS Follow-up Hi

Kirsten,

Just wanted to check in to see if you were able to get the HSRMS running. The evaluation period is fairly short so we are eagerly waiting to see if we can collect more data. We really appreciate your support with this.

Thanks, Jared
Church

-----Original Message-----

From: Church, Jared K CIV (USA)

Sent: Thursday, September 2, 2021 7:10 AM

To: Figueroa, Kirsten R. CIV (1ST A/E T-AKE 9) <Kirsten.R.Figueroa.civ@ake9.navy.mil>; Cruz, Edwin A CIV CPMS (USA) <edwin.a.cruz.civ@ake9.navy.mil>

Cc: Lee, Sang M CIV USN NSWC CRD BDA MD (USA) <sang.m.lee@navy.mil>; melissa.a.gooch@navy.mil; CHENG <CHENG@ake9.navy.mil>; Paynter, Danielle M CIV USN NSWC CRD BDA MD (USA)

<danielle.paynter@navy.mil>; timothy.m.kelly3@navy.mil Subject:
RE: OWS Follow-up

Kirsten,

Sounds good. Thanks for the update.

Thanks,

Jared Church

-----Original Message-----

From: Figueroa, Kirsten R. CIV (1ST A/E T-AKE 9) <Kirsten.R.Figueroa.civ@ake9.navy.mil>
Sent: Thursday, September 2, 2021 5:47 AM

To: Church, Jared K CIV (USA) <jared.k.church.civ@us.navy.mil>; Cruz, Edwin A CIV CPMS (USA)

<edwin.a.cruz.civ@ake9.navy.mil>

Cc: Lee, Sang M CIV USN NSWC CRD BDA MD (USA) <sang.m.lee@navy.mil>; melissa.a.gooch@navy.mil; CHENG <CHENG@ake9.navy.mil>; Paynter, Danielle M CIV USN NSWC CRD BDA MD (USA)

<danielle.paynter@navy.mil>; timothy.m.kelly3@navy.mil Subject:
RE: OWS Follow-up

Jared,

We have not gotten around to it. We just left port and the oil 3rd assisting me in the process has been relieved. I will notify on further progress in the near future.

v/r

Kirsten Figueroa

1st Assistant Engineer

USNS Matthew Perry (T-AKE 9)

-----Original Message-----

From: Church, Jared K CIV (USA) [mailto:jared.k.church.civ@us.navy.mil]
Sent: Wednesday, September 01, 2021 11:15 AM

To: Figueroa, Kirsten R. CIV (1ST A/E T-AKE 9); Cruz, Edwin A. CIV (CHENG T-AKE 9)

Cc: Lee, Sang M CIV USN NSWC CRD BDA MD (USA); melissa.a.gooch@navy.mil; CHENG; Paynter, Danielle M CIV USN NSWC CRD BDA MD (USA); timothy.m.kelly3@navy.mil

Subject: RE: OWS Follow-up Hi

Kirsten,

Just wanted to check in to see if you were able to get the HSRMS running.

Thanks, Jared
Church

-----Original Message-----

From: Figueroa, Kirsten R. CIV (1ST A/E T-AKE 9) <Kirsten.R.Figueroa.civ@ake9.navy.mil>
Sent: Thursday, August 19, 2021 8:08 PM

To: Church, Jared K CIV (USA) <jared.k.church.civ@us.navy.mil>; Cruz, Edwin A CIV CPMS (USA)

<edwin.a.cruz.civ@ake9.navy.mil>

Cc: Lee, Sang M CIV USN NSWC CRD BDA MD (USA) <sang.m.lee@navy.mil>; melissa.a.gooch@navy.mil; CHENG <CHENG@ake9.navy.mil>; Paynter, Danielle M CIV USN NSWC CRD BDA MD (USA)

<danielle.paynter@navy.mil>; timothy.m.kelly3@navy.mil Subject:
RE: OWS Follow-up

Jared,

I finally was able to download the files you dropped off, we'll take a look and report back with any findings.

v/r

Kirsten Figueroa

1st Assistant Engineer

USNS Matthew Perry (T-AKE 9)

-----Original Message-----

From: Church, Jared K CIV (USA) [mailto:jared.k.church.civ@us.navy.mil]
Sent: Tuesday, August 17, 2021 7:14 PM

To: Figueroa, Kirsten R. CIV (1ST A/E T-AKE 9); Cruz, Edwin A. CIV (CHENG T-AKE 9)

Cc: Lee, Sang M CIV USN NSWC CRD BDA MD (USA); melissa.a.gooch@navy.mil; CHENG; Paynter, Danielle M CIV USN NSWC CRD BDA MD (USA); timothy.m.kelly3@navy.mil

Subject: RE: OWS Follow-up

Resending this email without attachments since I received an undeliverable message. I just sent you the referenced tech documents via dodsafe.

-----Original Message-----

From: Church, Jared K CIV (USA)

Sent: Tuesday, August 17, 2021 2:21 PM

To: Paynter, Danielle M CIV USN NSWC CRD BDA MD (USA) <danielle.paynter@navy.mil>; Figueroa, Kirsten

R. CIV (1ST A/E T-AKE 9) <Kirsten.R.Figueroa.civ@ake9.navy.mil>; jared.k.church@navy.mil; timothy.m.kelly3@navy.mil

Cc: Lee, Sang M CIV USN NSWC CRD BDA MD (USA) <sang.m.lee@navy.mil>; melissa.a.gooch@navy.mil; CHENG - PERRY <Cheng@ake9.navy.mil>; Cruz, Edwin A CIV CPMS (USA)

<edwin.a.cruz.civ@ake9.navy.mil>
Subject: RE: OWS Follow-up

Hi Kirsten,

After talking with the manufacturer, there are a few steps we can try to resolve the issue with the VFD, working from simple to more complicated.

1) Try operating the system again over multiple days. The manufacturer thinks the fault could be due to a voltage fluctuation. Simply trying the system again should fix the problem.
2) Check voltage supply to both VFDs. This should be 480V AC. You can measure incoming to the cabinet or at the VFDs.
3) Check parameter 210 on the VFD following pg 29 of BOP-2 document. It should say 480V AC here.
4) Adjust parameter 210 following pgs 30 to 32 in the BOP-2 document.

Thanks again for letting us know about this issue. Hopefully it is resolved just by trying to operate the system again.

Thanks,

Jared Church

-----Original Message-----

From: Paynter, Danielle M CIV USN NSWC CRD BDA MD (USA) <danielle.paynter@navy.mil>

Sent: Friday, August 13, 2021 3:08 PM

To: Figueroa, Kirsten R. CIV (1ST A/E T-AKE 9) <Kirsten.R.Figueroa.civ@ake9.navy.mil>; jared.k.church@navy.mil; timothy.m.kelly3@navy.mil

Cc: Lee, Sang M CIV USN NSWC CRD BDA MD (USA) <sang.m.lee@navy.mil>; melissa.a.gooch@navy.mil; CHENG - PERRY <Cheng@ake9.navy.mil>; Cruz, Edwin A CIV CPMS (USA)

<edwin.a.cruz.civ@ake9.navy.mil> Subject:
RE: OWS Follow-up

Hi Kirsten,

Just wanted to reach back. So it looks like it's an issue with the supply voltage to the VFD. We've reached out to the manufacturer, and he suggested checking the voltage between the of the two VFDs on the system to see if there is a difference between the one you receive a fault with and the one that gives no error.

We are getting more clarification on how to resolve.

Thanks for letting us know the issue.

V/r, Danielle

-----Original Message-----

From: Figueroa, Kirsten R. CIV (1ST A/E T-AKE 9) <Kirsten.R.Figueroa.civ@ake9.navy.mil>
Sent: Friday, August 13, 2021 5:45 AM

To: Paynter, Danielle M CIV USN NSWC CRD BDA MD (USA) <danielle.paynter@navy.mil>; Church, Jared K CIV (USA) <jared.k.church@navy.mil>; Kelly, Timothy M CIV USN NSWC CRD BDA MD (USA)

<timothy.m.kelly3@navy.mil>

Cc: Lee, Sang M CIV USN NSWC CRD BDA MD (USA) <sang.m.lee@navy.mil>; Gooch, Melissa A CIV USN COMSC LANT NORFOLK (USA) <melissa.a.gooch@navy.mil>; CHENG - PERRY <Cheng@ake9.navy.mil>; Cruz, Edwin A. CIV (CHENG T-AKE 9) <Edwin.A.Cruz.civ@ake9.navy.mil>

Subject: RE: OWS Follow-up

All,

We are attempted to run the other day and came upon the error 'P-110 VFD faulty' and 'P-110 locked'. These alarms occur after the user attempts to initiate production and these are not the 'normal' alarms that come up after power cycling the unit. Looking in the cabinet during the time the faults come up, the siemens VFD controller reads 'Faults

0. F6310'. Since the pump isn't trying to restart after fault, they alarms reset and clear and it's back to square one.

v/r

Kirsten Figueroa

1st Assistant Engineer

USNS Matthew Perry (T-AKE 9)

-----Original Message-----

From: Paynter, Danielle M CIV USN NSWC CRD BDA MD (USA) [mailto:danielle.paynter@navy.mil] Sent: Tuesday, August 10, 2021 1:20 PM

To: Figueroa, Kirsten R. CIV (1ST A/E T-AKE 9); Church, Jared K CIV (USA); Kelly, Timothy M CIV USN NSWC CRD BDA MD (USA)

Cc: Lee, Sang M CIV USN NSWC CRD BDA MD (USA); Gooch, Melissa A CIV USN COMSC LANT NORFOLK (USA); CHENG; Cruz, Edwin A. CIV (CHENG T-AKE 9)

Subject: RE: OWS Follow-up

Kirsten,

Really appreciate the data download and additional feedback. We do have wiring diagrams, but there were significant changes during the installation, and they have not been revised. I know a 3rd party is responsible for updating the ship drawings, and I will check if electrical is included. In the meantime, we will work to do a rough red-line. Also, Jared and Tim were the ones primarily doing the wiring changes, and they can support if you have any questions.

V/r, Danielle

-----Original Message-----

From: Figueroa, Kirsten R. CIV (1ST A/E T-AKE 9) <Kirsten.R.Figueroa.civ@ake9.navy.mil>
Sent: Tuesday, August 10, 2021 6:22 AM

To: Paynter, Danielle M CIV USN NSWC CRD BDA MD (USA) <danielle.paynter@navy.mil>; Church, Jared K CIV (USA) <jared.k.church@navy.mil>

Cc: Lee, Sang M CIV USN NSWC CRD BDA MD (USA) <sang.m.lee@navy.mil>; Gooch, Melissa A CIV USN COMSC LANT NORFOLK (USA) <melissa.a.gooch@navy.mil>; CHENG - PERRY <Cheng@ake9.navy.mil>; Cruz, Edwin A. CIV (CHENG T-AKE 9) <Edwin.A.Cruz.civ@ake9.navy.mil>

Subject: RE: OWS Follow-up

Danielle,

I have sent you and your team the data as requested via DoD Safe. I apologize I haven't replied earlier but I will answer your questions from the previous emails.

Remote indicator light - not a requirement just an observation. I can look through documentation left behind if there is an electrical schematic and we can trace it back for a loose wire. If you have drawings on hand it would be appreciated. Just another note, there were no real wire tags or placards installed with the unit just masking tape and sharpie. We will try to keep them well preserved during the OWS' residency.

Operating the system is straight forward. The instructions are clear and also we have trained everyone to be able to use it with no problems in lightoff/shut down.

Unattended operation - there is no issue here. Our tanks have been mostly water and haven’t had an issue of getting slugs of oil. There hasn't been any trips that I'm aware of other than when the tank gets low and the pump loses head pressure. If anything.. the only monitoring we have to do is with the amount it fills up the bilges but that has already been addressed.

In our down time, we can try to figure out a better way to divert the dumped water into a better suited location.

v/r

Kirsten Figueroa

1st Assistant Engineer

USNS Matthew Perry (T-AKE 9)

APPENDIX N: EPA 1664 REPORT

Analytical Report for

Naval Surface Warfare Center - Carderock

Certificate of Analysis No.: 18060522

Project Manager: James Chiang
Project Name : HSRMS
Project Location: West Bethesda



June 14, 2018

Phase Separation Science, Inc.
6630 Baltimore National Pike
Baltimore, MD 21228
Phone: (410) 747-8770
Fax: (410) 788-8723

OFFICES:
6630 BALTIMORE NATIONAL PIKE
ROUTE 40 WEST
BALTIMORE, MD 21228
410-747-8770
800-932-9047
FAX 410-788-8723

PHASE SEPARATION SCIENCE, INC.



Sample Summary

Client Name: Naval Surface Warfare Center - Carderock

Project Name: HSRMS

Work Order Number(s): 18060522

The following samples were received under chain of custody by Phase Separation Science (PSS) on 06/05/2018 at 01:15 pm

Lab Sample Id	Sample Id	Matrix	Date/Time Collected
18060522-001	8-C-0	WASTE WATER	06/01/18 08:17
18060522-002	8-B-4	WASTE WATER	06/01/18 11:08
18060522-003	8-A-4	WASTE WATER	06/01/18 11:13
18060522-004	8-D1-4	WASTE WATER	06/01/18 11:16
18060522-005	8-A-9-T1	WASTE WATER	06/01/18 16:04
18060522-006	8-A-9-T2	WASTE WATER	06/01/18 16:04
18060522-007	8-A-9-T3	WASTE WATER	06/01/18 16:04
18060522-008	12-C-0	WASTE WATER	06/04/18 11:08
18060522-009	12-B-4	WASTE WATER	06/04/18 11:23
18060522-010	12-A-4	WASTE WATER	06/04/18 11:26
18060522-011	12-D1-4	WASTE WATER	06/04/18 11:27
18060522-012	12-A-9-T1	WASTE WATER	06/04/18 16:18
18060522-013	12-A-9-T2	WASTE WATER	06/04/18 16:20
18060522-014	12-A-9-T3	WASTE WATER	06/04/18 16:21

Please reference the Chain of Custody and Sample Receipt Checklist for specific container counts and preservatives. Any sample conditions not in compliance with sample acceptance criteria are described in Case Narrative Summary.

Notes:

1. The presence of a common laboratory contaminant such as methylene chloride may be considered a possible laboratory artifact. Where observed, appropriate consideration of data should be taken.
2. Unless otherwise noted in the case narrative, results are reported on a dry weight basis with the exception of pH, flashpoint, moisture, and paint filter test.
3. Drinking water samples collected for the purpose of compliance with SDWA may not be suitable for their intended use unless collected by a certified sampler [COMAR 26.08.05.07.C.2].
4. The analyses of 1,2-dibromo-3-chloropropane (DBCP) and 1,2-dibromoethane (EDB) by EPA 524.2 and calcium, magnesium, sodium and iron by EPA 200.8 are not currently promulgated for use in testing to meet the Safe Drinking Water Act and as such cannot be used for compliance purposes. The listings of the current promulgated methods for testing in compliance with the Safe Drinking Water Act can be found in the 40 CFR part 141.1, for the primary drinking water contaminates, and part 141.3, for the secondary drinking water contaminates.
5. Sample prepared under EPA 3550C with concentrations greater than 20 mg/Kg should employ the microtip extraction procedure if required to meet data quality objectives.
6. The analysis of acrolein by EPA 624 must be analyzed within three days of sampling unless pH is adjusted to 4-5 units [40 CFR part 136.3(e)].
7. Method 180.1, The Determination of Turbidity by Nephelometry, recommends samples over 40 NTU be diluted until the turbidity falls below 40 units. Routine samples over 40 NTU may not be diluted as long as the data quality objectives are not affected.
8. Alkalinity results analyzed by EPA 310.2 that are reported by dilution are estimated and are not in compliance with method requirements.

Standard Flags/Abbreviations:

B	A target analyte or common laboratory contaminant was identified in the method blank. Its presence indicates possible field or laboratory contamination.
C	Results Pending Final Confirmation.
E	The data exceeds the upper calibration limit; therefore, the concentration is reported as estimated.
Fail	The result exceeds the regulatory level for Toxicity Characteristic (TCLP) as cited in 40 CFR 261.24 Table 1.
J	The target analyte was positively identified below the reporting limit but greater than the MDL.
MDL	This is the Laboratory Method Detection Limit which is equivalent to the Limit of Detection (LOD). The LOD is an estimate of the minimum amount of a substance that an analytical process can reliably detect. This value will remain constant across multiple similar instrumentation and among different analysts. An LOD is analyte and matrix specific.
ND	Not Detected at or above the reporting limit.
RL	PSS Reporting Limit.
U	Not detected.

Sample Summary

Client Name: Naval Surface Warfare Center - Carderock
Project Name: HSRMS

Work Order Number(s): 18060522

Certifications:

NELAP Certifications: PA 68-03330, VA 460156
State Certifications: MD 179, WV 303
Regulated Soil Permit: P330-12-00268
NSWC USCG Accepted Laboratory
LDBE MWAA LD1997-0041-2015

OFFICES:
6630 BALTIMORE NATIONAL PIKE
ROUTE 40 WEST
BALTIMORE, MD 21228
410-747-8770
800-932-9047
FAX 410-788-8723

PHASE SEPARATION SCIENCE, INC.

CERTIFICATE OF ANALYSIS
No: 18060522
Naval Surface Warfare Center - Carderock, West Bethesda, MD
June 14, 2018

Project Name: HSRMS
Project Location: West Bethesda

Sample ID: 8-C-0 **Date/Time Sampled: 06/01/2018 08:17** **PSS Sample ID: 18060522-001**
Matrix: WASTE WATER **Date/Time Received: 06/05/2018 13:15**

Oil and Grease — Analytical Method: EPA 1664 A

	Result	Units	RL	Flag	Dil	Prepared	Analyzed	Analyst
Oil & Grease, Total Recovered	**48**	mg/L	2.2		1	06/12/18	06/12/18 09:00	1022

Total Petroleum Hydrocarbons — Analytical Method: EPA 1664 A

	Result	Units	RL	Flag	Dil	Prepared	Analyzed	Analyst
TPH	**17**	mg/L	2.2		1	06/12/18	06/12/18 18:08	1022

Sample ID: 8-B-4 **Date/Time Sampled: 06/01/2018 11:08** **PSS Sample ID: 18060522-002**
Matrix: WASTE WATER **Date/Time Received: 06/05/2018 13:15**

Oil and Grease — Analytical Method: EPA 1664 A

	Result	Units	RL	Flag	Dil	Prepared	Analyzed	Analyst
Oil & Grease, Total Recovered	**650**	mg/L	2.2		1	06/12/18	06/12/18 09:00	1022

Total Petroleum Hydrocarbons — Analytical Method: EPA 1664 A

	Result	Units	RL	Flag	Dil	Prepared	Analyzed	Analyst
TPH	**330**	mg/L	2.2		1	06/12/18	06/12/18 18:08	1022

Sample ID: 8-A-4 **Date/Time Sampled: 06/01/2018 11:13** **PSS Sample ID: 18060522-003**
Matrix: WASTE WATER **Date/Time Received: 06/05/2018 13:15**

Oil and Grease — Analytical Method: EPA 1664 A

	Result	Units	RL	Flag	Dil	Prepared	Analyzed	Analyst
Oil & Grease, Total Recovered	ND	mg/L	2.4		1	06/12/18	06/12/18 09:00	1022

Total Petroleum Hydrocarbons — Analytical Method: EPA 1664 A

	Result	Units	RL	Flag	Dil	Prepared	Analyzed	Analyst
TPH	ND	mg/L	2.4		1	06/12/18	06/12/18 18:08	1022

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PHASE SEPARATION SCIENCE, INC.

CERTIFICATE OF ANALYSIS
No: 18060522
Naval Surface Warfare Center - Carderock, West Bethesda, MD
June 14, 2018

Project Name: HSRMS
Project Location: West Bethesda

Sample ID: 8-D1-4 **Date/Time Sampled: 06/01/2018 11:16** **PSS Sample ID: 18060522-004**
Matrix: WASTE WATER **Date/Time Received: 06/05/2018 13:15**

Oil and Grease — Analytical Method: EPA 1664 A

	Result	Units	RL	Flag	Dil	Prepared	Analyzed	Analyst
Oil & Grease, Total Recovered	**3.4**	mg/L	2.3		1	06/12/18	06/12/18 09:00	1022

Total Petroleum Hydrocarbons — Analytical Method: EPA 1664 A

	Result	Units	RL	Flag	Dil	Prepared	Analyzed	Analyst
TPH	ND	mg/L	2.3		1	06/12/18	06/12/18 18:08	1022

Sample ID: 8-A-9-T1 **Date/Time Sampled: 06/01/2018 16:04** **PSS Sample ID: 18060522-005**
Matrix: WASTE WATER **Date/Time Received: 06/05/2018 13:15**

Oil and Grease — Analytical Method: EPA 1664 A

	Result	Units	RL	Flag	Dil	Prepared	Analyzed	Analyst
Oil & Grease, Total Recovered	ND	mg/L	2.3		1	06/12/18	06/12/18 09:00	1022

Total Petroleum Hydrocarbons — Analytical Method: EPA 1664 A

	Result	Units	RL	Flag	Dil	Prepared	Analyzed	Analyst
TPH	ND	mg/L	2.3		1	06/12/18	06/12/18 18:08	1022

Sample ID: 8-A-9-T2 **Date/Time Sampled: 06/01/2018 16:04** **PSS Sample ID: 18060522-006**
Matrix: WASTE WATER **Date/Time Received: 06/05/2018 13:15**

Oil and Grease — Analytical Method: EPA 1664 A

	Result	Units	RL	Flag	Dil	Prepared	Analyzed	Analyst
Oil & Grease, Total Recovered	ND	mg/L	2.4		1	06/12/18	06/12/18 09:00	1022

Total Petroleum Hydrocarbons — Analytical Method: EPA 1664 A

	Result	Units	RL	Flag	Dil	Prepared	Analyzed	Analyst
TPH	ND	mg/L	2.4		1	06/12/18	06/12/18 18:08	1022

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BALTIMORE, MD 21228
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800-932-9047
FAX 410-788-8723

PHASE SEPARATION SCIENCE, INC.

CERTIFICATE OF ANALYSIS
No: 18060522
Naval Surface Warfare Center - Carderock, West Bethesda, MD
June 14, 2018

Project Name: HSRMS
Project Location: West Bethesda

Sample ID: 8-A-9-T3 **Date/Time Sampled: 06/01/2018 16:04** **PSS Sample ID: 18060522-007**
Matrix: WASTE WATER **Date/Time Received: 06/05/2018 13:15**

Oil and Grease — Analytical Method: EPA 1664 A

	Result	Units	RL	Flag	Dil	Prepared	Analyzed	Analyst
Oil & Grease, Total Recovered	ND	mg/L	2.4		1	06/12/18	06/12/18 09:00	1022

Total Petroleum Hydrocarbons — Analytical Method: EPA 1664 A

	Result	Units	RL	Flag	Dil	Prepared	Analyzed	Analyst
TPH	ND	mg/L	2.4		1	06/12/18	06/12/18 18:08	1022

Sample ID: 12-C-0 **Date/Time Sampled: 06/04/2018 11:08** **PSS Sample ID: 18060522-008**
Matrix: WASTE WATER **Date/Time Received: 06/05/2018 13:15**

Oil and Grease — Analytical Method: EPA 1664 A

	Result	Units	RL	Flag	Dil	Prepared	Analyzed	Analyst
Oil & Grease, Total Recovered	**10**	mg/L	2.3		1	06/12/18	06/12/18 09:00	1022

Total Petroleum Hydrocarbons — Analytical Method: EPA 1664 A

	Result	Units	RL	Flag	Dil	Prepared	Analyzed	Analyst
TPH	ND	mg/L	2.3		1	06/12/18	06/12/18 18:08	1022

Sample ID: 12-B-4 **Date/Time Sampled: 06/04/2018 11:23** **PSS Sample ID: 18060522-009**
Matrix: WASTE WATER **Date/Time Received: 06/05/2018 13:15**

Oil and Grease — Analytical Method: EPA 1664 A

	Result	Units	RL	Flag	Dil	Prepared	Analyzed	Analyst
Oil & Grease, Total Recovered	**760**	mg/L	2.2		1	06/12/18	06/12/18 09:00	1022

Total Petroleum Hydrocarbons — Analytical Method: EPA 1664 A

	Result	Units	RL	Flag	Dil	Prepared	Analyzed	Analyst
TPH	**450**	mg/L	2.2		1	06/12/18	06/12/18 18:08	1022

OFFICES:
6630 BALTIMORE NATIONAL PIKE
ROUTE 40 WEST
BALTIMORE, MD 21228
410-747-8770
800-932-9047
FAX 410-788-8723

PHASE SEPARATION SCIENCE, INC.

CERTIFICATE OF ANALYSIS
No: 18060522
Naval Surface Warfare Center - Carderock, West Bethesda, MD
June 14, 2018

Project Name: HSRMS
Project Location: West Bethesda

Sample ID: 12-A-4 **Date/Time Sampled: 06/04/2018 11:26** **PSS Sample ID: 18060522-010**
Matrix: WASTE WATER **Date/Time Received: 06/05/2018 13:15**

Oil and Grease — Analytical Method: EPA 1664 A

	Result	Units	RL	Flag	Dil	Prepared	Analyzed	Analyst
Oil & Grease, Total Recovered	ND	mg/L	2.4		1	06/12/18	06/12/18 09:00	1022

Total Petroleum Hydrocarbons — Analytical Method: EPA 1664 A

	Result	Units	RL	Flag	Dil	Prepared	Analyzed	Analyst
TPH	ND	mg/L	2.4		1	06/12/18	06/12/18 18:08	1022

Sample ID: 12-D1-4 **Date/Time Sampled: 06/04/2018 11:27** **PSS Sample ID: 18060522-011**
Matrix: WASTE WATER **Date/Time Received: 06/05/2018 13:15**

Oil and Grease — Analytical Method: EPA 1664 A

	Result	Units	RL	Flag	Dil	Prepared	Analyzed	Analyst
Oil & Grease, Total Recovered	**2.5**	mg/L	2.3		1	06/12/18	06/12/18 09:00	1022

Total Petroleum Hydrocarbons — Analytical Method: EPA 1664 A

	Result	Units	RL	Flag	Dil	Prepared	Analyzed	Analyst
TPH	ND	mg/L	2.3		1	06/12/18	06/12/18 18:08	1022

Sample ID: 12-A-9-T1 **Date/Time Sampled: 06/04/2018 16:18** **PSS Sample ID: 18060522-012**
Matrix: WASTE WATER **Date/Time Received: 06/05/2018 13:15**

Oil and Grease — Analytical Method: EPA 1664 A

	Result	Units	RL	Flag	Dil	Prepared	Analyzed	Analyst
Oil & Grease, Total Recovered	ND	mg/L	2.4		1	06/12/18	06/12/18 09:00	1022

Total Petroleum Hydrocarbons — Analytical Method: EPA 1664 A

	Result	Units	RL	Flag	Dil	Prepared	Analyzed	Analyst
TPH	ND	mg/L	2.4		1	06/12/18	06/12/18 18:08	1022

OFFICES:
6630 BALTIMORE NATIONAL PIKE
ROUTE 40 WEST
BALTIMORE, MD 21228
410-747-8770
800-932-9047
FAX 410-788-8723

PHASE SEPARATION SCIENCE, INC.

CERTIFICATE OF ANALYSIS
No: 18060522
Naval Surface Warfare Center - Carderock, West Bethesda, MD
June 14, 2018

Project Name: HSRMS
Project Location: West Bethesda

Sample ID: 12-A-9-T2 **Date/Time Sampled: 06/04/2018 16:20** **PSS Sample ID: 18060522-013**
Matrix: WASTE WATER **Date/Time Received: 06/05/2018 13:15**

Oil and Grease — Analytical Method: EPA 1664 A

	Result	Units	RL	Flag	Dil	Prepared	Analyzed	Analyst
Oil & Grease, Total Recovered	ND	mg/L	2.2		1	06/12/18	06/12/18 09:00	1022

Total Petroleum Hydrocarbons — Analytical Method: EPA 1664 A

	Result	Units	RL	Flag	Dil	Prepared	Analyzed	Analyst
TPH	ND	mg/L	2.2		1	06/12/18	06/12/18 18:08	1022

Sample ID: 12-A-9-T3 **Date/Time Sampled: 06/04/2018 16:21** **PSS Sample ID: 18060522-014**
Matrix: WASTE WATER **Date/Time Received: 06/05/2018 13:15**

Oil and Grease — Analytical Method: EPA 1664 A

	Result	Units	RL	Flag	Dil	Prepared	Analyzed	Analyst
Oil & Grease, Total Recovered	ND	mg/L	2.4		1	06/12/18	06/12/18 09:00	1022

Total Petroleum Hydrocarbons — Analytical Method: EPA 1664 A

	Result	Units	RL	Flag	Dil	Prepared	Analyzed	Analyst
TPH	ND	mg/L	2.4		1	06/12/18	06/12/18 18:08	1022

Case Narrative Summary

Client Name: Naval Surface Warfare Center - Carderock

Project Name: HSRMS

Work Order Number(s): 18060522

Any holding time exceedances, deviations from the method specifications, regulatory requirements or variations to the procedures outlined in the PSS Quality Assurance Manual are outlined below.

The analyses of chlorine, pH, dissolved oxygen, temperature and sulfite for drinking water and non-potable samples tested for compliance have a maximum holding time of 15 minutes. As such, all laboratory analyses for these analytes exceed holding times.

Matrix spike and matrix spike duplicate analyses may not be performed due to insufficient sample quantity. In these instances, a laboratory control sample and laboratory control sample duplicate are analyzed unless otherwise noted or specified in the method.

Unless otherwise noted, surrogate recoveries outside of the acceptance criteria are most often the result of sample matrix interference and/or sample dilution.

Quality control samples that display a high bias will not be narrated when sample target compounds are not detected.

Sample Receipt:

All sample receipt conditions were acceptable.

NELAP accreditation was held for all analyses performed unless noted below. See www.phaseonline.com for complete PSS scope of accreditation.

Analytical Data Package Information Summary

Work Order(s): 18060522
Report Prepared For: Naval Surface Warfare Center - Carderock, W
Project Name: HSRMS
Project Manager: James Chiang

Method	Client Sample Id	Analysis Type	Lab Sample Id	Analyst	Mtx	Prep Batch	Analytical Batch	Sampled	Prepared	Analyzed
EPA 1664 A	8-C-0	Initial	18060522-001	1022	W	154190	154190	06/01/2018	06/12/2018 09:00	06/12/2018 09:00
	8-B-4	Initial	18060522-002	1022	W	154190	154190	06/01/2018	06/12/2018 09:00	06/12/2018 09:00
	8-A-4	Initial	18060522-003	1022	W	154190	154190	06/01/2018	06/12/2018 09:00	06/12/2018 09:00
	8-D1-4	Initial	18060522-004	1022	W	154190	154190	06/01/2018	06/12/2018 09:00	06/12/2018 09:00
	8-A-9-T1	Initial	18060522-005	1022	W	154190	154190	06/01/2018	06/12/2018 09:00	06/12/2018 09:00
	8-A-9-T2	Initial	18060522-006	1022	W	154190	154190	06/01/2018	06/12/2018 09:00	06/12/2018 09:00
	8-A-9-T3	Initial	18060522-007	1022	W	154190	154190	06/01/2018	06/12/2018 09:00	06/12/2018 09:00
	12-C-0	Initial	18060522-008	1022	W	154190	154190	06/04/2018	06/12/2018 09:00	06/12/2018 09:00
	12-B-4	Initial	18060522-009	1022	W	154190	154190	06/04/2018	06/12/2018 09:00	06/12/2018 09:00
	12-A-4	Initial	18060522-010	1022	W	154190	154190	06/04/2018	06/12/2018 09:00	06/12/2018 09:00
	12-D1-4	Initial	18060522-011	1022	W	154190	154190	06/04/2018	06/12/2018 09:00	06/12/2018 09:00
	12-A-9-T1	Initial	18060522-012	1022	W	154190	154190	06/04/2018	06/12/2018 09:00	06/12/2018 09:00
	12-A-9-T2	Initial	18060522-013	1022	W	154190	154190	06/04/2018	06/12/2018 09:00	06/12/2018 09:00
	12-A-9-T3	Initial	18060522-014	1022	W	154190	154190	06/04/2018	06/12/2018 09:00	06/12/2018 09:00
	154190-1-BKS	BKS	154190-1-BKS	1022	W	154190	154190	--------	06/12/2018 09:00	06/12/2018 09:00
	154190-1-BLK	BLK	154190-1-BLK	1022	W	154190	154190	--------	06/12/2018 09:00	06/12/2018 09:00
	154190-1-BSD	BSD	154190-1-BSD	1022	W	154190	154190	--------	06/12/2018 09:00	06/12/2018 09:00
EPA 1664 A	8-C-0	Initial	18060522-001	1022	W	154238	154238	06/01/2018	06/12/2018 18:08	06/12/2018 18:08
	8-B-4	Initial	18060522-002	1022	W	154238	154238	06/01/2018	06/12/2018 18:08	06/12/2018 18:08
	8-A-4	Initial	18060522-003	1022	W	154238	154238	06/01/2018	06/12/2018 18:08	06/12/2018 18:08
	8-D1-4	Initial	18060522-004	1022	W	154238	154238	06/01/2018	06/12/2018 18:08	06/12/2018 18:08
	8-A-9-T1	Initial	18060522-005	1022	W	154238	154238	06/01/2018	06/12/2018 18:08	06/12/2018 18:08
	8-A-9-T2	Initial	18060522-006	1022	W	154238	154238	06/01/2018	06/12/2018 18:08	06/12/2018 18:08
	8-A-9-T3	Initial	18060522-007	1022	W	154238	154238	06/01/2018	06/12/2018 18:08	06/12/2018 18:08
	12-C-0	Initial	18060522-008	1022	W	154238	154238	06/04/2018	06/12/2018 18:08	06/12/2018 18:08
	12-B-4	Initial	18060522-009	1022	W	154238	154238	06/04/2018	06/12/2018 18:08	06/12/2018 18:08
	12-A-4	Initial	18060522-010	1022	W	154238	154238	06/04/2018	06/12/2018 18:08	06/12/2018 18:08
	12-D1-4	Initial	18060522-011	1022	W	154238	154238	06/04/2018	06/12/2018 18:08	06/12/2018 18:08
	12-A-9-T1	Initial	18060522-012	1022	W	154238	154238	06/04/2018	06/12/2018 18:08	06/12/2018 18:08

Analytical Data Package Information Summary

Work Order(s): 18060522
Report Prepared For: Naval Surface Warfare Center - Carderock, W
Project Name: HSRMS
Project Manager: James Chiang

Method	Client Sample Id	Analysis Type	Lab Sample Id	Analyst	Mtx	Prep Batch	Analytical Batch	Sampled	Prepared	Analyzed
EPA 1664 A	12-A-9-T2	Initial	18060522-013	1022	W	154238	154238	06/04/2018	06/12/2018 18:08	06/12/2018 18:08
	12-A-9-T3	Initial	18060522-014	1022	W	154238	154238	06/04/2018	06/12/2018 18:08	06/12/2018 18:08
	154238-1-BKS	BKS	154238-1-BKS	1022	W	154238	154238	--------	06/12/2018 18:08	06/12/2018 18:08
	154238-1-BLK	BLK	154238-1-BLK	1022	W	154238	154238	--------	06/12/2018 18:08	06/12/2018 18:08
	154238-1-BSD	BSD	154238-1-BSD	1022	W	154238	154238	--------	06/12/2018 18:08	06/12/2018 18:08

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QC Summary 18060522

Naval Surface Warfare Center - Carderock
HSRMS

Analytical Method: EPA 1664 A

Seq Number: 154190 Matrix: Water

MB Sample Id: 154190-1-BLK LCS Sample Id: 154190-1-BKS LCSD Sample Id: 154190-1-BSD

Parameter	MB Result	Spike Amount	LCS Result	LCS %Rec	LCSD Result	LCSD %Rec	Limits	%RPD	RPD Limit	Units	Analysis Date	Flag
Oil & Grease, Total Recovered	<2.000	40.00	37.70	94	36.90	92	78-114	2	11	mg/L	06/12/18 09:00	

Analytical Method: EPA 1664 A

Seq Number: 154238 Matrix: Water

MB Sample Id: 154238-1-BLK LCS Sample Id: 154238-1-BKS LCSD Sample Id: 154238-1-BSD

Parameter	MB Result	Spike Amount	LCS Result	LCS %Rec	LCSD Result	LCSD %Rec	Limits	%RPD	RPD Limit	Units	Analysis Date	Flag
TPH	<2.000	20.00	19.00	95	18.50	93	64-132	3	28	mg/L	06/12/18 18:08	

F = RPD exceeded the laboratory control limits
X = Recovery of MS, MSD or both outside of QC Criteria
H= Recovery of BS,BSD or both exceeded the laboratory control limits
L = Recovery of BS,BSD or both below the laboratory control limits

Phase Separation Science, Inc

Sample Receipt Checklist

Work Order #	18060522	**Received By**	Thomas Wingate
Client Name	Naval Surface Warfare Center - Carc	**Date Received**	06/05/2018 01:15:00 PM
Project Name	HSRMS	**Delivered By**	Trans Time Express
Disposal Date	07/10/2018	**Tracking No**	Not Applicable
		Logged In By	Thomas Wingate

Shipping Container(s)
No. of Coolers 2

		Ice	Present
Custody Seal(s) Intact?	N/A	Temp (deg C)	6
Seal(s) Signed / Dated?	N/A	Temp Blank Present	No

Documentation

		Sampler Name	James C./Adam G.
COC agrees with sample labels?	Yes	MD DW Cert. No.	N/A
Chain of Custody	Yes		

Sample Container

		Custody Seal(s) Intact?	Not Applicable
Appropriate for Specified Analysis?	Yes	Seal(s) Signed / Dated	Not Applicable
Intact?	Yes		
Labeled and Labels Legible?	Yes		

Total No. of Samples Received 14 Total No. of Containers Received 20

Preservation

Total Metals	(pH<2)	N/A
Dissolved Metals, filtered within 15 minutes of collection	(pH<2)	N/A
Orthophosphorus, filtered within 15 minutes of collection		N/A
Cyanides	(pH>12)	N/A
Sulfide	(pH>9)	N/A
TOC, DOC (field filtered), COD, Phenols	(pH<2)	N/A
TOX, TKN, NH3, Total Phos	(pH<2)	N/A
VOC, BTEX (VOA Vials Rcvd Preserved)	(pH<2)	N/A
Do VOA vials have zero headspace?		N/A
624 VOC (Rcvd at least one unpreserved VOA vial)		N/A
524 VOC (Rcvd with trip blanks)	(pH<2)	N/A

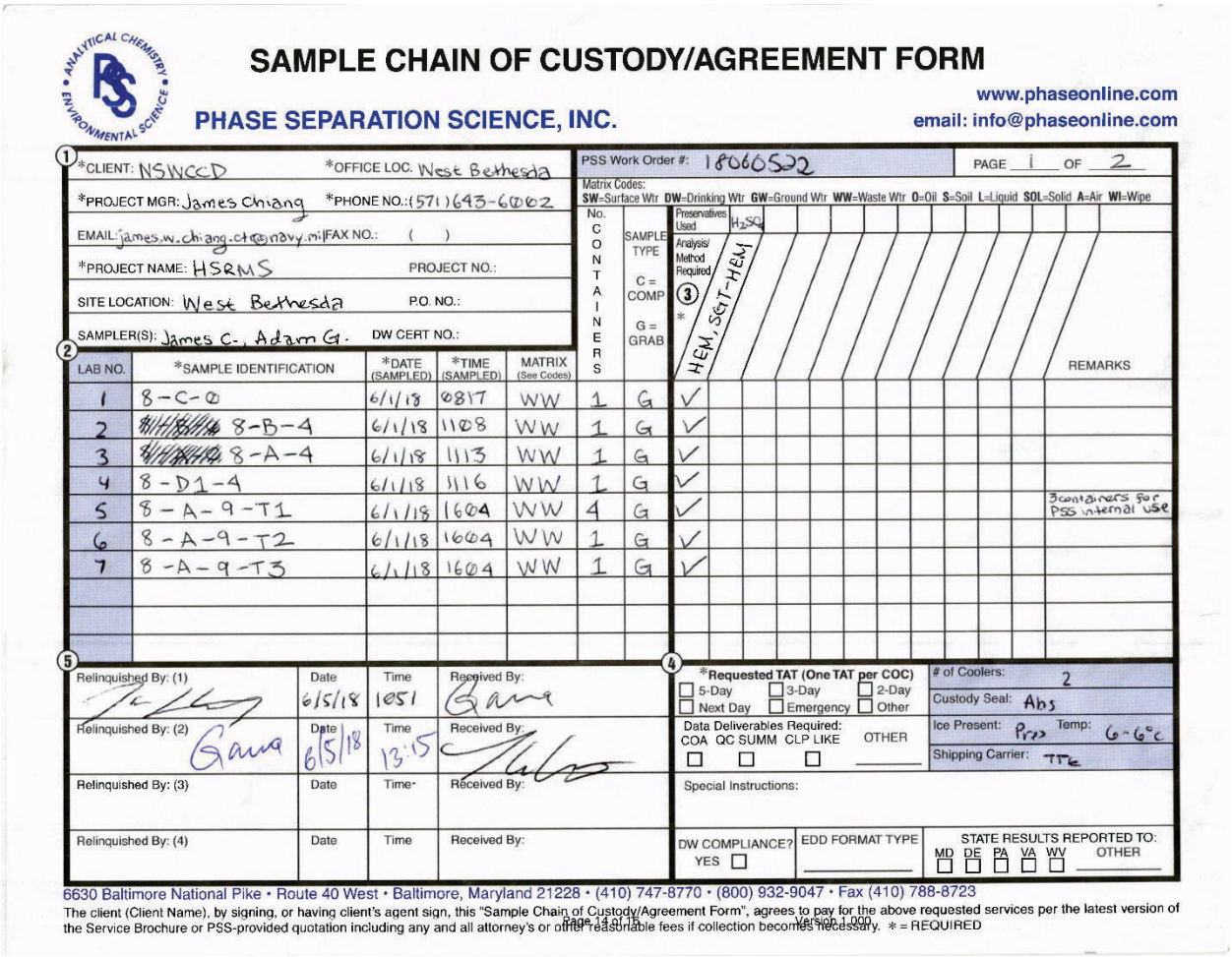
Comments: (Any "No" response must be detailed in the comments section below.)

For any improper preservation conditions, list sample ID, preservative added (reagent ID number) below as well as documentation of any client notification as well as client instructions. Samples for pH, chlorine and dissolved oxygen should be analyzed as soon as possible, preferably in the field at the time of sampling. Samples which require thermal preservation shall be considered acceptable when received at a temperature above freezing to 6°C. Samples that are hand delivered on the day that they are collected may not meet these criteria but shall be considered acceptable if there is evidence that the chilling process has begun such as arrival on ice.

Samples Inspected/Checklist Completed By: Thomas Wingate Date: 06/05/2018

PM Review and Approval: Amber Confer Date: 06/05/2018

APPENDIX O: SAMPLE CHAIN OF CUSTODY



SAMPLE CHAIN OF CUSTODY/AGREEMENT FORM

PHASE SEPARATION SCIENCE, INC.

www.phaseonline.com
email: info@phaseonline.com

*CLIENT: NSWCCD *OFFICE LOC. West Bethesda
*PROJECT MGR: James Chiang *PHONE NO.: (571) 693-6002
EMAIL: james.w.chiang.civ@navy.mil FAX NO.: ( )
*PROJECT NAME: HSRMS PROJECT NO.:
SITE LOCATION: West Bethesda P.O. NO.:
SAMPLER(S): James C., Adam G. DW CERT NO.:

PSS Work Order #: 1806522 PAGE 1 OF 2

Matrix Codes: SW=Surface Wtr DW=Drinking Wtr GW=Ground Wtr WW=Waste Wtr O=Oil S=Soil L=Liquid SOL=Solid A=Air WI=Wipe

LAB NO.	*SAMPLE IDENTIFICATION	*DATE (SAMPLED)	*TIME (SAMPLED)	MATRIX (See Codes)	No. CONTAINERS	SAMPLE TYPE C=COMP G=GRAB	Preservatives Used: H_2SO_4 / Analysis/Method Required: HEM, SGT-HEM	REMARKS
1	8-C-0	6/1/18	0817	WW	1	G	✓	
2	8-B-4	6/1/18	1108	WW	1	G	✓	
3	8-A-4	6/1/18	1113	WW	1	G	✓	
4	8-D1-4	6/1/18	1116	WW	1	G	✓	
5	8-A-9-T1	6/1/18	1604	WW	4	G	✓	3 containers for PSS internal use
6	8-A-9-T2	6/1/18	1604	WW	1	G	✓	
7	8-A-9-T3	6/1/18	1604	WW	1	G	✓	

	Date	Time	Received By:
Relinquished By: (1)	6/5/18	1051	
Relinquished By: (2)	6/5/18	13:15	
Relinquished By: (3)	Date	Time	Received By:
Relinquished By: (4)	Date	Time	Received By:

*Requested TAT (One TAT per COC): ☐ 5-Day ☐ 3-Day ☐ 2-Day ☐ Next Day ☐ Emergency ☐ Other

Data Deliverables Required: COA QC SUMM CLP LIKE OTHER

# of Coolers: 2
Custody Seal: Abs
Ice Present: Pres Temp: 6-6°C
Shipping Carrier: TTE

Special Instructions:

DW COMPLIANCE? YES ☐ EDD FORMAT TYPE

STATE RESULTS REPORTED TO: MD DE PA VA WV OTHER

6630 Baltimore National Pike • Route 40 West • Baltimore, Maryland 21228 • (410) 747-8770 • (800) 932-9047 • Fax (410) 788-8723

The client (Client Name), by signing, or having client's agent sign, this "Sample Chain of Custody/Agreement Form", agrees to pay for the above requested services per the latest version of the Service Brochure or PSS-provided quotation including any and all attorney's or other reasonable fees if collection becomes necessary. * = REQUIRED

Page 14 of 15 Version 1.000

SAMPLE CHAIN OF CUSTODY/AGREEMENT FORM

PHASE SEPARATION SCIENCE, INC.

www.phaseonline.com
email: info@phaseonline.com

1 *CLIENT: NSWCCD *OFFICE LOC: West Bethesda
*PROJECT MGR: James Chiang *PHONE NO.: (571) 643-6002
EMAIL: james.w.chiang.civ@mail.mil FAX NO.: ( )
*PROJECT NAME: HSRMS PROJECT NO.:
SITE LOCATION: West Bethesda P.O. NO.:
SAMPLER(S): James C., Adam G. DW CERT NO.:

PSS Work Order #: 1806052 PAGE 2 OF 2

Matrix Codes: SW=Surface Wtr DW=Drinking Wtr GW=Ground Wtr WW=Waste Wtr O=Oil S=Soil L=Liquid SOL=Solid A=Air WI=Wipe

2 3

LAB NO.	*SAMPLE IDENTIFICATION	*DATE (SAMPLED)	*TIME (SAMPLED)	MATRIX (See Codes)	No. CONTAINERS	SAMPLE TYPE C=COMP G=GRAB	Preservatives Used: H2SO4	Analysis/ Method Required: * HEM, SGT-HEM	REMARKS
8	12-C-0	6/4/18	1108	WW	1	G	✓		
9	12-B-4	6/4/18	1123	WW	1	G	✓		
10	12-A-4	6/4/18	1126	WW	1	G	✓		
11	12-D1-4	6/4/18	1127	WW	1	G	✓		
12	12-A-9-T1	6/4/18	1618	WW	4	G	✓		3 containers for PSS internal use
13	12-A-9-T2	6/4/18	1620	WW	1	G	✓		
14	12-A-9-T3	6/4/18	1621	WW	1	G	✓		

5

Relinquished By:	Date	Time	Received By:
(1)	6/5/18	1051	
(2)	6/5/18	1315	
(3)			
(4)			

4 *Requested TAT (One TAT per COC): ☐ 5-Day ☐ 3-Day ☐ 2-Day ☐ Next Day ☐ Emergency ☐ Other

Data Deliverables Required: COA ☐ QC SUMM ☐ CLP LIKE ☐ OTHER

# of Coolers: 2
Custody Seal: Abs
Ice Present: Pres Temp: 6.6°C
Shipping Carrier: TTE

Special Instructions:

DW COMPLIANCE? YES ☐ EDD FORMAT TYPE: STATE RESULTS REPORTED TO: MD ☐ DE ☐ PA ☐ VA ☐ WV ☐ OTHER

6630 Baltimore National Pike • Route 40 West • Baltimore, Maryland 21228 • (410) 747-8770 • (800) 932-9047 • Fax (410) 788-8723

The client (Client Name), by signing, or having client's agent sign, this "Sample Chain of Custody/Agreement Form", agrees to pay for the above requested services per the latest version of the Service Brochure or PSS-provided quotation including any and all attorney's or other reasonable fees if collection becomes necessary. * = REQUIRED

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APPENDIX P: EMULSION SAMPLE PHOTOGRAPHS

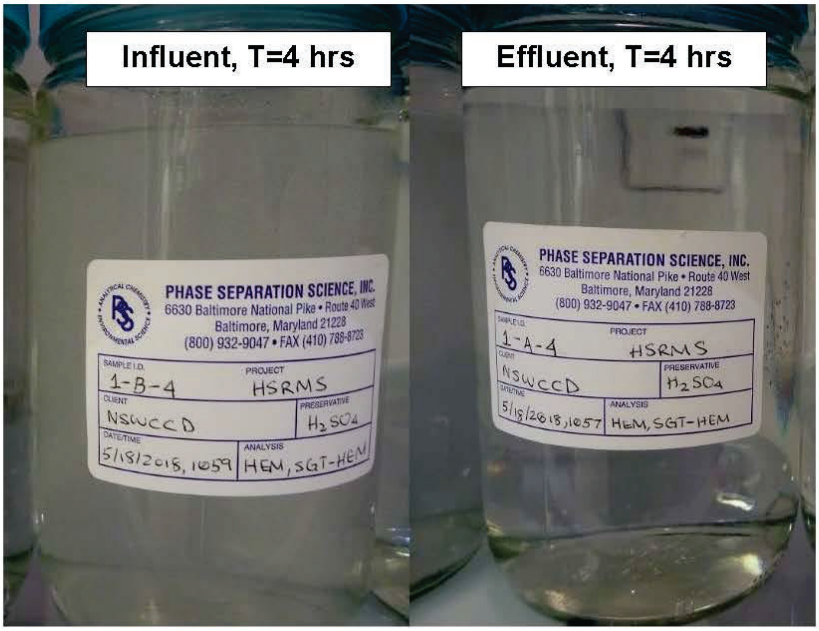


Figure P-1. Performance Test #1 - Influent and Effluent Samples

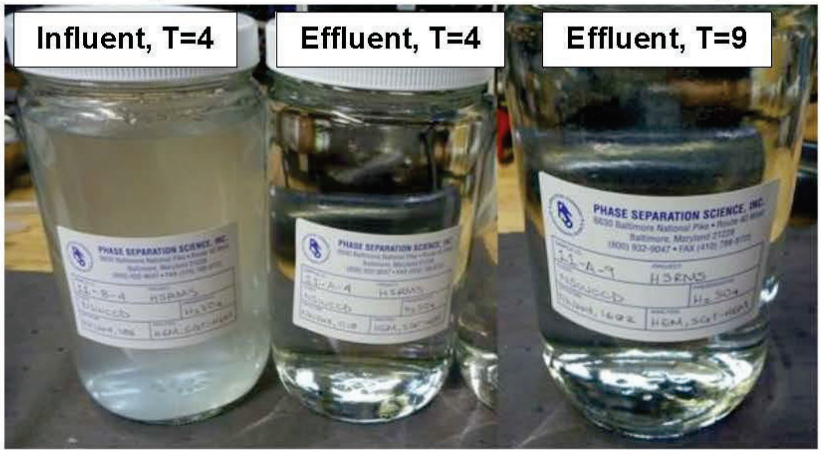


Figure P-2. Performance Test #11 - Influent and Effluent Samples

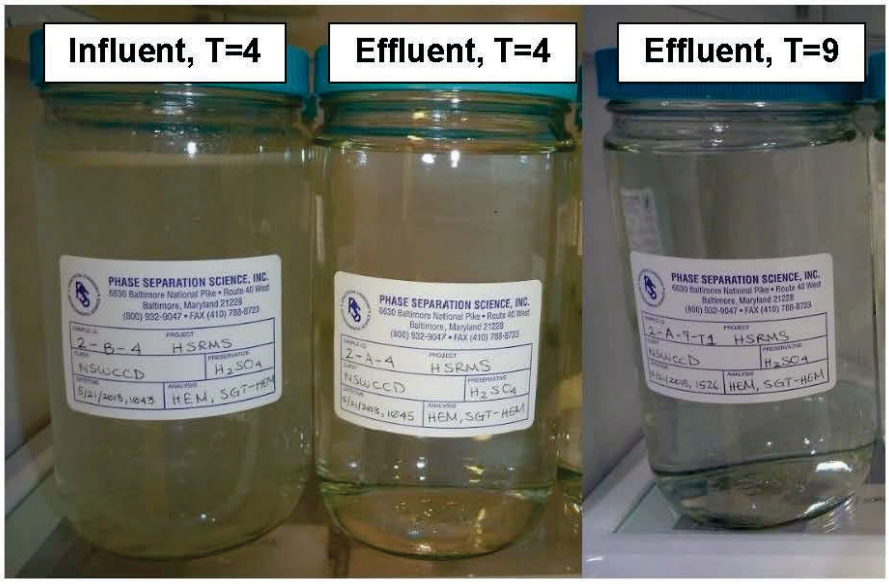


Figure P-3. Performance Test #2 – Influent and Effluent Samples

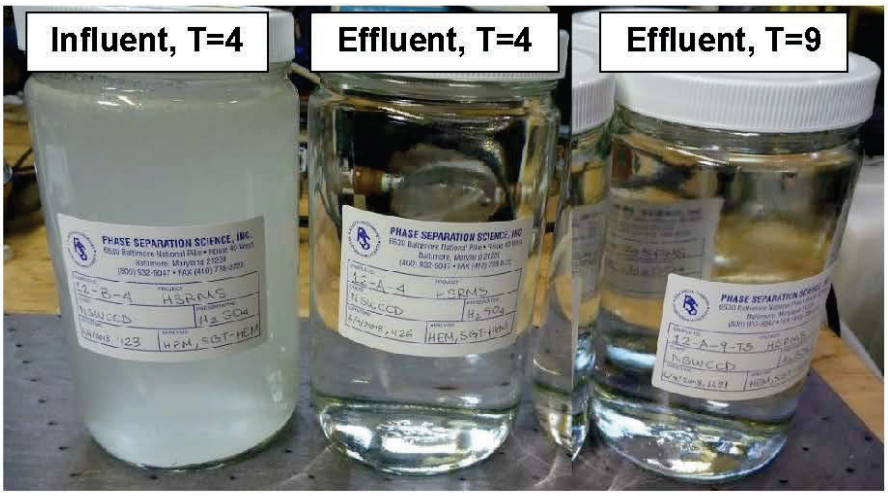


Figure P-4. Performance Test #12 - Influent and Effluent Samples

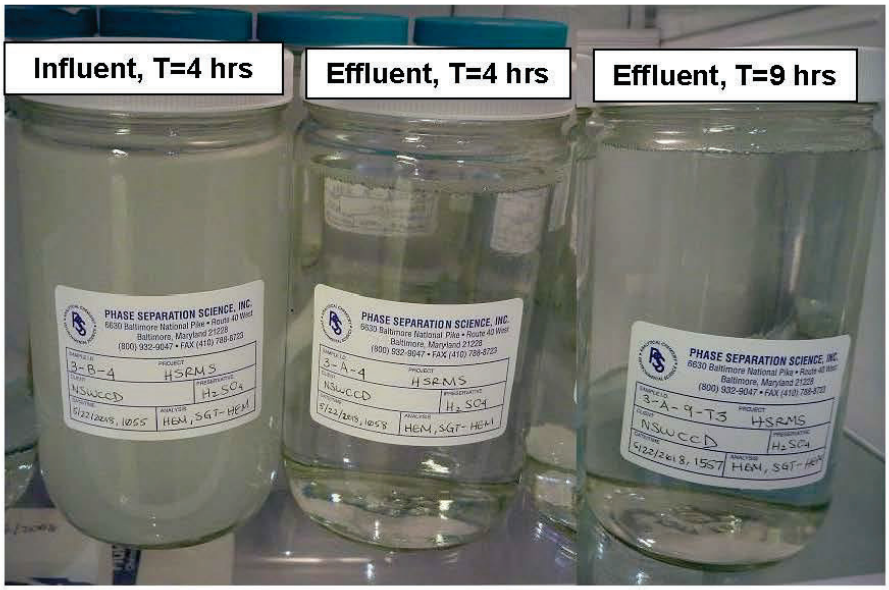


Figure P-5. Performance Test #3 – Influent and Effluent Samples



Figure P-6. Performance Test #13 – Influent and Effluent Samples

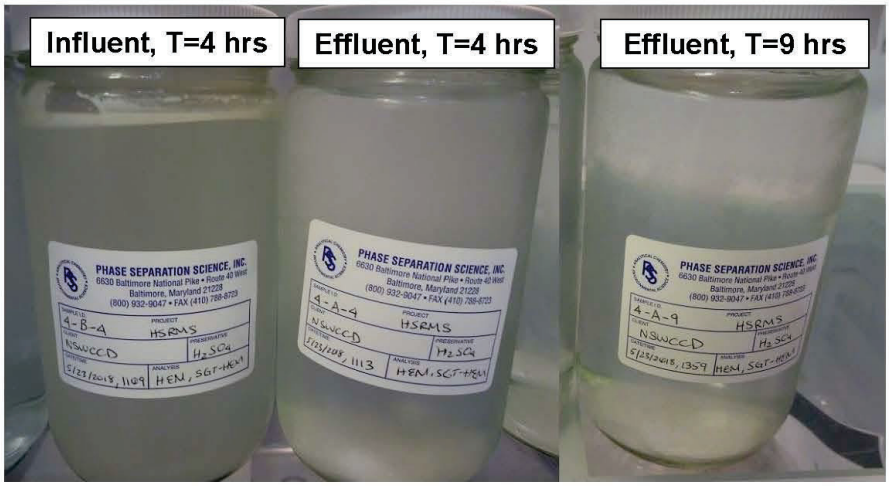


Figure P-7. Performance Test #4 – Influent and Effluent Samples

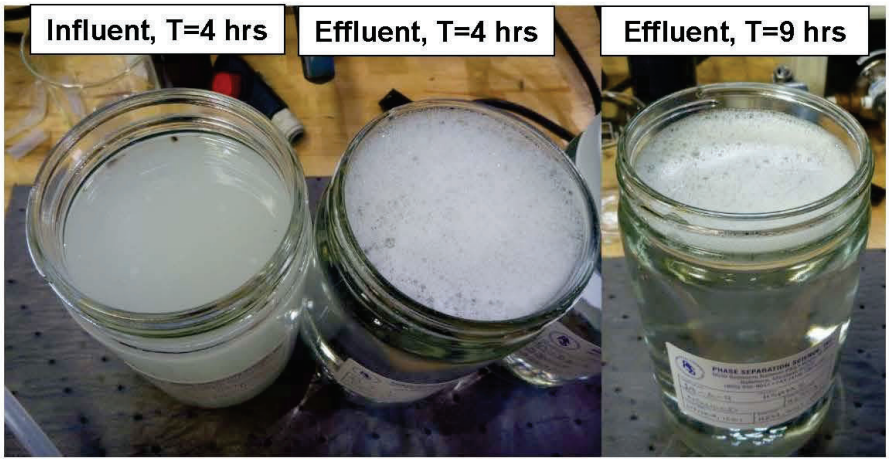


Figure P-8. Performance Test #14 – Influent and Effluent Samples

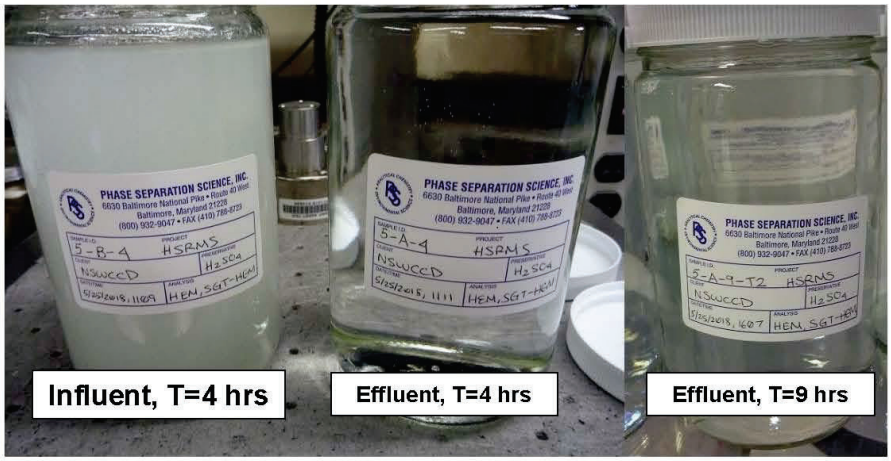


Figure P-9. Performance Test #5 – Influent and Effluent Samples

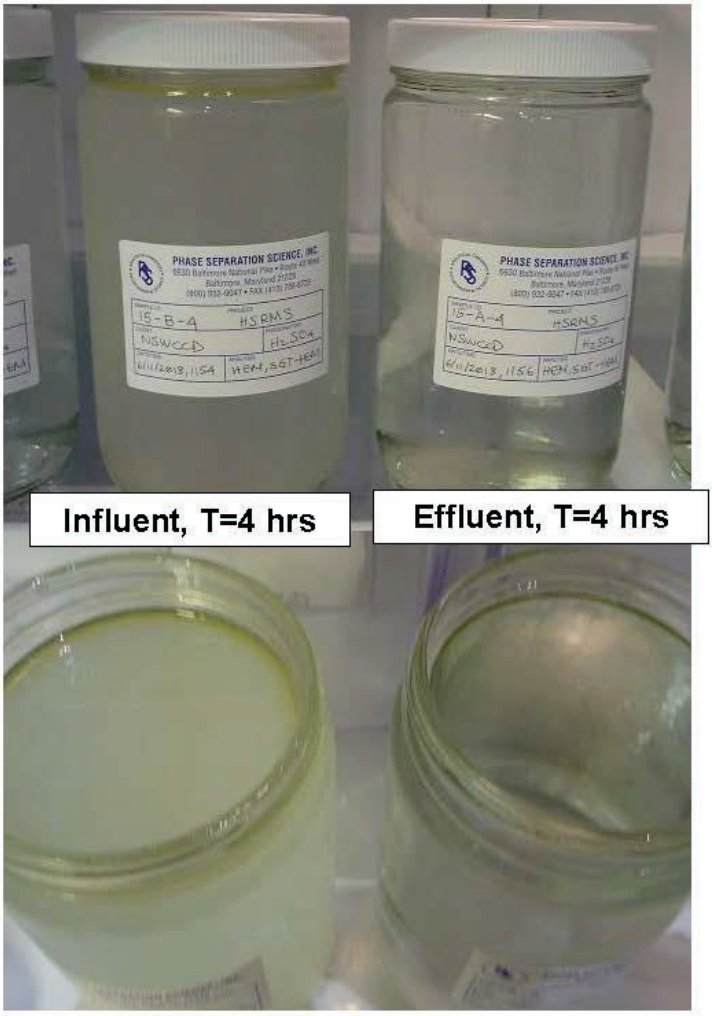


Figure P-10. Performance Test #15 – Influent and Effluent Samples

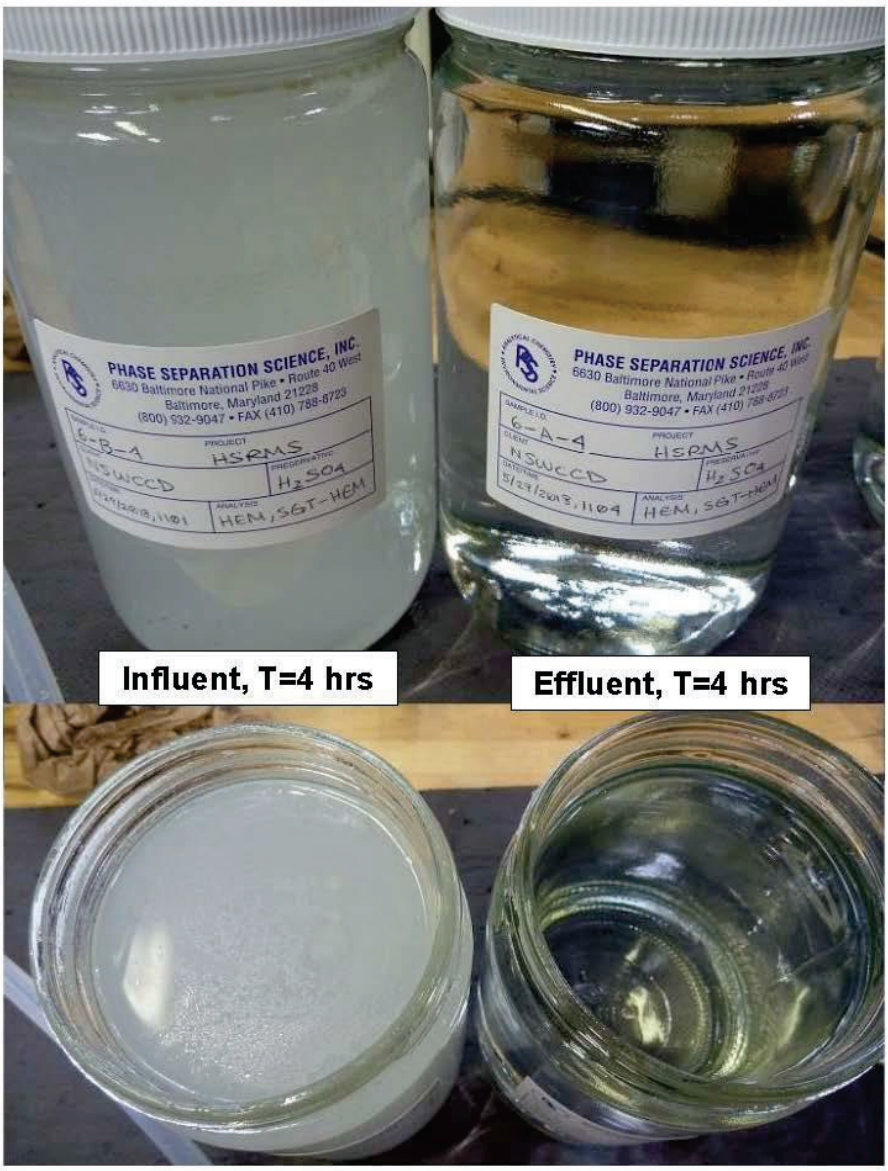


Figure P-11. Performance Test #6 - Influent and Effluent Samples

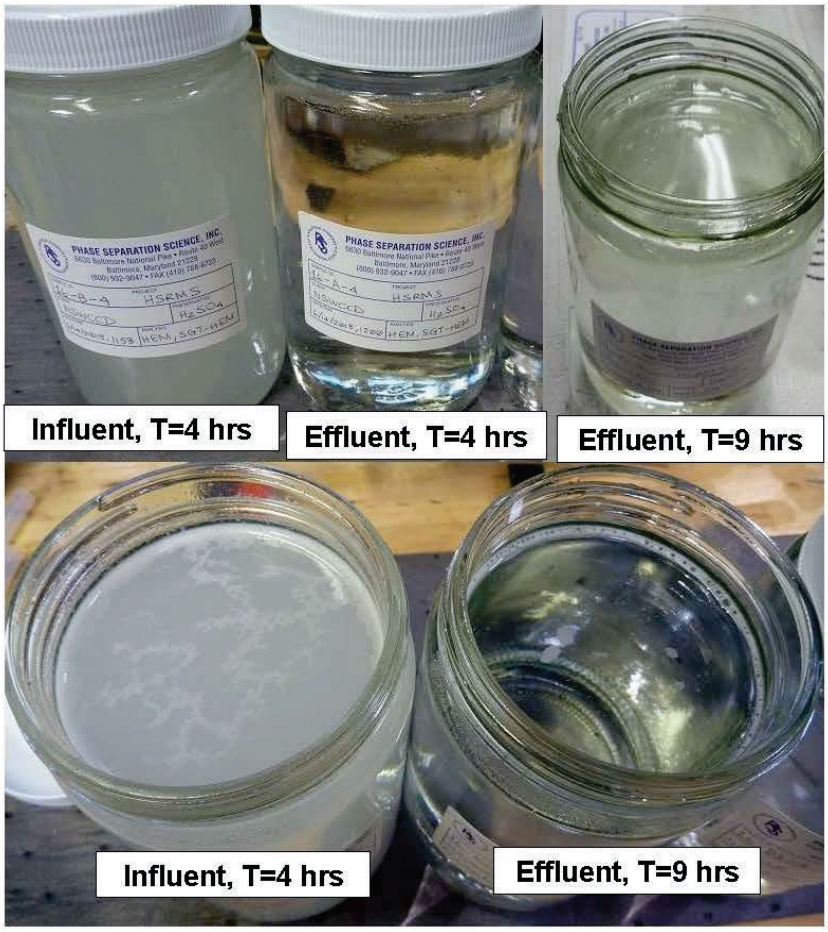


Figure P-12. Performance Test #16 - Influent and Effluent Samples



Figure P-13. Performance Test #7 - Influent and Effluent Samples



Figure P-14. Performance Test #17 - Influent and Effluent Samples

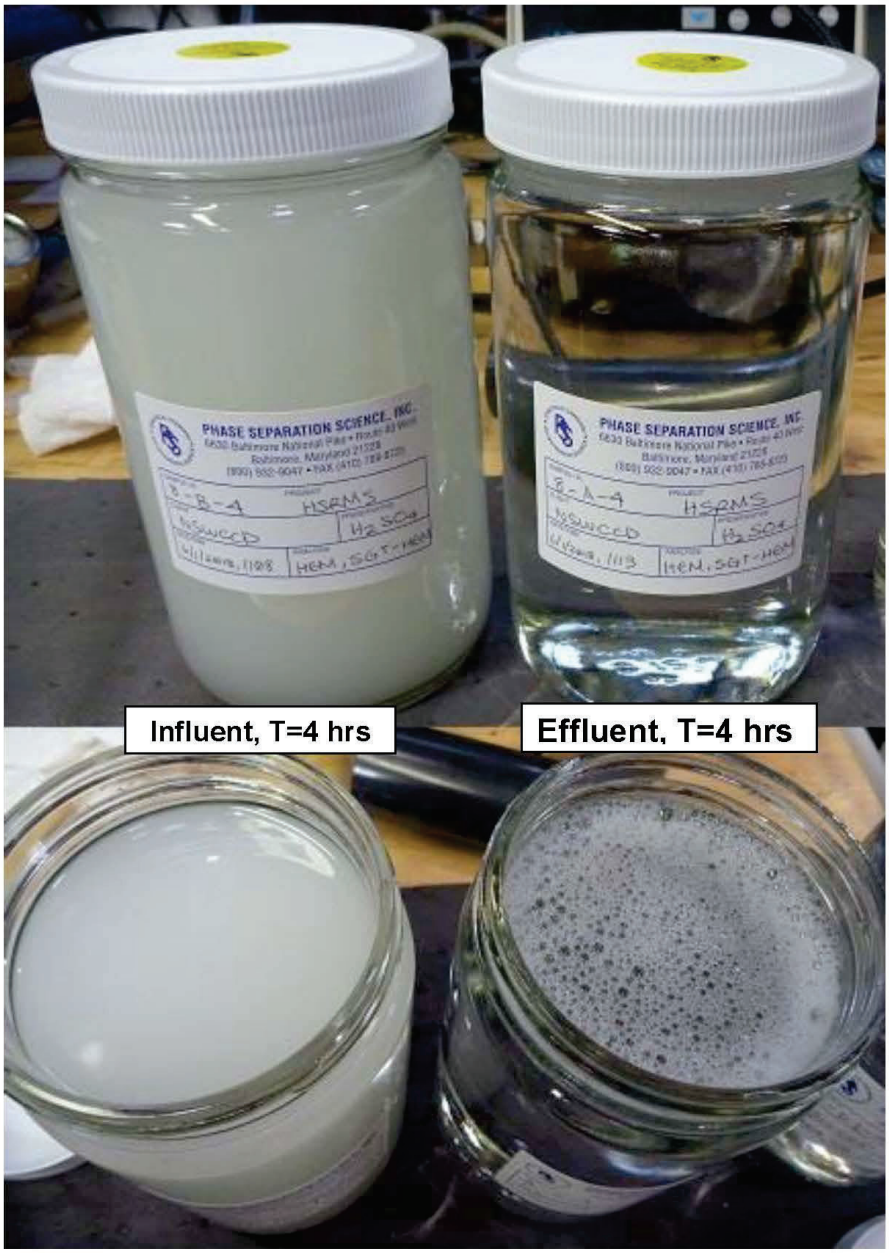


Figure P-15. Performance Test #8 - Influent and Effluent Samples

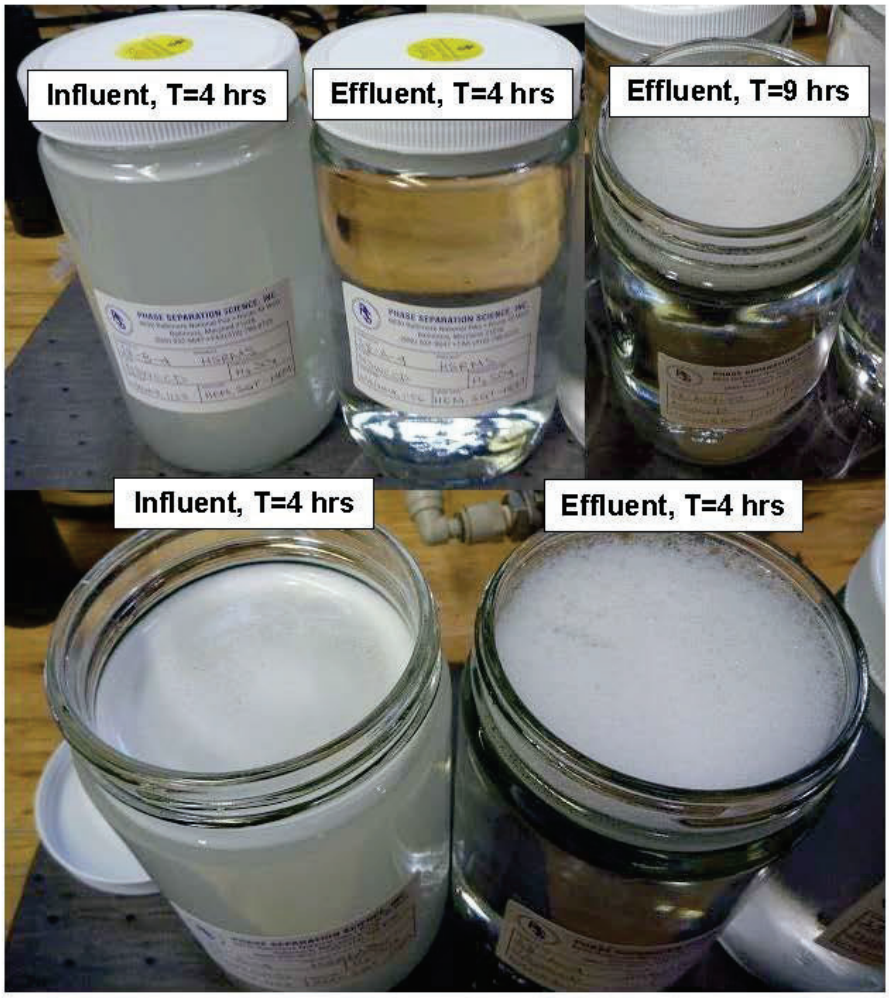


Figure P-161. Performance Test #18 - Influent and Effluent Samples

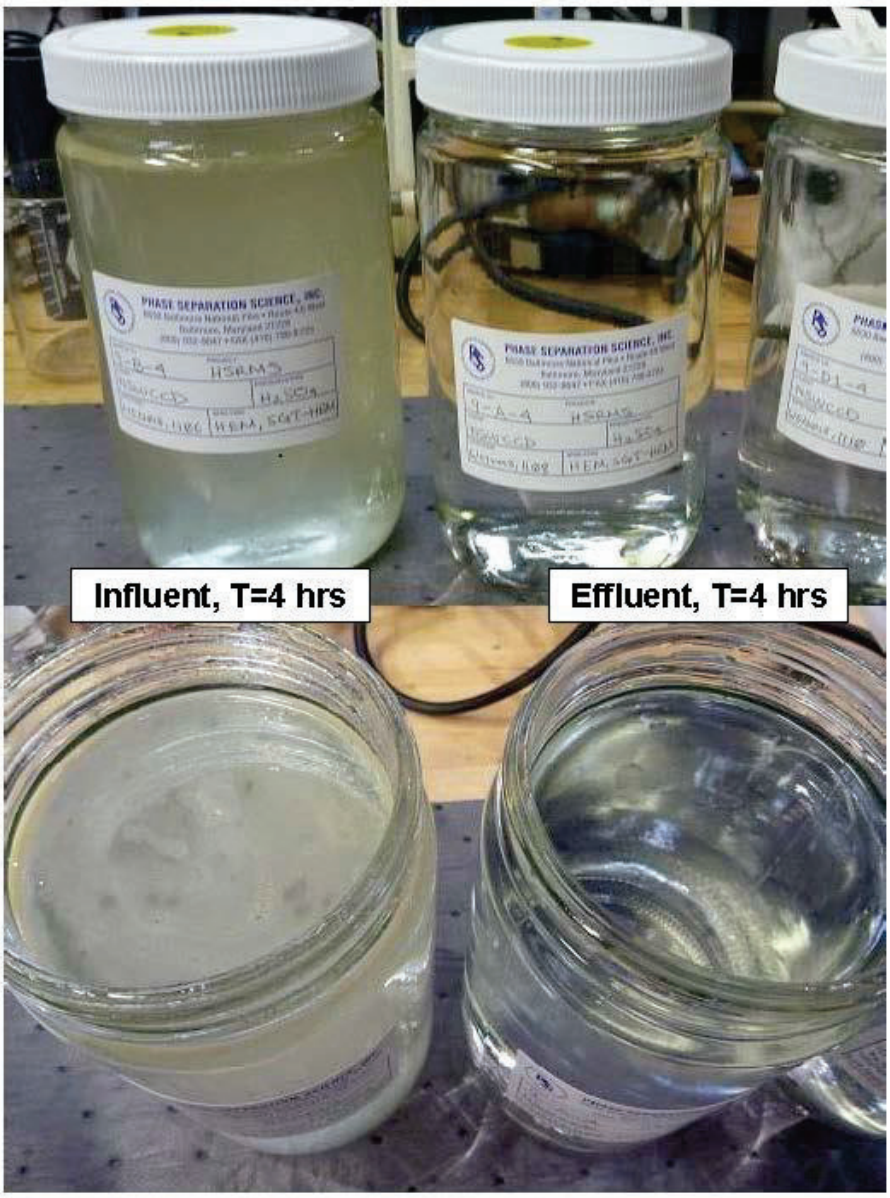


Figure P-17. Performance Test #9 - Influent and Effluent Samples

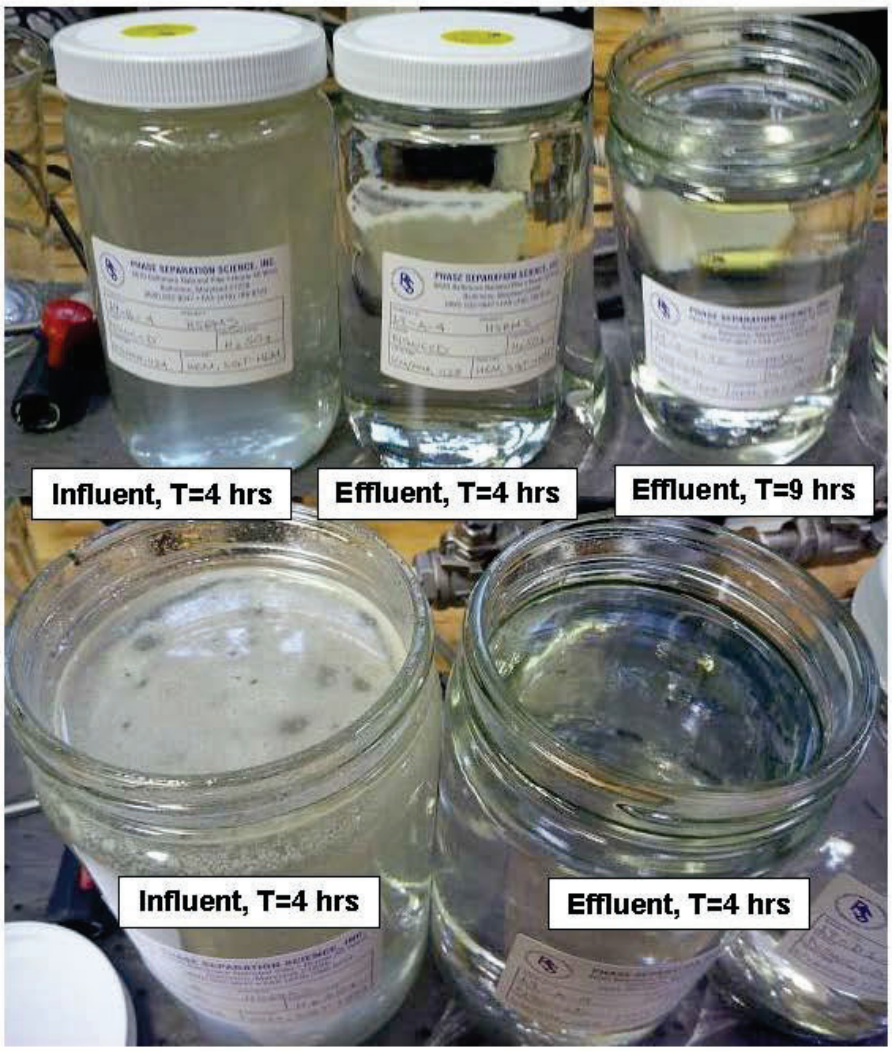


Figure P-18. Performance Test #19 - Influent and Effluent Samples

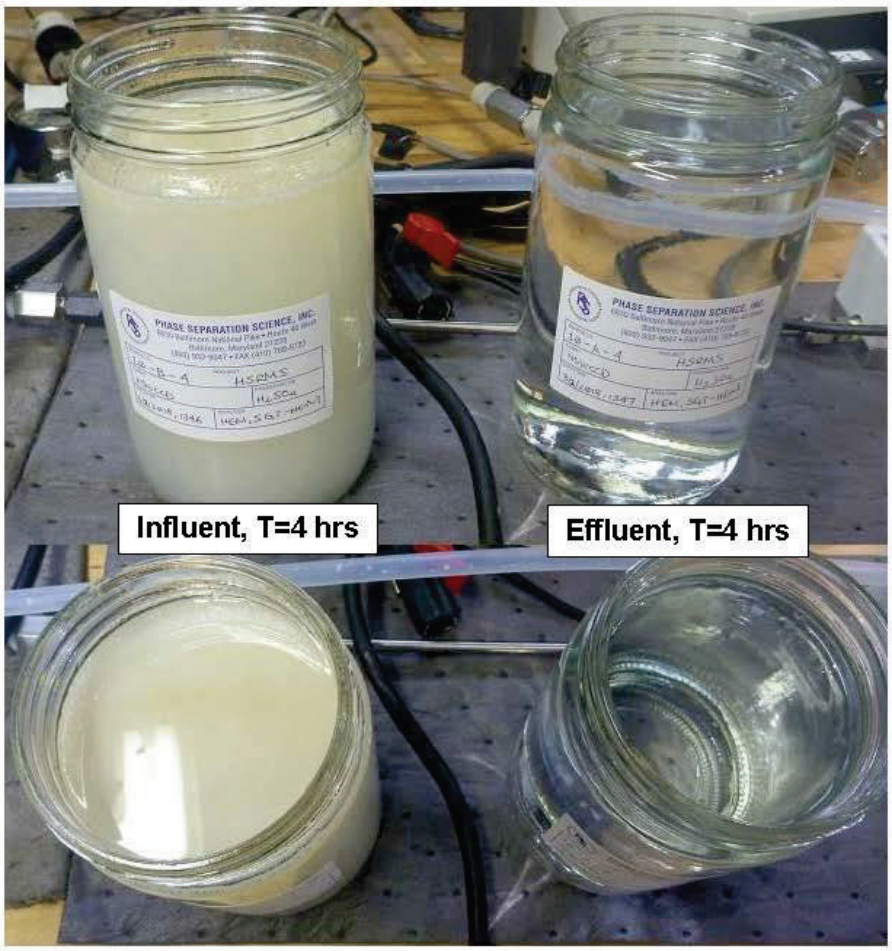


Figure P-19. Performance Test #10 - Influent and Effluent Samples



Figure P-20. Performance Test #20 - Influent and Effluent Samples

APPENDIX Q: SHIPBOARD DATA

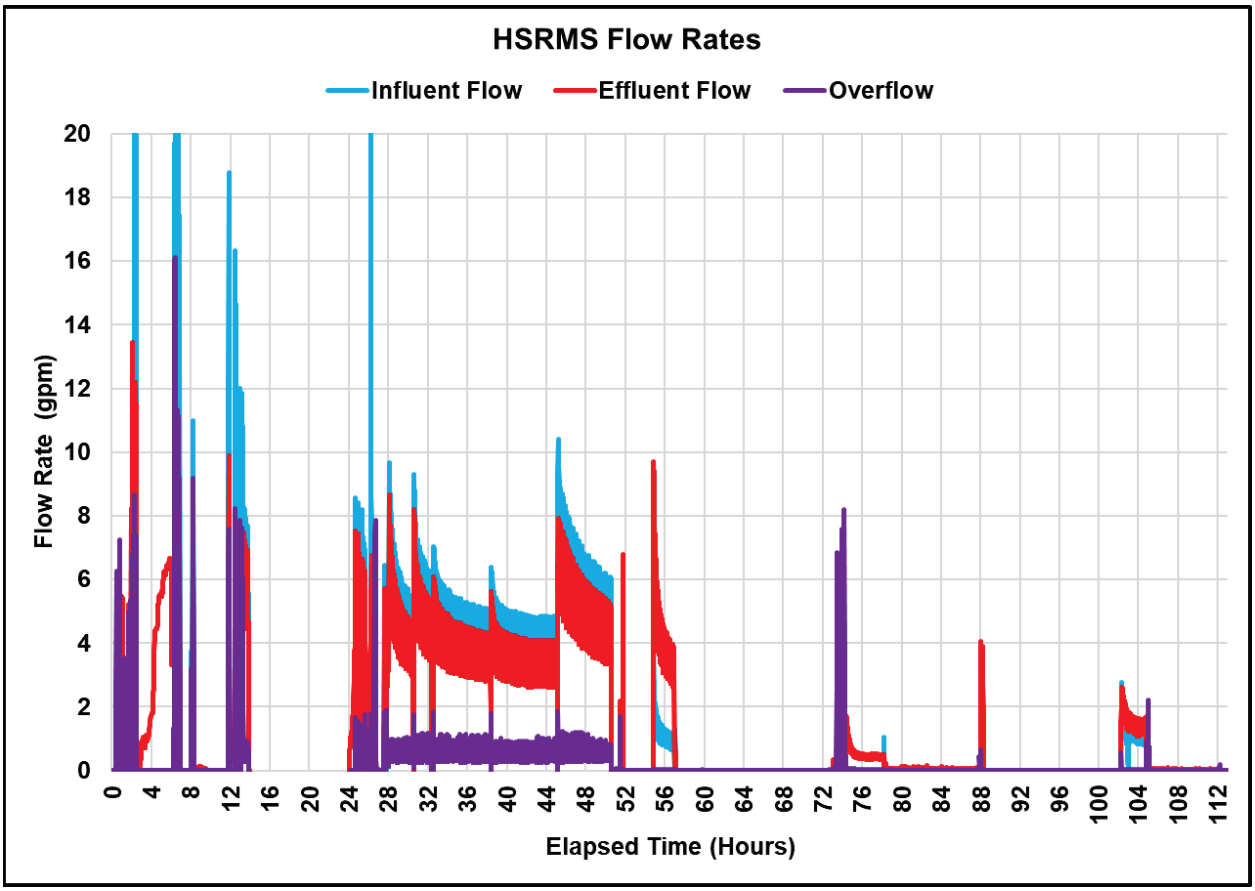


Figure Q- 1: HSRMS Flow Rates Over Elapsed Time Powered During the Shipboard Demonstration

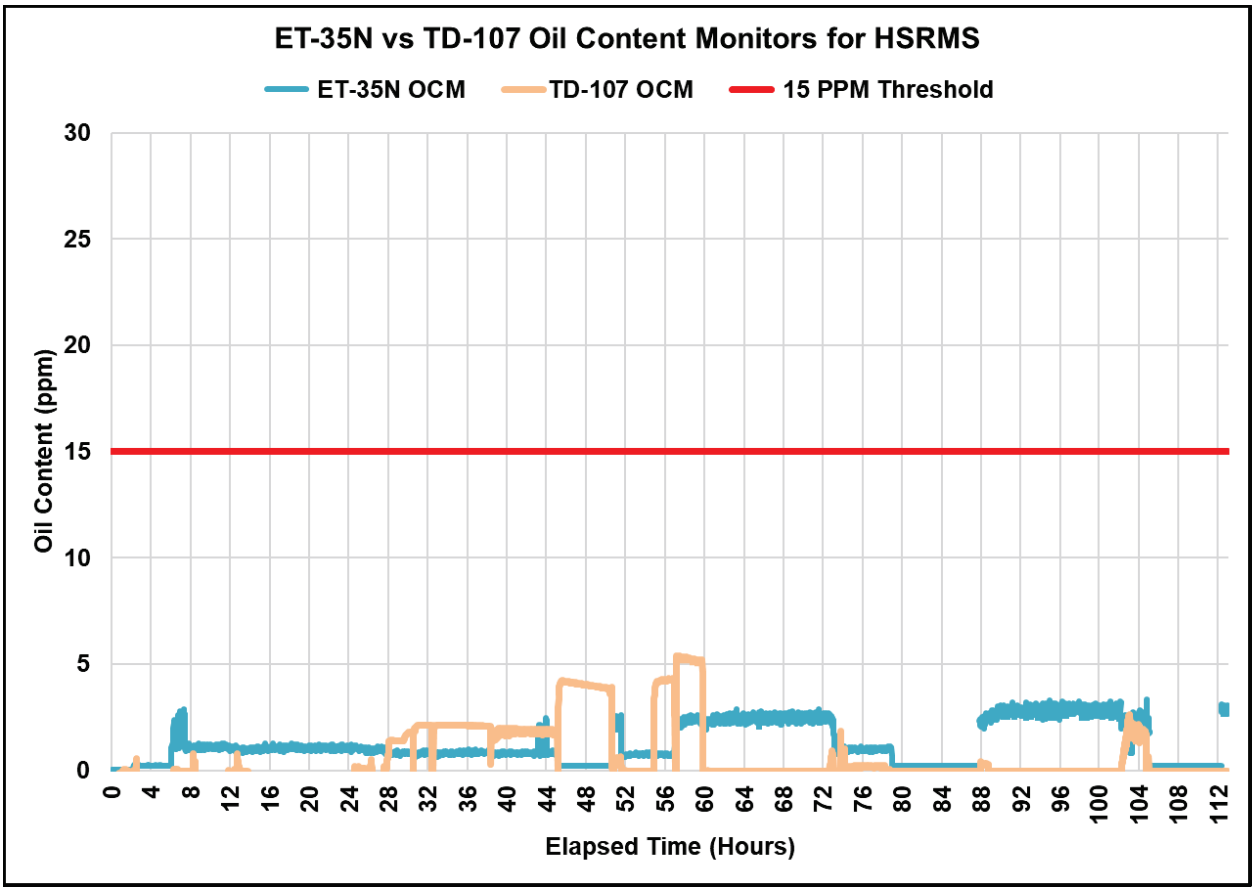


Figure Q- 2: Oil Content Over Elapsed Time Powered During the Shipboard Demonstration

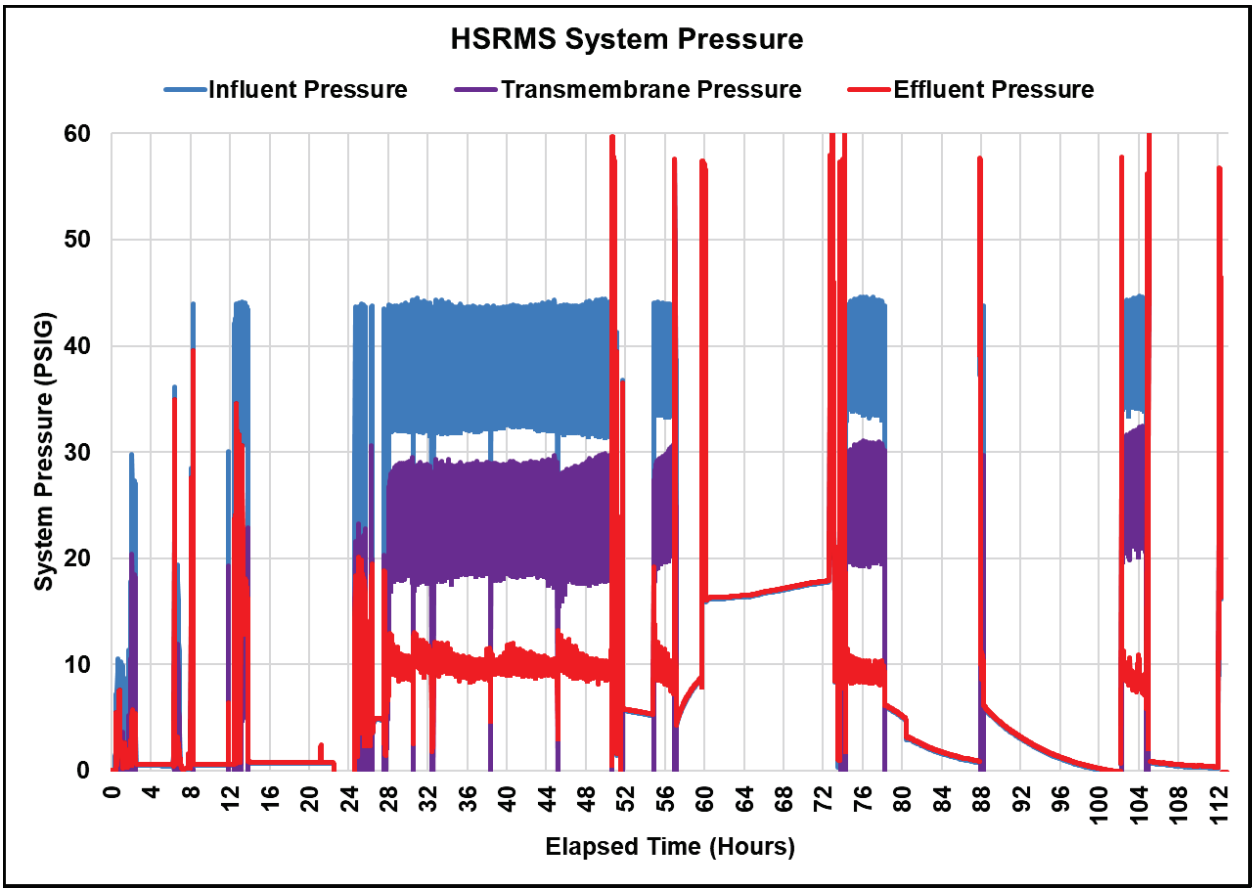


Figure Q- 3: HSRMS Pressures Over Elapsed Time Powered During the Shipboard Demonstration

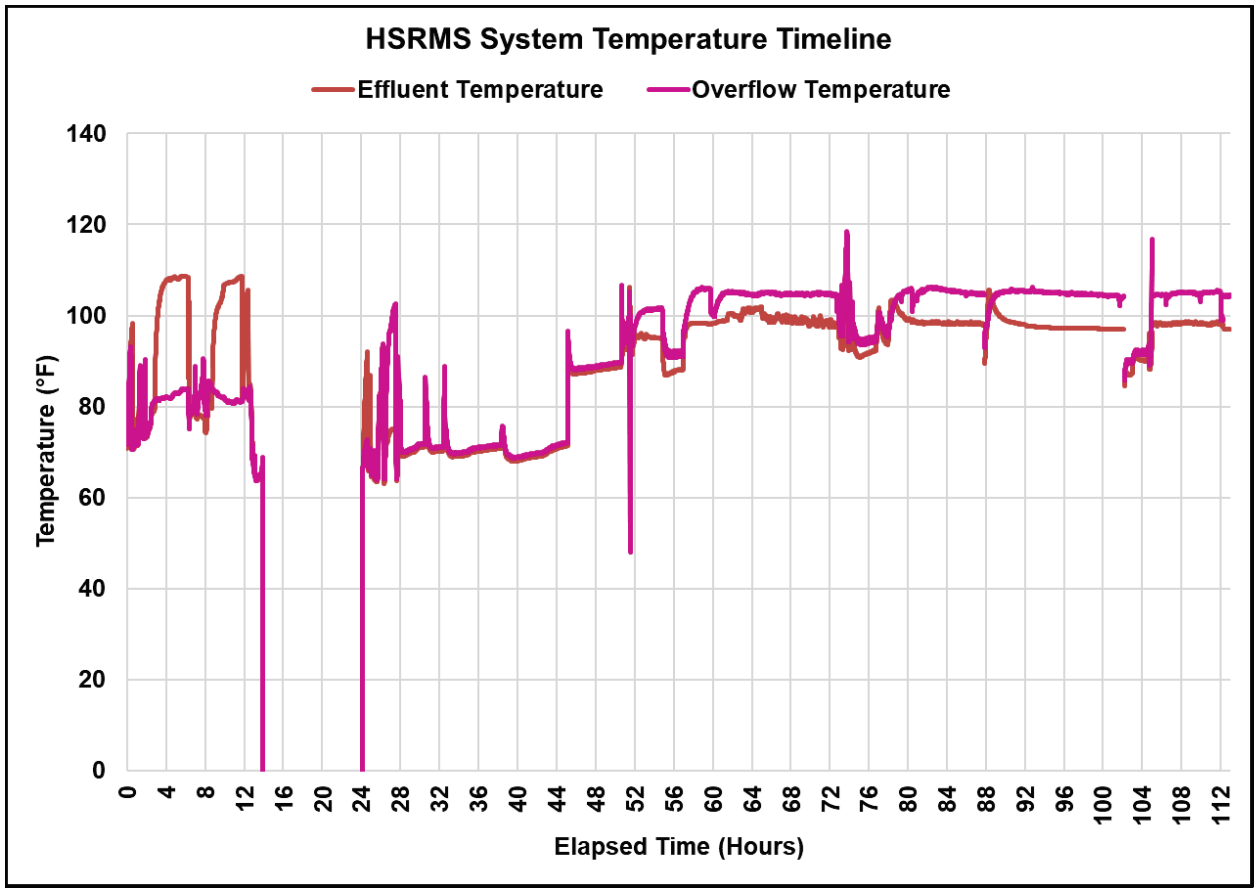


Figure Q- 4: Temperature Flow Rates Over Elapsed Time Powered During the Shipboard Demonstration

APPENDIX R: COST ASSESSMENT CALCULATIONS

Table R-1. System Maintenance and Parts

Item Name	Specification	Part No.	Source	Frequency in 30 Year Lifecycle	Total per Event	Cost (Each)	Hours/Event	Labor Cost/Event
OWMS	NCDF-10	NCDF-10	Novoflow	2	1	$ 116,361.00		
Gear Drive			SEW Eurodrive	2	1	$ 2,995.17	20	$ 1,392.60
Oil seal	W BAOFSF27x47x6/7-FKM	13262378	SEW Eurodrive	10	1	$ 10.12	8	$ 557.04
Oil seal	W A40x52x7-FKM-FKO	13261819	SEW Eurodrive	10	1	$ 17.17	8	$ 557.04
Bearing Grease		Renolit CX-TOM 15	Fuchs	10	1	$ 10.00	2	$ 139.26
Lubricant		S4WE 220	Shell	10	1	$ 200.00	2	$ 139.26
CONTROL VALVE		550 10D 1AC2 511 G1	Gemü	2	2	$1025.00	8	$ 557.04
CONTROL VALVE		550 25D 1AC2 511 G1	Gemü	2	4	$1025.00	8	$ 557.04
CONTROL VALVE		550 8D 137 510G1	Gemü	2	6		8	$ 557.04
LEVEL MEASURING INSTRUMENT		FTW23 AA4MWVJ	E+H	2	5	$ 206.00	8	$ 557.04
FLOW MEASURING INSTRUMENT		SM 8004	IFM	2	2	$ 778.00	8	$ 557.04
PRESSURE MEASURING INSTRUMENT		Cerebar PMP23 AA1M1PB3CJ	E+H	2	2	$ 366.00	8	$ 557.04
Pump		CRN 1-4 A-FGJ-G1-V-HQQV	Grundfos	2	1	$ 947.16	25	$ 1,740.75

Item Name	Specification	Part No.	Source	Frequency in 30 Year Lifecycle	Total per Event	Cost (Each)	Hours/Event	Labor Cost/Event
Pump		CRN 3-5 A-FGJ-GI-V-HQQV	Grundfos	2	1	$ 1,696.72	25	$ 1,740.75
Pump		CXM 25 FTT-V	Almatec	2	1		25	$ 1,740.75
Ceramic Filters		SSDF 2-15-374	Kerafol	6	100	$ 121.68	16	$ 1,114.08
Spare Parts	10 ss hubs with 10 ss distance rings, 10 interior o-ring seals; 1 mechanical seal; 1 rotary filtrate mechanical seal; 2 plastic counter		Novoflow	30	1	$ 5,110.63	8	$ 557.04
Membrane Cleaners	Micro 90; A07		International Products Corp	30	1	$ 2,566.76	10	$ 696.30

Notes/Assumptions:

1. System life is expected to be a maximum of 15 years

2. Primary component life is expected to be half that of system life in the absence of replacement data

3. Other wear part maintenance frequencies are derived from the OEM or operation manual and are therefore cell specific

4. Labor cost in 2013 was $61.83/hr based on VS-50+ cost comparison; assume 2% increase per year for 12 years, current labor cost is $69.63/hr

5. 2x system cost should be applied consistent with Alfa Laval commercial system conversion to military qualified upgrades; this cost factor does not apply to independent parts

6. System and spare part costs derived from contract N00167-17-P-00145

7. Independent part cost derived from web searches and quote requests

Table R-2. Wastewater Offload Costs

Parameter	Amount
In-port (gal/day)	62.5 gal/day
Underway (gal/day)	250 gal/day
% in-port	0.45
% underway	0.55
Disposal Cost per gal	$ 0.25
Total Gallons Underway	50187.5 gal
Total Gallons In-port	10265.625 gal
Total Cost In-port	$ 2,566.41
Total Cost Underway (HSRMS)	$ 1,254.69
Total Cost Underway (10NP/OWMS)	$ 627.34
HSRMS Disposal Costs/Year	$ 3,821.09
10NP/OWMS Disposal Costs/Year	$ 3,193.75

Notes/Assumptions:

1. Though Novoflow HSRMS was originally sized as a 10 gpm system, laboratory results showing an effective processing rate of near 5 gpm

2. The 10NP with 5-gpm membrane (10NP/OWMS) selected for comparison

3. Applicable ship class selected is FFG-56 (< 10 gpm OWS)

4. Used UNDS based daily bilge generation rate for FFG-56 of 250 gal/day

5. Used 25% underway generation for in-port generation rate (62.5 gal/day in-port) consistent with 10NP cost comparison

6. Used 45% in port and 55% underway assumption consistent with 10NP cost comparison

7. 10NP/OWMS is able to process 95% of wastewater generated underway as documented in LCS CAoA

8. Novoflow HSRMS is able to process 90% of the wastewater generated underway based on laboratory evaluation results

9. Membrane regeneration procedures for both 10NP/OWMS and HSRMS are the same, and waste volume generated assumed to be the same and is therefore not included

10. Average worldwide disposal costs were $0.20/gal in 2010 according to VS-50+ cost comparison; assuming 2%/year increase, disposal costs are now $0.24

11. All waste generated in-port will be offloaded; all waste generated underway will be processed overboard by the OWS, as long as it meets the 15 ppm effluent criteria

Table R-3. HSRMS Upfront and Operation Costs

Parameter	Value
HSRMS ILS Package	$ 5,272.47
Installation cost	Platform Dependent
Yearly Operation Costs	$ 1,671.12
Energy Cost	N/A
Training	$ 10,694.24
10NP/OWMS ILS Package	$ 5,272.00

Notes/Assumptions:

1. Only operational cost calculation used in the 30-year estimate
2. 2% inflation
3. 1hr of operation per production cycle and 2 production cycles per month
4. Training 3 people for two 8 hr days

Table R-4. 30 Year Cost Benefit Summary

System	Cost	Year										
		1	3	9	12	15	18	21	24	27	30	Total
HSRMS	System Cost	$233K				$307K						$540K
	Wastewater Disposal	$4K	$4K	$4K	$5K	$5K	$5K	$6K	$6K	$6K	$7K	$155K
	Operation Costs	$2K	$2K	$2K	$2K	$2K	$2K	$2K	$3K	$3K	$3K	$68K
	Maintenance Costs	$9K	$9K	$12K	$13K		$15K	$16K	$17K	$18K	$19K	$492K
10NP/OWMS	System Cost	$399K				$536K						$925K
	Wastewater Disposal	$3K	$3K	$4K	$4K	$4K	$4K	$5K	$5K	$5K	$6K	$130K
	Operation Costs	$2K	$2K	$2K	$2K	$2K	$2K	$2K	$3K	$3K	$3K	$68K
	Maintenance Costs	$30K	$31K	$35K	$37K	$39K	$41K	$44K	$47K	$50K	$52K	$1198K
	Yearly Cost Savings	$20K	$19K	$21K	$23K	$257K	$26K	$27K	$29K	$34K	$33K	$1066K
	30 Year ROI= $1,066K											

*Table only shows data for every 3 years of calculations. The cost benefit for every year was used to determine the 30-year ROI

Notes/Assumptions:

1. System replacement after 15 yrs
2. 2% inflation
3. Consistent bilgewater production over 30 yrs

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