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Final Report

USATHAMA

U.S. Army Toxic and Hazardous Materials Agency

**ECONOMIC EVALUATION OF TWO
BIOLOGICAL PROCESSES FOR
TREATMENT OF BALL POWDER
PRODUCTION WASTEWATER**

(TASK ORDER NO. 10)

February 1989
Contract No. DAAK11-85-D-0008

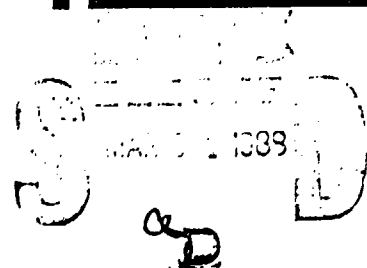
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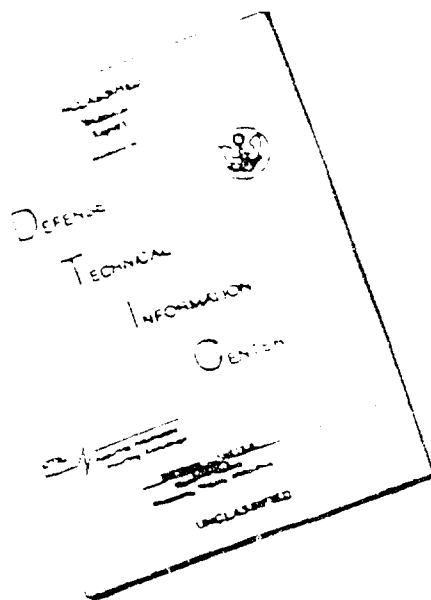
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**Final Report to
United States Army
Toxic and Hazardous
Materials Agency
February 1989**

Economic Evaluation of Two Biological Processes for Treatment of Ball Powder Production Wastewater

(Task Order Number 10)

Final Report

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Currently, Badger Army Ammunition Plant (AAP) has no facility other than lagoons for treating wastewater generated during the production of BALL POWDER[®] propellant. Because of the lack of an environmentally acceptable treatment facility, the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) desired to evaluate technologies that would effectively treat ball powder production wastewater and, subsequently, allow its discharge [within the National Pollutant Discharge Elimination System (NPDES) requirements] to the Wisconsin River.

Pilot test results indicated that in the absence of nitroglycerin (NG) both the sequencing batch reactor (SBR) and extended aeration systems were capable of meeting NPDES requirements continuously. When NG was present in the ball powder wastewater, pilot test results showed that NG was toxic to the biomass. The toxic effect of the NG caused a decrease in the biomass efficiency to perform carbonaceous oxidation, nitrification and denitrification. The toxicity also caused further problems by adversely affecting the bacteria's ability to (continued)

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#18 (continued): • Aerobic Biological Oxidation • Diphenylamine Pollutants • Dibutyl-phthalate Pollutants • n-Nitrosodiphenylamine Pollutants • Capital Cost • Operating Cost

#19 (continued): Form flocs, which resulted in a significant quantity of the biomass overflowing with the effluent, and thereby decreasing the concentration of biomass in the reactor. The end result of NG's toxicity was to produce an unstable biological system that could not meet NPDES requirements.

Because of NG's toxic effect and both systems' ability to meet NPDES limits in the absence of NG, preliminary full-scale designs for both extended aeration and SBR systems were prepared based on the removal of NG in a pretreatment system. These preliminary designs were then used to develop budgetary capital and operating costs to compare the economics of both biological systems. Within the range of accuracy (plus 40/minus 10%) of the budgetary estimates, both systems were found to be approximately equal in cost.

The final conclusion, based on the pilot studies, conducted at Badger AAP, and the cost analysis, was that either biological system was capable of meeting NPDES limits and that both systems were equivalent on a capital and operating cost basis. The systems were also equivalent with respect to:

- System safety,
- Throughput rate,
- Reliability,
- Ease of operation, and
- Permitting.

Consequently, based on both technical and economic merits, we conclude that either biological system is capable of treating ball powder wastewater at Badger AAP; however, the wastewater must first be pretreated for NG removal. (RLO)

TABLE OF CONTENTS

	<u>Page</u>
List of Tables	ii
List of Figures	ii
EXECUTIVE SUMMARY	ES-1
1.0 INTRODUCTION	1-1
2.0 SYSTEM DESCRIPTION	2-1
2.1 System 100 - Collection and Equalization	2-1
2.2 System 200 - pH and Nutrient Control	2-1
2.3 System 300 - Extended Aeration and Aerobic Digestion	2-4
2.4 System 400 - Sequencing Batch Reactor and Aerobic Digestion	2-4
2.5 System 500 - Sludge Dewatering and Control Building	2-7
3.0 COST ESTIMATION AND ECONOMIC EVALUATION	3-1
3.1 Approches to Cost Estimation	3-1
3.2 Capital Investment	3-1
3.3 Operating Cost/Economic Evaluation	3-1
4.0 CONCLUSIONS AND RECOMMENDATIONS	4-1
5.0 REFERENCES	5-1
APPENDIX A	A-i

LIST OF TABLES

<u>Table No.</u>		<u>Page</u>
1.1	Design Basis for Full-Scale Biological Treatment System at Badger AAP	1-3
1.2	Preliminary Design Summary	1-5
3.1	Capital Investment Costs for Extended Aeration and Sequencing Batch Reactor Systems	3-2
3.2	Annual Operating Cost for Extended Aeration with Nonhazardous Waste	3-3
3.3	Annual Operating Cost Sequencing Batch Reactor with Nonhazardous Waste	3-4
3.4	Annual Operating Cost for Extended Aeration with Hazardous Waste	3-6
3.5	Annual Operating Cost for Sequencing Batch Reactor with Hazardous Waste	3-7

LIST OF FIGURES

<u>Figure No.</u>		<u>Page</u>
2.1	100 - Collection and Equilization Basin	2-2
2.2	200 - pH and Nutrient Control	2-3
2.3	300 - Extended Aeration and Aerobic Digestion	2-5
2.4	400 - Sequencing Batch Reactors and Aerobic Digestion	2-6
2.5	500 - Sludge Dewatering	2-8

EXECUTIVE SUMMARY

Currently, Badger Army Ammunition Plant (AAP) has no facility other than lagoons for treating wastewater generated during the production of BALL POWDER® propellant*. Because of the lack of an environmentally acceptable treatment facility, the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) desired to evaluate technologies that would effectively treat ball powder production wastewater and, subsequently, allow its discharge [within the National Pollutant Discharge Elimination System (NPDES) requirements] to the Wisconsin River.

Pilot test results¹ indicated that in the absence of nitroglycerin (NG) both the sequencing batch reactor (SBR) and extended aeration systems were capable of meeting NPDES requirements continuously. When NG was present in the ball powder wastewater, pilot test results² showed that NG was toxic to the biomass. The toxic effect of the NG caused a decrease in the biomass efficiency to perform carbonaceous oxidation, nitrification and denitrification. The toxicity also caused further problems by adversely affecting the bacteria's ability to form flocs, which resulted in a significant quantity of the biomass overflowing with the effluent, and thereby decreasing the concentration of biomass in the reactor. The end result of NG's toxicity was to produce an unstable biological system that could not meet NPDES requirements.

Because of NG's toxic effect and both systems' ability to meet NPDES limits in the absence of NG, preliminary full-scale designs for both extended aeration and SBR systems were prepared based on the removal of NG in a pretreatment system. These preliminary designs were then used to develop budgetary capital and operating costs to compare the economics of both biological systems. Within the range of accuracy (plus 40/minus 10%) of the budgetary estimates, both systems were found to be approximately equal in cost.

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- System safety,
- Throughput rate,
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Consequently, based on both technical and economic merits, we conclude that either biological system is capable of treating ball powder wastewater at Badger AAP; however, the wastewater must first be pretreated for NG removal.

*BALL POWDER propellant is a registered trademark of Olin Corporation.

1.0 INTRODUCTION

Currently, Badger Army Ammunition Plant (AAP) has no facility other than lagoons for treating wastewater generated during the production of BALL POWDER® propellant*. Because of the lack of an environmentally acceptable treatment facility, the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) desired to evaluate technologies that would effectively treat ball powder production wastewater and, subsequently, allow its discharge [within the National Pollutant Discharge Elimination System (NPDES) requirements] to the Wisconsin River.

Arthur D. Little, Inc. was contracted by USATHAMA under Contract No. DAAK11-85-D-0008 to evaluate the technical and economic feasibility of technologies for treating ball powder propellant wastewater. In a previous task (Task Order Number 11/Subtask 11.1) entitled "Ball Powder Production Wastewater Biodegradation Support Studies," Arthur D. Little designed, installed, and operated two biological oxidation pilot plants to evaluate extended aeration and sequencing batch reactor (SBR) systems.^{1,2} The objectives of this pilot-scale testing were threefold:

- (1) Determine the ability of each system to treat ball powder production wastewater [with and without nitroglycerin (NG)] and meet anticipated NPDES requirements;
- (2) Determine the toxic effect, if any, of ball powder propellant wastewater (both with and without NG) on the biological systems; and
- (3) Develop preliminary design criteria for use in the ultimate engineering, design, and costing of a full-scale wastewater treatment system.

During the evaluation of the pilot test data, we determined that NG exhibited a toxic effect on the biomass (regardless of the type system) which negatively impacted the system's performance resulting in the treated wastewater exceeding the anticipated NPDES requirements for most parameters [biochemical oxygen demand (BOD), total suspended solids (TSS), and N-nitrosodiphenylamine (NDPA)]. In additional pilot plant tests, however, we determined that both the extended aeration and SBR systems were capable of treating ball powder wastewater without NG and meeting anticipated NPDES requirements. Thus, the recommendation was made to install a pretreatment system for the removal of NG prior to the wastewater being introduced to the full-scale biological treatment system. Since our contract (Scope of Work) with USATHAMA did not include the testing and/or evaluation of NG pretreatment systems, we have made the assumption, for this cost analysis, that an effective NG pretreatment system already exists at Badger AAP. Therefore, we have excluded any capital and operating costs which would be associated

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with such a pretreatment system from this cost analysis. Consequently, we have used the data from the pilot-scale testing (without NG) to develop the preliminary design criteria (Tables 1.1 and 1.2) which was used in preparing the required capital and operating cost estimates.

The objective of this task (Task Order Number 10), entitled "Computerization and Application of a Standard Cost Evaluation Method," under USATHAMA Contract No. DAAK11-85-D-0008, was to conduct an economic comparison of both extended aeration and SBR full-scale wastewater treatment systems in order to allow USATHAMA personnel to make a direct comparison between them. To meet this objective, we developed process flow diagrams, equipment lists, equipment specifications, operating requirements, and associated capital and operating costs for both systems.

Arthur D Little

TABLE 1.1

DESIGN BASIS FOR FULL-SCALE BIOLOGICAL TREATMENT SYSTEM AT BADGER AAPBall Powder Production

Anticipated Throughput:	1.0 - 3.0 million lb ball powder/month
Wastewater Generated:	1.0 - 3.0 million gal wastewater/day

Wastewater Inlet Characterization

BOD	950 mg/L
COD	1,400 mg/L
TSS	30 mg/L
TDS	3,500 mg/L
Ethyl Acetate	340 mg/L
Collagen	300 mg/L
DBP	1.1 mg/L
NDPA	1.9 mg/L
NG	8 mg/L
NO ₃ -N	1.3 mg/L
NH ₄ -N	14 mg/L
TKN	65 mg/L
pH	7

Anticipated NPDES Limits

pH	6.0 - 9.0
BOD	45 mg/L (daily)
	30 mg/L (avg)
Total Phthalates	3.0 ug/L
Total Nitrosoamines	3.0 ug/L
TSS	50 mg/L
TDS	no limit assumed
NO ₃ -N	50 mg/L
SO ₄	no limit assumed
DO	6-8 mg/L

TABLE 1.1 (Continued)

DESIGN BASIS FOR FULL-SCALE BIOLOGICAL TREATMENT SYSTEM AT BADGER AAPOptimum Operating Conditions

F:M ratio	
• Extended aeration	0.11 day ⁻¹
• SBR	0.14 day ⁻¹
Dissolved oxygen uptake rate	
• Extended aeration	0.27 mg/L/min
• SBR	0.33 mg/L/min
Concentration of biomass in reactor (MLSS)	
• Summer months	3,500 mg/L
• Winter months	4,500 mg/L
Concentration of settled biomass (MLSS)	10,000 mg/L
Growth rate of biomass	0.3 lb biomass/lb BOD
Aerobic Digestion	
• Optimum retention time	15 days ³
• Biomass reduction	40% ³
• Concentration of settled biomass	10,000 mg/L
Percent solids from belt filter	20%

Source: Arthur D. Little, Inc.

TABLE 1.2
PRELIMINARY DESIGN SUMMARY

<u>Biological Reactor</u>	<u>Extended Aeration</u>	<u>SBR</u>
Reactor Volume	7.3 million gal	5.7 million gal
Number of Reactors	2	3
Hydraulic Retention Time	58 hr	46 hr
Biomass Growth	7,130 lb/day	7,130 lb/day
Biomass Retention Time	30 days	23 days
Nitrogen Supplied	0 lb/day	0 lb/day
Phosphorus Supplied	250 lb/day	250 lb/day
<u>Aeration System</u>		
Biological Oxygen Requirement	980 lb/hr	1,200 lb/hr
Air Flow Rates (STP)	4,000 ft ³ /min	4,880 ft ³ /min
<u>Clarifier</u>		
Percent Recycle	77%	NA
Clarifier Area	7,500 ft ²	NA
Number of Clarifiers	2	NA
Dimensions of each Clarifier		
• Diameter	70 ft	NA
• Depth	15 ft	NA
<u>Aerobic Digester</u>		
Reactor Volume	1.3 million gal	1.3 million gal
Retention Time	15 days	15 days
Sludge to Digester	86,000 gal/day	86,000 gal/day
<u>Sludge Dewatering and Disposal</u>		
Sludge Dewatered	51,600 gal/day	51,600 gal/day
Sludge to Disposal	21,500 lb/day	21,500 lb/day

NA - Not Applicable

Source: Arthur D. Little, Inc.

2.0 SYSTEM DESCRIPTION

We have prepared preliminary process designs for both a full-scale extended aeration system and a full-scale SBR system based on the design criteria shown in Table 1.1. The major assumption in our design was that the wastewater had been pretreated for removal of NC prior to its introduction to either biological system. For ease of review, the design has been divided into five systems:

- System 100 - Collection and Equalization
- System 200 - pH and Nutrient Control
- System 300 - Extended Aeration and Aerobic Digestion
- System 400 - Sequencing Batch Reactor and Aerobic Digestion
- System 500 - Sludge Dewatering and Control Building

Systems 100, 200, and 500 are common to both the SBR and extended aeration systems, and only the design and costing of Systems 300 and 400 differentiate the two cases.

2.1 System 100 - Collection and Equalization

Figure 2.1 shows the process flow diagram for the collection and equalization of the wastewater. The design is straightforward with the ball powder propellant wastewater entering two clarifiers (100-1 and 100-2) for preliminary clarification. These two clarifiers already exist at Badger AAP and, therefore, would not have to be purchased or installed. The clarified wastewater then flows into a sump where it is pumped to a large equalization basin to even out fluctuations in wastewater composition. The equalization basin (100-7) is designed to hold one day's flow at the maximum flow rate of 3.0 MGD. The basin is to be lined first with clay and then a Hypalon® liner to prevent wastewater percolation into underlying soil. The wastewater is then pumped from the basin to pH and nutrient control (System 200).

2.2 System 200 - pH and Nutrient Control

The pilot studies indicated that there was sufficient nitrogen in the wastewater to provide for all biomass requirements for such without the need for an additional source; however, it also indicated that the wastewater did not have a sufficient supply of phosphorous. The nutrient system, therefore, uses phosphoric acid (H_3PO_4) to supply the additional phosphorous required (Figure 2.2).

In the pilot studies, we found that the pH of the wastewater averaged 7.0 with a range of 6.5 to 7.5; therefore, there was no need for a pH control system. However, because a pH outside the optimum range (5.0-8.0) for biological systems could adversely affect the biomass, a pH control system was added as a precautionary measure. In cases where the pH was in the proper range, the wastewater feed would bypass the pH control system. In the rare instance where pH is outside the optimum range, the wastewater would be directed to the pH control system where

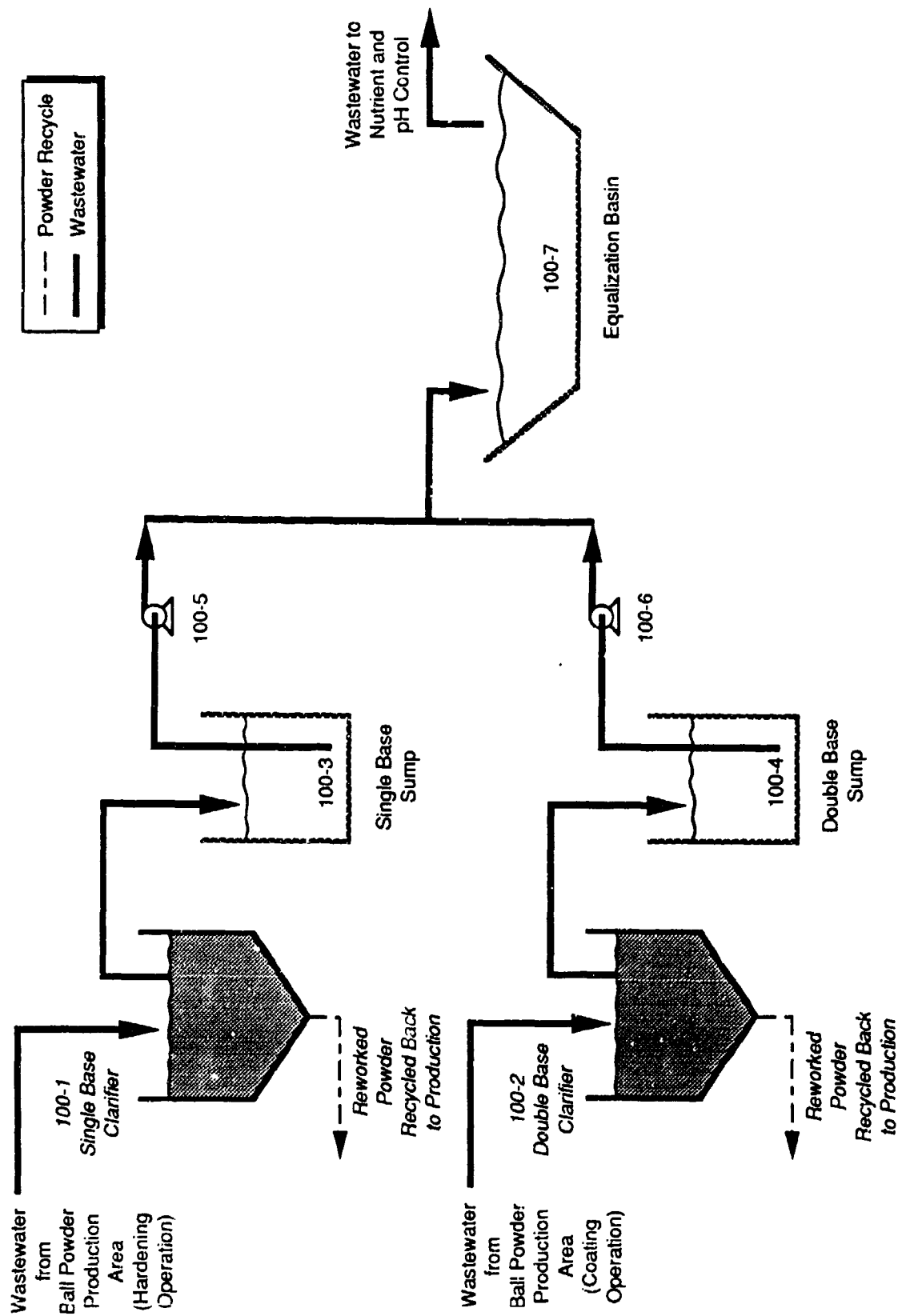
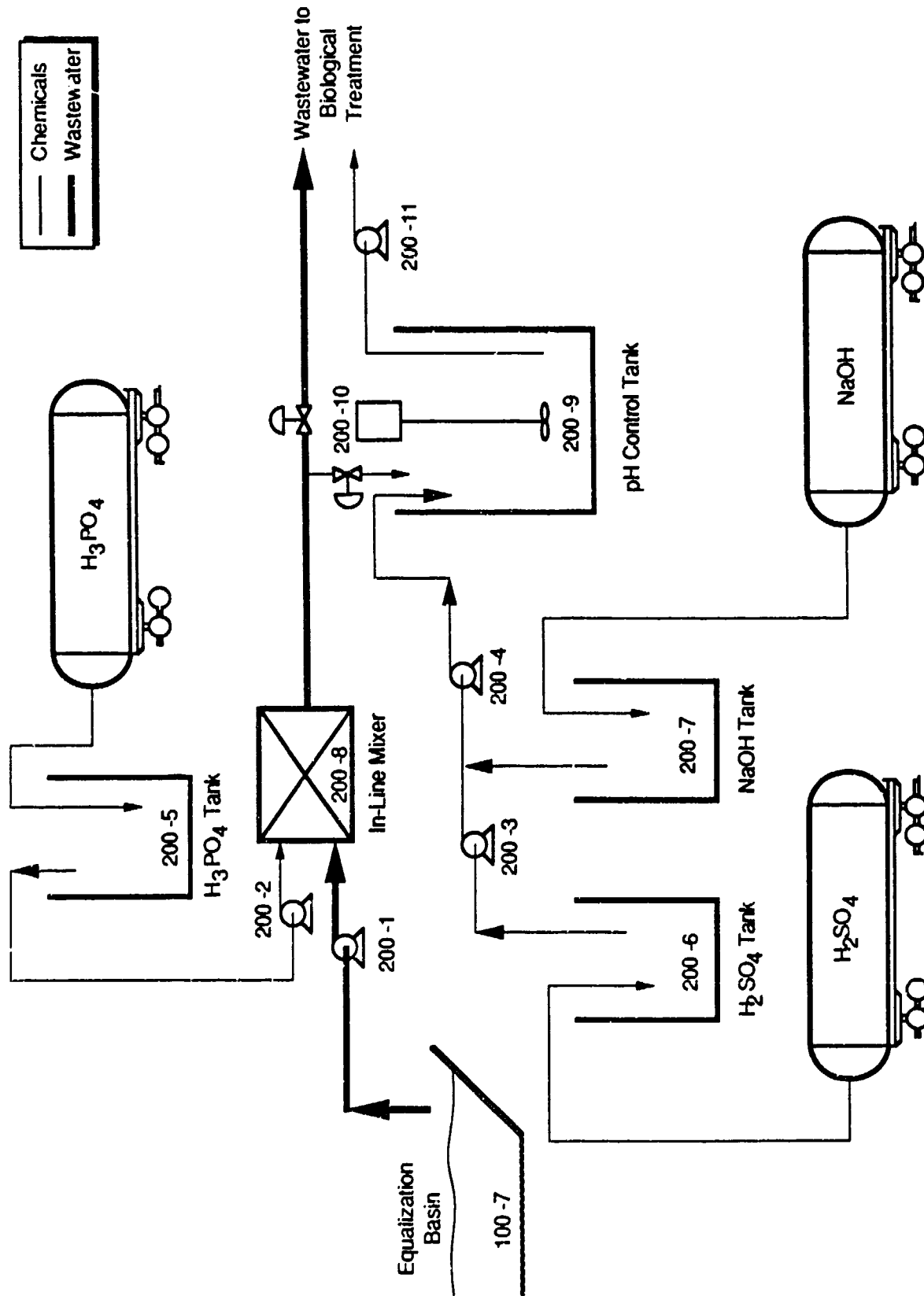


FIGURE 2.1
100 - COLLECTION AND EQUALIZATION BASIN

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Source: Arthur D. Little

FIGURE 2.2
200 - pH AND NUTRIENT CONTROL

either sulfuric acid (H_2SO_4) or sodium hydroxide (NaOH) could be added to adjust the pH. After the pH control system, the wastewater would be pumped to either the SBR or extended aeration treatment system.

2.3 System 300 - Extended Aeration and Aerobic Digestion

In the case of extended aeration, upon exiting the pH control system, the wastewater is divided into two streams and is continuously fed to both biological oxidation basins (Figure 2.3). Each basin (300-1) is equipped with three two-speed aerators (300-2) which can be used to vary the relative sizes of the aeration and anoxic zones and to give the operators of the basins the 3-to-1 turndown ratio that Badger AAP requires. Two variable height weirs (300-3) also facilitate turndown in throughput and serve as the points for overflow to the two clarifiers (300-5).

The treated wastewater and suspended biomass flow to the clarifiers for separation into treated effluent and concentrated biomass sludge. Both clarifiers are 70 ft in diameter and 14 ft deep with geodesic domes covering them to prevent freezing in the winter. From the bottom of the clarifier, the concentrated biomass is either recycled to the head of the oxidation basins or wasted to the aerobic digester. The clarified effluent flows by gravity from the clarifiers to the chlorinator (300-15), where it is disinfected prior to its discharge to the river.

The sludge to be wasted is pumped to an aerobic digester (300-9), where the biomass and any remaining biodegradable organics are oxidized, the sludge mass and volume are reduced, and the sludge is conditioned for further processing. The aerobic digestion system was included for two reasons:

- (1) To insure that the bacteria had sufficient time to degrade any priority pollutants [NDPA and dibutylphthalate (DBP)] in the biomass, in order to increase the potential for delisting the sludge; and
- (2) To reduce the total amount of biomass that needed to be disposed of as either a hazardous or nonhazardous waste.

The waste sludge from the digester is then pumped to sludge dewatering (System 500) for removal of water to produce a dewatered sludge for disposal.

2.4 System 400 - Sequencing Batch Reactor and Aerobic Digestion

In the case of the SBR (Figure 2.4), the wastewater from the pH and nutrient control system is directed to the SBR basin (one of three) currently in the fill phase. The operating sequence of the basins (400-1) would be such that one of the three basins would always be filling; this insures a continuous flow of wastewater to the SBR system. Upon completion of the fill cycle, the SBR would run through

Source: Arthur D. Little

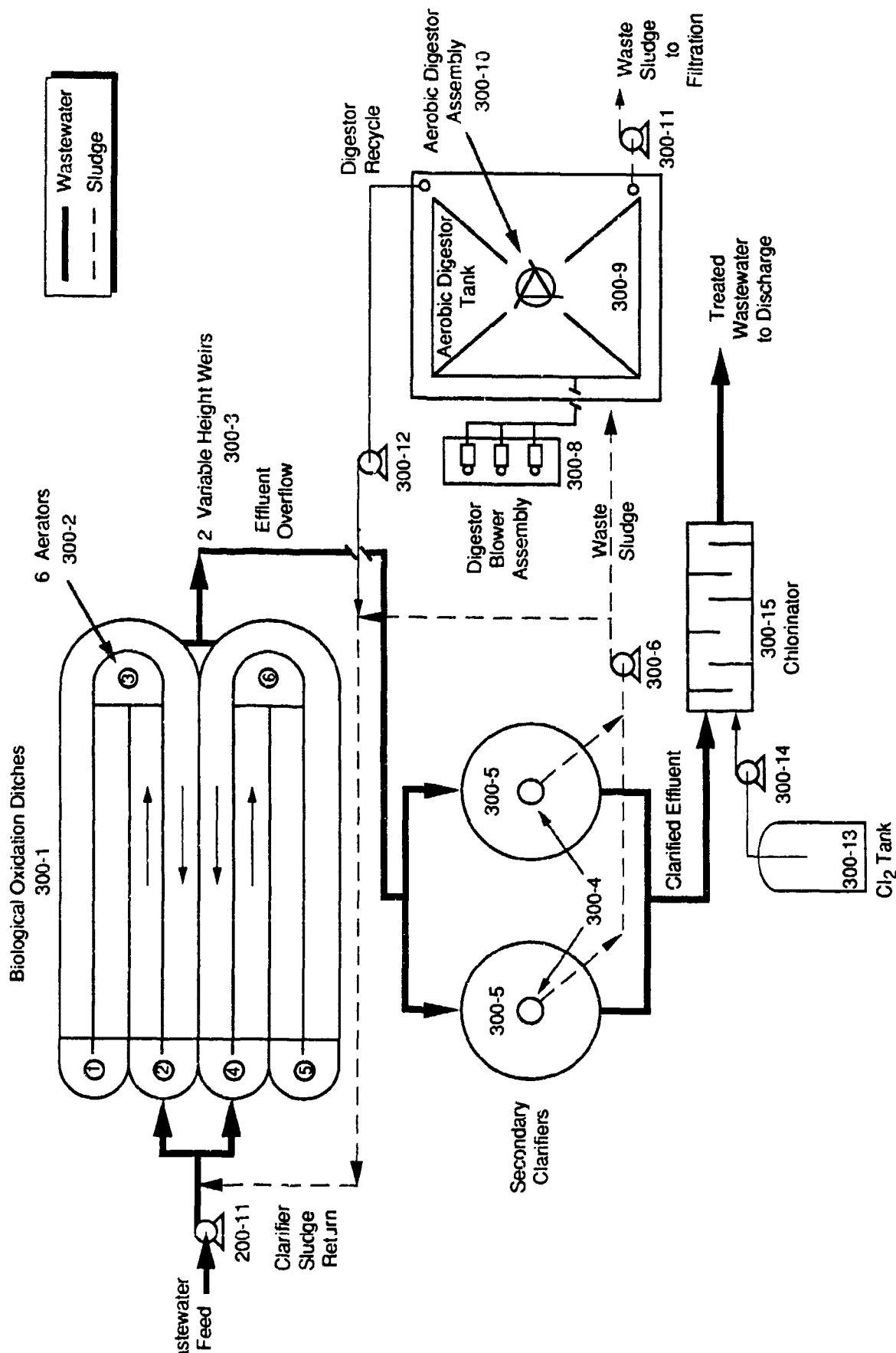


FIGURE 2.3

300 - EXTENDED AERATION AND AEROBIC DIGESTION

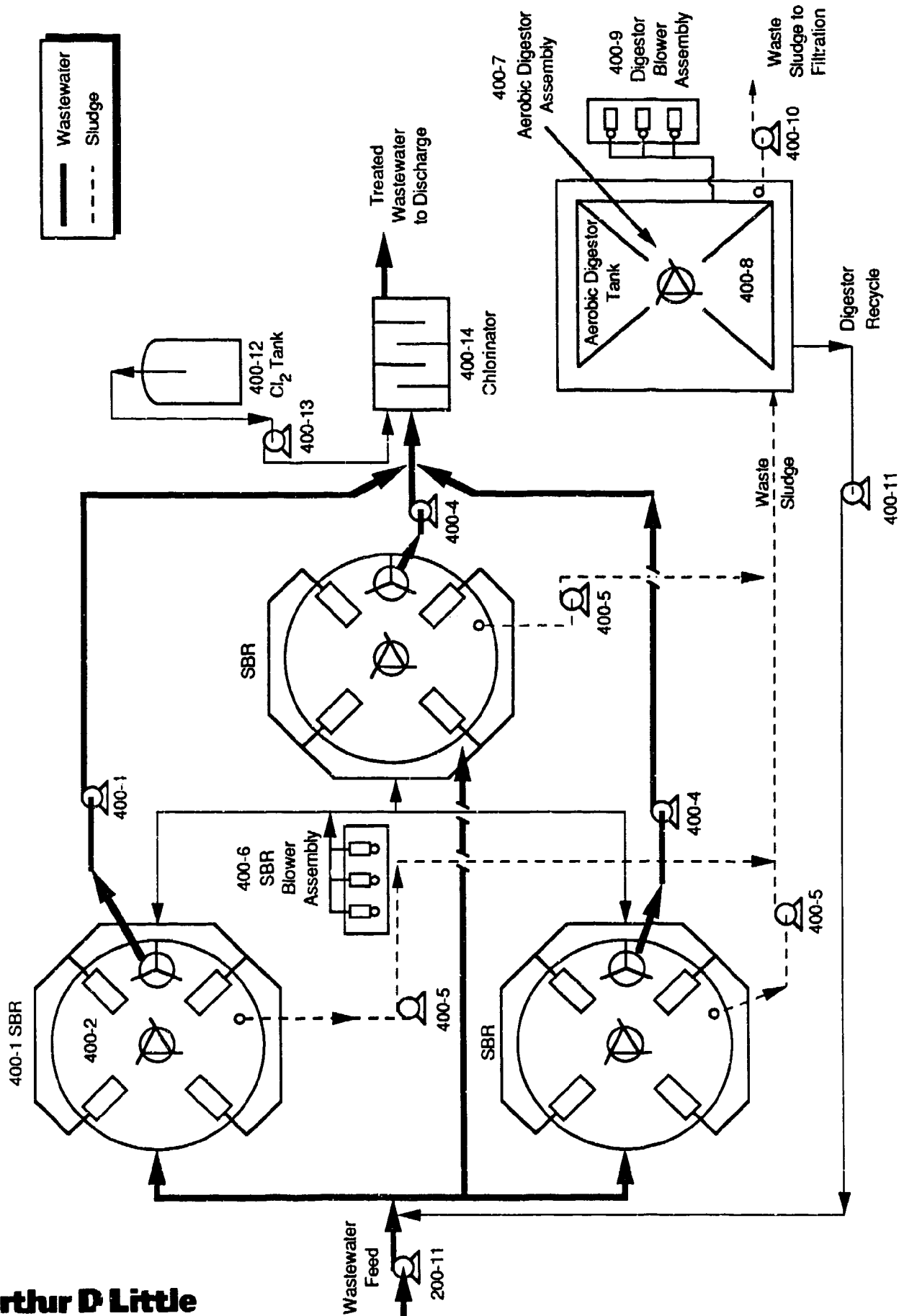


FIGURE 2.4
400 - SEQUENCING BATCH REACTORS AND AEROBIC DIGESTION

Sources: Arthur D. Little

the react, settle, decant, and sludge wasting phases. The treated effluent would then be disinfected with chlorine (400-14) prior to its discharge to the environment.

The excess sludge is pumped to an aerobic digester (400-8) where, as in the extended aeration system, the biomass and any remaining biodegradable organics are oxidized, the sludge mass and volume are reduced, and the sludge is conditioned for further processing. Similarly, the aerobic digestion system was added for two reasons:

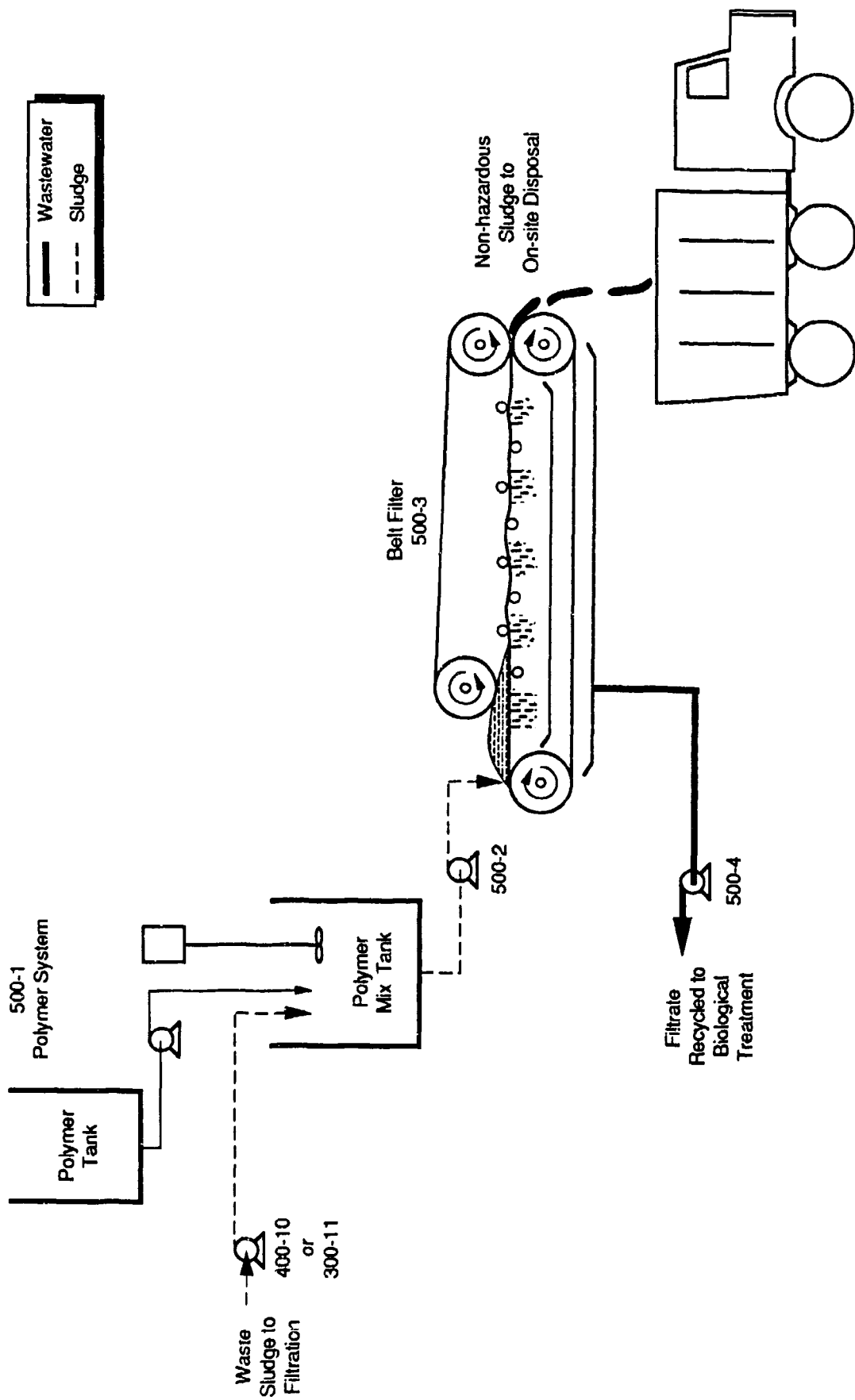
- (1) To insure that the bacteria had sufficient time to degrade any priority pollutants [NDPA and dibutylphthalate (DBP)] in the biomass, in order to increase the potential for delisting the sludge; and
- (2) To reduce the total amount of biomass that needed to be disposed of as either a hazardous or nonhazardous waste.

The waste sludge from the digester would then be pumped to sludge dewatering (System 500) to remove water and produce a dewatered sludge for disposal.

2.5 System 500 - Sludge Dewatering and Control Building

The waste sludge is retained in the aerobic digester for 15 days where the sludge volume is reduced by approximately 40%. After the 15-day retention time, the sludge is pumped to the sludge dewatering system (Figure 2.5). Prior to the actual filtration, a flocculant (500-1) is added to the sludge for improved drainage of the water from the sludge solids. The sludge is then loaded on the belt filter (500-3). The filtrate is collected and recycled back to the biological treatment system; the solids are collected and disposed of on-site as a nonhazardous waste.

The assumption is that Badger AAP will be able to petition the Environmental Protection Agency (EPA) to have the sludge delisted as a nonhazardous waste. The results of the pilot program suggest that delisting the sludge may be possible because of the low concentrations of NDPA and DBP components in the sludge. Another indication that Badger AAP may be able to delist the sludge is the fact that Radford AAP currently operates a biological treatment system for wastewater with similar chemical compositions generated in their single- and double-base operations and has had the sludge produced in this treatment facility delisted. With the sludge delisted, Radford AAP land disposes of the sludge on-site in a landfill; Badger AAP may be able to do this as well.



Source: Arthur D. Little

FIGURE 2.5
SYSTEM 500 - SLUDGE DEWATERING

3.0 COST ESTIMATION AND ECONOMIC EVALUATION

3.1 Approaches to Cost Estimation

The preliminary process engineering analysis and equipment sizing performed on the two biological treatment systems established the basis for estimating the capital investment and operating costs. For component or subsystem costs, we used a combination of general published cost curves, current cost estimation manuals, and budgetary quotations from equipment suppliers. We used Guthrie's Modular Factor method to convert purchased component costs to installed costs. The modular factor, specific to each type of equipment, is intended to account for all direct and indirect cost elements in placing a piece of equipment into operation. These cost elements include engineering, procurement, freight, insurance, taxes, field installation (materials and labor), contractor's fee and contingency. The specific modular factors that were used, along with an equipment list and the purchased equipment component costs, are shown by system in Appendix A.

All cost data were brought to current Fourth Quarter, 1988, by using the Chemical Engineering Plant Cost Index. All costs are budgetary in nature and have an uncertainty of plus 40/minus 10%.

Operating costs were developed based upon the operating requirements established in the mass balances and equipment sizing calculations as discussed in the previous section. Costs for operating materials were obtained from suppliers of such. Costs for labor and utilities were supplied by Badger AAP personnel.

3.2 Capital Investment

Capital investments for extended aeration and SBR systems, as summarized in Table 3.1, are \$5.5 million and \$6.0 million, respectively. In addition to the process equipment, allowances are made to include plant building, office and laboratory space, and the associated equipment for such offices and laboratories. The slightly higher (8%) capital cost for the SBR system is the result of the higher cost associated with constructing three separate concrete basins for the SBR system in contrast to the two basins for extended aeration. The additional costs for the clarifiers required for the extended aeration system brought its capital cost closer to that of the SBR system, but SBR system capital cost remained slightly higher.

3.3 Operating Cost/Economic Evaluation

Operating requirements and their associated costs for the Badger AAP wastewater treatment system (using both biological treatment technology options) are shown in Tables 3.2 and 3.3 for extended aeration and SBR, respectively. The operating costs are grouped into two categories, variable costs and fixed costs. Variable costs include costs for utilities, chemicals, operating labor, and on-site disposal of the

Table 3.1
Capital Investment Costs for
Extended Aeration and Sequencing Batch Reactor Systems

<u>System Number</u>	<u>Description</u>	<u>Extended Aeration Installed Cost (1988 Dollars)</u>	<u>SBR Installed Cost (1988 Dollars)</u>
100	Collection and Equalization Basin	\$485,000	\$485,000
200	pH and Nutrient Control	\$330,000	\$330,000
300	Extended Aeration and Aerobic Digestion	\$4,105,000	\$0
400	Sequencing Batch Reactors and Aerobic Digestion	\$0	\$4,580,000
500	Sludge Dewatering System and Control Building	\$640,000	\$640,000
	Total Capital Investment	\$5,560,000	\$6,035,000

Source: Arthur D. Little, Inc.

Table 3.2
Annual Operating Cost for
Extended Aeration with Nonhazardous Waste

<u>Item</u>	<u>Units/ Year</u>	<u>Cost/Unit (1988 Dollars)</u>	<u>Annual Cost (1988 Dollars)</u>
Variable Costs			
Raw Materials			
•Phosphoric Acid	17.5 Ton	\$64.50 /Ton	\$1,130
•Sulfuric Acid	2 Ton	\$48.00 /Ton	\$100
•Sodium Hydroxide	2 Ton	\$190.00 /Ton	\$380
•Polymer	3 Ton	\$3,000.00 /Ton	\$9,000
Labor			
•Operating	4,160 hours	\$13.50 /hour	\$56,200
•Supervisory	2,080 hours	\$21.00 /hour	\$43,700
Utilities			
•Electricity	9,408,000 kwh	\$0.04 /kwh	\$376,300
•Fuel	4,000 Gal	\$0.49 /Gal	\$2,000
•Water	350,000 Gal	\$30.00 /MMGal	\$10
Sludge Disposal (On-site as a Nonhazardous Waste)	3750 Tons	\$20.00 /Ton	<u>\$75,000</u>
Subtotal Variable Costs			<u>\$563,820</u>
Fixed Costs			
Maintenance			
•Labor and Materials	4% of Capital Investment		\$222,400
Plant Overhead	105% of Labor and Maintenance		\$338,400
Depreciation	10% of Capital Investment		\$556,100
Taxes and Insurance	2% of Capital Investment		<u>\$111,200</u>
Subtotal Fixed Costs			<u>\$1,228,100</u>
Total Operating Cost			<u>\$1,791,920</u>

Source: Arthur D. Little, Inc.

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Table 3.3
Annual Operating Cost for
Sequencing Batch Reactor with Nonhazardous Waste

<u>Item</u>	<u>Units/ Year</u>	<u>Cost/Unit (1988 Dollars)</u>	<u>Annual Cost (1988 Dollars)</u>
Variable Costs			
Raw Materials			
•Phosphoric Acid	17.5 Ton	\$64.50 /Ton	\$1,130
•Sulfuric Acid	2 Ton	\$48.00 /Ton	\$100
•Sodium Hydroxide	2 Ton	\$190.00 /Ton	\$380
•Polymer	3 Ton	\$3,000.00 /Ton	\$9,000
Labor			
•Operating	4,160 hours	\$13.50 /hour	\$56,200
•Supervisory	2,080 hours	\$21.00 /hour	\$43,700
Utilities			
•Electricity	11,390,000 kwh	\$0.04 /kwh	\$455,600
•Fuel	4,000 Gal	\$0.49 /Gal	\$2,000
•Water	350,000 Gal	\$30.00 /MMGal	\$10
Sludge Disposal (On-site as a Nonhazardous Waste)	3,750 Tons	\$20.00 /Ton	<u>\$75,000</u>
Subtotal Variable Costs			\$643,120
Fixed Costs			
Maintenance			
•Labor and Materials	4% of Capital Investment		\$241,500
Plant Overhead	105% of Labor and Maintenance		\$358,400
Depreciation	10% of Capital Investment		\$603,600
Taxes and Insurance	2% of Capital Investment		<u>\$120,700</u>
Subtotal Fixed Costs			<u>\$1,324,200</u>
Total Operating Cost			<u><u>\$1,967,320</u></u>

Source: Arthur D. Little, Inc.

Arthur D Little

waste biomass as a nonhazardous waste. Fixed costs include items such as plant overhead, maintenance (materials, labor and supplies), depreciation, taxes and insurance. The operating costs for both the SBR and extended aeration are similar with the extended aeration again being slightly (about 10%) less. The differences stem largely from lower charges related to lower capital costs for the extended aeration system and less electrical energy usage by this system.

As discussed in Section 2.5, the assumption has been made that the sludge generated in either biological treatment system will be delisted and can, therefore, be disposed of as a nonhazardous waste. However, if delisting is not possible, the cost of disposing of the sludge as a hazardous waste will be very expensive (\$1,000/ton vs \$20/ton). This case is shown in Tables 3.4 and 3.5 for extended aeration and SBR, respectively. It is obvious from these tables that the annual operating cost increases (for either system) by nearly 300% if the sludge is considered a hazardous waste. This is due solely to the vast increase in cost for disposing of the sludge as a hazardous waste (\$3.75 million/year) in contrast to a nonhazardous waste (\$75,000/year).

Table 3.4
Annual Operating Cost for
Extended Aeration with Hazardous Waste

Item	Units/ Year	Cost/Unit (1988 Dollars)	Annual Cost (1988 Dollars)
Variable Costs			
Raw Materials			
•Phosphoric Acid	17.5 Ton	\$64.50 /Ton	\$1,130
•Sulfuric Acid	2 Ton	\$48.00 /Ton	\$100
•Sodium Hydroxide	2 Ton	\$190.00 /Ton	\$380
•Polymer	3 Ton	\$3,000.00 /Ton	\$9,000
Labor			
•Operating	4,160 hours	\$13.50 /hour	\$56,200
•Supervisory	2,080 hours	\$21.00 /hour	\$43,700
Utilities			
•Electricity	9,408,000 kwh	\$0.04 /kwh	\$376,300
•Fuel	4,000 Gal	\$0.49 /Gal	\$2,000
•Water	350,000 Gal	\$30.00 /MMGal	\$10
Sludge Disposal (Off-site as a Hazardous Waste)	3750 Tons	\$1,000.00 /Ton	<u>\$3,750,000</u>
<i>Subtotal Variable Costs</i>			<i>\$4,238,820</i>
Fixed Costs			
Maintenance			
•Labor and Materials	4% of Capital Investment		\$222,400
Plant Overhead	105% of Labor and Maintenance		\$338,400
Depreciation	10% of Capital Investment		\$556,100
Taxes and Insurance	2% of Capital Investment		<u>\$111,200</u>
<i>Subtotal Fixed Costs</i>			<i>\$1,228,100</i>
Total Operating Cost			<u>\$5,466,920</u>

Source: Arthur D. Little, Inc.

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Table 3.5
Annual Operating Cost for
Sequencing Batch Reactor with Hazardous Waste

<u>Item</u>	<u>Units/ Year</u>	<u>Cost/Unit (1988 Dollars)</u>	<u>Annual Cost (1988 Dollars)</u>
Variable Costs			
Raw Materials			
•Phosphoric Acid	17.5 Ton	\$64.50 /Ton	\$1,130
•Sulfuric Acid	2 Ton	\$48.00 /Ton	\$100
•Sodium Hydroxide	2 Ton	\$190.00 /Ton	\$380
•Polymer	3 Ton	\$3,000.00 /Ton	\$9,000
Labor			
•Operating	4,160 hours	\$13.50 /hour	\$56,200
•Supervisory	2,080 hours	\$21.00 /hour	\$43,700
Utilities			
•Electricity	11,390,000 kwh	\$0.04 /kwh	\$455,600
•Fuel	4,000 Gal	\$0.49 /Gal	\$2,000
•Water	350,000 Gal	\$30.00 /MMGal	\$10,500
Sludge Disposal (Off-site as a Hazardous Waste)	3,750 Tons	\$1,000.00 /Ton	\$3,750,000
Subtotal Variable Costs			\$4,318,120
Fixed Costs			
Maintenance			
•Labor and Materials	4% of Capital Investment		\$241,500
Plant Overhead	105% of Labor and Maintenance		\$358,400
Depreciation	10% of Capital Investment		\$603,600
Taxes and Insurance	2% of Capital Investment		\$120,700
Subtotal Fixed Costs			\$1,324,200
Total Operating Cost			\$5,642,320

Source: Arthur D. Little, Inc.

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4.0 DISCUSSION AND CONCLUSIONS

Pilot test results¹ indicated that in the absence of NG both the SBR and extended aeration systems were capable of meeting NPDES requirements continuously. When NG was present in the ball powder wastewater, pilot test results² showed that NG was toxic to the biomass. The toxic effect of the NG caused a decrease in the biomass efficiency to perform carbonaceous oxidation, nitrification and denitrification. The toxicity also caused further problems by adversely affecting the bacteria's ability to form flocs, which resulted in a significant quantity of the biomass overflowing with the effluent, and thereby decreasing the concentration of biomass in the reactor. The end result of NG's toxicity was to produce an unstable biological system that could not meet NPDES requirements.

Because of NG's toxic effect and both systems' ability to meet NPDES limits in the absence of NG, preliminary full-scale designs for both extended aeration and SBR systems were prepared based on the removal of NG in a pretreatment system. These preliminary designs were then used to develop budgetary capital and operating costs to compare the economics of both biological systems. Within the range of accuracy (plus 40/minus 10%) of the budgetary estimates, both systems were found to be approximately equal in cost.

The final conclusion, based on the pilot studies, conducted at Badger AAP, and the cost analysis, was that either biological system was capable of meeting NPDES limits and that both systems were equivalent on a capital and operating cost basis. The systems were also equivalent with respect to:

- System safety,
- Throughput rate,
- Reliability,
- Ease of operation, and
- Permitting.

Consequently, based on both technical and economic merits, we conclude that either biological system is capable of treating ball powder wastewater at Badger AAP; however, the wastewater must first be pretreated for NG removal.

5.0 REFERENCES

1. Balasco, A.A. and R.C. Bowen, et al., "Ball Powder Production Wastewater Pilot-Scale Biodegradation Support Studies (Final Report)," prepared for USATHAMA under Contract No. DAAK11-85-D-0008 by Arthur D. Little, Inc., Cambridge, MA, February 1989.
2. Balasco, A.A. and R.C. Bowen, et al., "Ball Powder Production Wastewater Pilot-Scale Biodegradation Support Studies - with Nitroglycerin (Final Report)," prepared for USATHAMA under Contract No. DAAK11-85-D-0008 by Arthur D. Little, Inc., Cambridge, MA, February 1989.
3. Aasheim, S.E., and B.W. Newbry, "Sludge Stabilization," Water Pollution Control Federation, 1985.
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8. Guthrie, K.M., "Process Plant Estimation Evaluation and Control," 1974.

Appendix A

- Table A.1 — Equipment List/Specifications/ Cost for Collection System and Equilization Basin — System 100
- Table A.2 — Equipment List/Specifications/ Cost for pH and Nutrient Control — System 200
- Table A.3 — Equipment List/Specifications/ Cost for Extended Aeration and Aerobic Digestion — System 300
- Table A.4 — Equipment List/Specifications/ Cost for Sequencing Batch Reactor and Aerobic Digestion — System 400
- Table A.5 — Equipment List/Specifications/ Cost for Sludge Dewatering and Control Building — System 500

Table A.1
Equipment List/Specifications/ Cost for
Collection System and Equalization Basin — System 100

ITEM	DESCRIPTION	UNIT COST	NUMBER OF UNITS	NEW TOTAL COST	MODULAR FACTOR	NEW INSTALLED COST
100-1	Single Base Clarifier	Existing	1	-----	-----	-----
100-2	Double Base Clarifier	Existing	1	-----	-----	-----
100-3	Single Base Sump (In Ground Concrete Tank, 25,000 Gallons)	\$18,000	1	\$18,000	1.38	\$24,840
100-4	Double Base Sump (In Ground Concrete Tank, 25,000 Gallons)	\$18,000	1	\$18,000	1.38	\$24,840
100-5	Single Base Pump (35 hp - 1,800 GPM)	\$7,800	2	\$15,600	3.38	\$52,728
100-6	Double Base Pump (6 hp - 280 GPM)	\$3,000	2	\$6,000	3.38	\$20,280
100-7	Equalization Basin (Clay Lined with Rubber (Hypalon) liner, 3 Million Gallons)	\$262,000	1	\$262,000	1.36	\$361,560
SYSTEM 100 SUBTOTALS				\$319,600		\$484,248

Source: Arthur D. Little, Inc.

Table A.2
Equipment List/Specifications/ Cost for
pH and Nutrient Control — System 200

ITEM	DESCRIPTION	UNIT COST	NUMBER OF UNITS	TOTAL COST	MODULAR FACTOR	INSTALLED COST
200-1	Waste Feed Pump (40 hp - 2000 GPM)	\$8,800	2	\$17,600	3.38	\$59,488
200-2	Phosphoric Acid Metering Pump (Stainless Steel, Variable Speed, 5 GPM)	\$2,500	2	\$5,000	3.38	\$16,900
200-3	Sulfuric Acid Metering Pump (Stainless Steel, Variable Speed, 5 GPM)	\$2,500	2	\$5,000	3.38	\$16,900
200-4	Caustic Metering Pump (Stainless Steel, Variable Speed, 5 GPM)	\$2,500	2	\$5,000	3.38	\$16,900
200-5	Phosphoric Acid Storage Tank (Fiberglass Tank, 5,000 Gallons)	\$11,000	1	\$11,000	2.55	\$28,050
200-6	Sulfuric Acid Storage Tank (Fiberglass Tank, 5,000 Gallons)	\$11,000	1	\$11,000	2.55	\$28,050
200-7	Caustic Storage Tank (Fiberglass Tank, 5,000 Gallons)	\$11,000	1	\$11,000	2.55	\$28,050
200-8	Inline Mixer	\$10,000	2	\$20,000	1.38	\$27,600
200-9	pH Control Tank (Baffled, Fiberglass Tank, 10,000 Gallons)	\$17,000	1	\$17,000	2.55	\$43,350
200-10	Agitator for pH Control Tank (2 hp - Turbine Blade)	\$1,500	1	\$1,500	2.55	\$3,825
200-11	Neutralized Waste Pump (40 hp - 2000 GPM)	\$8,800	2	\$17,600	3.38	\$59,488
SYSTEM 200 SUBTOTAL				\$121,700		\$328,601

Source: Arthur D. Little, Inc.

Table A.3
Equipment List/Specifications/ Cost for
Extended Aeration and Aerobic Digestion — System 300

ITEM	DESCRIPTION	UNIT COST	NUMBER OF UNITS	TOTAL COST	MODULAR FACTOR	INSTALLED COST
300-1	Biological Oxidation Ditch (In-Ground Concrete Tank, 3.7 Million Gallons, Including: Excavation, Materials, Labor, and Backfilling)	\$607,000	2	\$1,214,000	1.38	\$1,675,320
300-2	Two Speed Mechanical Aerators (150 hp Aerators and Auxiliary Equipment)	\$102,900	6	\$617,400	1.38	\$852,012
300-3	Variable Height Weir	\$10,000	2	\$20,000	1.38	\$27,600
300-4	Clarifier Mechanism (70 foot Diameter, Including: Scum Skimmers, Weirs, and Baffles)	\$46,500	2	\$93,000	1.38	\$128,340
300-5	Clarifier Tank (In-Ground Concrete Tank, 430,000 Gallons, Including: Excavation, Materials, Labor, and Backfilling)	\$104,000	2	\$208,000	1.38	\$287,040
300-6	Clarifier Waste Sludge Pump (5 hp)	\$2,400	2	\$4,800	3.38	\$16,224
300-7	Geobiotic Doms (70 foot diameter)	\$85,000	2	\$170,000	1.38	\$234,600
300-8	Digestors Blower Assembly (100 hp Aerators & Auxiliary Equipment)	\$31,000	3	\$93,000	1.38	\$128,340
300-9	Aerobic Digester Tank (In-Ground Concrete Tank, 1.3 Million Gallons, Including: Excavation, Materials, Labor, and Backfilling)	\$283,200	1	\$283,200	1.38	\$390,816
300-10	Aerobic Digester Assembly (Including: 60 hp DDM Mixer, Floating Decant Pump, Control Panel, 4 Aeration Headers)	\$80,000	1	\$80,000	1.38	\$110,400
300-11	Waste Sludge Pump (5 hp)	\$2,400	2	\$4,800	3.38	\$16,224
300-12	Digester Effluent Return Pump (5 hp)	\$2,400	2	\$4,800	3.38	\$16,224
300-13	Chlorine Storage Tank (Spherical Steel Tank - 200 psi, 5,000 Gallons)	\$30,000	2	\$60,000	2.57	\$154,200
300-14	Chlorine Metering Pump (Stainless Steel, Variable, 5 GPM)	\$2,500	2	\$5,000	3.38	\$16,900
300-15	Chlorinator (Horizontal Pressure Tank- 200 psi, 5,000 Gallons)	\$18,000	1	\$18,000	2.87	\$51,660
SYSTEM 300 SUBTOTAL				\$2,876,000		\$4,105,900

Table A.4
Equipment List/Specifications/ Cost for
Sequencing Batch Reactor and Aerobic Digestion — System 400

ITEM	DESCRIPTION	UNIT COST	NUMBER OF UNITS	TOTAL COST	MODULAR FACTOR	INSTALLED COST
400-1	SBR Assembly (40 hp DDM Mixer, Decanter, Diffuser Drop Assemblies, Influent Baffles, Controls)	\$246,000	3	\$738,000	1.38	\$1,018,440
400-2	SBR Tank (In-Ground Concrete Tank, 1.9 Million Gallons, Including: Excavation, Materials, Labor and Backfilling)	\$370,500	3	\$1,111,500	1.38	\$1,533,870
400-3	Geodesic Dome (140 foot diameter)	\$155,000	3	\$465,000	1.38	\$641,700
400-4	Effluent Pump (40 hp - 200 GPM)	\$8,800	3	\$26,400	3.38	\$89,232
400-5	Waste Sludge Pump (10 hp - 60 GPM)	\$3,900	3	\$11,700	3.38	\$39,546
400-6	SBR Blower Assembly (300 hp Aerators and Digestors)	\$88,000	3	\$264,000	1.38	\$364,320
400-7	Aerobic Digester Assembly (Including: 60 hp DDM Mixer, Floating Decant Pump, Control Panel, 4 Aeration Headers)	\$80,000	1	\$80,000	1.38	\$110,400
400-8	Aerobic Digester Tank (In Ground Concrete Tank, 1.3 Million Gallons, Including: Excavation, Materials, Labor, and Backfilling)	\$283,200	1	\$283,200	1.38	\$390,816
400-9	Aerobic Digester Blower Assembly (100 hp Aerators and Auxiliary Equipment)	\$31,000	3	\$93,000	1.38	\$128,340
400-10	Aerobic Digester Pump (5 hp)	\$2,400	2	\$4,800	3.38	\$16,224
400-11	Digester Effluent Return Pump (5 hp)	\$3,800	2	\$7,600	3.38	\$25,688
400-12	Chlorine Storage Tank (Spherical Steel Tank - 200 psi, 5,000 Gallons)	\$30,000	2	\$60,000	2.57	\$154,200
400-13	Chlorine Metering Pump (Stainless Steel, Variable, 5 GPM)	\$2,500	2	\$5,000	3.38	\$16,900
400-14	Chlorinator (Horizontal Pressure Tank - 200 psi, 5,000 Gallons)	\$18,000	1	\$18,000	2.87	\$51,660
SYSTEM 400 SUBTOTAL				\$3,168,200		\$4,581,336

Table A.5
Equipment List/Specifications/Cost for
Sludge Dewatering and Control Building — System 500

ITEM	DESCRIPTION	UNIT COST	NUMBER OF UNITS	TOTAL COST	MODULAR FACTOR	INSTALLED COST
500-1	Polymer System (300 gal Stainless Steel Tank, 1/2 hp Mixer, Dry Polymer Eductor, and Variable Speed Cavity Pump)	\$18,500	1	\$18,500	1.38	\$25,530
500-2	Filter Feed Pump (7.5 hp - 100 gpm)	\$13,500	2	\$27,000	1.38	\$37,260
500-3	Belt Filter (1 meter belt press, air compressor and wash water pump)	\$96,500	1	\$96,500	1.33	\$133,170
500-4	Recycle Wash Water Pump (5 hp)	\$2,400	2	\$4,800	3.80	\$18,240
500-5	Laboratory/Control Building (3,000 sq ft Facility)	\$310,000	1	\$310,000	1.38	\$427,800
SYSTEM 500 SUBTOTALS				\$456,800		\$642,000

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