FINAL REPORT

Oily Sludge Biodetoxification

ESTCP Project WP-200307

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14. ABSTRACT
NFESC constructed a full scale Oily Sludge Bioreactor treatment system at the Scranton Army Ammunition Plant (SCAAP), Scranton, PA. The system consists of 2 bioreactors that can be operated in series. The first reactor functions as a pretreatment tank & skims excess oil that can be recycled. The second reactor (40k gallon capacity) consists of commercial pumps & blowers used to recirculate & aerate the wastewater. Bacterial growth is enhanced by the addition of organic & inorganic nutrients & the system requires a pH controller. Treated wastewater is discharged through a tube filter & a filter press is used to consolidate the solids (biomass & graphite). Full scale operational testing of the treatment system shows that the hydrocarbons in the oily sludge are degraded to below the discharge limit (100ppm) in less than one week after the bulk of the oil from the pretreatment tank is removed. Exhaust air from the reactors is passed through activated carbon & the concentration of the VOCs in the air vented to the atmosphere is below practical quantitation limits (PQL). Biological treatment can be cost effective & eliminate liabilities.

15. SUBJECT TERMS
Oily Sludge; Oily Waste; Wastewater; Sequencing Batch Reactor Treatment System; Biodetoxification

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ACRONYMS AND SYMBOLS

API	American Petroleum Institute
BOD_5	Five Day Biochemical Oxygen Demand
BOWTS	Bilge Oily Wastewater Treatment System
BQL	Below Quantitative Limit
BTEX	Benzene, Toluene, Ethylbenzene, and Xylenes
CNC	Computer Numeric Control
COD	Chemical Oxygen Demand
COTS	Commercial-off-the-Shelf
DO	Dissolved Oxygen
DoD	Department of Defense
EPA	Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
F/M	Food to Microorganism Ratio
FNU	Formazan Nephelometric Units
FOG	Floatable Oil and Grease
GC	Gas Chromatography
GC/MS	Gas Chromatography Mass Spectroscopy
gpd	Gallons per Day
ISO	International Organization for Standardization
MDL	Minimum Detection Level
MLSS	Mixed Liquor Suspended Solids
MLVSS	Mixed Liquor Volatile Suspended Solids
NAVFAC ESC	Naval Facilities Command Engineering Service Center
NESDI	Navy Environmental Sustainability Development to Integration
NAVSTA	Naval Station
NT	Not Tested
OWPP	Oily Wastewater Pretreatment Plant
OWS	Oil Water Separator
PCB	Polychlorinated Biphenyl
P&ID	Piping and Instrumentation Drawing
PQL	Practical Quantitation Limits

ACRONYMS AND SYMBOLS *(continued)*

ppm	Parts Per Million
PWC	Public Works Center
SBR	Sequencing Batch Reactor
SCAAP	Scranton Army Ammunition Plant
STLC	Soluble Threshold Limit Concentration
SVOC	Semi-volatile Organic Compound
TCE	Trichloroethylene
TCLP	Toxicity Characteristic Leaching Procedure
TOC	Total Organic Carbon
TPH	Total Petroleum Hydrocarbons
TRPH	Total Recoverable Petroleum Hydrocarbons
TSS	Total Suspended Solids
TTLC	Total Threshold Limit Concentration
WRI	Wastewater Resources Incorporated
VOC	Volatile Organic Compound
VSS	Volatile Suspended Solids

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EXECUTIVE SUMMARY

BACKGROUND

Scranton Army Ammunition Plant (SCAAP) in Scranton, PA is a one of the few industrial facilities capable of forging large caliber projectiles used by the military. To keep the hot (2300°F) freshly forged projectiles from sticking to the forge, a mineral oil based lubricant that has graphite suspended in it is used to lubricate the forge. The spent forging oil along with cooling water collects in trenches under the forges. In the past, the oily wastewater was sent to an oil water separator and the recovered sludge was landfilled. However, the oil water separator functioned poorly and the concentration of oil in the discharge water often exceeded the permitted limit. During the course of the project, SCAAP installed a skimmer that captures much of the oil which is recycled. However, even after skimming, the concentration of oil in the water exceeds the discharge limit permitted by the Scranton Sewer Authority.

In addition to Scranton, treatment plants, washracks, fuel depots, industrial operations, and maintenance facilities at Department of Defense (DoD) activities annually generate millions of gallons of wastewater contaminated with thousands of tons of oily sludge. Collecting and disposing the oily sludge is costly and time consuming and even though much of it is recycled, some of it has no value and is drummed and landfilled. In the Navy, the yearly operation and maintenance (O&M) costs associated with oil water separators and bilge oily wastewater treatment system (BOWTS) units are estimated to be twenty-four million dollars and the Army estimates that the cost for disposing of oily sludge generated at wash racks alone is $150,000 per base and the Environmental Protection Agency (EPA) estimates the yearly cost in the civilian sector for handling and disposing of oily sludge at two billion dollars per year. As an alternative to the current practice (landfill disposal) which is increasingly costly and restricted, on-site bioremediation offers attractive cost savings and eliminates long-term liability associated with landfill disposal.

Since oily waste is composed of refined petroleum hydrocarbons most of which are well known to be biodegradable, on-site treatment of oily waste is technically feasible and has been confirmed in lab and pilot scale tests. Most importantly, bacteria capable of degrading oily waste are already present in the waste, thus one of the primary requirements for successful treatment is to create conditions that optimize the growth and activity of the indigenous hydrocarbon degrading bacteria. The most direct approach, which was used at SCAAP, is simply a well-mixed tank or sequencing batch reactor (SBR) into which oily waste (the primary food source) is fed. To ensure that the water insoluble oil is easily accessible to the bacteria, it is mechanically emulsified and the reactor is supplemented with inorganic (nitrogen, phosphorous) and organic (vitamins and amino acids) nutrients which make it easier for the bacteria to grow. The addition of the organic nutrients also supports a more metabolically diverse population of hydrocarbon degrading bacteria. To further promote growth, a near neutral pH is maintained and an aeration system provides oxygen and helps keep the tank mixed.

Ideally, oily waste should be burned or re-refined, however the physical chemical characteristics of this material are not compatible with currently available reuse technologies. Thus, DoD and the civilian sector are faced with recurrent and escalating costs for landfilling oily waste which is in addition to the cost of removing it from the waste stream. Furthermore, DoD remains liable for the material once it is landfilled. Since on-site biological treatment does not require separation prior to treatment, these costs (which can be considerable) are reduced if not eliminated and once the waste is degraded, it is no longer a liability. Compared to the recurrent cost of landfilling, biological treatment is cost effective and the payback period can be as short as one year.

OBJECTIVES OF THE DEMONSTRATION

The objective of the project was to Dem/Val an innovative application of bioreactors for the on-site treatment of oily sludge generated at DoD activities. More specifically it was shown that:

- Reactor easily assembled on-site using commercially available components
- Operation of the reactor was optimized to treat oily wastewater
- Design, cost, and performance data were developed

The two primary quantitative performance objectives which were both met were: (i) the design and operation of the reactor would permit the oily waste to be degraded within design time to or below the discharge limits (see Table 8-1); and (ii) the use of the reactor would reduce costs and the payback compared to the current practice of ~ 3 years.

DEMONSTRATION RESULTS

Following installation and shake-down of the treatment system, it was tested with oily wastewater and the initial performance as indicated by the concentration of oil in the treated water met the discharge requirements. However, subsequent testing indicated that the concentration of oil entering the system exceeded 40,000 ppm as opposed to the 2000 – 8000 ppm that was expected. This was caused by changes in how SCAAP managed the wastewater. Subsequently, a drum skimmer was installed and used to remove excess oil which was sold to a recycler. At the same time, the treatment system was modified to address some unexpected problems associated with the physical properties of the oily sludge and the scale of the system. Subsequent testing of the treatment system demonstrated that the concentration of residual oil in the wastewater was reduced to the permitted level and a simple carbon canister (rather than the originally proposed biofilter) was sufficient to remove volatile organic compounds in the SBR exhaust air.

IMPLEMENTATION ISSUES

During the course of the project, three implementation issues arose: (i) SCAAP reduced the volume of cooling water which increased the concentration of oil beyond the treatment capacity. This was addressed by installing a skimmer to recover the oil which is purchased by a recycler; (ii) Oil pooled on the surface of the reactor which limited bacterial accessibility and created impossibly long treatment times; and (iii) Pooled oil congealed on the surface and sunk to the bottom of the reactor where it accumulated. The last two problems were solved by installing a weir at the surface of the SBR that collected the pooled oil before it could congeal. This oil and water were recirculated through a centrifugal pump which kept the oil mechanically emulsified and readily available to the bacteria. Concurrently, it was recognized that the aeration system was not adequate and the new air headers were fabricated and installed. These modifications enhanced mixing which improved degradation and reduced the potential for the oil to congeal and accumulate on the bottom of the SBR. Shortly after the project was completed, SCAAP substituted a water based lubricant for the previously used mineral oil lubricant that has proven to be biodegradable and they replaced the tube filter with a membrane filter that has enabled them to use all of the treated wastewater for plant cooling.

1.0 INTRODUCTION

1.1 BACKGROUND

One of the few industrial facilities capable of forging large caliber projectiles used by the military is the Scranton Army Ammunition Plant in Scranton, PA. To keep the hot (2300°F) freshly forged projectiles from sticking to the forge, the forge is lubricated with a mineral oil based lubricant infused with graphite. The spent lubricant along with cooling water collects in trenches under the forges. In the past the oily wastewater flowed into sumps from which it was sent to an oil water separator and the recovered sludge was landfilled. However, the oil water separator functioned poorly which caused the concentration of oil in the discharge water to exceed the permitted limit and recurring disposal costs continue to increase.

Since oily waste is derived from refined petroleum hydrocarbons most of which are well known to be biodegradable, on-site treatment of this waste is technically feasible and has been confirmed in numerous lab and pilot tests. However, there has been little or no documented full-scale testing of this approach, which is the purpose of this project. Most importantly, bacteria capable of degrading oily waste are already present in the waste, thus the primary requirement is to create conditions that optimize the growth of the desired bacteria. The most direct approach, which was used at SCAAP, is simply a well-mixed tank into which oily waste (the primary food source) is fed. To ensure that the water insoluble oil is easily accessible to the bacteria, a centrifugal pump is used to mix the tank and mechanically emulsify the oil. The emulsified oil droplets are colonized by bacteria that degrade the oil from the outside. In addition to nitrogen and phosphorous which are absolutely required, bacterial growth and diversity is enhanced by supplementing the reactor with vitamins and amino acids. A pH controller is used to maintain a near neutral pH and an aeration system provides oxygen and helps keep the SBR mixed.

In addition to Scranton, DoD facilities (e.g., industrial waste treatment plants, washracks, fuel depots, industrial operations, and maintenance facilities) annually generate millions of gallons of wastewater contaminated with thousands of tons of oily sludge. Collecting and disposing the oily sludge is costly and time consuming and ultimately much of it is drummed and landfilled. Based on NAVFAC ESC survey, the handling and disposal cost to the Navy alone for fuel tank bottoms and bilge and oily wastewater treatment systems (BOWTS) is in excess of $6.5 million per year. As an alternative to the current practice (landfill disposal) which is increasingly costly and restricted, on-site bioremediation offers attractive cost savings and eliminates long-term liability associated with landfill disposal.

Ideally, oily waste should be burned or re-refined, however the physical chemical properties of this material are not compatible with current technologies. Thus, DoD and the civilian sector are faced with recurrent and escalating costs for landfilling oily waste which is in addition to the cost of removing it from the wastewater. In addition, DoD remains liable for the material once it is landfilled. Since on-site biological treatment does not require separation prior to treatment, these costs (which can be considerable) are reduced if not eliminated and once the waste is degraded, it is no longer a liability. Compared to the recurrent cost of landfilling, biological treatment is cost effective and the payback period can be as short as one year.

1.2 OBJECTIVES OF THE DEMONSTRATION

The objective of the project was to Dem/Val an innovative application of bioreactors for the on-site treatment of oily sludge generated at Scranton Army Ammunition Plant (SCAAP). The two primary quantitative performance objectives which were both met were: (i) the design and operation of the reactor would permit the oily waste to be degraded within design time to or below discharge limit; and (ii) the use of the reactor would reduce costs and the payback compared to the current practice of less than two years. In addition the project demonstrated that:

- Treatment system assembled on-site using commercially available components
- Operation of the treatment system optimized to treat SCAAP oily wastewater
- Design, cost, and performance data were developed

Although it was not anticipated, changes that SCAAP made in how they manage their wastewater after the system was designed and installed were easily accommodated by on-site modification of the SBR. Coincidently, the successful outcome supports the robustness of this approach to the management of oily wastewater.

The long-term objective is to facilitate the use of biological reactors at DoD installations. To facilitate meeting this objective, a patent awarded to the Navy which covers this application has been licensed by a vendor (Wastewater Resources Inc., Scottsdale, AZ). This licensing agreement should ease the implementation of this technology which has been demonstrated to reduce the cost of oily wastewater disposal and the inherent liability associated with landfilling.

1.3 REGULATORY DRIVERS

Regulatory drivers include: Resource Conservation and Recovery Act (42 USC 6901) and Executive Order 12856 (Federal Compliance with the Right-to-Know Laws and Pollution Prevention Requirements).

The proposed project addresses the treatment of oily sludge that has been identified as a high priority by DoD mandates (Navy: 2.II.01.q Control/Treat Industrial Wastewater Discharge and Army: A(2.2.e) Improve Oil and Grease Removal/Treatment Technologies for Contaminated Wastewaters and Sludges/Soils).

1.4 STAKEHOLDER/END-USER ISSUES

When the system was designed, SCAAP was producing ~ 300,000 gallons per month of oily wastewater (peak 500,000 gallons) with an average hydrocarbon concentration of 4,000 ppm. After the system was installed, SCAAP reduced the volume of wastewater to <40,000 gallons per month, which effectively increased the oil concentration to >40,000 ppm. In effect, the trenches below the forges acted as gravity oil water separators and SCAAP was sending the water to the oil water separator and the oil along with the remaining water was sent to the SBR. As discussed in Sections 5.4 and 5.6, this necessitated changes in how the treatment system was operated.

The current practice at SCAAP is to pass the wastewater through an oil water separator. However, the oil water separator requires considerable ongoing maintenance and the treated water does not meet permitted levels for oil and grease. As a result, there are significant recurrent costs and long-term liability are associated with discharge violations and disposal of the recovered sludge. Directing the wastewater directly into the SBR eliminates handling the oily sludge recovered from the oil water separator and on-site biological treatment reduces the hydrocarbon concentration to or below permitted discharge level. Graphite and residual biomass are periodically removed from the SBR, captured in a filter press and the dry cake can be landfilled.

In the Navy, the yearly operation and maintenance (O&M) costs associated with oil water separators and BOWTS units are estimated to be $24 million. The Army incurs yearly recurring costs of approximately $150,000 per base for the disposal of oily sludge generated from wash racks alone and the EPA estimates the yearly cost in the civilian sector for handling and disposing of oily sludge at $2 billion. Thus, in both DoD and the civilian sector, on-site biological treatment has the potential for considerable cost savings and reduction of environmental liability.

2.0 DEMONSTRATION TECHNOLOGY

Industrial facilities commonly use an oil water separator (OWS) to remove oil from their oily wastewater. If the properties of the recovered oil permit, it is sold to utilities or other certified users which use it for fuel or in some cases it may be re-refined. However, most often, the physical chemical properties and the presence other chemicals (e.g., surfactants and metals) preclude any type of recycling and the oil is placed in drums and landfilled. In addition, OWSs often require extensive maintenance which if it not performed on a regular basis leave oil in the wastewater at concentrations that exceed permitted limits. Because costs continue to increase and landfill disposal is increasingly restrictive and remains a long term liability, generators are interested in cost effective on-site treatment that will meet regulatory requirements.

Since oily sludge consists of petroleum-derived hydrocarbons and most refined hydrocarbons including the SCAAP forging lubricant which has undergone extensive thermal degradation are biodegradable, biological treatment is a promising alternative to the current practice. Furthermore, when compared to other treatment technologies (e.g., steam reforming), biological treatment is considerably more cost effective and biological degradation is more complete which reduces handling and ultimately eliminates the long-term liability associated with landfill disposal.

2.1 TECHNOLOGY DESCRIPTION

Biological treatment is increasingly used to treat a wide variety of organic rich waste streams. The most common and oldest application is sewage treatment, however food processors, feedlots, the pulp and paper industry, oil refineries, and the automotive industry often use dedicated on-site treatment facilities to treat their industrial organic waste. One of the advantages of on-site treatment is a reduction in sewage charges associated with high biological demand (BOD) waste along with reduced handling and disposal costs. In addition, higher costs are driving the development of technologies that make it possible to capture and recycle the treated water.

In most applications, biological treatment systems are designed to promote the growth of naturally occurring bacteria adapted to grow on and degrade the organic compounds in the waste stream. This approach as opposed to the use of engineered bacteria has the advantage that a very diverse and robust bacterial population resistant to system upsets is rapidly established and easily maintained. The basic requirements are that the system be well mixed, maintain a near neutral pH, and for most applications use an aeration system to keep the system aerobic and well mixed. However, to reduce the amount of residual biomass and to generate methane, which may be captured and used as fuel, some waste streams are treated in anaerobic digesters. In general, anaerobic treatment is slower than aerobic processes and the longer residence time means that the volumetric capacity of the anaerobic system is larger than a comparable aerobic system. In either case industrial waste has to be supplemented with nitrogen and phosphorus which are essential and low concentrations of vitamins and amino acids which promote bacterial growth. In recent years, technological enhancements, e.g., trickling filters, rotating bio-contactors, membrane reactors, and activated sludge systems have been developed to maximize bacterial contact with the waste and reduce processing time. However, for most industrial wastes, a stirred tank in which waste is treated in batches or in continuous flow is often adequate.

The most common tank configuration is the sequencing batch reactor which is operated in batch mode (Figure 2-1). The operating sequence is; fill (charge with fresh wastewater), react (treat the wastewater), settle (allow the biomass and other particulates to settle), and decant (remove the treated wastewater). The advantage of this approach is that the settled biomass harbors a fresh bacterial inoculum that is ready to go when the SBR is filled with fresh wastewater. As a result, degradation of the waste (oil at SCAAP) begins as soon as the fresh wastewater is introduced. Another advantage of an SBR is that the same tank functions as a clarifier during the settle phase. At Scranton, a tube filter is used to remove particulates and bacteria that failed to settle. Periodically, excess biomass and associated sludge that accumulates in the SBR are wasted. The amount of biomass that is wasted depends on the amount of biomass that is required for effective waste degradation and has to be determined for each application.

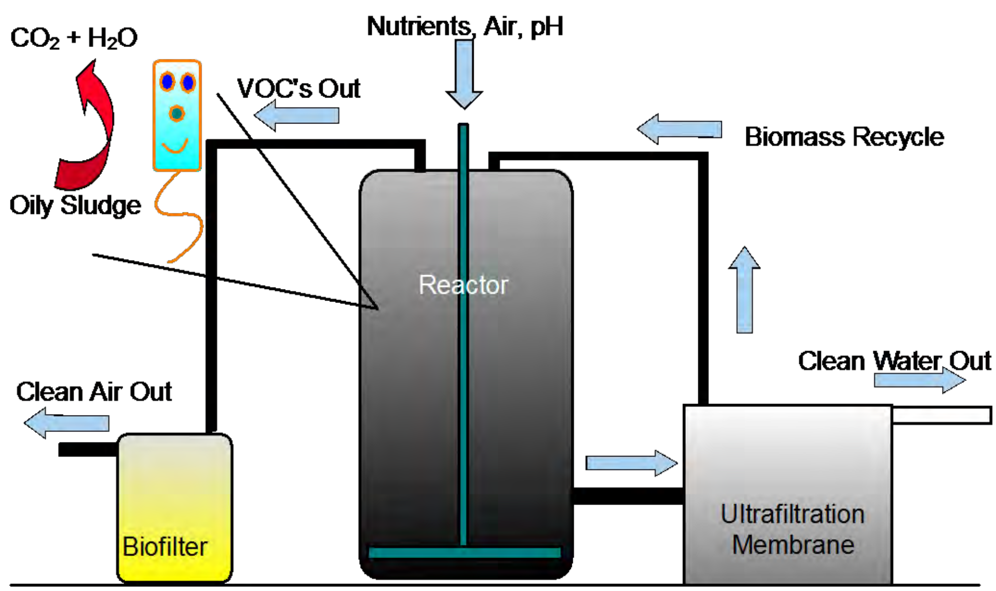


Figure 2-1. A schematic illustration of a SBR and the principal subsystems. During the react cycle, oily sludge is degraded and the bacterial population increases. Bacteria are captured by the microfilter and recycled to maintain a robust bacterial population. Bacteria in the biofilter capture and degrade VOCs in air vented from the SBR.

Since biological treatment will degrade more than 90 percent of suspended and dissolved organic compounds, it is the most cost effective treatment available for organic waste. However, excessive concentrations of heavy metals, some organic compounds, e.g., chlorinated solvents, high salinity, extreme pH or temperature will hinder and in some cases poison biological treatment systems. Fortunately, these effects are usually transient and systems rapidly recover when normal conditions are restored. Also, some organic pollutants (e.g., polychlorinated biphenyls (PCBs)) are either resistant to biodegradation or the rate of biodegradation is so slow that biological treatment is not currently practical.

Since aerobic treatment often requires vigorous aeration, the production of volatile compounds during biodegradation or their presence in the waste stream may result in air emissions. However, these compounds can be captured and degraded by passing the exhaust air through biofilters which are closed containers (usually cylindrical) filled with a mixture of inert filler (to maintain porosity) and compost (supplemented with nitrogen and phosphorous) which provides a matrix that supports bacterial growth. Bacteria growing on the compost have been shown to capture and degrade volatile hydrocarbons and some inorganic compounds, e.g., hydrogen sulfide and ammonia. More recently the use of an inorganic foam matrix that is continuously bathed in liquid nutrients has been investigated as an alternative to compost. Alternatively, if the concentration of VOCs in the exhaust air is low, they can be removed with activated carbon.

The end product of biological treatment in the SBR is primarily biomass, i.e., dead bacteria and cell remnants and at SCCAP graphite that has been scrubbed of oily waste by the bacteria. Unless the concentration of metals exceeds allowable limits, the residual biomass is usually non-toxic and non-hazardous and can be captured in a filter press, landfarmed, landfilled, or composted.

2.2 TECHNOLOGY DEVELOPMENT

With support from the Navy Environmental Sustainability Development to Integration (NESDI or YO817) program, the Naval Facilities Engineering Service Center (NAVFAC ESC), Port Hueneme, CA conducted bench and pilot-scale tests that demonstrated the potential for bioremediating oily sludge generated at industrial facilities operated by the Navy. A critical result of this work was the demonstration that bacteria already present in and adapted to oily sludge from a variety of sources are easily stimulated to degrade hydrocarbons in the sludge within two weeks to less than 100 ppm (Figure 2-2). In addition, the concentrations of heavy metals (primarily zinc and copper) and total suspended solids in treated wastewater from these sources and residual biosolids were shown to be within discharge limits.

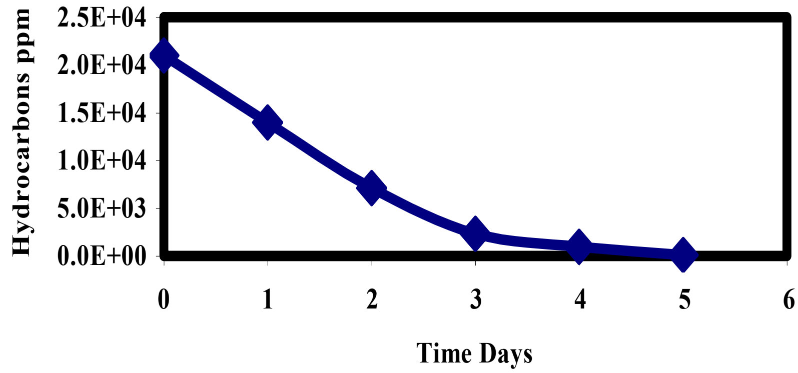


Figure 2-2. T II SBR.

Because of the high disposal costs for oily sludge in Hawaii, the Public Works Center (PWC) Pearl Harbor collaborated with NAVFAC ESC to install a 10,000 gallon SBR with that can treat 1,000-2,000 gallons of oily sludge per month (Figure 2-3). To achieve the high bacterial densities essential for rapid biodegradation and eliminate the need for a clarifier, the system uses microfilters to capture and concentrate bacteria and particulates that have not settled in the supernatant. The use of concentrated biomass increases the throughput without having to increase the volume of the SBR and the oily waste undergoes rapid degradation (currently 4-5 days). Another unique aspect of this project is that the biomass, which accumulates in the reactor, is landfarmed at the Navy operated Barbers Point Landfarming Facility (Figure 2-4).

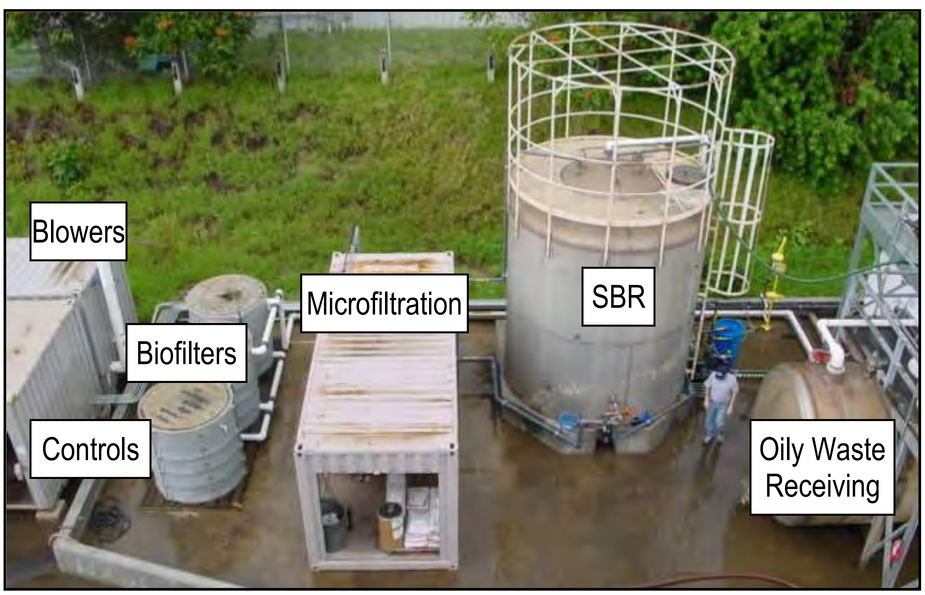


Figure 2-3. The NAVSTA Pearl Harbor, HI SBR facility. The microfilters, blowers, and system controls are housed in refurbished shipping containers. A 20,000 gallon tank is used to receive and hold oily waste which is treated in 1,000 – 2,000 gallons batches in the 10,000 gallon SBR.

Flow control valves are used to minimize the production of concentrate by the microfilter, currently 1.5 gallons of concentrate for every 30 gallons of permeate. Permeate produced by the microfilter is a dilute solution of inorganic nutrients that is either discharged to the sewer or used to dilute incoming oily sludge prior to charging the reactor (elevated salinity precludes any reclamation or recycling). The concentrate is discharged to a holding tank where it is held until it is landfarmed along with excess biomass in the SBR. This unique approach eliminates the need for landfilling and results in the essentially complete degradation of hydrocarbons and other organic components in the sludge leaving only process water and biomass as non-toxic byproducts.

The pilot project is generating performance and cost data that will be used to design and install a larger system at PWC Pearl that will triple the treatment capacity. The current system has successfully treated more than 40,000 gallons of oily sludge from various sources including the BOWTS facility.

Figure 2-4. Landfarming accumulated SBR sludge. Tank bottoms from the SBR were pumped into the vacuum truck and spread on the treatment cell at the Navy operated Barbers Point landfarm.

The Pearl Harbor project made extensive use of excess components (tanks, concrete pad and berm, microfiltration unit, and biofilters) that were available at the site, so it is not necessarily representative of the technology, waste stream, and/or climatic conditions at other activities. To increase the throughput of the filtration unit, the original membranes were replaced with a polysulfone blend spiral wound microfilters, wide spacer, 165 ft^2 total area spiral wound microfilter membranes. The spiral wound membranes have more than twice the surface area and one-fifth the footprint of the original tubular membranes. After each use, the membranes are washed with detergent in fresh water (400 gallons) and rinsed (400 gallons). The wash unit is built into the unit and to enhance cleaning efficiency, the wash water can be heated. The wash water and rinse water are discharged to the SBR. The output of these membranes has remained constant at ~30 gallons per minute and their projected life expectancy is five years. Membranes in similar applications have proven to be quite robust (Knoblock, et al., 1994; Novachis, 1998). The volumetric production of the membranes enables the operator to run the ultrafiltration unit over night and the reactor is ready to be charged with fresh oily wastewater in the morning.

Since the system in Hawaii has not been optimized nor tested with other types of problematic oily sludge (e.g. emulsified oils, fuel tank bottom sludge), more widespread implementation will require prior demonstration of commercially available components and methods for disposing of residual solids that accumulate in the reactor. The effort at SCAAP seeks to demonstrate and validate an innovative application of bioreactor technology for treating a different type of oily sludge, specifically the spent forging lubricant sludge that is generated at SCAAP.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The main advantages of the biological treatment are:

- Complete degradation of the hydrocarbons in oily sludge.
- High bacterial densities maintained by using a microfilter to capture and recycle bacteria.
- Permeate produced by the filter can potentially be recycled.
- Reactor system is simple to operate.
- Eliminates oily sludge handling and disposal.

The main limitations of the technology are:

- Excessive hydrocarbon loading can reduce effectiveness.
- Can be poisoned by extremes of pH, salinity, or high concentrations of heavy metals.
- Winter in Pennsylvania necessitates the use of an enclosed building to maintain a temperature of 70-80°F which will be provided by capturing waste heat from the forges.

The major operational issues are ensuring that the Scranton Sewer Authority discharge limits are met and disposal of biomass that accumulates in the reactor when landfarming or composting is not an option. At Pearl Harbor, ~5,000 gallons per year of accumulated biomass and sludge are landfarmed. At Scranton, solids which include graphite will be captured in a filter press and disposed in a conventional landfill.

The sludge generated at SCAAP is not regulated as hazardous waste and analysis of the raw sludge for metals (Section 8) shows that levels of the concentrations of priority metals are well below the total threshold limit concentration (TTLC). Otherwise, sequencing batch reactors are a mature technology and increasingly used to treat a variety of high BOD waste streams (Brindle et al., 1999; Cicek et al., 1999; Guerin, 2001; Knoblock et al., 1994; Marchese et al., 2000, Sutton et al., 1999; Woolard and Irvine, 1995; Yocum et al., 1995).

3.0 PERFORMANCE OBJECTIVES

Since the primary objective of the project is to DEM/VAL the on-site treatment of oily wastewater in a SBR, the primary criteria used to judge the projects effectiveness is the successful treatment of the targeted waste at less cost than the current practice while meeting the permitted discharge requirements. The quantitative and qualitative performance criteria, metrics and results are summarized in Tables 3-1 and 3-2 respectively.

Table 3-1. Primary quantitative performance objectives

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
Reactor performance hydrocarbon degradation of the forge sludge	Hydrocarbon concentration in the treated effluent	SW846 Methods: 8015M 8270B - GC/MS	< 100 ppm	<50 ppm
Cost reduction – includes capital and O&M	Payback compared to current practice	Standard cost tracking and accounting practices	< 2 years	~3 years
Discharge treated wastewater to the sewer	Wastewater discharge permit requirements	Standard analytical methods specified by the Sewer Authority	Meet permit limits	Permit limits met
Air Emissions	Concentration of VOC's in SBR exhaust air	SW 846 Methods: 8010 8015A 5030 - Purge and Trap, GC/MS	Meet permit requirements	Air emission limits met
Waste disposal	Metals concentration in the solid waste	TTLC - Metals	Meet permit requirements	Solid waste permit limits met
Secondary Quantitative Criteria				
Treatment time	Hydraulic residence time	Achieve targeted hydrocarbon concentration in reactor effluent	< 8 days	5-9 days

Table 3-2. Primary qualitative performance objectives

Qualitative Performance Objectives				
Ease of component procurement	Off the shelf items and on time delivery	Project Experience	Ready availability of off the shelf components	No delays in procuring components
SBR assembly	Within contractors estimate	Project Experience	Does not require overly complicated installation requirements	SBR assembled and modified as required o site.
Start up and optimization	Within projected project timeline	Project Experience	Within the projected schedule	Unanticipated changes led to a longer than expected start up and optimization
Ease of operation and maintenance	Actual time-Compare to current practice	Project Experience	Requires only routine maintenance of pumps, valves, and sensors	With the exception of the microprocessor, the system is easily maintained
Operator safety	Compare to current practice	Project Experience	Operation does not create a safety hazard	No safety issues have been identified
System reliability	System downtime/uptime	Project Experience	System works month-to-month as designed	Various pump seals may not be appropriate for this application

4.0 SITE/PLATFORM DESCRIPTION

4.1 TEST PLATFORMS/FACILITIES

Scranton Army Ammunition Plant (Figure 4-1) is a government owned contractor operated facility. It is located in Scranton, PA and occupies 15.3 acres of the former Delaware, Lackawanna, and Western Railroad and has been used for heavy industrial fabrication and manufacturing since the mid-1800s. Buildings currently used by the Army were constructed between 1907 and 1909 and until 1947 were used for building and repairing steam locomotives and manufacturing T-rail for the railroad. The Army bought the property in 1951 and over the next two years installed the forges and mills that are used to produce large caliber projectiles. The original contractor was the U.S. Hoffman Machinery Company and in 1963, Chamberlain Manufacturing Corporation became the contractor and operated the plant until 2006 when it was acquired by General Dynamics. The plant was modernized in 1967 and plans for updating the plant are in progress.

The product line has grown from one in the early 1960's to twenty six lines today. During this time, more than 21 million products, primarily large caliber ammunition projectiles for the United States Department of Defense have been produced. Munitions manufactured include a variety of 105 mm, 120-mm and 155-mm munitions for the Army and 5-inch 54 caliber munitions for the Navy. The facility also supplies international customers with products and technical know-how. Recently, the Army modified its existing five-year contract with Chamberlain to produce an additional $22.3 million worth of 155-millimeter M107 artillery shell casings through September 30, 2004.

All production takes place within the ~500,000 square foot facility and all engineering including prototyping and manufacturing design is conducted in house. The main production facilities are forging, annealing, finishing, and assembly. Each of the six forges is fed by individual furnaces where the billets are heated to 2300°F. As the billets exit the furnace, robotic arms place them in the forge and recover the forged projectile (Figure 4-2).

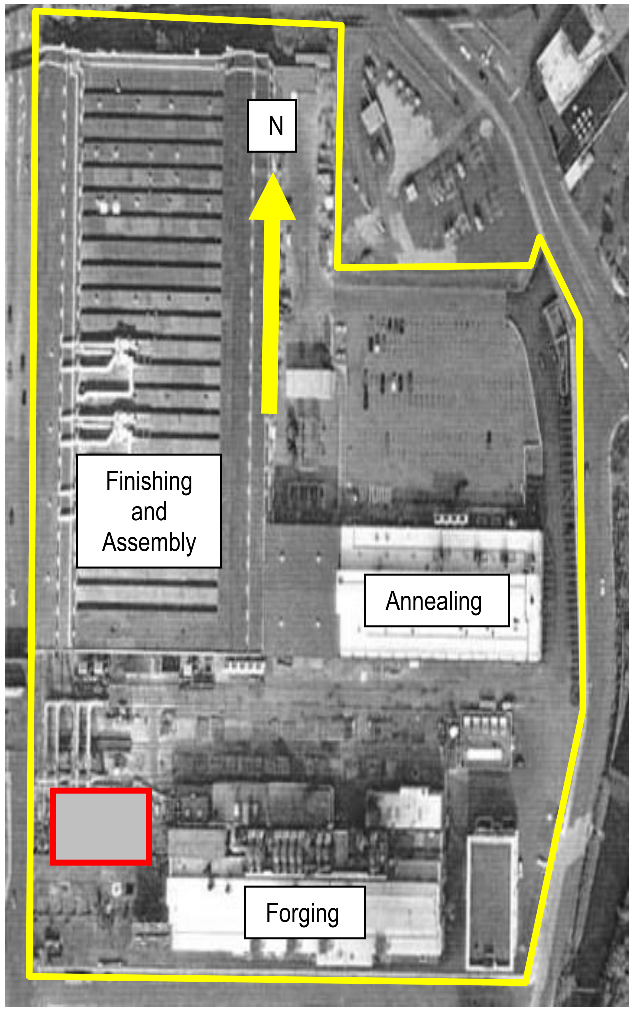


Figure 4-1. Aerial view of the Scranton Army Ammunition Plant (yellow outline) showing the shops and the biological treatment facility (red outline).

The lubricant (graphite suspended in a mineral oil base) used to keep the billets from sticking to the forge is sprayed on the hot billets and is collected in trenches under the forges. Oily wastewater flows through trenches to sumps from which it is pumped to the oily wastewater pretreatment plant (OWPP). Alternatively the wastewater can be pumped to the biological treatment facility. All operations are computer controlled and monitored on closed circuit television. A sophisticated fire monitoring and prevention system has been installed in these traditionally high-risk operations. The final machining is done in the finishing shop which is equipped with more than 60 computer numeric controlled (CNC) lathes. The final production step is a fully automated painting and coating operation. The plant has an established replacement value in excess of $350 million, and is ISO 9002 qualified by the British Standards Institute and American Petroleum Institute (API) certified.

Figure 4-2. A robotic arm removes a red-hot freshly forged projectile (foreground) from the forge (background). The forge oil is easily ignited at the forging temperature (~2300°F).

4.2 PRESENT OPERATIONS

Scranton was chosen because the sludge represents a waste that differs significantly from sludge produced by the BOWTS system, vehicle washracks, and tank bottoms. To validate the technology, and demonstrate a wider applicability it is essential to show that it works with oily waste and sludge that vary in composition and can be treated on site. In addition, the temperature in Scranton drops below freezing in the winter, which necessitates additional features. Specifically, the facility has to be installed in a heated building, which constrains design flexibility. However, the plant is an essential DoD facility that cannot be moved or replaced. Thus, this site presents a challenging waste stream in a unique industrial setting and environment.

4.3 SITE-RELATED PERMITS AND REGULATIONS

Liquid Effluent. To treat oily waste from its forging operations, SCAAP currently operates an oily waste pretreatment plant (OWPP). Discharges to the sewer from the OWPP must meet the permit standards established for the entire plant (Table 4-1). Since the biological treatment system is tied into the OWPP, it is only necessary to request a modification of the current permit. However, wastewater discharged from the biological treatment system must comply with the requirements of the existing permit and as the data show samples collected on the discharge side of the tube filter meet the permit limits..

Table 4-1. Discharge limits for SCAAP wastewater discharged to the sewer and analytical results for wastewater produced during biodegradation of SCAAP oily sludge

Parameter	Sample Results (mg/L)	SCAAP Limit (mg/L)
Cadmium	BQL	0.23
Chromium - Hexavalent	BQL	1.4
Chromium - Total	0.12	2.77
Copper	2.6	0.23
Lead	0.066	0.69
Mercury	BQL	0.005
Nickel	1.6	2.8
Silver	0.014	0.16
Zinc	0.72	2.61
Cyanide - Total	BQL	1.2
Toluene	BQL	0.8
Xylenes - Total	0.6	3.0
BOD	130	7,000
Ammonia Nitrogen	130	375
Total Suspended Solids	7530	Monitor for Surcharge
Floatable Fats, Oils, Grease (FOG)	NT	No Floatable FOG
FOG - Petroleum Origin	88	100
FOG - Total	110	1,500
Color (C.U.)	100	200
MBAS	3.9	5.0
pH Range (S.U.)	6.8	6.0 to 9.0
Total Toxic Organics (TTO)	BQL	2.13

BQL: Below Practical Quantitation Limit
NT: Not Tested

The results show that the wastewater discharged from the reactors following biological treatment of oily sludge meets the requirements for wastewater discharged from the OWPP to the sanitary sewer. The exception is copper, which compared to historical data for wastewater from the OWPP is anomalously high (historical monthly average 0.2 mg/L). In fact, the OWPP only treats for hydrocarbon in the waste stream. If copper or other metals prove to be a problem, they can be removed at the end of the process by passing the wastewater through an adsorbent column. Wastewater samples were also analyzed for VOC's and semivolatile organic compounds (SVOC's) with all compounds reported as BQL.

Solid Waste. Solid waste produced by the treatment process is recovered using a filter press. This waste consists of biomass and graphite that is a component of the forge lubricant. The TCLP data show that the concentrations of all metals (with the exception of barium) were below the Practical Quantitation Limit (range 0.005 – 0.1 mg/L) and the concentration of all metals is less than the soluble threshold limit concentration (STLC) limits for landfill disposal.

Table 4-2. Analytical results for reactor solids and STLC limits for landfilling solid waste

Metal	STLC Limit (mg/L)	TCLP Results(mg/L)	PQL (mg/L)
Arsenic	5	BQL	0.01
Barium	100	0.036	0.02
Cadmium	100	BQL	0.01
Chromium	560	BQL	0.01
Lead	5	BQL	0.1
Mercury	0.2	BQL	0.005
Selenium	1	BQL	0.01
Silver	5	BQL	0.01

BQL: Below Practical Quantitation Limit
PQL: Practical Quantitation Limit

Air Emissions. Since oily sludge may contain volatile organic compounds (VOCs) that would be emitted during vigorous aeration of the reactor, air samples were taken within one hour of charging the SBR with fresh oily sludge and analyzed for priority air pollutants (EPA Method TO14) which analyzes for 35 compounds. The concentrations of all VOCs with the exception of benzene and toluene were less than the PQL (0.06 – 0.28 ppm), Table 8-3. To ensure that no VOCs are emitted, exhaust air is passed through activated carbon. It should be noted that the original proposal used biofilters, however activated carbon is more practical and cost effective for the low concentrations' of VOCs

Table 4-3. Compounds detected in air emissions from the SBR

Compounds Detected	Concentration (ppm)
Benzene	0.8
Toluene	1.1

5.0 TEST DESIGN

5.1 CONCEPTUAL TEST DESIGN

When the project was proposed, the OWS (Figure 5-1) would continue to be used and the SBR would be used to treat the sludge produced by the OWS. However, this would require additional plumbing and the recovered sludge would have to be diluted to a concentration appropriate for biological treatment. As more detailed operational data become available, the concentration of hydrocarbons in the wastewater going to the OWS was determined to be well within the range for biological treatment. Thus, the treatment system was designed so that the wastewater recovered from the sumps could be fed directly into the SBR. This approach eliminated the need for the oil water separator and fresh water to re-dilute the sludge.

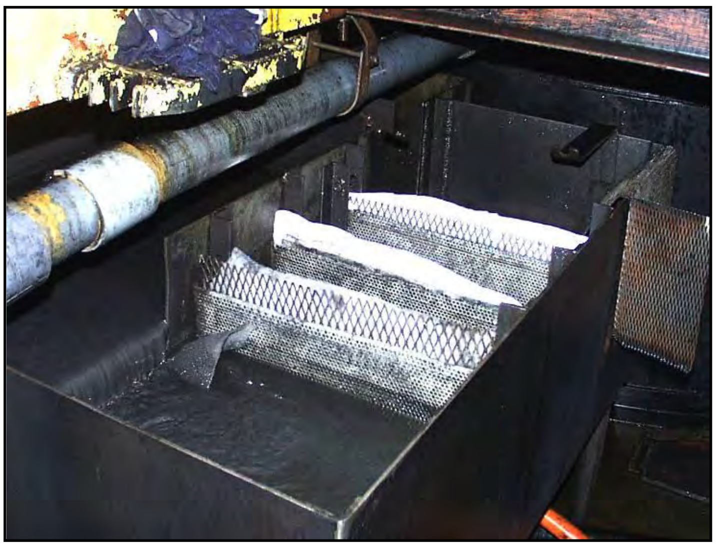


Figure 5-1. Scranton oil water separator uses adsorbent pads to remove residual oil prior to discharging the wastewater to the sewer.

Initially, Scranton was producing ~300,000 gallons of oily wastewater per month (500,000 gallons peak) and recovering ~700,000 pounds of sludge per year from the oil water separator and ~200,000 pounds from the trenches under the forges. If sludge from the trenches were suspended in the wastewater the average monthly load of sludge in the wastewater would be 75,000 pounds (i.e., (700,000 + 200,000)/12 months) and the average combined hydrocarbon concentration in the wastewater would be 25%, (i.e., 75,000 pounds of sludge per month/300,000 gallons of oily wastewater per month). However, the average hydrocarbon concentration in the sludge is 20% by weight which suggests that if all of the waste were combined the total hydrocarbon concentration would be one-fifth of 25% or ~5% (5000 ppm).

Since the system in Hawaii takes five days to degrade the equivalent hydrocarbon concentration to 100 ppm, it would be expected that five to six days of treatment would reduce the concentration to or below the SCAAP discharge limit. To provide six days of treatment at a maximum flow of 500,000 gallons of wastewater per month would require 100,000 gallons of reactor capacity. Because of floor loading and space limits, a single large reactor was not practical or necessarily desirable so two 50,000 gallon SBRs were installed.

In addition to the SBR, the major subsystems are; nutrient addition, pH control, aeration, a membrane filter which is used to remove residual solids from the settled wastewater discharged during the decant phase, a filter press is used to capture wasted biomass and solids (primarily graphite) that accumulate in the SBR along with concentrate from the filter which are dried and landfilled, and carbon canisters capture VOCs in air vented from the SBR. Clean water is stored and can be used for makeup water in the SBR. However, all of the filtrate is currently used for cooling water and it has not been necessary to discharge to the sewer. These components, inputs, and outputs are shown in Figure 5-2.

As discussed in Section 5.6 it was necessary to modify the treatment system to accommodate unexpected properties of the oily waste and changes in how SCAAP managed their wastewater. The process diagram (Figure 5-2) reflects these changes. Briefly, SBR B is used as a gravity separator and a skimmer was added to recover oil which is recycled. This was possible because changes in wastewater management reduced the volume of wastewater, but not that of the oil much of which is recovered and recycled. As a result, the residual oil concentration in the wastewater is a few hundred parts per million which is degraded in SBR A.

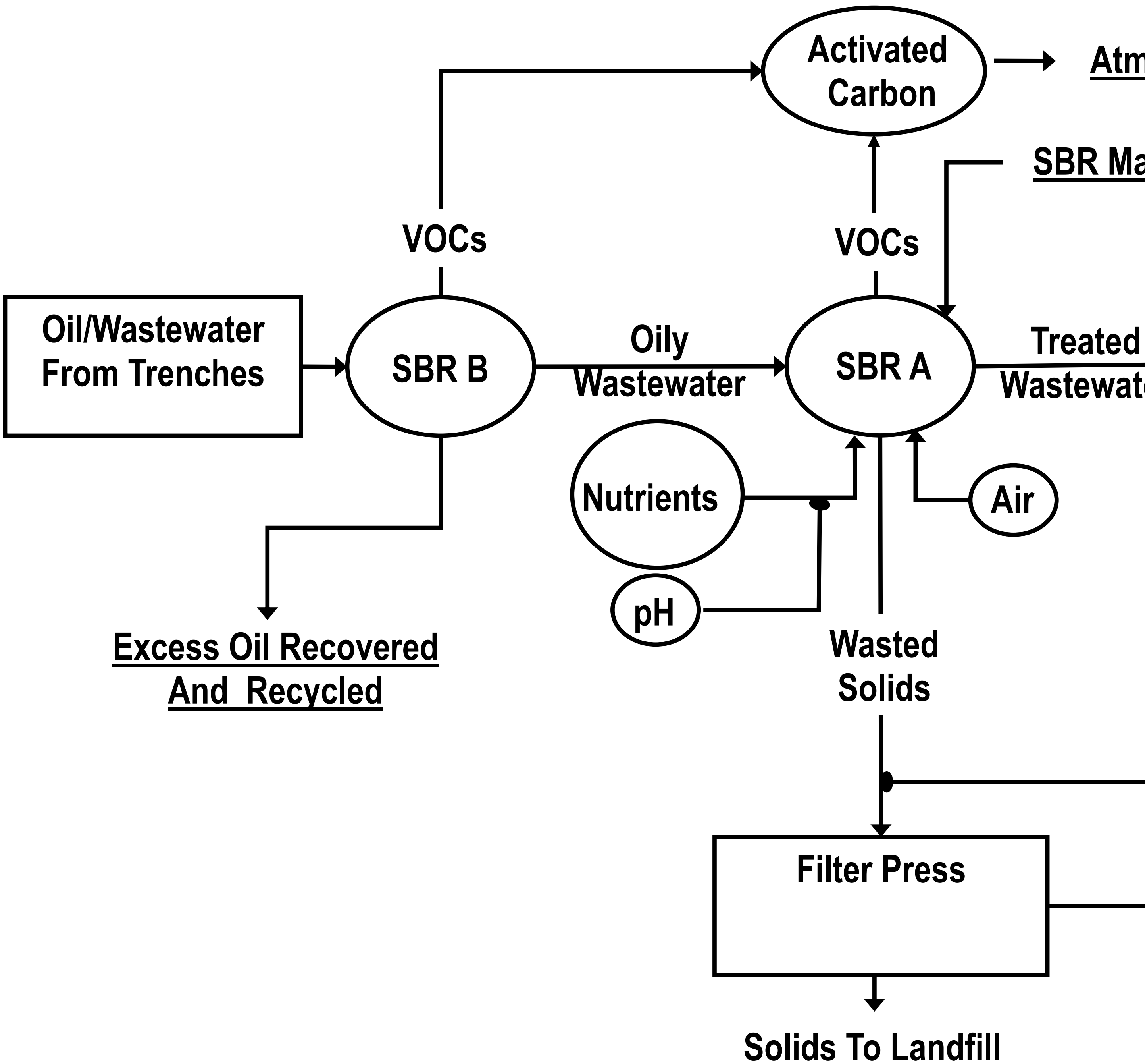


Figure 5-2. Process diagram of the SCAAP oily wastewater treatment system.

5.2 BASELINE CHARACTERIZATION

As with previous work, pilot studies were used to determine if was feasible to treat the SCAAP sludge. These studies used a 20 gallon air lift reactor (Figure 5-3) equipped with a pH controller and oxygen electrode. Sludge recovered from the trenches and OWS was mixed with nutrients and at regular intervals samples were analyzed by total petroleum hydrocarbons and bacteria (heterotrophs and hydrocarbon degraders). Representative data are shown in Figure 5-3 and show that the hydrocarbons in the sludge were degraded within 4-5 days to less than 100 ppm which coincided with an increase in the population of hydrocarbon degrading bacteria. Chromatograms (Figure 5-4) of the oil sludge extracted confirm that extensive degradation of the hydrocarbons in the sludge occurred.

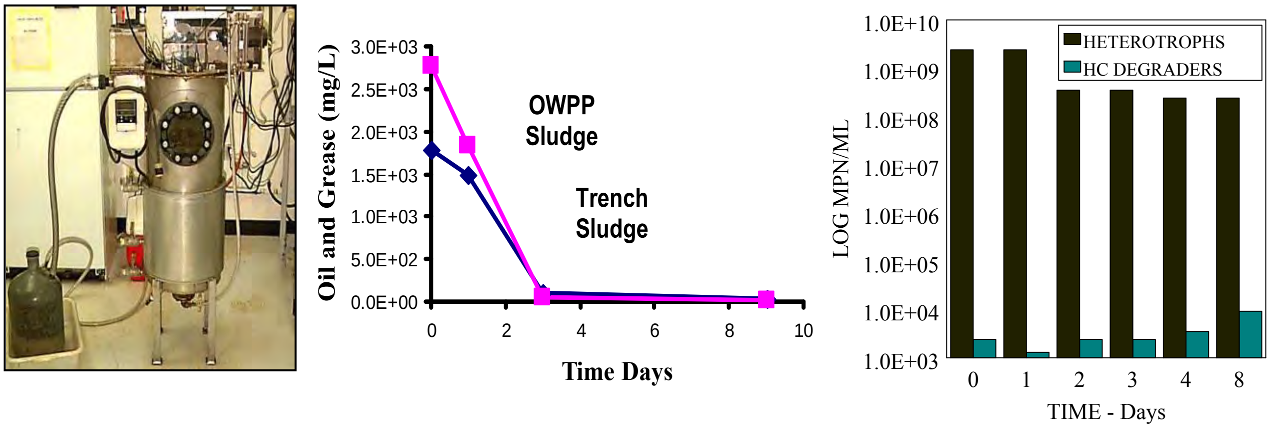


Figure 5-3. Biodegradability testing of SCAAP oily sludge in a pilot reactor (left) demonstrated that sludge from two sources (OWPP and Trenches) in the plant was rapidly degraded (middle) which coincided with an increase in the number of hydrocarbon degrading bacteria (right).

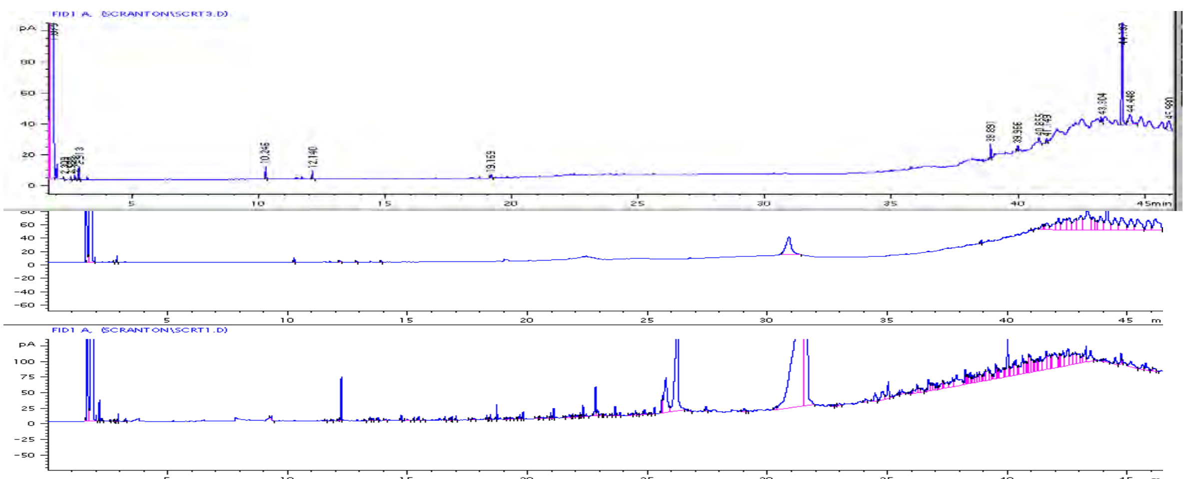


Figure 5-4. Chromatograms of oily sludge samples treated in the pilot scale reactor. Samples were taken at time 0 (lower), day 2 (middle), and day 6 (upper). The concentrations correspond to 4370, 1340, and 53 ppm as total hydrocarbons respectively. The large peak on the left at ~2 minutes is the solvent.

Based on the results of the pilot test, it was concluded that biological treatment of the SCAAP oily sludge was technically feasible and a full-scale system was designed and installed.

5.3 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

Figure 5-5 shows the general layout of the treatment system in relation to the forge shop and oily wastewater pretreatment plant (OWPP) and a side view shows the position of one of the SBRs and a holding tank in relation to the floor supports. Since the treatment system is located on the roof of the lower level of the plant, the floor, which dates to the early 1900's, had to be tested to ensure that it was capable of supporting the weight of the two SBRs when they were filled with water. Once it was determined that the floor would support the SBRs, a building was assembled on-site to house the treatment system and the SBRs were installed.

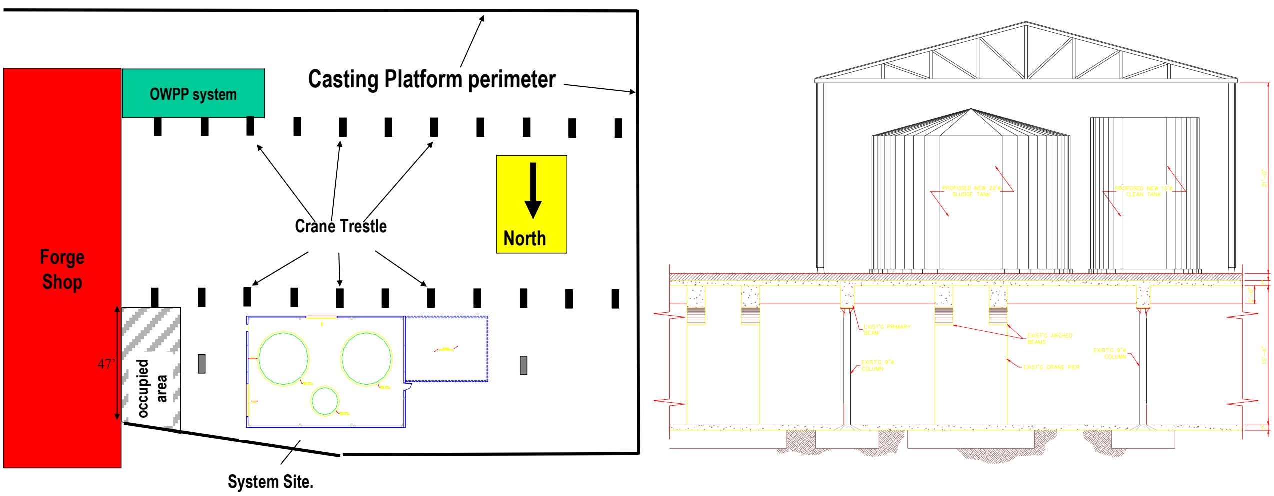
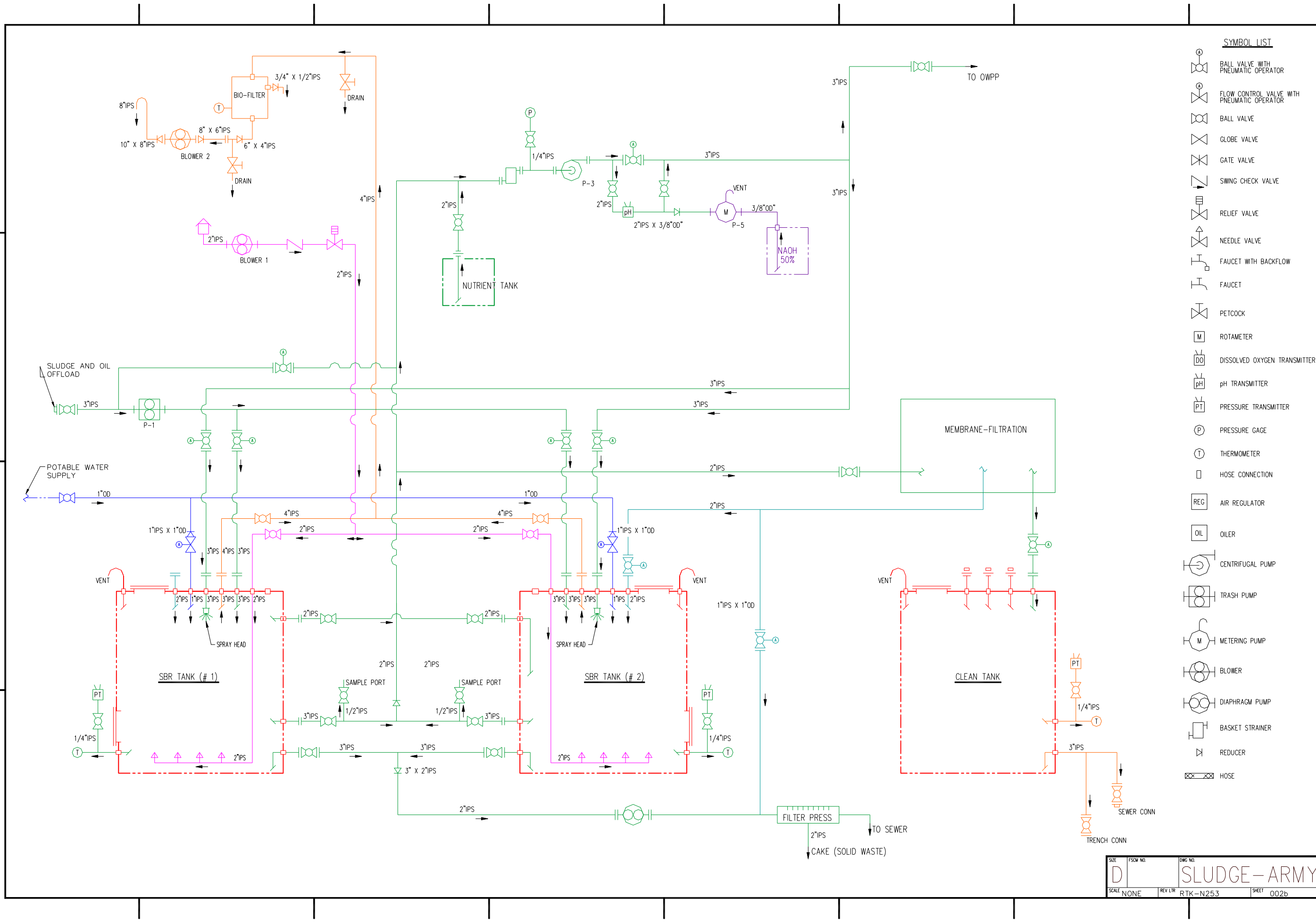


Figure 5-5. Plan view of the treatment plant (left) and a side view (right) shows one of the SBRs and a 10,000 gallon holding tank in relation to the floor supports.

Various phase of construction are shown in Figure 5-6 and a piping and instrumentation drawing (P&ID) of the installation including the subsystems is shown in Figure 5-7. The process diagram (Figure 5-2) show final configuration of the system including the products: (i) Air vented from the SBR's is scrubbed of VOCs by passing it through activated carbon before it is vented to the atmosphere; (ii) excess oil is recovered and recycled; (iii) a filter press is used to dewater solids (wasted biomass and graphite from the SBR and concentrate from the filter). The dewatered solids are landfilled (nonhazardous) and the water discharged to the sewer; (iv) treated wastewater decanted from the SBR is filtered to remove residual solids and the filtrate is stored on-site and is currently used as cooling water in the plant. It can also be used as makeup water in the SBR or discharged to the sewer.

Figure 5-6. Photos showing construction of the building that houses the treatment system (left) and the placement of the bottom drains (center) for the SBRs. The photo at the right shows part of the completed system.



structurally adequate, the installation of the treatment system was completed in the last two quarters of 2005. After testing the functioning and integrity of the system, testing with oily wastewater (referred to as Phase I) was initiated. Even though the initial results showed that the oily sludge was rapidly degraded, as testing progressed, it was recognized that the system as installed did not provide adequate mixing. Modifications to correct these problems were designed and installed in the second and third quarter of 2007 and testing resumed. However, the concentration of oil entering the reactor greatly exceeded what was expected and was beyond the design capacity of the system. In discussions with SCAAP it was revealed that new wastewater management policies had reduced the wastewater flow by one third from 300,000 gallons per month to slightly more than 100,000 gallons per month. In addition, the trenches were being used as gravity oil wastewater separators and to meet their discharge limits, only the lower water layer was being treated at the OWPP. Thus, when the SBR was charged following the modifications, the concentration of oily sludge exceeded 40,000 ppm which was more than ten times the expected concentration. This problem was addressed by using one of the SBRs as a gravity oil water separator and installing a skimmer in the tank that removed the floating oil which is sold to a recycler for $0.85 per gallon. Following these modifications, testing (referred to as Phase II) was resumed and completed during the first two quarters of 2009.

Table 5-1. Summary of the Major Project Phases for the Installation and Testing of the Oily Waste Treatment System at SCAAP

Project Phase	**2005**		**2006**				**2007**				**2008**				**2009**	
	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2
Installation Completed	■	■														
Phase I Testing			■	■	■	■	■									
System Modifications								■	■							
Phase I Testing Continued										■	■					
System Modifications												■	■			
Phase II Testing														■	■	■

5.5 SAMPLING PROTOCOL

As the spent forging fluid is degraded, there will be a transient increase in the concentration of carboxylic acids that are intermediate products of hydrocarbon degradation. The production of these compounds is expected to be correlated with an increase in sodium hydroxide consumption (measured by the cumulative timer on the pH pumps) and an increase in turbidity and suspended solids which are indirect measures of bacterial growth. Simultaneously, the concentrations of petroleum hydrocarbons, ammonia, and phosphate should decrease. In addition to demonstrating that degradation of the oily waste is occurring, growth and degradation are correlated with the concentrations of phosphate and ammonia, so that the optimal amounts of these nutrients as well as the supplements (NZ-Amine, and yeast extract) can be determined.

At regular intervals, the pH, temperature, and dissolved oxygen concentration reported by sensors in each tank were recorded along with the cumulative operating time of the pH pumps. Wastewater in the SBR was sampled during the react cycle and analyzed on-site using Hach kits for:

- Ammonia Nitrogen
- Phosphorous - Reactive
- Suspended Solids
- Turbidity

Samples from the SBR were also sent to a commercial lab and analyzed for hydrocarbons, metals, and solids (total and volatile), BOD_5, and COD. To ensure that regulatory requirements were met, samples of exhaust air and solids were also analyzed. The analyses, sampling points, relative frequency, and where appropriate the quantitation limit are summarized in Table 5-2.

Table 5-2. Summary of analytical methods, sampling frequency, and method limits

Parameter and Method	Medium and Sampling Frequency	Quantitation Limit
Commercial Laboratory Analyses		
Hydrocarbons SW846 8015M	Daily/weekly samples from the SBR and effluent.	20 - 100 μg/L
Semi-Volatile Organics SW 846 8270B	Weekly samples from the reactor and effluent as well as air samples entering and exiting the biofilters.	5 – 20μg/L
Volatile Organic Compounds SW 846 Methods: 8010,8015A 5030	Weekly Samples – including air entering and exiting the biofilters.	5 – 20μg/L
Fixed and Volatile Solids (Measure Biomass) Standard Method 2540E	Daily/weekly Samples from the SBR	1 mg/L
Total Suspended Solids (TSS) Standard Method 2540 D	Daily/weekly samples from the SBR	1 mg/L
Metals Standard Method 3120 B ICP	Monitor metals in the SBR and solids	2- 100 μg /kg
Biological Oxygen Demand (BOD_5) Standard Method 5210 A	Weekly samples from the SBR	1 mg/L
Chemical Oxygen Demand (COD) Standard Method 5220 D	Weekly samples from the SBR	3 mg/L
On-Site Analyses		
Inorganic Species Hach Kits	Daily/weekly samples from the SBR to adjust nitrogen and phosphorous as required	0.03 – 0.05 mg/L
Process Monitoring		
pH Calibrated pH Electrode	Monitoring pH in the SBR	Process Specific
Oxygen Concentration Oxygen Electrode	Monitoring oxygen in the SBR	0.2 mg/L
Liquid Flow Calibrated Flow Meters	Monitoring wastewater flow into the SBR	Process Specific
Air Flow Calibrated Flow Meters	Monitoring of air flow in the SBR and carbon canisters	Process Specific

Samples were also taken on the discharge side of the tube filter and sent to a commercial lab where they were analyzed for the analytes specified by the Scranton Sewer Authority (Table 5-3).

Table 5-3. Analyses and Daily and Monthly Limits Required by the Scranton Sewer Authority for Water Discharged Through the Tube Filter to the Sewer

Parameter	Daily Maximum Concentration (mg/l)	Monthly Average Concentration (mg/l)
Cadmium	0.23	0.09
Chromium - Hexavalent	1.4	1.27
Chromium - Total	2.77	1.71
Copper	0.23	0.20
Lead	0.69	0.43
Mercury	0.005	0.002
Nickel	2.8	1.13
Silver	0.16	0.06
Zinc	2.61	1.48
Cyanide - Total	1.2	0.65
Toluene	0.8	0.8
Xylenes - Total	3.0	3.0
BOD	7,000	
Ammonia - Nitrogen	375	
Total Suspended Solids	Monitor for Surcharge	
Fats, Oils, Grease (FOG) Total	1,500	
FOG Petroleum Origin - Total	100	
FOG - Floatable	No Floatable FOG	
Color	200	
MBAS	5.0	
pH Range	6.0 to 9.0	
Total Toxic Organics (TTO)	2.13	

Samples sent to an outside lab were used to confirm that the spent forging fluid was degraded and that the discharge would meet the Scranton Sewer Authority requirements. The BOD, COD, and volatile suspended solids (VSS) results were used to calculate the food to microorganism ratio (F/M) which is used to determine how much biomass should be retained in the reactor. The on-site indirect measurements of bacterial growth (turbidity and suspended solids) can be correlated with the laboratory measured values for total solids, volatile solids (an indirect measure of bacterial growth) and suspended solids. These correlations enable the operator to conduct on-site analyses of critical operating parameters. For example, when there is insufficient nitrogen, bacteria (as was observed during the initial startup) will convert their food source (spent forging fluid) to polysaccharides or if the concentration of phosphorous is too low, the bacteria will not grow or grow poorly.

5.6 SAMPLING RESULTS

Phase I. After the treatment system was installed and the integrity of its system verified, one of the SBRs was charged with oily wastewater and amended with nutrients. Samples were sent to a commercial lab and analyzed for VSS, TSS, and hydrocarbons and the solids analyzed for metals. These results (Figure 5-8 and Table 5-4) show that the oily waste was rapidly degraded and the concentrations of metals of concern in the solids were below the PQL and or regulatory levels.

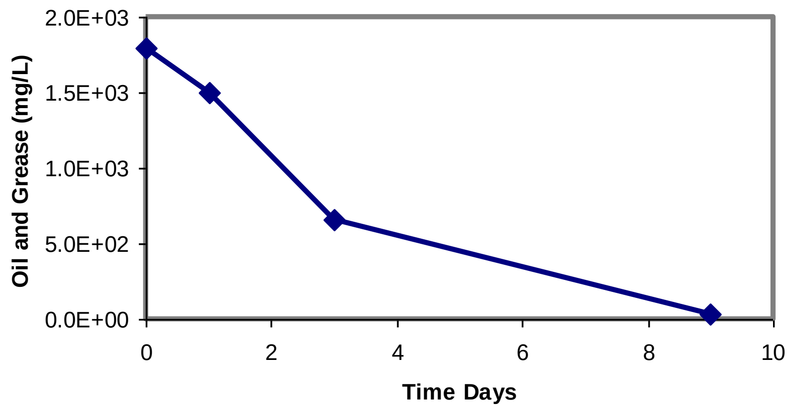


Figure 5-8. Time course showing rapid degradation of oil and grease in the SCAAP SBR.

Table 5-4. Concentrations (TCLP) of Select Metals in Settled Solids from the SCAAP SBR

Metal	Concentration mg/L
Arsenic	BQL[1]
Barium	0.034
Cadmium	BQL
Chromium	0.034
Lead	BQL
Mercury	BQL
Selenium	BQL
Silver	BQL

[1]BQL Below Quantitative Limit

However, the performance of the treatment system degraded over the next few months and during a site visit it appeared that the major problem was inadequate mixing which allowed the oil to pool on the surface where it congealed and sank to the bottom of the SBR. To correct this problem, a more efficient aerator and a surface weir that captured and recirculated pooled oil were designed and installed in July August 2007. Subsequently, a preliminary evaluation suggested that these modifications corrected the inadequate mixing. Additional modifications also carried out during this time included:

- Activated carbon canister added to each exhaust line
- Software modified to allow operation in either batch or series
- Filter tube backwash modified to provide additional filter press capacity
- Strainer installed in the oily wastewater inlet
- Throttling valves installed on the main recirculation lines on each tank

Aeration capacity was increased by cutting into and welding perforated stainless steel extensions to the bottoms of the existing headers. These headers extend from the central header out to the center of the SBR and back to and along the wall of each tank. The extensions increase the dissolved oxygen concentration, provide better mixing, and minimize dead space in the SBRs.

The weir was fabricated out of stainless steel and connected to main recirculation pump via a flange at the top of the tank that in the original design was used to recirculate wastewater by drawing it from the bottom of the tank and injecting it into perforated PVC pipe laid around the wall at the bottom of each tank. Stainless steel pipe was used to connect the weir to the flange and the pipe was supported by bolting it to a bracket welded to an air header. As in the original design, a trash pump is used to recirculate and mechanically emulsify oily wastewater drawn from the drain in the bottom of the tank and the weir at the surface. This water is injected back into the tank ~ 4 feet off the bottom where it is entrained by the aeration system. Prior to closing the manway, the performance of the recirculation system was observed by pumping the fresh water used to level the aeration headers through the line that serves the floor drain. The aeration system was also operated to ensure that all of the headers were working. Full-scale operation of the system was observed in each tank using ~ 40,000 gallons of retained wastewater that was transferred between the tanks for testing.

Figure 5-9 shows the redesigned recirculation line undergoing testing and the weir installed at the top of the tank. Figure 5-10 shows that oil and polysaccharides floating on the surface were drawn into the weir and mechanically emulsified by the trash pump. (It should be noted that the residual polysaccharide which the bacteria synthesized when the nitrogen concentration was too low should not be a problem in the future.) Since the treatment system relies on mechanical emulsification of the spent forging oil, the performance observed with the residual polysaccharides and entrapped oil suggested that the weir would function as designed when the SBRs are charged with fresh oily wastewater.

Figure 5-9. Testing the newly installed recirculation line (left) and the stainless steel weir centered in the SBR attached to an aeration header and flange at the tank wall.

Figure 5-10. Polysaccharide and residual oil floating on top of the tank prior to starting the recirculation pump (left), flowing into the weir (center) and emulsified polysaccharide and residual oil after running the recirculation pump.

The main recirculation line combines wastewater drawn from the drain at the bottom of the SBR and the weir. Input from each of these sources is adjusted with gate valves that were installed on the intake side of the main trash pump. Since the primary function of the floor drain is to capture and recirculate solids that fall to the floor, the system has to be operated with this valve partially open. To adjust the recirculation system, the floor drain is closed and the gate valve on the line from the weir closed until the pump begins to cavitate at which point the valve on the line from the floor drain can be opened until the pump stops cavitating. After adjusting the valves, the weir is checked to ensure that pooled oil on the surface is flowing into it.

To operate the system, SBR B was filled with fresh oily wastewater. Since oily wastewater production has decreased to an average of 3800 gallons per day (Figure 5-11), this took approximately two weeks. During filling, the aeration system was operated at a rate sufficient to ensure turbulent mixing and until the wastewater reached the weir, the gate valve for the floor drain was fully open. Nutrients were added in proportion to the volume of wastewater in the tank. Nutrient concentrations (nitrogen and phosphorous) were determined on-site by taking samples and analyzing them with Hach kits and the concentrations adjusted as necessary.

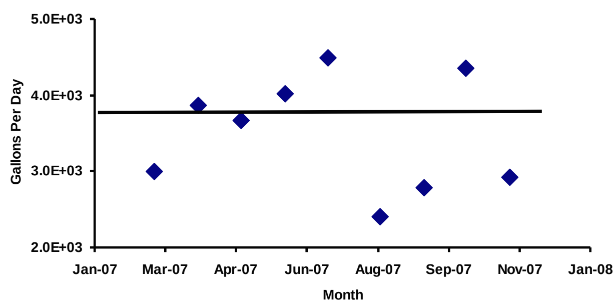


Figure 5-11. Wastewater production from March to November 2007. The solid line is the nine month daily average (3800 gpd).

To make room in Tank B for fresh wastewater, treated water is transferred from SBR B to SBR A. The volume transferred is sufficient to allow one or more days of wastewater to be pumped from the pits to SBR B. For example, transferring 12,000 gallons of treated waste from SBR B to SBR A, would enable 2 - 4 days of average production to be pumped to SBR B. To free up space in SBR A, 12,000 gallons would be discharged through the tube filter. Operating the tanks in series will provide 21 days of residence time (based on an average production rate of 3800 g/d and total SBR operating capacity of 80,000 gallons). Given adequate mixing and sufficient aeration and nutrients, this is more than adequate time to reduce the hydrocarbon concentration to an acceptable discharge level and provides excess capacity to deal with high rainfall events and forge failures that dump additional oil into the trenches.

Tank A was filled with ~40,000 gallons of oily wastewater over the course of four days. During and after filling, samples were analyzed for essential nutrients (nitrogen and phosphorous) and the concentrations of these nutrients were adjusted by adding Accelerator II from Novozyme along with NZ Amine and yeast extract which provide vitamins and amino acids. Accelerator II is a liquid which contains 0.65 pounds of nitrogen and 0.13 pounds of phosphorous per gallon and yeast extract and NZ amine are dry powders. All nutrients were mixed with fresh water in the nutrient addition tank and then pumped into SBR A. To ensure that all the nutrients were transferred to SBR A, the nutrient addition tank was flushed with fresh water. During filling, the aeration system was operated at 70% of the drive motor capacity and the valve from drain on the bottom of the tank to the main recirculation line was fully open and the line from the weir was closed. When the wastewater reached the level of the weir, the valves on the recirculation lines were adjusted as previously described and the drive motor for the aeration system was operated at 80-90 % of capacity.

When Tank A was full, samples were taken daily and analyzed for nitrogen, phosphorous, oil, and indirectly for biomass. Hach analytical kits in conjunction with a Hach 2000 DR colorimeter were used to analyze samples for nitrogen and phosphorous and total suspended solids (biomass) were analyzed using the pre-programmed functions. To estimate biomass, water samples were filtered (5µ filter) and the light scattering of the filtrate was measured and the results displayed as ppm. A Horiba instrument was used to measure total recoverable hydrocarbons (EPA method 418.1) which were extracted with perchloroethylene. This instrument, which measures the infra red absorption of the C-H bond stretching characteristic of hydrocarbons, was calibrated with a virgin sample of hot forge oil.

The temperature, pH, and cumulative time that the sodium hydroxide chemical addition pump operated were also recorded. Errors associated with sampling and analyses were estimated by analyzing three separate samples in triplicate (i.e., nine separate analyses each for nitrogen, phosphorous, biomass, and oil) from which the average and the standard deviation were calculated. The percentage of the standard deviation for each analysis was expressed as a percentage of the average value and used to estimate the error for the individual measurements.

Figure 5-12 shows that once Tank A was filled, the hydrocarbon concentration rapidly decreased over the course of four days (28 September through 1 October) from ~30,000 ppm to ~5000 ppm (measured with the Horiba instrument). As was expected the decrease in hydrocarbon concentration was accompanied by a rapid increase in the consumption of sodium hydroxide which neutralizes the intermediate carboxylic acids produced during hydrocarbon breakdown. That the degradation of the oil was caused by bacterial growth is shown by the increase in biomass which parallels the decrease in the hydrocarbon concentration, Figure 5-13.

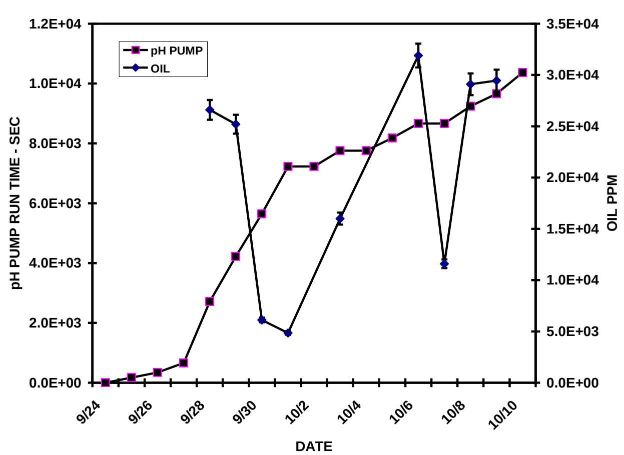


Figure 5-12. Hydrocarbon concentration and sodium hydroxide consumption in SBR A.

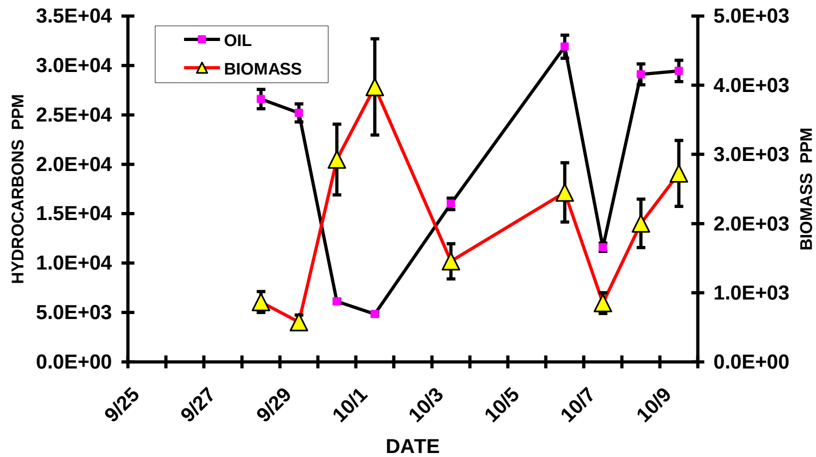


Figure 5-13. Concentration of biomass and hydrocarbons in SBR A.

After 4 days the data (Figure 5-12) suggest that the hydrocarbon concentration increased. However, this is probably due to an artifact of the 418.1 method used the Horiba instrument which does not distinguish hydrocarbons present in the wastewater from hydrocarbon like molecules produced by and found in the biomass. These compounds (e.g., fatty acids which are found of all cellular organisms) are extracted along with the hydrocarbons and inflate the hydrocarbon concentration. This interpretation is supported by reports in the literature (e.g., http://www.google.com/#sclient=psy&hl=en&q=method+418.1+interference&aq=f&aqi=&aql=&oq=&pbx=1&fp=38ed6da7faad07f1) and data in Table 5-2 which shows that hydrocarbon concentrations measured with the Horiba instrument are more than an order of magnitude higher than the values reported when EPA Method 8015m was used.

The decrease in biomass (Figure 5-13) may have been caused by the bacterial depletion of nitrogen and phosphorous to such a low level that bacterial growth could not be maintained (Figure 5-14). Alternatively, the amount yeast extract and NZ amine added to the tank as it was filling may have been inadequate to support the bacterial growth required to degrade the remaining oil. However, without an independent measure of the actual number of bacteria in the tank, it would be premature to conclude that the number of bacteria declined.

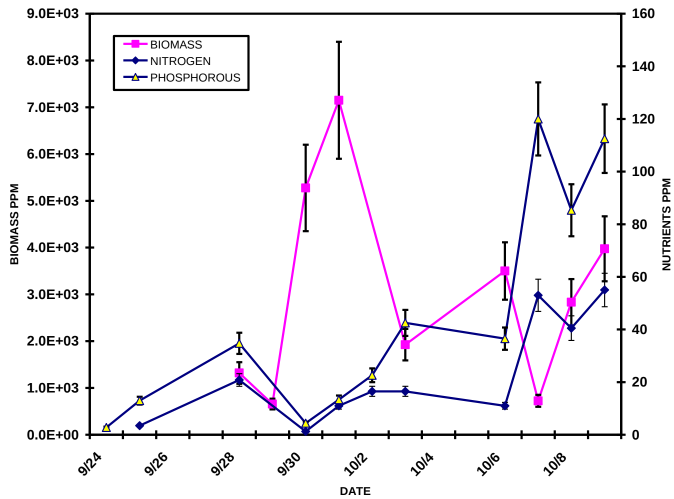


Figure 5-14. Nitrogen, phosphorus, and biomass in SBR A (as required, fertilizer was added to restore the concentrations of nitrogen and phosphorous).

Based on the pilot study and oily wastewater production data, it was assumed that the concentration of oil in the wastewater would be no greater than 10,000 ppm and the concentration of nutrients was based on this number. Since the hydrocarbon concentration appears to have been three times that, this may explain why the nutrients were rapidly depleted.

Alternatively, the high pressure blower used to aerate the reactor, also caused the temperature to rise ~100°F which was associated with what appears to have been a decrease in biomass (Figure 5-15). However, the Hawaii SBR operates near this temperature with no apparent degradation of performance.

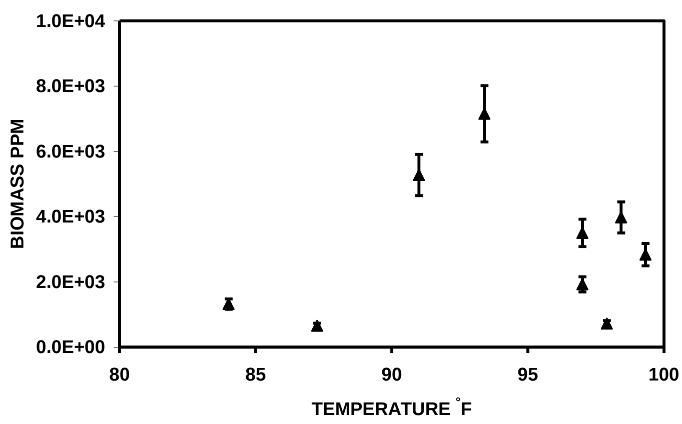


Figure 5-15. SBR A temperature and biomass.

As shown in Figures 5-13, there is a very strong correlation between the decrease in the oil concentration and the increase in biomass which suggests that the oil was being degraded and converted into biomass (bacteria). The rapid consumption of sodium hydroxide that occurred during this period (Figure 5-12) further supports the observed hydrocarbon degradation and corresponding increase in biomass. That bacterial growth was responsible for the degradation of the oil is also supported by the rapid and concurrent depletion of nitrogen and phosphorous that accompanied the increase in biomass (Figure 5-14). It should be noted that increases in the concentrations of nitrogen and phosphorous (Figure 5-14) were caused by periodic additions of fertilizer. However, even with these additions, the data show that hydrocarbon degradation was not maintained and that the amount of biomass declined. Loss of bacterial activity and decreases in biomass at high population densities may be associated with the depletion of some essential nutrient, buildup of an inhibitor, the increase in temperature, or a combination of these factors.

Overall, the data are consistent with what was observed in the pilot studies and our experience with this treatment system. Even though the decrease in oil concentration was significant, it is not sufficient to meet the discharge requirements. However, the concentration of oil (~30,000 ppm) was much higher than the system was designed to treat. While additional degradation may occur if the system is supplemented with micronutrients and operated in series, it is doubtful that the target of <100 ppm will be achieved.

As was previously discussed, the amount of oil pumped into the reactor may have been accumulating in the 1-2 months prior to start up of the system and may not be representative of the average daily production of waste oil. In fact, the hydrocarbon concentrations in recent samples taken from the Bliss and Erie sumps were 4700 ppm and 2400 ppm respectively. From the pilot study, these are typical of the concentrations that were expected and which the system should be able to treat to meet the discharge requirements.

While the incoming oil content of the wastewater may be unacceptable, it provided a strenuous test of the system modifications. Specifically, the weir successfully captured and kept the oil emulsified and the SBR was uniformly agitated and aerated.

Samples were also taken of the oil and oily wastewater in the pits as well as the wastewater in the SBR and sent to an outside laboratory for detailed characterization of the hydrocarbons using gas chromatography and mass spectroscopy. Representative chromatograms (Figure 5-16) show that untreated hydrocarbons remained in the reactor and that the hydrocarbons are primarily high molecular weight hydrocarbons typical of lubricating oils with an average chain length centered at C_{29}.

A comparison of these chromatograms with chromatograms, obtained using slightly different run conditions, from the pilot study (Figure 5-4) suggests that the composition of the waste stream may have changed. Even though all the chromatograms show a preponderance of high molecular weight hydrocarbons, the oily waste used for the pilot study appears to contain a less pronounced mixture of long-chain hydrocarbons as compared to the more distinctive unresolved hydrocarbons shown in Figure 5-16 centered on a chain length of C_{29}.

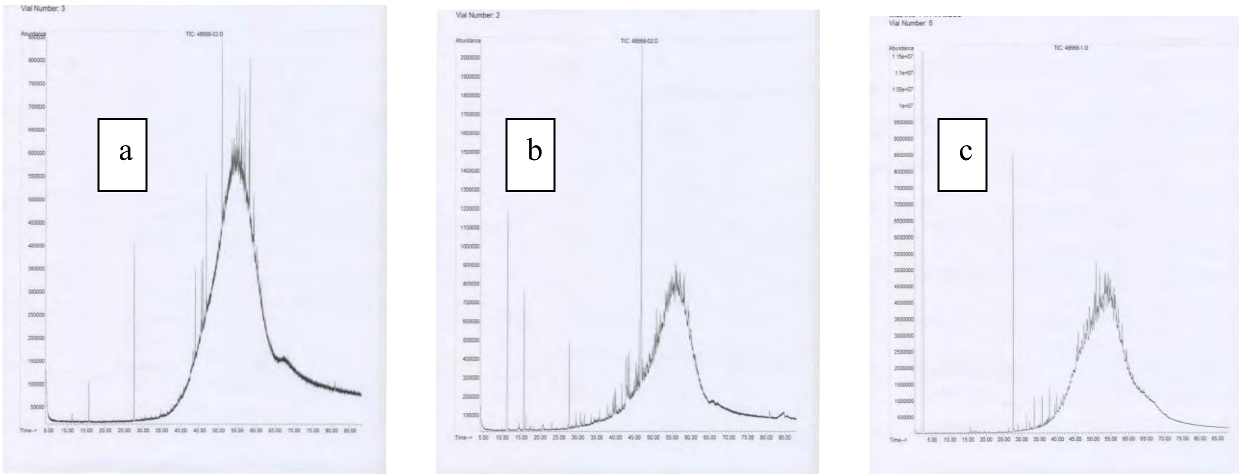


Figure 5-16. Chromatograms of treated wastewater (a) and the water (b) and oil fraction (c) from one of the pits under the forges. The y-axis scale for (a) is one-half that of (b) and one-tenth that of (c).

Testing of the modified treatment system demonstrated the ability of the system to treat the oily wastewater. However, additional changes in the way SCAPP manages its wastewater resulted in higher than expected hydrocarbon concentrations (>40,000 ppm) and because of the heavy nature of these hydrocarbons, the system cannot degrade it in a reasonable time and meet the discharge requirements. As a result, the system was reconfigured to operate in series using one SBR for pretreatment and the second as the active degradation tank. To remove and recycle the excess, SCAAP installed an oil skimmer on the pretreatment tank (Figure 5-17). It should be noted that the more concentrated oil stream makes it cost effective to recover and recycle it rather than simply dispose of it. A further advantage of this approach is that the hydrocarbon concentration in the wastewater going to the treatment tank is more consistent (2000 – 4000 ppm) which makes the system more biologically stable, easier to operate, and less susceptible to system upsets caused by too much or too little oil.

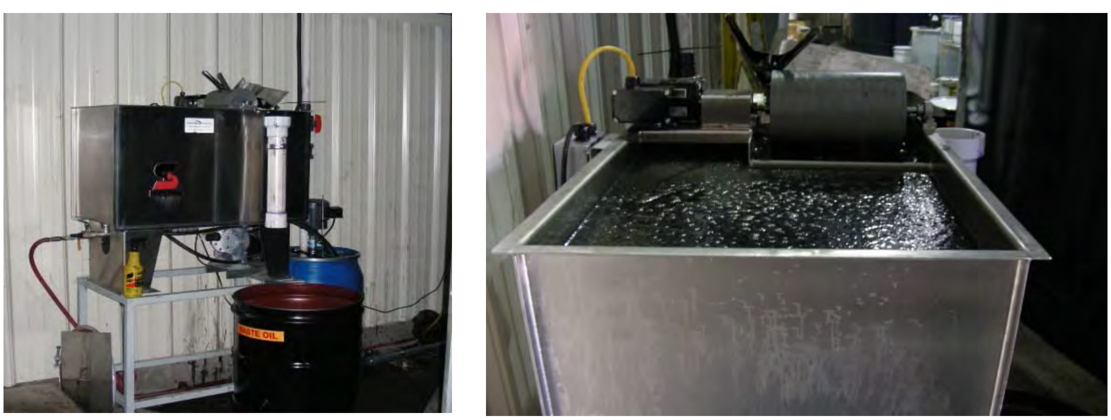


Figure 5-17. Oil skimmer installed at Scranton Army Ammunition Plant. Floating oil in SBR B is skimmed and to the drum skimmer where the oil is recovered and water is returned to the tank. The processing rate is 25 gallons per hour.

Phase II Testing. Over the period 10/25/08 – 10/31/08 approximately 27,000 gallons of water from which the oil had been skimmed was transferred from SBR B to SBR A. To further minimize the transfer of free oil, water was transferred from the bottom of the SBR B. When the transfer was complete, 30 pounds of yeast extract, 10 pounds of NZ Amine, 10 gallons of Accelerator II, and 1 pound of Accelerator V were added.

During the following week (11/3/08 – 11/5/08), SBR A was filled to its working capacity (40,000 gallons) and additional nutrients were added as required. On November 18 SBR A was shut down and allowed to settle. Samples were taken from the reactor before and after it settled and the filtrate that passed through the tube filter. Samples were analyzed on-site (Table 5-5) and samples were also sent to a commercial lab and analyzed for hydrocarbons, total organic carbon, total suspended solids and volatile suspended solids.

Samples analyzed on-site were filtered through a 5µm filter and the Hach spectrophotometer was used to measure turbidity and total suspended solids in the filtrate. The samples were then filtered through a 0.45 µm filter and Hach kits were used to measure nitrogen and phosphorous in the filtrate. Hydrocarbons were extracted with tetrachloroethane, filtered through a 0.22 µm nylon filter, dried with anhydrous sodium sulfate and passed through a silica Sep-Pak filter to remove polar compounds. The Horiba instrument calibrated with virgin forge oil was used to measure the total hydrocarbon concentration in the extract.

Table 5-5. Summary of analyses conducted on samples collected during the react and settle cycles and on samples taken after the tube filter (1-5 µm bag filter). Analyses for nitrogen, phosphorous, turbidity, total suspended solids (TSS) and total petroleum (TPH) hydrocarbons (Horiba instrument) were conducted on-site. Analyses for TPH (gas chromatography – GC), mixed liquor volatile suspended solids (MLVSS), mixed liquor suspended solids (MLSS), total organic carbon (TOC), and chemical oxygen demand (COD) were conducted by a commercial lab. All units with the exception of turbidity are ppm. Temperature, pH, and dissolved oxygen were recorded with sensors in the SBR

Date	Nitrogen	Phosphorous	TPH		Turbidity	Solids			DO	pH	T °F	TOC	COD
			Horiba	GC		TSS	MLVSS	MLSS					
React													
10/31/08				157±14			930±71	1305±488				335±21	5760±905
11/01/08	406	175	560		510	665			8.24	9.62	69.3		
11/08/08				120.2			1770	1960	7.3	8.08	79	500	7910
11/10/08				42			1770	2400	8.2	8.33	80.78	270	7790
11/11/08									7.1	8.20	81.68		
11/12/08				4			1800	2010	7	8.18	82.58	150	6630
11/13/08									7	8.16	84.02		
11/14/08				12.6			1750					140	6400
11/18/08	152	255	427	8.5±1.3	1515	2200	1075±191	1460±170				155±21	4190
Settle													
11/18/08					70	30							
11/19/08					78	34							
Filtrate													
11/18/08					69	25							
11/9/08			556	16±12	75	31	105±7	145±7				155±7	1120

The increases in turbidity, TSS, MLVSS, and MLSS between 1 and 18 November (Figure 5-18) suggest that significant bacterial growth occurred during this time period. As would be expected, the nitrogen concentration decreased. The relatively high phosphate concentration is a result of the excess ammonium phosphate fertilizer that was added to neutralize the NaOH that was inadvertently added when the pH electrode failed while the SBR was being filled. The ammonia was used by the bacteria to remodel the carbon rich hydrocarbons into amino acids and other nitrogen rich compounds characteristic of living organisms. However, bacteria require considerably less phosphate and much of the captured phosphate is recycled which also accounts for the apparent excess. After 2-3 fill and react cycles it would be expected that the phosphate would be consumed and the concentration will decrease. The TPH concentration measured with the Horiba instrument does not show any change in the hydrocarbon concentration which is a problem with this method when it is used with a biological treatment system.

Samples were also sent to an off-site lab for analysis of TPH, TOC, MLSS, MLVSS and the results are included in Table 5-5 and shown in Figure 5-18. In contrast to the hydrocarbon concentration measured on-site with the Horiba instrument, the TPH concentration measured using gas chromatography was reduced from 157±14 ppm in the incoming wastewater to 16±12 ppm in the treated wastewater that passed through the tube filter filtrate after the SBR was settled. Chromatograms (Figure 5-19) show extensive degradation of resolved peaks occurred during the react cycle. As the hydrocarbons were degraded, there was a transient increase in TOC and MLVSS which are indirect measures of bacterial growth (Figure 5-18).

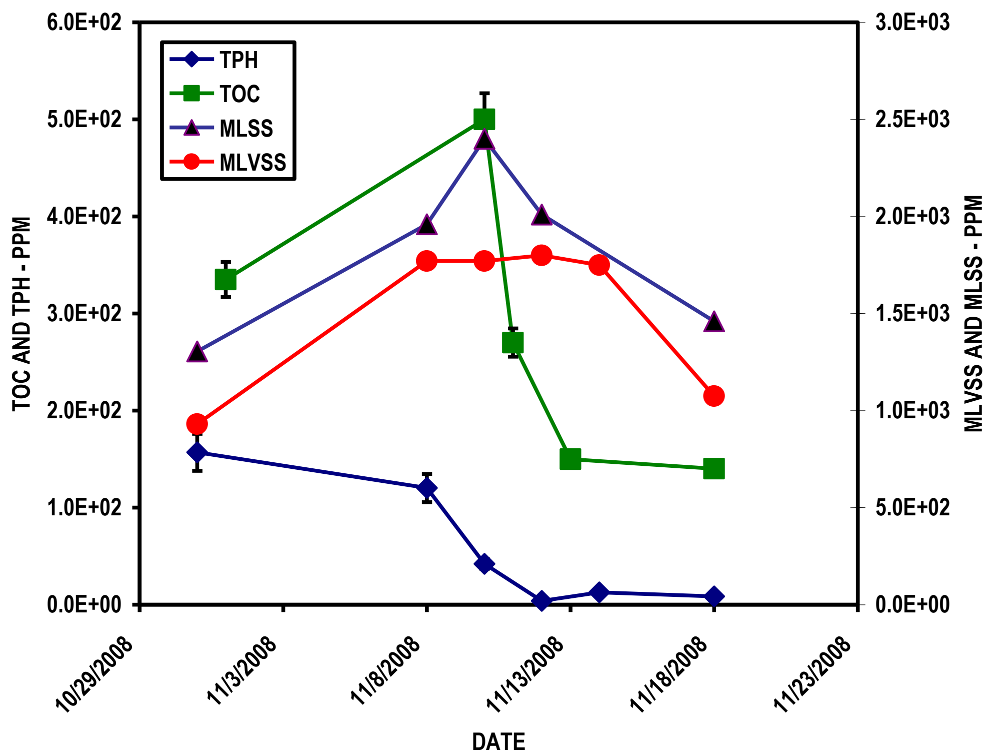
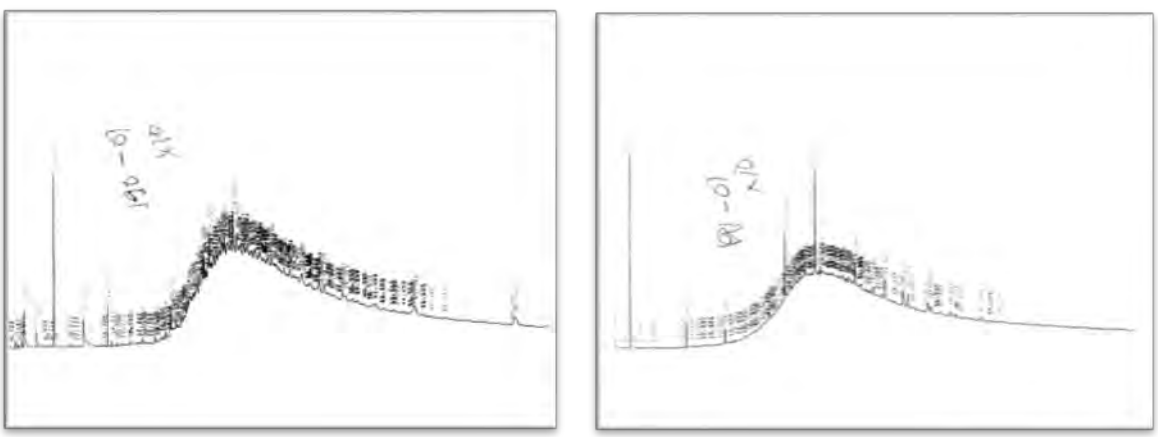


Figure 5-18. Changes in TPH, TOC, MLSS, and MLVSS during the react cycle in the SBR.
Figure 5-19. Chromatograms of samples taken from the SBR on 10/31/08 (left) and 11/18/08 (right).

Even though the target value for the food to microorganism ratio is in the range 0.1 - 0.5, it is not unexpected that the SBR would be biomass deficient during startup which is what an F/M ratio of ~4 indicates (data not shown). However, the decrease in the F/M ratio during the react cycle was accompanied by a decrease in TPH hydrocarbons and other nutrients (decreases in COD and TOC) which were converted to biomass as measured by MLVSS and turbidity. During future react cycles, more biomass will accumulate in the SBR and the F/M ratio would be expected to decrease. As the SBR stabilizes, the F/M ratio will converge on a value that is a function of the hydrocarbon loading, active biomass, and residence time in the SBR which based on an average daily wastewater production of 4000 gallons and an SBR capacity of 40,000 gallons is ten days. Once the SBR stabilizes, the objective of day-to-day operations will be to maintain the corresponding value of the F/M ratio. Since the TPH concentration in the incoming wastewater should remain relatively constant, it will be necessary to control the amount of biomass through periodic wasting and nutrient addition.

The decrease in turbidity (1515) and TSS (2200) to 70 and 30 respectively within a few hours of settling with no real change after overnight settling (Table 5-5) suggests that the biomass in the SBR is a consortium of highly desirable rapidly settling bacteria as opposed to the non-settling or bulking and filament rich variety. To further reduce the loading of suspended solids in the filtrate, the settling phase will be progressively shortened. The reason for this is that shortening



the settling phase selects for rapidly settling biomass, and biomass that remains suspended is drawn off during decant. Since the bag filter removed little if any of the remaining solids (i.e., turbidity and TSS in the settled SBR were 78 and 34 respectively and in the filtrate the corresponding values were 75 and 31 respectively, it may be possible to replace the 1-5 μm bag filter with a microfilter which would remove more of the particulates. However, the exact filtration requirements will be determined by the discharge permit requirements.

Phase II Testing Continued. A second round of testing was conducted in February 2009. To reduce the amount of biomass in Tank A, ~10,000 gallons was decanted without settling and sent to the forge pit. The tank was then settled and the following day 350 gallons of solids were removed from the bottom of Tank A and sent to the filter press. The filter press was pre-coated (20 pounds of diatomaceous earth in 200 gallons of water) and the sludge (175 gallon batches) was mixed with twenty pounds of kaolin and pumped into the press. After the second batch of sludge was pressed, the press was blown down with compressed air for ~24 hours before it was opened.

On 26 February ~10,000 gallons of oily wastewater was transferred from SBR B to SBR A; and nutrients (15 pounds of yeast extract, 5 pounds of casamino acids, 2 pounds of Accelerator V, 50 pounds of fertilizer, and 20 gallons of Accelerator II) were added to SBR A. On 27 February an additional 20 gallons of Accelerator V was added to SBR A which was nitrogen deficient and some polysaccharide (sticky scum at the surface of the tank) was present. However, as the concentration of ammonia nitrogen in the tank increased, the polysaccharide was degraded and little or no polysaccharide was present on 28 February.

Samples analyzed on-site or at a commercial lab were filtered through a 5µm filter and the Hach spectrophotometer was used to measure turbidity and total suspended solids in the filtrate. The samples were then filtered through a 0.45 µm filter and Hach kits were used to measure nitrogen, phosphorous, sulfate, nitrate, nitrite, and fatty acids in the filtrate (Table 5-6). Samples sent to a commercial lab were analyzed for total petroleum hydrocarbons (TPH; GC/FID), total recoverable petroleum hydrocarbons (TRPH), mixed liquor volatile suspended solids (MLVSS), mixed liquor suspended solids (MLSS), total organic carbon (TOC), Biological oxygen demand (BOD_5), and chemical oxygen demand (COD) (Tables 5-6 and 5-7).

Table 5-6. Summary of analyses (average and standard deviation) for nitrogen, phosphorous, sulfate, nitrate, nitrite, fatty acids, turbidity, and total suspended solids (TSS). The units for turbidity are formazan nephelometric units (FNU) and all others are ppm

Date	Turbidity	TSS	Phosphate	Ammonia	Sulfate	Nitrate	Nitrite	Fatty Acids
2/25/09	3625	5000	169±34	66.1±6.7	35	0	0	1681±221
2/26/09	4000	5300	167±15	66.1±6.7	35	1.88±0.88	0	2019±405
2/27/09	Nutrient Addition							
3/3/09	4000	5300	177±40	185±7	25	10.8	0	1214±138
3/5/09	2050	2675	178±22	177.5±10.6	35	23.3	0	1309±244
3/10/09	3100	3950	153±28	36.1±16.7	30	1.7	0	1548±410
3/12/09	3050	3675	148±26	22.2±13.4	30	0.8	0.2	1646±171

Table 5-7. Summary of analyses for, total recoverable petroleum hydrocarbons (TRPH), mixed liquor volatile suspended solids (MLVSS), mixed liquor suspended solids (MLSS), Biological oxygen demand (BOD_5), and chemical oxygen demand (COD). All units are ppm

Date	TRPH	BOD_5	MLSS	MLVSS	COD
2/25/09		298	5100	4780	5805
2/26/09		143	7320	6960	14,000
2/27/09		106	4600	4333	

3/3/09	13	85.8	3900	3600	4770
3/5/09	<5	70.5	4100	3833	8033
3/10/09	20	389	1733	1567	4214
3/12/09	47.9	382	2300	2133	4674

In addition, to the above analyses, the oxygen uptake rate, biomass settling, and biomass volume were measured. Oxygen uptake (Figure 5-20) was measured with a Yellow Springs oxygen electrode on fresh samples that were continuously stirred. Biomass settling time and biomass volume (Figure 5-21) were measured with a one-liter Imhoff cone using fresh samples.

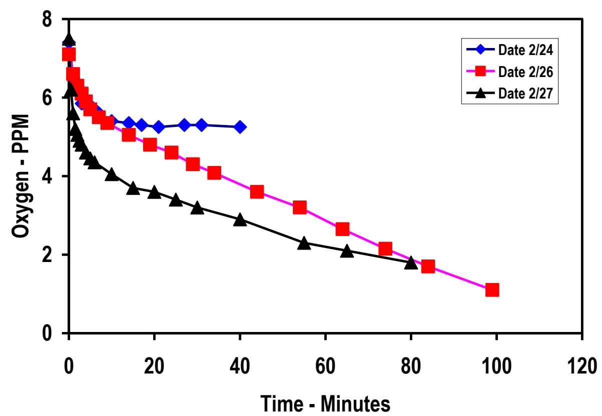


Figure 5-20. Oxygen uptake measured on samples taken from the SBR on the dates shown.

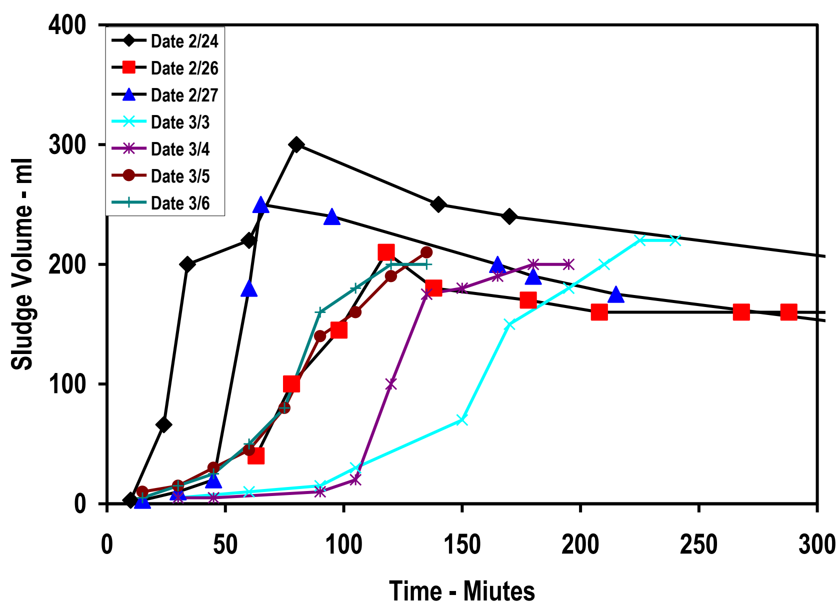


Figure 5-21. Sludge settling and equilibrium sludge volume measured using an Imhoff cone on samples taken on the dates shown.

While the values for the turbidity and TSS parallel each other as do the values for MLVSS, and MLSS (Figure 5-22), it would have been expected that all these measures would show the same trend (i.e., increase/decrease in parallel). None-the-less, the high values suggest that significant bacterial growth occurred. These results are also consistent with the oxygen uptake measurements (Figure 5-20) which show increasingly faster rates of uptake over the sampling period.

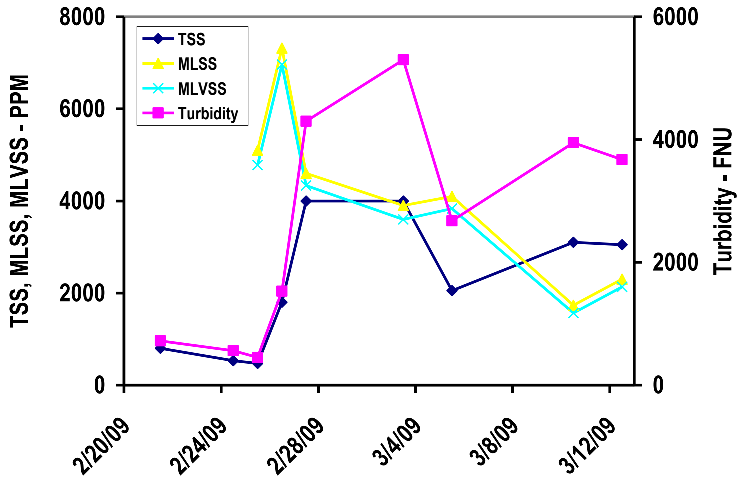


Figure 5-22. Values for turbidity and TSS which were measured on-site and MLSS and MLVSS measured by a commercial lab.

As would be expected, the nitrogen and phosphorous were consumed and these results parallel the increases in turbidity and TSS (Figure 5-23). Ammonia is used by the bacteria to remodel the carbon rich hydrocarbons into amino acids and other nitrogen rich compounds characteristic of living organisms. However, bacteria require considerably less phosphate and much of the captured phosphate is recycled which accounts for the apparent excess. After the SBR has gone through 4-5 additional react cycles more of the phosphate will be consumed and the concentration should decrease.

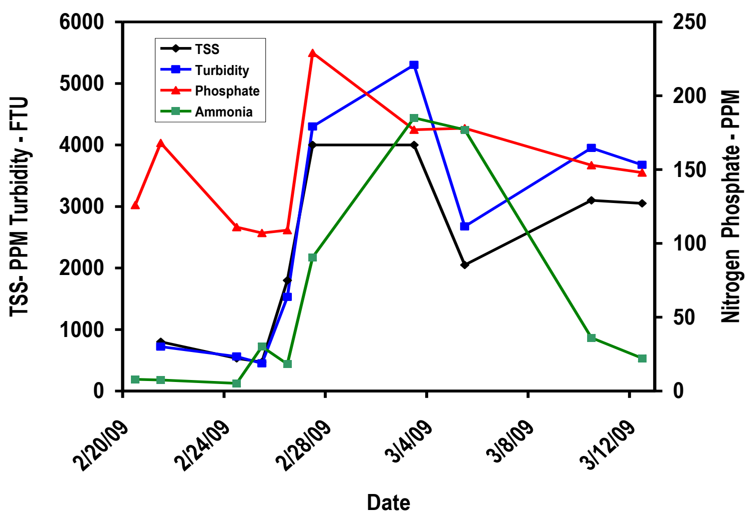


Figure 5-23. Values for turbidity, TSS, nitrogen, and phosphorous which were measured on-site.

Petroleum hydrocarbons were measured as TRPH by a gravimetric method specified by the Scranton Sewer Authority showed that the forging fluid hydrocarbons are degraded to below the discharged limit (Table 5-8). As the hydrocarbons were degraded, there was a transient increase in MLVSS and a progressive increase in the BOD_5 (Figure 5-24). The increase in BOD_5 suggests that the initial degradation reaction of the more recalcitrant forge oil releases more easily degraded compounds that are used for food and energy source. The increase in fatty acids (Table 5-8) which are transient breakdown products produced during hydrocarbon degradation supports this interpretation.

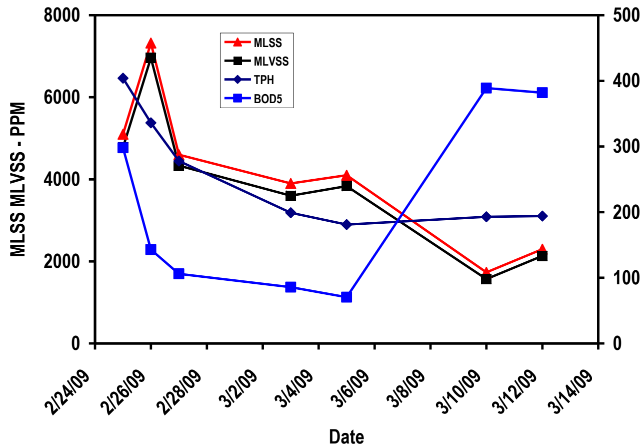


Figure 5-24. Outside lab values for MLSS, MLVSS, TPH and BOD_5.

The BOD_5 and MLVSS values were used to calculate the food to microorganism (F/M) ratio (Figure 5-25) which is a parameter that is commonly used to optimize reactor performance. The relatively constant F/M ratio during the react cycle (Figure 5-25) was accompanied by a decrease in hydrocarbons and other nutrients which were converted to biomass measured indirectly by TSS and turbidity which increase in proportion to the amount of available food (i.e., F/M remains relatively constant until the end of the react cycle). The increase in the BOD_5 towards the end of the react cycle may have been, as previously discussed, due to the production of degradation intermediates would seem to be confirmed by the transient increase and subsequent decrease in the F/M ratio back towards its equilibrium value. Death and lysis of the microbial biomass could also increase the BOD_5 (i.e., release of cell components) and decrease the MLVSS is also consistent with the data. As a more optimally adapted bacterial population accumulates in the SBR, the F/M ratio would be expected to stabilize around a value that is a function of the hydrocarbon loading, active biomass, and residence time in the SBR (assuming that the average daily wastewater production continues to be 4000 gallons and the hydrocarbon concentration remains at 100-500 ppm).

Based on this round of testing, the target F/M value would appear to be 0.03 ± 0.018. The corresponding values of the turbidity, TSS, and settleable sludge volume are 2200, 2600 and 0.175 L/L respectively – all of which are easily measured on-site and can monitor microbial growth. Since the TPH concentration in the incoming wastewater is expected to remain relatively constant, it should only be necessary to monitor and maintain the settleable sludge volume through nutrient addition and periodic sludge wasting. At this point, the results suggest that the total settleable sludge volume required to maintain an F/M ratio of 0.03 in a 40,000 gallon SBR ratio is 7000 gallons (i.e., 0.175x40,000). Thus, if the settleable sludge volume increases to 0.2 L/L, 1000 gallons of settled sludge would have to be wasted to keep the F/M ratio at or near the target value which is the objective of day-to-day operations.

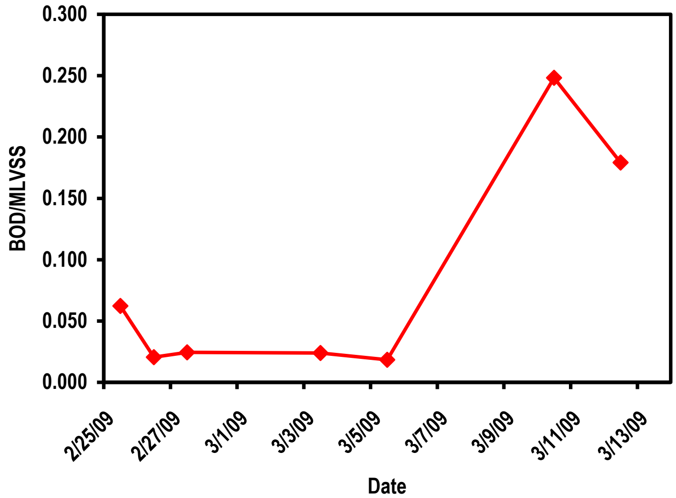


Figure 5-25. Value of the food to microorganism ration (F/M) during the February react cycle.

Previously, the decrease in turbidity and TSS were used as indicators of biomass settling. These measurements suggested that the biomass settled within a few hours and that there was little additional settling at longer times. The results in Figure 5-21 confirm that the biomass settles within a few hours and that there is no advantage to longer settling times.

Together these results suggest that the biomass in the SBR is a consortium of highly desirable rapidly settling bacteria as opposed to the non-settling or bulking and filament rich variety. As was previously discussed, the loading of suspended solids in the filtrate can be reduced by shortening the settling phase. The reason for this is that shortening the settling phase selects for rapidly settling biomass, and biomass that remains suspended is drawn off during decant. Since it was previously shown that the bag filter removed little if any of the remaining solids, the potential for using a microfilter to remove more of the particulates should be investigated. However, the exact filtration requirements will be determined by the discharge permit requirements.

6.0 PERFORMANCE ASSESSMENT

The results presented here and data from previous pilot scale and prototype (Hawaii) demonstrations of oily sludge biodegradation show that the wastewater, solids, and air emissions meet the compliance and regulatory limits set by the city of Scranton and the state of Pennsylvania.

6.1 PRIMARY QUANTITATIVE PERFORMANCE OBJECTIVES

Although the startup of the treatment system experienced some setbacks related to inadequate mixing and changes in the management of the wastewater by SCAAP, the Phase II testing demonstrated that the hydrocarbons in the spent forge lubricant were easily degraded to below the regulatory requirements within the design hydraulic retention time. In addition, the wastewater discharge from the treatment system meets the limits set by the Scranton Sewer Authority, the minimal air emissions are captured with activated carbon filters, and the solid waste is not hazardous. Furthermore, the cost analysis (Section 7.0) shows that on-site treatment is cost-effective with a projected payback of approximately three years. It should be noted that this does not include the value of the recycled oil.

6.2 SECONDARY QUALITATIVE PERFORMANCE OBJECTIVES

The primary difficulties encountered with implementing the project were that the mixing and agitation were not adequate and had to be redesigned and installed. However, these changes were easily accomplished on-site. An additional and unanticipated change was how SCAAP managed the wastewater which reduced the volume at least threefold and a concurrent ten-fold increase in the amount of oil. This change resulted in the installation of an oil recovery system with the oil being sold to a recycler and changes in how the SBRs were configured and operated. However, the effluent from the SBR easily met the Scranton Sewer Authority permit requirements.

Experience with the modified treatment system has revealed recurrent problems with some of the pump seals which suggest that the seals may not be appropriate for this waste stream. In addition, the Allen Bradley microprocessor that is used to control the system seems unnecessarily complex for this application and alternatives should be investigated.

7.0 COST ASSESSMENT

7.1 COST MODEL

Table 7-1 summarizes the capital costs (2005 dollars) for the SCAAP treatment system including the modifications. The operation and maintenance costs are summarized in Table 7-2. These costs are based on system capable of treating 900,000 pounds per year of oily sludge or 100,000 to 500,000 gallons per month of oily wastewater with a nominal hydrocarbon concentration of 4000 – 8000 ppm.

Table 7-1. Capital costs for a biological reactor treating 900,000 pounds per year of oily sludge

Item	Units	Unit Cost (2005$)	Number of Units	Total Cost
Tank SBR (40K Gallons) w/ Aerators	ea	$55,000	2	$110,000
Receiving Tank (10K Gallons)	ea	$8,300	1	$8,300
Tube Filter	ea	$23,000	1	$23,000
Filter Press	ea	$42,000	1	$42,000
Blowers	ea	$1,400	2	$2,800
Chemical Feed System	ea	$900	2	$1,800
Biofiltration (carbon filter drum)	ea	$1,200	4	$4,800
Level Sensors & Meters	ea	$1,400	2	$2,800
Control Panel	ea	$3,000	1	$3,000
Piping Material	ea	$6,000	1	$6,000
Valves	ea	$3,000	1	$3,000
Electrical	ea	$2,500	1	$2,500
Secondary Containment	ea	$5,000	1	$5,000
Contingencies/Misc.	ea	$6,000	1	$6,000
System Modification	ea	$42,000	1	$42,000
Shipping Cost	ea	$2,000	1	$2,000
Total Equipment Cost				$265,000
Installation Cost (30% of capital costs)				$79,500
Total Installed Cost				**$344,500**

Table 7-2. Yearly operation and maintenance (O&M) costs for the SCAAP SBR

Item	Units	Unit Cost	Number of Units	Cost
Electricity	KWhr	$0.120	20,000	$2,400
Water & Sewer	3600 gal	$13.00	140	$1,820
Biomass Disposal	gal	$0.55	6000	$3,300
Nutrients	ea	$3,000	2	$6,000
Operating Labor	hr	$50	400	$20,000
Plant Overhead (105% of labor)	hr	$50	420	$21,000
Maintenance (3% of capital investment)	ea			$10,335
Total Annual Cost				**$64,855**

While some costs will be fixed simply by the size of the treatment system (e.g., SBR capacity, pumps, piping, etc.) the specific waste stream and or location may incur additional costs. Examples of problems and suggested solutions are given in Table 7-3. All of the solutions will incur additional costs that will have to be factored into the cost benefit analysis for that particular site and waste.

Table 7-3. Examples of problems that may be encountered with individual waste streams and or sites

Problem	Requirement	Solution
Elevated VOCs	Air filtration	Install Biofilter
Heterogeneous Waste Stream	A "homogeneous" waste	Preconditioning or Mixing Tank
Concentrated Waste Stream	Dilute the incoming waste	Use reclaimed water
Waste Stream too Dilute	Increase the concentration	Concentrate the waste using ceramic microfilters
Elevated Concentrations of Metals in the Waste Stream	Reduce the metal concentration	Use adsorbent, e.g., iron activated alumina to remove metals
Temperature Extremes at the Site	Minimize temperature extremes	Additional ventilation at high temperatures and waste eat capture and insulation at low temperatures

7.2 COST ANALYSIS AND COMPARISON

Using the costs in Tables 7-1 and 7-2, single line depreciation was used to calculate the cost for treating the oily sludge at SCAAP in the modified SBR, Table 7-4. The cost to dispose of the oily sludge is in excess of $100K per year and does not include the O&M costs for the OWPP. This is a recurring cost and long term liability. In contrast, biological treatment at $0.11 per pound (comparable to the cost in Hawaii) includes all O&M costs as well as depreciation and the pay back is approximately three years.

Table 7-4. Treatment cost based on single line depreciation

Capital Cost	Cost Operation and Maintenance	Salvage Value	Yearly SLD
$344,500	$64,855	$0	$99,305
Treatment Cost - per Pound			**$0.110**

The cost analysis along with the performance data demonstrates that on-site biological treatment of oily waste is technically feasible and cost effective.

8.0 IMPLEMENTATION ISSUES

This project has demonstrated that on-site biological treatment of even a challenging oily waste such as spent forging fluid is technically feasible and cost effective. Moreover, the treatment system was easily assembled on-site from readily available commercial components. Furthermore, and unexpectedly, the demonstration showed that the treatment system is easily modified as conditions demanded to meet the treatment requirements. In general it should be possible to implement this technology at any site that has oily waste. The primary operating requirements are a SBR sized to provide 4-8 days of treatment that is equipped with a pH controller, aeration system, centrifugal pump to mechanically emulsify the oil, and a weir that captures oil that pools on the surface of the SBR. As a general rule of thumb, nutrients are added in proportion to the volume of oily wastewater being treated (Table 8-1) and the target values for nitrogen and phosphorous are 200 ppm and 80 ppm respectively. In addition one pound of Novozyme Accelerator V which provides trace nutrients should be added to the SBR when the total volume of wastewater that has been treated and decanted is 40,000 gallons. Operation of the SBR should be tracked using the format shown in Table 8-2.

Table 8-1. Quantity of each nutrient added per 1000 gallons of fresh oily wastewater added to SBR A

Nutrient	Amount Per 1000 gallons of Fresh Wastewater
Yeast Extract	0.5 Pounds
NZ Amine	0.2 Pounds
Accelerator II	1 Gallon

Table 8-2. Suggested table format for recording daily operation and monitoring of the SBR

DATE	TIME	SBR – CYCLE F- Fill R- React S - Settle D-Decant	NUTRIENTS					T	pH	DO
			Yeast Extract	NZ Amine	Accelerator II	Accelerator V	Fertilizer			

An unexpected problem was the presence of suspended solids in the wastewater discharged from the SBR after it was settled. Since the solids rapidly settled in the pilot studies, the original filtration system (an ultrafilter) was replaced with a tube filter. However, a 1-5 µ filter (the smallest available) removed little if any of the suspended solids. Ongoing experience with the system in Hawaii has shown that the ultrafilter was an inappropriate choice, but suspended solids are easily removed by spiral wound microfilters in series with a 1-5 µ bag filter. Furthermore, these filters (sized for the application) produce 30 gallons per minute of permeate and the use of these units at SCAAP is recommended. However, after Phase II testing was completed, SCAAP switched to a water-based forge lubricant and this project was not funded to investigate its fate in the treatment system.

Preliminary testing of spent forging oil degradability demonstrated that on-site treatment was technically feasible. In addition, the economics of on-site treatment compared to off-site disposal was cost-effective (payback ~2 years) and would reduce (ideally eliminate) recurrent and expensive violations of the SCAAP discharge permit. However, two unanticipated problems arose after the system was installed that had a significant negative effect on treatment performance and had to be solved if the system was to perform as intended. The first problem was caused by the high viscosity and cohesiveness of the spent oil. While these properties were noted during the feasibility study and the system was designed to accommodate these characteristics, the requirements for handling this material in a full-scale system were not fully comprehended. The second problem was a result of how SCAAP managed the oil that collected in the trenches, a detail that only became evident after SCAAP reduced the volume of wastewater.

The first problem was solved by modifying the plumbing in the SBR so that the oil was kept suspended and emulsified. The second problem was more challenging and arose because the trenches under the forges were (unknown to us) used as gravity oil water separators. As a result, the bulk of the oil remained in the trenches and SCAAP treated (ineffectively) only the lower mostly water phase in their oily wastewater plant - a fact that did not become apparent until the system was installed and testing begin. Specifically, the incoming oil concentration (all of the oily wastewater, not just the lower mostly water phase was pumped to the biological treatment system) was at least an order of magnitude greater than the system was designed to treat (i.e., expected 4000 - 5000 ppm and actual >40,000 ppm). This problem was solved by converting SBR B to a gravity oil water separator and installing a skimmer to recover spent oil which was sold to a recycler (a market that was previously not available). The lower water phase was pumped to the SBR A where residual oil was degraded. Subsequently SCAAP added a membrane filter to remove particulates from the treated wastewater and all of the reclaimed water is used for cooling.

In retrospect, the obvious lesson is to ensure that the characteristics of the waste stream at the source (not just from samples) and how it is actually managed are understood as thoroughly as circumstances permit. Spending more time observing and discussing how the wastewater was generated and managed might have led to a better understanding of these issues.

Simplicity and reliability of operation are also helped by dedicated microprocessors that are used to automate and monitor the treatment system. However, the industrial microprocessors that are most often used are expensive and require a high level of programming skill. The latter is particularly problematic when (not if) errors occur, components are upgraded, or changes are made in the treatment system, all of which require program changes. As an alternative, control systems (e.g., Opto22) that run on a laptop (rather than an expensive industrial microprocessor), are easier to program, and provide a more intuitive interface may be more appropriate for this and similar applications.

9.0 REFERENCES

Brenner, A., S. Belkin, S. Ulitzur, A. Abeliovich. 1994. Utilization of a bioluminescence toxicity assay for optimal design of biological and physicochemical wastewater treatment processes. Environ. Toxicol. and Water Qual.: An Int'l. J, **9:**311-316.

Brindle, K., T. Stephenson, M. J. Semmens. 1999. Pilot-plant treatment of a high-strength brewery wastewater using a membrane-aeration bioreactor. Water Environ. Res. **71:**1197-1204.

Cicek, N., J. P. Franco, M. T. Suidan, V. Urbain, J. Manem. 1999. Characterization and comparison of a membrane bioreactor and a conventional activated sludge system in the treatment of wastewater containing high-molecular-weight compounds. Water Environ. Res. **71:**64-70.

Ergas, S. J., E. D. Schroeder, D. P. Y. Chang, and R. L. Morton. 1995. Control of volatile organic compound emissions using a compost biofilter. Water Environ. Res. **67:**816-821.

Guerin, T. F. 2001. Bioremediation of dissolved and free phase oil in wastewater from equipment maintenance facilities. Remediation **11:**129-143.

Hunkeler, D., P. Hohener, S. Bernasconi, and J. Zeyer. 1999. Engineered in situ bioremediation of a petroleum hydrocarbon-contaminated aquifer: assessment of mineralization based on alkalinity, inorganic carbon and stable isotope balances. J. Contamin. Hydrology. **37:**201-223.

Knoblock, M.D., P. M. Sutton, P. N. Mishra, K. Gupta, and A. Janson. 1994. Membrane biological reactor system for treatment of oily sludgewaters. Water Environ. Res. **66:**133-139.

Marchese, J., N. A. Ochoa, C. Pagliero, and C. Almandoz. 2,000. Pilot-scale ultrafiltration of an emulsified oil wastewater. Environ. Sci.Technol. **34:**2990-2996.

Metcalf and Eddy, Inc. 2003. Wastewater Engineering: Treatment and Reuse, Fourth Edition. McGraw-Hill, Boston.

Mohseni, M. And D. G. Allen. 1999. Transient performance of biofilters treating mixtures of hydrophilic and hydrophobic volatile organic compounds. J. Air & Waste Manage. Assoc. **49:**1434-1441.

Novachis, L. 1998. Design and operation of membrane bioreactor technology for industrial and municipal wastewater treatment. Presented at WEFTEC'98.

Sutton, P., J. Hurvid, and M. Hoeksema. 1999. Biological fluidized-bed treatment of wastewater from byproduct coking operations: full-scale case history. Water Environ. Res. **71:**5-9.

Swanson, W. J. And R. C. Loehr. 1997. Biofiltration: fundamentals, design and operations principles, and applications. J. Environ. Eng. **123:**538-546.

Weyant, R., C. W. Moss, R. Weaver, C. Norton, and M. W. LeChevallier. 2000. A pilot study of bacteriological population changes through potable water treatment and distribution. App. Environ. Microbiol. **66:**268-276.

Woolard, C. R. And R. L. Irvine. 1995. Treatment of hypersaline wastewater in the sequencing batch reactor. Wat. Res. **29:**1159-1168.

Yocum, P. S., R. L. Irvine, and J. A. Bumpus. 1995. Bioremediation of water contaminated with jet fuel-4 in a modified sequencing batch reactor. Water Environ. Res. **67:**174-180.

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