Evaluating Wastewater Treatment Technologies at Ford Powertrain

by

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ABSTRACT

In preparation for an upcoming EPA proposal regarding Free Oil & Grease (FOG) and metal ion content in wastewater effluent, a study was performed for Ford Motor Company that assesses various secondary wastewater treatment technologies. The three water purification technologies, membrane filtration, biological treatment, and clay media adsorption, were evaluated as secondary water treatment solutions for oily wastewater. Three different types of membrane technologies were tested: polymeric, ceramic, and sintered stainless steel. In regards to FOG, the membrane technologies and the clay media were able to reduce FOG levels below the EPA proposal of 17 mg/L. However, the clay media did not show a strong affinity for metal ions. The membrane technologies were able to reduce all iron levels below the recommended limits (1.3 mg/L). However, they were not able to reduce aluminum below the proposed limit (1 mg/L). This implies that additional downstream processing would be required to remove the aluminum if the membrane solution was implemented and the regulation passes as proposed. The biological wastewater treatment was not tested during these trials, but was assumed to be able to meet all FOG and metal requirements proposed by the EPA.

Based on these experimental results and basic design assumptions, an economic analysis over a ten-year period indicated that the biological waste treatment system was the lowest in costs, followed by the polymeric membranes. The estimated installed and operating costs for both technologies was $800,000 and $1,200,000 respectively. The nearest alternative solution, the stainless steel membranes, was over 200% more expensive than the lowest cost option. Based on this economic analysis, Ford should pursue additional research and experiments into the feasibility of using biological wastewater treatment to meet EPA proposed regulations. More specifically, experiments should be conducted to help verify the assumptions used and economic results obtained in this study. As a secondary option, in the absence of additional data, polymeric membranes are recommended as the best solution, despite additional processing needed to remove aluminum ions from water effluent.

In addition, the biological waste treatment option has the potential to reduce chemical oxygen demand (COD) measurements below the levels seen by any of the membrane technologies. None of the membrane technologies investigated were capable of reducing COD levels below 200 mg/L on a consistent basis, thus indicating that this might be a fixed barrier for these technologies. Although not relevant today, COD measurements might have significant importance in future EPA water regulations, and should be taken into account when recommending a treatment solution.

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CHAPTER 1 INTRODUCTION

As developed nations reflect on their current environmental disposition and economic/industrial models, governments and environmental groups are asking corporations and businesses to reduce their environmental pollution. Many of these groups are asking businesses and industries to align their operations and business models with the concept of global sustainability, which encompasses more effective resource utilization, among other things. This has resulted in increased pressure on governments to pass legislation addressing these issues.

One well-known example is the Kyoto agreement in 1997, where developed nations agreed to reduce global greenhouse gases levels. Given the increasingly stringent nature of environmental legislation and the overall political climate, resource-intensive industries and companies must successfully predict and prepare to deal with future regulations that affect their business practices and operations.

1.1 The Automotive Industry and Ford:

The automobile industry consists of several large plants that convert thousands of raw materials into finished products daily. In the overall process, significant amounts of waste and by-products are created that must be addressed. Currently, the US requires the automobile manufacturing plants to meet specific air and water purity levels before they can discharge these products to the US. However, in congruence with the general trend with environmental issues, the Environmental Protection Agency (EPA) is constantly evaluating whether any of these standards need to be made more stringent.

A relevant example is the pending EPA regulations pertaining to the Metal and Parts Machining (MPM) industries. This legislation attempts to reduce levels of specific chemicals known as Free Oil and Grease (FOG), and metals such as aluminum, iron, and nickel that are found in typical wastewater effluent from machine operations. The wastewater results as a byproduct of general machining operations used to make intermediate or finished products. By definition, all engine and transmission automotive manufacturing plants in the US are grouped into the MPM industries, and thus, will be required to comply with these new regulations when they are finalized. Because this is a federal mandate, the new limits will supersede any existing local codes set by municipalities, except where local codes are more stringent.

Because engines and transmission are a basic intermediate product needed to build cars, the EPA's regulations will directly impact the daily operations at many of Ford's plants throughout the US. Thus, to ensure the stable and consistent operation of Ford's plants, it would be helpful to understand the overall implication of these new regulations on the current operations. From this knowledge, an appropriate strategic plan can be developed that effectively deals with the challenges and issues presented by the new regulations. Specifically, this thesis investigates various technologies related to secondary wastewater treatment that will help Ford to comply with the pending EPA regulations concerning wastewater discharge limits to the environment.

1.2 Project Overview

The EPA is currently proposing that FOG levels in wastewater effluent should not exceed 17 mg/L, and that levels of various metal ions should not exceed levels ranging from 0.4 – 1.3 mg/L depending on the metals. Currently, most of Ford's engine plants discharge water with FOG levels ranging from 25-100 mg/L. In addition, although most of the plants discharge water that is in the proposed range for metals, the two metals of most concern are iron and aluminum. Aluminum is not currently tested so it is difficult to assess how well it is removed during the normal chemical treatment process.

Thus, Ford needs to understand the appropriate steps required to ensure compliance with this pending proposal. These regulations are expected be finalized within the next one or two years. Based on this, the EPA will expect full compliance by 2004/2005. From a technical perspective, it is known that the water can be purified to the levels needed through a variety of technologies currently available on the market. However, the bigger question becomes 'at what cost'. Given that the automotive industry is facing severe competition in all sectors, Ford, as well as its industry peers, are under extreme pressure to lower manufacturing costs while simultaneously improving its products and services to customers. Part of this strategy entails reducing overall capital expenditures and operating costs at all of its manufacturing plants.

Thus, given the competitive environment, Ford sees its ultimate mission in regards to wastewater purification as 'compliance at the lowest cost.' As such, the environmental engineering and research groups at Ford have been exploring various technologies alternatives that would meet this objective. These technologies would be used in conjunction with current treatment processes, in an effort to leverage existing capital infrastructure and reduce new investment. However, some of these technologies have not been tested for this specific application either in the laboratory or the plant level. Thus, to better understand the advantages and disadvantages of each solution, a thorough technical and economic analysis will provide additional direction and insight. This study will provide a roadmap in regards to the best next steps to enable Ford to meet is overall objective: **compliance at the lowest cost.**

To better evaluate each technology, the project was broken into two different phases:

1. Laboratory-scale experiments
2. Plant-scale experiments

The various technologies considered were:

1. Membrane filtration
    1.1. Polymeric
    1.2. Ceramic
    1.3. Sintered-Stainless Steel
2. Biological treatment
3. Clay media filtration

The experiments were used to gather technical and operating performance data on the various technologies that would aid in the feasibility and economic analysis. The information from the laboratory scale experiments was used to characterize each technology and aid in the overall design of experiments at the plant. The experiments at both levels were performed with wastewater effluent that was generated from the existing treatment process at the plant. Thus, each technology was evaluated as a secondary treatment step, in supplement to the current process. Finally, all of the data gathered was then used to conduct a technical and economic analysis on the various technologies. Based on this, final recommendations and next steps were given to Ford.

1.3 Results

For various experimental reasons, the biological treatment technology was not tested. The project team agreed that the technology would be evaluated from an economic perspective, based on the premise that it would be able to purify the water to the EPA proposed levels. In regards to FOG, both the membrane technologies and the clay media were able to reduce FOG levels below the EPA proposal. In regards to metal ions, the only metals tested for were aluminum, copper, iron, nickel, and zinc. In all cases, the treated primary effluent contained levels of copper, nickel, and zinc that were lower than the proposed EPA limits. Thus, these ions were not a problem to begin with. However, aluminum and iron were often above the proposed limits in the initial test water.

The clay media did not show a strong affinity for metal ions, indicating that it would be a poor choice for this specific application. The membrane technologies were able to reduce the level of iron below the proposed EPA regulations, but not aluminum. This implies that additional downstream processing after the membranes would be required.

Based on these results, an economic analysis on the total life-cycle costs, over a ten-year period, indicated that the biological waste treatment system was most favored, followed by the polymeric membranes. The estimated installed and operating costs for both technologies was $800,000 and $1,200,000 respectively. The nearest alternative solution was over 200% more expensive than the lowest cost option, the stainless steel membranes. In addition, the biological waste treatment choice has the potential to reduce Chemical Oxygen Demand (COD) measurements more than the other technologies. This might have significant importance in future EPA regulations.

However, the analysis was based on hypothesized results for biological wastewater treatment. Based on these positive financial results, Ford should pursue additional research into the feasibility of using biological wastewater treatment to meet EPA proposed regulations. More specifically, experiments should be conducted to help verify the assumptions used and economic results obtained in this study. As a secondary option, in the absence of additional data, polymeric membranes are recommended as the best solution, despite additional processing needed to remove aluminum ions from water effluent.

1.4 Thesis Structure:

The thesis begins with an introduction in Chapter 2 about the Ford and its current organizational structure. From there, the thesis explains the specific project proposal, the overall importance to the organization, the key stakeholders involved, and the expected results.

Chapter 3 discusses the manufacturing operations that generate the wastewater and how it is currently treated. Chapter 4 presents a brief technical overview of each waste treatment technology evaluated during the experiment. Chapter 5 discusses the experimental methods, equipment, and analytical test methods employed during the study. Chapter 6 presents all of the data and the analysis performed on the treatment technologies. Chapter 7 concludes the results discussion with final recommendations and next steps. Finally, on a different note, Chapter 8 attempts to explore some different ideas related to environmental projects and their overall business impact. Much of the relevant data and other pertinent information is attached in the appendices.

CHAPTER 2 COMPANY BACKGROUND

2.1 The Ford Motor Company

When Henry Ford developed the idea of assembly line in 1913, laid the foundations for greatest stories in American corporate and business history. Today, the Ford Motor Company continues to play a significant and vital role not only in the automotive industry, but also, the overall global business world. With sales of over $160 billion/year, Ford directly impacts countless people and the world on a daily basis. For an organization this large, it is important to get a broad overview of its overall corporate structure and organization.

Although Ford is grouped into many regional operations around the world, it is possible to depict the organizational structure and supply chain in a general diagram. Figures 1 and 2 portray these respectively. From these two diagrams, it can be seen that engines and transmissions are produced as intermediate products within the overall supply chain and used in the final vehicle assembly. At present, Ford's design, development, and manufacturing of engines and transmissions is vertically integrated through the company. These specific activities are grouped within the Powertrain Operations group (PTO). Thus, the PTO Environmental Engineering group supports simply one part of the overall organization. Due to the scale and breadth of the corporation, each group maintains its separate engineering and design staffs to deal with daily issues. At some level, there are corporate groups that support individual division projects and help facilitate knowledge transfer throughout the organization. An example is the Environmental Quality Office (EQO), which resides out of the General Services group.

Within PTO, the overall group is segregated into many different units: Castings, Automatic Transmissions, Manual Transmissions, V-Engines, and I-Engines. Although these plants and product engineering groups are based all over the world, a significant number of the plants and facilities are located in North America, and specifically, the United States.

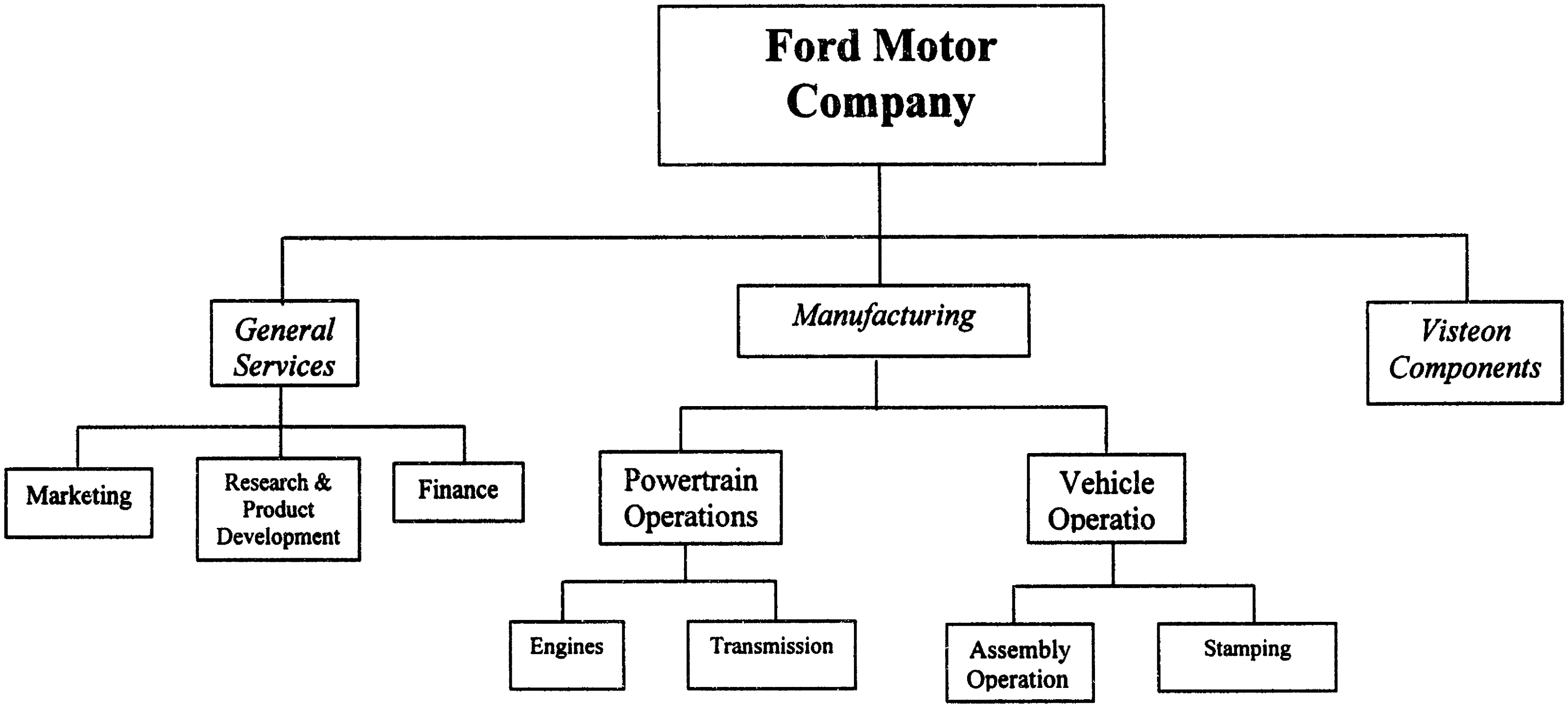

Figure 2.1 Organizational Chart for Ford Motor Company
Note: This chart is highly simplified from the true organizational chart. Also, does not include subsidiaries and other independent businesses (i.e. Ford Credit, Hertz)

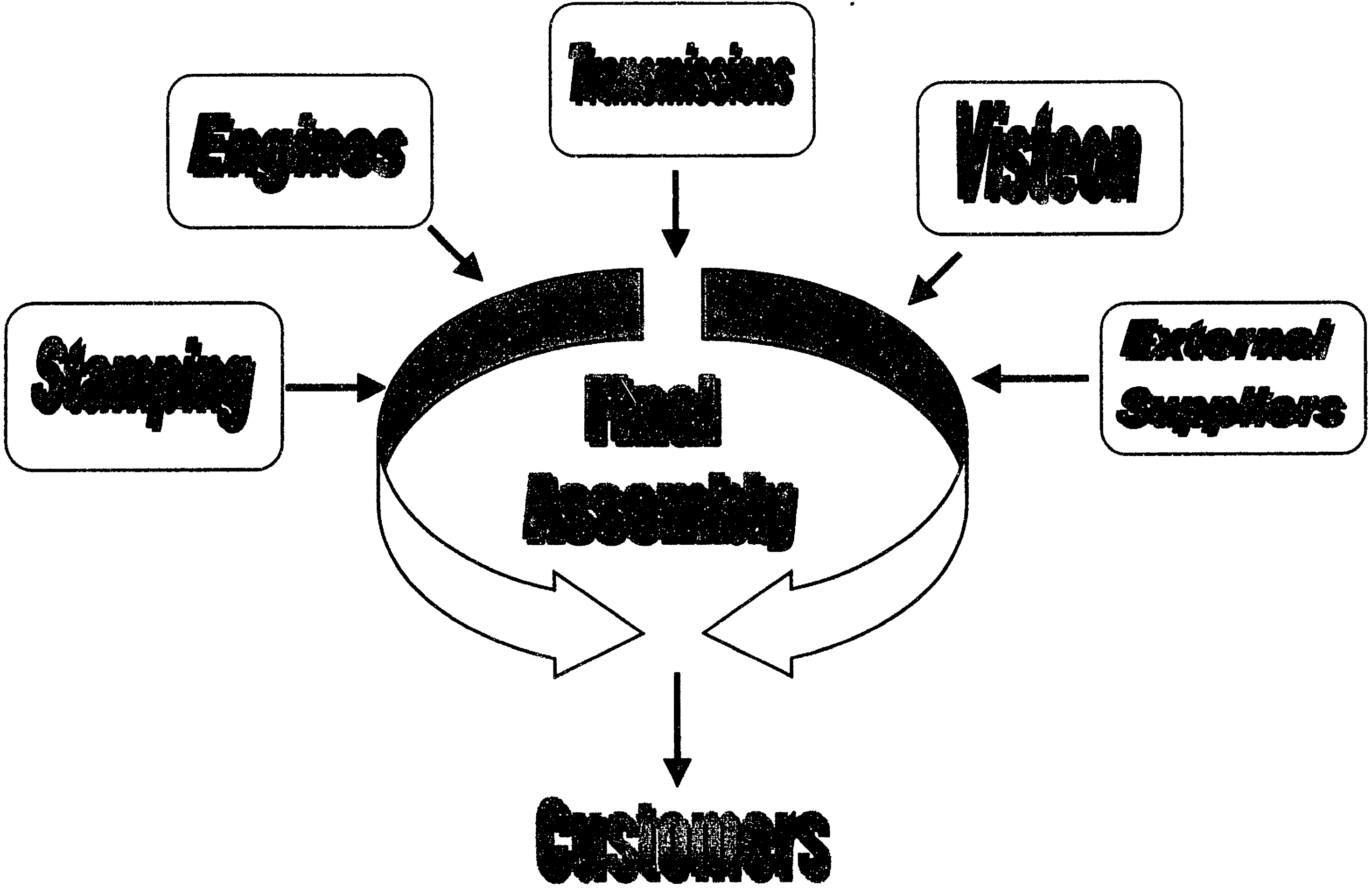

Figure 2.2 Supply Chain for Automotive Manufacturing at Ford

In regards to engines, transmissions, and associated components, the majority of the manufacturing is located in the US for both groups. Figures 2.3 and 2.4 give an overall breakdown by region of where these products are manufactured throughout the world.

The background information given has attempted to portray the structure and internal operation of the organization. In addition, it is hoped that the reader has a better idea of the role and purpose of this thesis and project and its general importance to the organization.

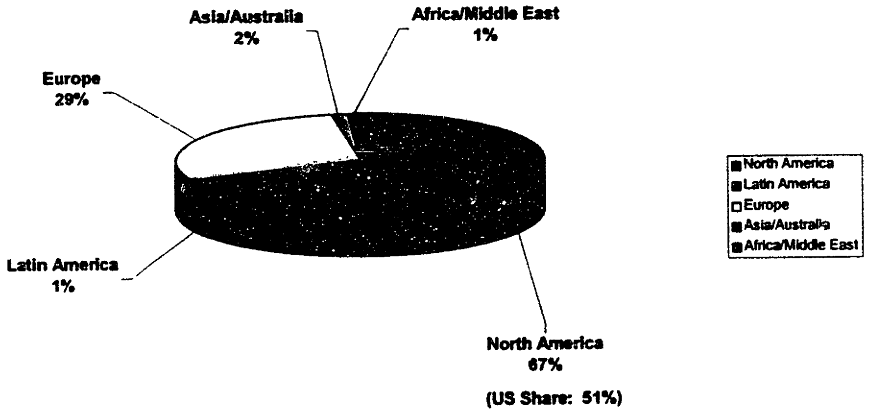

Figure 2.3 Engine and Associated Component Manufacturing by Region (by Unit Volume)

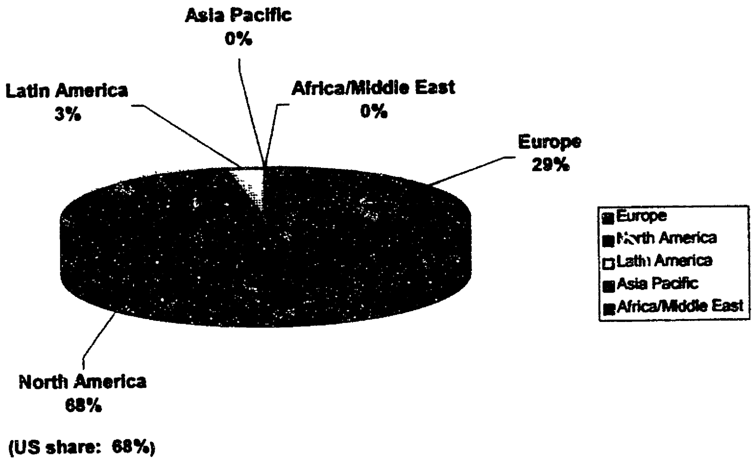

Figure 2.4 Transmissions and Associated Component Manufacturing by Region (by Unit Volume)

From the figures above, it can be seen that Ford's Powertrain group produces and manufactures over 50% of its engine and transmissions parts in the US. Thus, to prevent any future disruptions to Ford's overall supply chain, Ford must understand thoroughly understand the implications of the new EPA regulations regarding wastewater and what needs to be done to ensure compliance.

2.2 Specific Project Proposal:

Ford's Powertrain plants are responsible for the manufacturing of engines and transmissions for use in all Ford vehicles. During the manufacturing process, a large amount of wastewater containing Free Oil and Grease (FOG) is generated from the machining processes. This FOG is currently removed from the water using a series of chemical reaction steps, before discharging the water to the local municipality. The EPA is currently proposing new regulations that would limit the discharge levels FOG, as well as other heavy metals, to the environment. Given the large percentage of PTO operations based in the US (Figures 2.3 and 2.4), this new proposal directly affects several of Ford's operations. To better understand the proposal's impact, Ford desired a technical and economic evaluation of various proposed technologies that would enable its plants to meet these new regulations. Thus, given the significant business drivers and issues involved, Ford chose to take a pro-active and educated approach on these issues.

During the engine and transmission manufacturing process, lubricating and cooling chemicals are used to aid the overall process. These chemicals are mixed with water and result in the creation of wastewater with elevated levels of FOG.

Currently in the US, FOG discharge limits for Ford's Powertrain Facilities range from 100-2000 mg/L. However, the EPA has been attempting to pass new categorical guidelines pertaining to the metal products and machinery industries (MPM). These guidelines will establish federal limits that will regulate the levels of various metals and compounds in the effluent water stream. It is estimated that the final standards will be set either in year 2000/200, and full compliance is expected by 2004/2005.

The EPA's proposed standard for new FOG levels are currently proposed at 17 mg/L, and 0-2 mg/L for several metals such as aluminum, copper, iron, nickel, zinc. Table 2.1 below details some of the specific chemicals and limits proposed by the EPA:

Table 2.1 Proposed EPA Guidelines for FOG and Select Metals

Chemical/Parameter	*Monthly Average (mg/L)*	*Daily Maximum (mg/L)*
Aluminum	1.0	1.4
Cadmium	0.3	0.7
Chromium	0.2	0.3
Copper	0.6	1.3
Iron	1.3	2.4
Nickel	0.5	1.1
Zinc	0.4	0.8
Cyanide	0.02	0.03
Oil & Grease	17	35
TSS	36	73

Given these limits above, the beginning and end points regarding water quality were defined. The question that remained focused around how to reach this end point.

In addition, Ford wanted this optimal method to leverage the existing capital infrastructure at the plants that is currently used to treat the wastewater. Thus, any new purification technologies would be used in conjunction with the existing treatment processes at the plants and evaluated as an additional downstream processing step. To better evaluate some of these technologies, Ford needed to gather additional data, perform an overall technical/economic analysis, and compare all of the results. The experimental testing comprised of two separate phases:

1. Lab-scale tests and experiments at the Ford Scientific Research Labs (SRL)
2. Pilot trials at a Ford Powertrain plant.

Because each plant within Ford Powertrain is unique and there is a tremendous amount of variety in terms of products, processes, and wastes generated, it is practically impossible as well as imprudent to make a general recommendation for all plants. The overall goal of this study was to investigate and test several technologies that have the potential to reduce FOG levels, below the EPA's proposed limits and report the results. Because one plant must be chosen for the study, the results would be directly applicable to that specific plant. However, the experiments were designed such that the conditions and tests would be relevant to a more general set of conditions that might exist at other plants within Ford Powertrain.

This thesis details a technology roadmap discussing the various alternatives available to Ford to ensure compliance with the EPA proposed guidelines. Ultimately, the individual plants and PTO Environmental Engineering will decide how to ensure compliance. To aid in this effort, this thesis ranks the technologies according to a number of parameters that include both technical and economic aspects. However, it is still recommended that the other plants test a water purification technology before implementing it on a large scale. The information generated in this study will allow each plant to focus on the most appropriate and relevant technology based on its own specific constraints and conditions. Thus, rather than performing a similar study and reduplicating efforts at multiple sites, PTO Environmental Engineering and the individual plants will be able to quickly find a feasible solution that ensures regulatory compliance.

2.3 Key Stakeholders:

Given the broad and interdisciplinary nature of this work, a large number of people and throughout the organization were required to execute this project successfully. The key players and stakeholders in this thesis project were:

- LFM/MIT – LFM fellow, thesis advisors, MIT at large
- PTO Environmental Engineering
- Ford Research Laboratory (FRL)
- Lima Engine Plant (LEP)
- Environmental Quality Office (EQO)
- Chemical Suppliers – Mitco Chemicals
- Water purification suppliers
    - Koch Membranes, US Filter, Jmark Systems, Biomin, Rheox

All of these groups and parties contributed to the overall execution of this project. Each had its own interests and goals in the successful execution of the project. This provided the incentives and motivation to work through a number of issues and problems that arose. In a broader sense, this can also serve as a model on how to align a number of different functional groups and people towards a common goal and objective.

CHAPTER 3 WASTEWATER CREATION AND TREATMENT

3.1 The Nature of Oily Wastewater

At most PTO engine and transmission plants within Ford, wastewater is generated from two main sources, excluding the sanitary sewer system:

1. The overall manufacturing processes in the plant
2. The use of floor soaps and general cleaning agents in the plant

The first source accounts for the majority of the wastewater in the plant. However, it is important to discuss the second source as well. Given the nature and use of these floor soaps and cleaners, a variety of chemicals and detergents are available on the commercial market. These soaps can range from phosphate-based detergents, to metasilicates, to non-ionic surfactants, among others. Thus, this source of wastewater adds a significant amount of variability to waste streams among different plants.

During the manufacturing of both engines and transmissions, steel and aluminum are cut and machined to meet specific part tolerances and shapes. To aid the overall process, lubricating and cooling agents are sprayed onto the parts as they are being processed. For example, a Computer-Numerically-Controlled (CNC) operation produces metal parts using various machining operations. As the part is being processed through the machine, it is immersed in a mixture of lubricating agent and water. Eventually, this chemical/water mixture becomes spent over time and is discharged as a waste product. Also, when machines require repair, these cooling agents are discharged to the waste treatment facility, contributing to the overall wastewater stream. Within this stream, a large amount of metal fines, like aluminum and steel, are also present. Although many of the insoluble fines are recovered downstream, some of the metal particles are oxidized and thus, stay soluble in the wastewater. Final removal occurs through chemical precipitation during the waste treatment process.

These lubricating agents have evolved significantly over time. Initially, these agents consisted of soluble oils, such as a parafinnic mineral oil. As the chemical industries developed newer synthetic non-oily chemicals and emulsifiers, metal-machining operations had a broader range of lubricating agents to choose. Currently, the possible choices of these lubricating agents span the entire spectrum, ranging from soluble oils to completely synthetic systems that contain no mineral oil. Table 3.1 below compares soluble oils and synthetic cooling agents in terms of composition and benefits:

Table 3.1 Comparison of Soluble/Synthetic Coolant Systems

Type	Typical Composition	Benefits
Soluble Oils	Mineral oil, water, sulfonates and nonylphenols (emulsifiers), glycol ethers, oleic acids	• Low unit costs • Well defined properties and limitations • Easy to treat residual wastewater
Synthetics	TEA, DEA, isopropylamine, various glycol ethers and esters, oleic acid, turpenes	• Longer processing times (as compared to soluble oils) • less misting/VOC issues • extremely high heat dissipation • less micrebial growth problems

Although the two lubricating agents are both organic in nature, their use and functionality differ significantly. Although glycol ethers are used in both systems, in general synthetic cooling mixtures contain greater quantities than soluble oils. Thus, differences in chemical functionality lead to differences in the actual chemicals used and exact quantities[1].

Although the synthetic chemical systems offer several advantages over traditional soluble oils, they are extremely difficult if not impossible to treat using the waste treatment technologies at Ford. The amine compounds present in the synthetic agents dissolve readily into water and cannot be removed through simple chemical reactions that are used in Ford's US automotive wastewater treatment operations. Thus, although the synthetic and semi-synthetic lubricating agents might aid the manufacturing processes, they create larger and more important problems in regards to waste treatment. Thus, to maintain compliance, Ford's plants have decided to continue using soluble oils in the manufacturing processes.

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[1] Personal Communication with Alan J. Seiler, Mitco Chemicals, August 1999.

If Ford decided to switch its cooling agents from soluble oils to synthetic systems, each plant would need to modify the current wastewater treatment operations to ensure compliance with local codes. Given Ford's current focus towards reducing total operating costs and unnecessary capital expenditures on physical assets, PTO is unlikely to switch from soluble coolants to synthetic agents. In the absence of any quantitative benefits resulting from synthetic systems, Ford PTO's position on this issue is unlikely to change in the future.

In summary, both the source and generation of wastewater at engine and transmission plants within the US operations of PTO are both well understood. This knowledge helps to better define the questions and issues raised by the EPA's proposed limits on wastewater effluent discharge of FOG and certain metals.

3.2 Water Treatment Options

Because the relevant wastewater has now been defined in terms of source and generation, it is now appropriate to investigate the various methods available for treatment. Within the area of water treatment, there exists a range of viable technologies that are used in a wide array of industries. However, ultimately, the customer's needs for a specific application drive the technology employed. For instance, in the semiconductor industry, several of the manufacturing processes require extremely high-purity water (> 18 MΩ). Some of the technologies utilized to meet these needs include reverse osmosis, ion exchange resins, and electrodialysis, among others. These technologies are quite expensive to install and operate on long-term basis, and are only justified by ultimate process needs.

In the automotive industry, the treatment of wastewater serves a significantly different business need. This water is seen as a waste stream byproduct from the actual manufacturing process, not a raw material input into the finished product. Furthermore, this water undergoes additional treatment by the local municipality before reuse. Thus, the business need defined by the Ford, and in general, the industry, is simply regulatory compliance at the lowest total cost. The only exception to this philosophy occurs at several sites in Mexico, where total water reuse is given an extremely high priority. The primary reason is due to a scarcity of water resources and local regulatory codes that mandate zero-discharge to the environment. Traditional business models are unable to quantify any added benefit to purifying the water beyond simple compliance. Thus, given this mandate, the number of economically feasible technologies is reduced. Some of the technologies that are currently used by the automotive industry in North America are listed below:

1. Chemical Treatment
2. Ultrafiltration/Reverse Osmosis
3. Biological treatment
4. Hybrid systems:
    4.1. Membrane Biological Reactors
    4.2. Fluidized Bed Reactors

As mentioned before, a specific treatment technology is chosen based on the nature of the influent wastes and the local regulatory codes. Ultrafiltration technology provides a consistent level of FOG removal and is less sensitive to influent variability. This technology is becoming increasingly accepted as the standard solution for oil/water separation application.

Membrane Biological Reactors (MBR) have been commonly used to treat complex wastewater streams consisting of synthetic and semi-synthetic lubricants, which are usually left untreated in standard chemical treatment demulsification processes. Similarly, Fluidized Bed Reactors are used for the same types of applications as MBR.

Reverse Osmosis (RO) is often used in conjunction with other types of upstream processing. This technology is most commonly employed where local codes require plants to operate on a zero-discharge basis. All of the water processed by the RO membrane is typically sent for reuse by the plant, thereby significantly reducing the amount of fresh water needed as a raw material input.[2]

At Ford Motor Company, within the US, the most common technology employed to treat oily wastewater is a batch chemical treatment process. Thus, this technology deserves further detailed discussion in regards to the theory and benefits and drawbacks.

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[2] "Automotive Industry Waste Water Treatment Concepts in North America.", Ford Motor Land Services Corporation report prepared by McNamee Industrial Services, pp. 4-12.

3.3 Batch Chemical Treatment

Within Ford, this form of treatment is most commonly used for treating metalworking and oily wastewater. The overall benefits of a batch-type process are as follows:

1. Operational Flexibility: this technology is readily scalable in terms of water volumes that need to be processed. Because chemical processes are stoichiometric, operating costs vary linearly with the overall amount of wastewater processed. Also, the batch process facilitates process modifications when necessary.
2. Ease of Maintenance: standard equipment and designs supported by well-established vendors.
3. Simple Technology: the technology and the equipment are well defined.

However, there are also some disadvantages to this method of treatment:

1. Limited Applicability: synthetics and semi-synthetic chemical agents cannot be effectively treated with this technology.
2. Process Variability: the operators must be well trained and dedicated to the job. Because of the chemical variability of influent streams, significant process modifications are needed to ensure proper operation.
3. Inflexible Assets: these physical assets are not modular and are not easily translocated or moved and require significant support infrastructure.

Chemical treatment processes can be grouped into two different categories:

1. Inorganic Salt Preparation
2. The Polymer Method.

Both methods operate on similar physical principles. In soluble oil lubricating systems, oil droplets are dispersed into solution using emulsifying agents. These agents help to stabilize the electrostatic interactions between the oil and water phases. By lowering the overall energy state in the system, the emulsifiers create a thermodynamic equilibrium in the system, and hence, an emulsified solution.

The emulsifying agent is composed of two parts: a hydrophilic head and a hydrophobic tail. Hydrophobic ends of emulsifiers are attracted to teach other while hydrophilic ends are extended into water. The result is the formation of micelle structures throughout the solution. The center portion of the micelle represents a hydrophobic phase where oil droplets are partitioned away from the polar solvent. These emulsified micelles are often negatively charged.

In regards to waste treatment, the overall goal is to destabilize the emulsified system, separate the oil and water phases, and then collect the oil phase. A stable emulsified system uses electrostatic forces to keep the oil droplets dispersed in the water phase and prevent coalescence. Thus, this dispersed state is very sensitive to any changes in the positive or negative ion concentration in the solution. In this specific system, the addition of cations destabilizes the balanced state and allows the oil particles to aggregate and coalesce. However, if enough cations are added to solution, the oil particles can be restabilized, resulting in a homogeneous solution. Thus, the amount of cations added to solution must be carefully administered and monitored. This task becomes even further complicated by the daily variations in influent composition of the wastewater streams. Thus, the operator must always carefully monitor and adjust the treatment process as needed to ensure proper operation[3].

Inorganic treatment processes typically use monovalent, divalent, and trivalent cation species such as sodium chloride, calcium chloride, or aluminum sulfate. However, one major drawback of using inorganic salts as a flocculating agent is the significant increased in suspended and dissolved solids in the final wastewater effluent. Stricter environmental regulations seek to reduce the allowable limits for these parameters. In addition, the associated costs for these chemicals becomes a concern as plants seek to reduce overall operational costs. As a solution, the chemical industries have developed a number of polymer agents that are designed to be extremely efficient flocculating agents.

These polymers are designed to be charged compounds, either positive (cationic) or negative (anionic), and serve the same functional purpose as the inorganic salts. Although the polymers themselves are significantly more expensive on a unit basis, the amounts needed are significantly less and overall, provide and operational savings. In addition, the polymer compounds enable a more effective separation of the oil phase from the water. As metalworking fluid wastes become more complex and difficult to treat, this benefit often becomes the principal driver for the adoption of the polymer chemicals over inorganic salts.[4]

The end result of either process is the separation of oil phase and water phases that were once homogeneous. Because the specific gravity of oil is about 10-15% less than that of water, the oil phase, as well as any precipitated metals, rise to the top of the solution, while the water phase settles to the bottom. The resulting oil can then be skimmed from the surface of and the resulting water is released as treated effluent from the plant. The actual processing steps also involve pH adjustments through the addition of acid and base. The sequence of events is as follows:

1. Wastewater influent from the plant is collected in a batch tank.
2. Sulfuric acid is added to lower the pH to < 2.0 and the solution is heated to about 75° C. The acidic environment and heat helps destroy the integrity of the emulsifying agent.
3. A cationic agent is added to help separate the oil and water phases.
4. The system is agitated and allowed to react for a fixed amount of time.
5. Sodium hydroxide and is added to help precipitate the metals through the formation of metal hydroxides. Later, these precipitants usually become entrained in the oil phase and also rise to the top of the mixture. In addition, the sodium hydroxide neutralizes the water to the levels needed to meet discharge requirements. Also, anionic polymer is added to help further coalesce the oil droplets together.
6. The solution is mixed thoroughly to allow time for complete reaction. Next, the solution is allowed to settle. This allows the oil/metal hydroxide mixture to flocculate and rise to the top. The oil phase is then skimmed of using some type of mechanical means, and the remaining water is discharge as effluent from the plant.[5]

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[3] Personal communication with Byung Kim, Ford Motor Company, April 2000.
[4] Personal Communication with Alan Seiler, Mitco Chemicals, August 1999.
[5] Personal Communication with Richard Rower, Lima Engine Plant, August 1999.

Figure 3.2 below depicts the process from beginning to end:

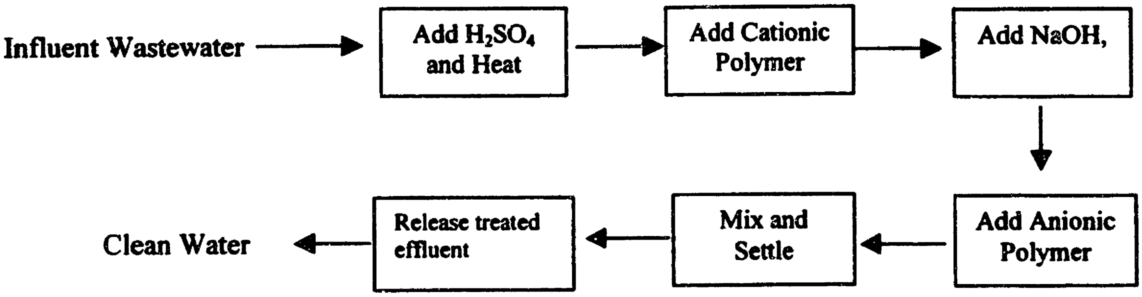

Figure 3.1 Schematic Flow Diagram of Chemical Treatment Process

In addition, Figure 3.3 below conveys a snapshot of the oil that is removed and separated during the standard chemical treatment process:

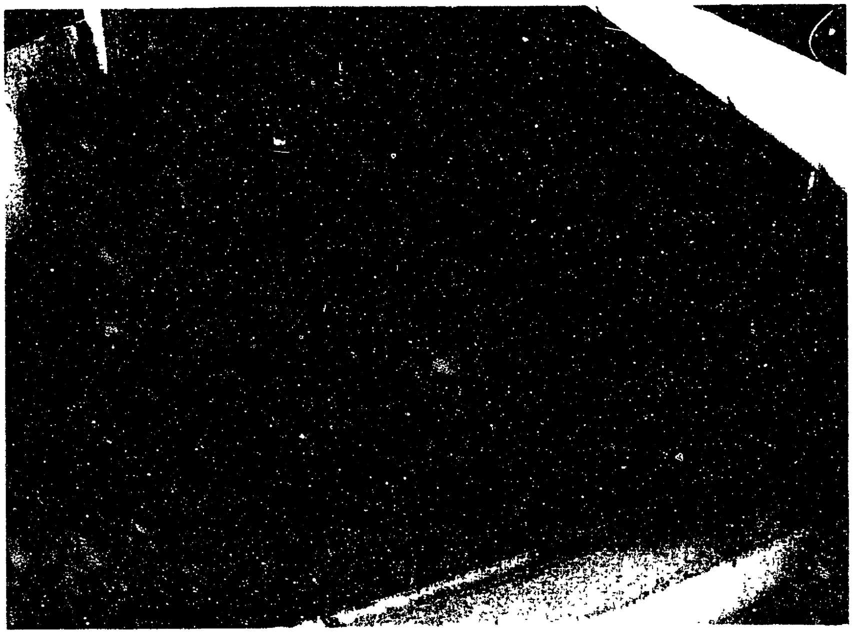

Figure 3.2 Oil Separated During the Chemical Demulsification Process

Although the underlying chemistry and technology employed in this process are relatively simple and straightforward, the nature and variability of the influent waste stream often presents operational issues. Each batch is unique and different, and requires experimental trial and error to determine the amounts of chemicals needed to separate the oil and water phases. Thus, the chemical treatment process often becomes an art, as well as a science. This even further highlights the needs for well-trained and effective operators to ensure proper operation of the plant.

At present, for the reasons outlined above, all the chemical waste treatment plants within Ford have adopted these polymer chemicals in place of inorganic salts. To date, the chemical demulsification process has been able to meet the needs of the US PTO operations of the Ford Motor Company. However, new, more stringent regulations. such as the proposed EPA mandate, are forcing Ford, as well other auto manufacturers, to revisit their overall strategies in regards to waste treatment. The next chapter discusses the proposed water treatment technologies that would allow Ford to comply with this pending EPA proposal.

CHAPTER 4 PROPOSED WATER TREATMENT TECHNOLOGIES

This chapter discusses some of the details regarding the specific technologies tested during the experimentation trials. It also tries to summarize some of the past work done at Ford and the internal knowledge that exists regarding each one.

From the onset of the project, the specific treatment technologies for testing had already been discussed and selected by PTO Environmental Engineering and FRL:

1. Ultrafiltration
2. Organoclay adsorption
3. Biological treatment

4.1 Ultrafiltration/Microfiltration:

Ultrafiltration (UF) and microfiltration (MF) are based on the premise of creating a physical barrier that allows selective passage to fluid and particles based on their particle size. UF/MF processes use a finely perforated membrane as the separating medium. The membrane retains one component, the retentate, while allowing another one, the permeate, to pass through. The passage of particles though the membrane depends exclusively on the pore size of the membrane and the particle size of the fluid and its dissolved or suspended particles. Thus, as the membrane's average pore size decreases, the smaller the particles that pass through. Figure 4.1 below depicts a picture of an UF membrane and its pore structure:

Actual Membrane Pores

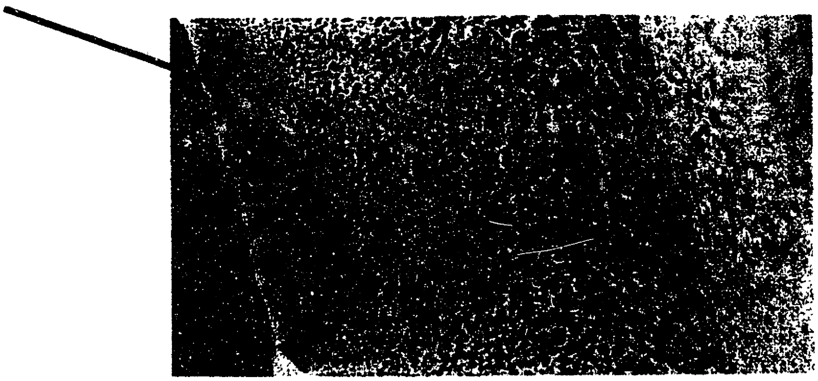

Figure 4.1 Cross-Section of a polymeric UF membrane[6]

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[6] Harriott, Peter, Unit Operations of Chemical Engineering, pp. 1034.

By strict pore size definitions, UF/MF membranes are rated to filter particles of the following dimensions:

- UF: D_p: 0.001-1.0 micrometers
- MF: D_p: 0.1-5.0 micrometers

These are approximate ranges for each technology. Thus, if the influent stream is well-characterized, then the appropriate sized membrane can be chosen for the specific application. However, in the typical PTO engine or transmission plant, the waste stream is a mix of many different types of chemicals and not easily characterized or consistent. Thus, choosing the appropriate pore-size range is a combination of engineering judgement and empirical evidence. In addition, a number of different membrane configurations exist, including tubular, hollow fiber, and spiral wound. Each has its own advantages and disadvantages in regards to specific applications. More details can be found in the relevant literature.[7]

UF/MF technologies are designed and based on many of the principles used in fluid dynamics and separation processes. For these types of systems, the permeate flux, or flow per unit time per unit area can be characterized as a function of several parameters:[8]

$$J = \frac{\varepsilon d^2{}_p \Delta P}{32 \Delta x \mu} \qquad \textit{(Eqn. 3.1)}$$

Where

J = volumetric flux rate

ε = surface porosity

d_p = mean pore diameter

ΔP = operating pressure or applied transmembrane pressure (average feed pressure – permeate pressure)

μ = viscosity of fluid

Δx = thickness of membrane skin layer

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[7] Harriott, Peter, Unit Operations of Chemical Engineering, pp. 1030-1040.

[8] Kim, et al., "Evaluation of commercial ultrafiltration system for treating automotive oily wastewater," Water Environment Research, Volume 70, Number 7, p. 1282.

Some of these variables, such as ε, d_p, and Δx can are inherent properties of the membrane material, while others, such as ΔP, and temperature, are operating parameters that can be directly controlled. Viscosity of the fluid is a physical property that can be modified by varying temperature. Thus, there are some tradeoffs regarding flux rates, specific material, operating constraints, and fluid properties. Some of these are as follows:

1. As pore size decreases, filtration effectiveness increases. However, flux rates also decrease non-linearly.
2. Flux rates are linearly dependent on the transmembrane pressure drop.
3. As thickness increases, the maximum pressure limits for the membrane increase. However, flux rates then decrease inversely.
4. Temperature increases reduce viscosity, and result in increase flux rates. However, temperature increases require additional energy, thereby increasing overall operating costs.

In regards to oily wastewater treatment and UF technology, Ford Motor Company undertook a study several years ago that evaluated the use of UF as a primary treatment technology. The study's main conclusions were as follows:

- Most UF membranes performed consistently, producing average permeate FOG concentrations of less than 100 mg/L and often as low as 30 mg/L.
- Tubular membranes outperformed spiral-wound membranes with respect to permeate flux rates.
- COD levels in the treated effluent ranged from 100-2000 mg/L, comparable to those found in effluent from chemically treated processes. This seemed to indicated that UF is not effective at removing dissolved organics from the water stream.
- Metals such as copper and zinc were found to be removed only when precipitated (pH > 8.0).
- The effect of temperature on permeate flux was well described by the temperature dependence of the viscosity of water.

Further details can be found in the paper by Kim et al.[9]

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[9] Kim, et al., "Evaluation of commercial ultrafiltration system for treating automotive oily wastewater," Water Environment Research, Volume 70, Number 7, p. 1280-1282.

Thus, this past knowledge was helpful in determining the appropriate type of filtration technology, UF vs. MF. Because the UF technology was not able to reduce FOG levels below 17 mg/L, it was believed that the MF membranes would not be capable of achieving this level of purity either. However, the significant difference in this range of experiments was that the influent to the filtration membrane would consist of chemically treated wastewater, which differs significantly in composition and characteristics from raw wastewater. Thus, to be conservative, the team agreed to start the testing with UF membranes.

Many of the study's results have been confirmed by a full-scale UF operation at a Ford PTO plant in Canada that was installed over three years ago. The system is used exclusively for primary wastewater treatment in substitution of the chemical process. Similarly, although the effluent levels of FOG have been below the 100 mg/L permit levels, the UF membrane has not been able to reduce FOG levels below 17 mg/L. Thus, there exists a significant amount of data that indicates that UF is quite capable of reducing FOG levels below 100 mg/L, but not below 17 mg/L.

4.2 Biological Treatment

In the biological treatment of wastewater, the primary objectives are to stabilize and decompose organic matter, as well as coagulate and remove organic and inorganic solids that do no settle or decompose, such as colloidal particles. The primary vehicle by which chemical decomposition occurs is through the growth of microorganisms. These bacteria grow by absorbing nutrients from the environment and converting them to new cellular mass and byproducts:

$$\text{Bacteria} + \text{Carbon Source} + \text{Inorganic nutrients} \longrightarrow \text{Additional Bacteria} + CO_2 + H_2O + \text{Inorganic compounds} + \text{Organic Wastes}$$

The above materials can be described in more detail:

Carbon Source: glucose, organic compounds (oils and greases, solvents)
Inorganic Nutrients: oxygen, nitrogen, phosphorous, sulfur, calcium, other trace elements
Inorganic wastes: sulfates, nitrates, etc.
Organic Wastes: Dead bacteria, other organic compounds

The bacteria use the carbon source and inorganic nutrients to generate energy and build additional cellular mass.[10]

4.2.1 *Kinetics of Biological Systems*

In order to design systems for biological waste treatment, it is important to quantify the overall growth process and how process variables such as temperature and substrate concentration affect this rate. Because biological waste treatment has been used and studied for years in municipal sewage systems, there is a vast amount of historical data and observations to draw upon. From empirical observations and data, engineers have developed a relationship between biological growth and substrate utilization:

$$\frac{dx}{dt} = y * \frac{df}{dt} - k_d x \qquad \textbf{Eqn. 3.2}$$

Where

dx/dt = net growth rate of microorganisms
y = growth-yield coefficient, mass of microorganisms/mass of substrate utilized
df/dt = rate of substrate utilization by microorganisms
k_d = microorganism-decay coefficient
x = concentration of microorganisms

This equation is general and must be applied to a specific reactor system that has a defined nutrient media, or the water influent in this case, and the relevant microorganism population. From experimental data, constants such as y and k_d can be determined. Thus, once a system has been characterized for the specific nutrient media that is being supplied, the dynamics and growth of the system can quantitatively determined. These calculations enable proper design and operation of the overall biological reactor system.[11]

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[10] Metcalf and Eddy, Biological Waste Treatment, pp. 373-376.
[11] Metcalf and Eddy, Biological Waste Treatment, pp. 391-392.

4.2.2 Different Biological Systems

In general, there are three different classes of biological treatment processes:

1. Aerobic processes - primary microorganisms require oxygen to survive.
2. Anaerobic Processes - primary microorganisms that require an absence of oxygen to survive.
3. Aerobic-Anaerobic Processes - primary microorganisms consists of species that need oxygen to survive, as well as species that need absence of oxygen to survive.

For the purpose of this study, based on the collective experiences of the project team, we focused on aerobic processes, and in particular, activated sludge.

In an aerobic activated-sludge system, the waste stream is stabilized biologically in a reactor under aerobic conditions. Oxygen is typically added though some type of mechanical means such as a compressor or blower. The reactor contents are referred to as the mixed liquor. After the waste is treated in the reactor, the resulting biological mass is separated from the liquid in a settling tank. A partial quantity of the settled biological mass is recycled and the remainder is sent as a waste stream. This is necessary to prevent the microorganisms from proliferating beyond the design limits. The level at which biological mass should be maintained depends on the desired treatment efficiency and the specific kinetics involved in the system.[12]

In the activated sludge-system, the bacteria are the most important part of the entire system. They decompose the organic material into cellular material as well as other by-products, including CO_2, NO_3, and SO_4.

The key to high performance biological treatment process lies in the bacteria forming a well-defined floc, thereby enabling an effective separation of biological solids in the settling unit. Past observations indicate that as the mean cell residence time is increased, the settling characteristics of the biological floc are enhanced.[13]

Despite proper flocculation formation, the overall system might perform poorly because of a variety of other factors. Some of these include high biological solids due to poor design of

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[12] Metcalf & Eddy, Biological Treatment, p. 409

[13] Metcalf & Eddy, Biological Treatment, p. 410.

the secondary settling unit, poor operation of the aeration unit, or because of unintended growth of microorganisms that adversely affect the system.

Finally, temperature is one of the most important variables that affects the performance and efficiency of the activated sludge. Temperature profoundly influences the rate of metabolic activities of the microbiological population because enzyme activity is strongly temperature dependent. In addition, mass transfer rates for dissolved oxygen as well as settling characteristics for biological solids are strongly dependent on temperature.

Thus, as can be seen from above, due to the inherent complexity of a biological system, this treatment solution requires significant attention and technical knowledge during its operation. There are a number of factors that influence and control how well the system performs, further highlight the importance of well-trained and dedicated operators. However, in the same respect, biological systems are capable of handling complex organic waste streams.

In addition, this treatment solution has been successful used in Ford's PTO in Chihuahua, Mexico to treat oily wastewater. Thus, internal data and knowledge exists that indicate that this solution is feasible in relation to this application. Based on this knowledge, and the constraints of the project, the team decided that we would not test biological treatment systems during experimental testing program. It would be assumed that a biological treatment system would be capable of meeting all of the EPA proposed limits for FOG and COD levels. However the solution would be compared from an economic perspective to the other technologies that were being tested.

4.3 Clay Adsorption Technology

Similar to the principles of behind using activated carbon, modified clay adsorbents can be used to remove various organic compounds, such as oils and greases, from water. However, the media cannot be regenerated and requires disposal once its equilibrium adsorption capacity has been reached.

These clay adsorbents are created by attaching quaternary amines to bentonite clay particles. The nitrogen end of the quaternary amine is placed onto the clay surface through ion exchange. This modification creates an organophilic clay particle that has an affinity for organic compounds, such as FOG.[14]

Similar to activated carbon, the adsorption capacity of organoclays can be characterized by adsorption isotherms for the chemicals of interest. Adsorption isotherms are frequently described with the Freundlich isotherm equation as shown below:

$$X = a C_{eq}^{1/b} \qquad \textbf{Eqn. 4.3}$$

where X = the amount of adsorbate (e.g., FOG) adsorbed per unit mass of adsorbent

a and b = coefficients from experimental data
C_{eq} = equilibrium concentration of adsorbate

A straight line results when Eq. 4.3 is plotted on a log-log scale. The coefficient, a, represents the amount adsorbed at $C_{eq} = 1$ mg/L, and 1/b represents the slope of the line. Even though the Freundlich equation is strictly empirical and limited in its usefulness to its ability to fit the data, some approximate analyses can be made with it. For example, a in Eq. 4.3 gives a measure of adsorption capacity of an adsorbent, and 1/b is a measure of adsorption intensity. In other words, higher values of a and 1/b indicate higher adsorption capacity and adsorption energy, respectively.[15]

Thus, from the equations above, for a given concentration, a specific loading capacity can be determined for the modified clay particles. This information will help determine the amount of clay media needed to lower the FOG levels below 17 mg/L. In addition, the frequency of replacement, and annual operating costs can also be determined from this information.

After giving a brief background for each technology, it is now appropriate to discuss the experimental testing program used to get the relevant data. This begins in the next chapter.

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[14] Alther, George, "The Use of Organoclay To Remove Oil From Water", Presented by George Alther at the Federal Environmental Restoration IV and Defense Cleanup Southeast Hazardous Material Control Institute.

[15] Mueller et al, "Removal of Oil and Grease and Chemical Oxygen Demand from Oily Wastewater by Adsorption", Ford Research Laboratory, Ford Motor Company, Dearborn, MI.

CHAPTER 5 EXPERIMENTAL TESTING

This section discusses the overall experimental testing program. To better optimize the tests and gather as much information as possible, the program was divided into two separate groups:

1. Laboratory-Scale Testing
2. Pilot Testing at a relevant PTO plant

The details of the materials and methods used in each testing phase are given below. Actual test results and analysis are presented in Chapter 6.

5.1 Phase I - Lab-Scale Testing, Ford Research Laboratory (FRL)

To better understand the capabilities and limits of the various treatment technologies, the project team decided to conduct tests at the laboratory-scale at the Ford Research Laboratory. This information would be used to optimize the set of experiments planned at the plant level. However, from the onset, the project team decided that the biological system would not be tested either at the laboratory or plant level. Because of the project time constraints, the team felt it would be unrealistic to set up and conduct meaningful trials and make any valid conclusions. However, based on similar data and operations of biological treatment systems at Ford and throughout the industry, the team felt that this option should still remain in the overall consideration set of options. Thus, although biological treatment system was not evaluated from a technical perspective, it was to the other technologies from a cost perspective. In addition, the team decided that the information gathered from the adsorption isotherm testing in the laboratory was sufficient for costs and technical analyses, and furthers testing at the plant was not needed.

5.1.1 Ultrafiltration

In regards to ultrafiltration technology, we wanted be to understand the largest pore size needed that would still enable the filter to reduce the levels of FOG below 17 mg/L. This information was then relayed to the membrane manufacturers, so that they could use the appropriate membranes for this specific application. Thus, a series of quick screening experiments were set up and run to gather the needed data. The analytical tests that were used to confirm water purity were both FOG and COD.

5.1.1.1 Methods and Materials:

Treated wastewater from the Lima Engine Plant (Lima, Ohio) was used as the test water. The water was treated using the standard chemical demulsification process outlined in Chapter 3. The water was passed filtered through a 0.45 μm membrane to remove large particles of debris and bacteria. The water was kept refrigerated at 40° C prior to use. The water was passed through a dead-head filtered stir cell (Millipore Inc., Bedford, MA) using a cellulose acetate membrane (Millipore, Bedford, MA) as the filter. Six different pore sizes were tested with the experimental setup: 500 MWCO, 1000 MWCO, 3000 MWCO, 10,000 MWCO, 30,000 MWCO, and 100,000 MWCO.

The filters were rated in terms of Molecular Weight Cut Off (MWCO), which is defined as the number at which 90% of the particles with a molecular weight that is greater than the rating are prevented from passing through the membrane. Molecular weight is commonly correlated to actual molecular size, so MWCO is a rough approximation to actual particle size.

5.1.1.2 Experimental Method

The system was run in a batch mode and for each different filter size that was tested. The nitrogen was used the motive force to pressurize the system and drive the water through the membrane. The overall flux rate was directly proportional to the overall pressure drop and pore size. Thus, the smaller the pressure drop or the smaller the pore size, or the lower MWCO, the longer the time needed to filter the water. This translates into a higher capacity, and thus, reduced capital costs. This hypothesis was confirmed during the lab trials.
The procedure used for each different membrane was as follows:

1. Rinse filter with reverse osmosis (RO) water.
2. Passed 50 mL of RO water through the membrane.
3. Added 300 mL of wastewater into the test reservoir.
4. The nitrogen source was activated and maintained at 68 psi (maximum pressure rating of the reactor was 70 psi).
5. The stir cell was activated to ensure a well-mixed sample in the test-water reservoir.
6. In each case, the first 50 mL of permeate sample was discarded. The residual water/alcohol preservation solution for the membrane may have been present. The remaining 250 mL was collected as permeate sample in a glass jar with a Teflon cap for further analytical testing.

The majority of the sample was collected for FOG testing (200 mL), while 50 mL was segregated for in-house COD testing.

5.1.1.3 Analytical Methods

COD was analyzed using Hach COD reagent vials (Hach, Loveland, CO), a Hach COD reactor, and a Lambda 20 UV/visible spectrophotometer (The Perkin-Elmer Corporation, Norwalk, CT) according to *Standard Methods* (1998).

FOG concentration was determined using EPA method 1654 for FOG testing by TriMatrix Laboratories, Inc. (Grand Rapids, MI). In addition, total petroleum hydrocarbon (TPH) was also analyzed with silica-gel treatment as part of the analysis.
The samples were tested by an outside analytical lab for FOG using EPA test 1654.

5.1.2 Clay Adsorption Testing:[16]

Details regarding the experimental procedures, methods and results can be found in the study by Mueller et al.

5.2 Phase II - Pilot Testing, PTO Engine Waste Treatment Facility, Lima, Ohio

This phase of the study required conducting pilot tests on treated wastewater using the filtration technology. The Lima Engine Plant (LEP) in Lima, Ohio was designated as the test site. Three different types of membranes were tested during the trials: polymeric, ceramic, and stainless steel/titanium. Details on the materials and procedures are given below.

5.2.1 Materials

The membranes used for the tests were supplied by three different vendors and can be classified as follows:

1. Polymeric Membranes constructed of Poly-vinylidene-di-flurol (PVDF)
   1.1. Tubular membrane configuration

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[16] Mueller et al, "Removal of Oil and Grease and Chemical Oxygen Demand from Oily Wastewater by Adsorption", Ford Research Laboratory, Ford Motor Company, Dearborn, MI.

        - 1.1.1. Neutral surface charge, 50,000 MWCO
        - 1.1.2. Neutral surface charge, 100,000 MWCO.
        - 1.1.3. Negative surface charge, 120,000 MWCO.
    - 1.2. Hollow fiber membrane configuration
2. Ceramic membranes – 0.02 average µm average pore size
3. Stainless steel/titanium membrane – 0.1 µm average pore size

The pore sizes and MWCO limits were determined by each vendor based on their experience with these types of applications in conjunction with the available products that each one manufactures.

The chemicals used in the upstream chemical demulsification treatment process were the standard chemicals discussed in Chapter 3, such as sulfuric acid, sodium hydroxide, and cationic/anionic polymers. In addition, chemicals such as nitric acid and specific caustic detergent cleaners provided by the vendors were used to clean the membranes when necessary.

5.2.2 Methods

The testing setup used during the trials is depicted in Figure 5.1 below:

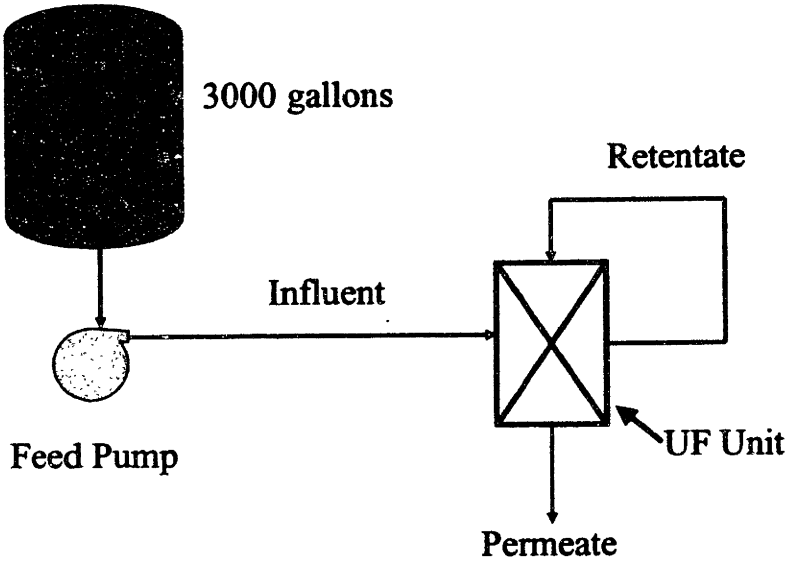

Figure 5.1 Schematic of Experimental Setup at LEP

A sample of the treated wastewater from the chemical demulsification system was segregated into the 3000 gallons reservoir tank depicted above. This tank served as the basis for each trial conducted during the testing. From this tank, the water was transported to the filtration unit. This unit was a self-contained unit that included pumps, temperature and pressure gauges, the membranes, and a process tank for the retentate produced. Actual pictures of the tank, the feed pump, and the ceramic membrane unit are given below:

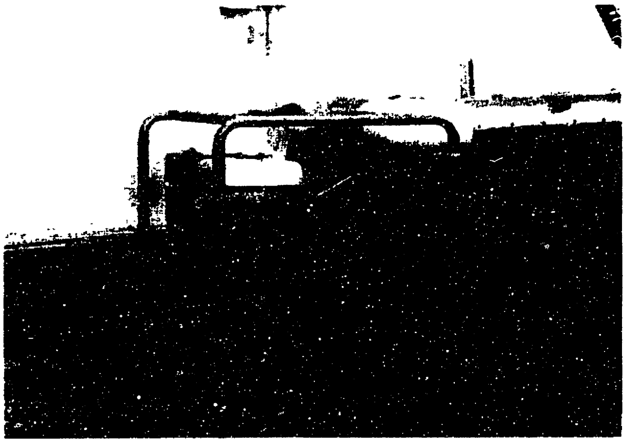

Figure 5.2 Reservoir Tank for Feed Water

Figure 5.3 Transfer pump

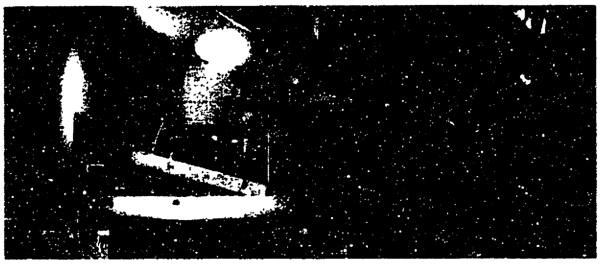

Figure 5.4 Ceramic Membrane Unit

In an effort to better simulate other PTO plants, the raw wastewater from the plant was mixed with waste coolant oils before treatment. The coolant oil stream consists of several emulsifiers and surfactant detergents. Typically, at LEP, these two streams are segregated prior to treatment, which aids the treatment process. However, not all plants within PTO are capable of separating their process streams. Thus, to generalize the study, the two streams were re-mixed in one of the large batch tanks prior to the initial chemical demulsification.

5.2.3 Chemical Treatment Process

1. Regular raw wastewater was collected from the plant over a certain period of time and segregated in a batch tank (50,000 to 90,000 gallons).
2. Waste coolant oil was transferred from a holding tank to the main batch tank. Due to equipment limitations in the plant, it was impossible to meter an exact amount of coolant oil into the batch tank. Typical amounts ranged from 1500 gallons to 5000 gallons depending on the amount of water in the batch tank. Because each batch tank of raw wastewater varied in composition and amounts of oil, there was no preset ratio of coolant oil and water. The color of the raw wastewater produced was used as an indicator of the approximate levels of FOG. Typically, a white-colored fluid was the ultimate goal. This color indicated a high amount of emulsified oils and greases present in solution.
3. Treatment of the water solution was usually begun through jar tests in the laboratory. This allowed a more precise determination of the amounts of chemicals required for treatment:
    - 3.1. A sample of raw water, already mixed with coolant oil, was extracted from the large tank.
    - 3.2. The pH was lowered below 2.5 using sulfuric acid. The tank solution was mixed thoroughly.
        - 3.2.1. Cationic polymer (Mitco Chemicals, Grand Rapids, MI) was added in different amounts varying from 0.006% - 0.03% in five different beakers.
        - 3.2.2. Each beaker was run through the entire treatment process, by adding the appropriate amount of anionic polymer and sodium hydroxide.
        - 3.2.3. The beaker that created a solution with the desired FOG level was chosen as the basis to scale-up the amount of chemicals needed to treat the large batch. Typically, the desired FOG level ranged from 20 mg/L – 100 mg/L. Initially, the FOG levels were measured using a Horiba OCMA-220 analyzer (Horiba Instruments, Inc., Irvine, CA). However, the instrument readings were drifting significantly despite discussions with the vendor and numerous troubleshooting attempts. Thus, this instrument was abandoned in favor of third-party analytical testing. Through an iterative process and accumulated experience, the visual clarity

of the solution was used to approximate the level of FOG in the treated water. Usually, the desired color bordered between a light gray color that was semi-opaque.

3.2.4. The necessary amount of chemicals required for treatment was added in accordance with the normal chemical demulsification process.

3.3. The resulting mixture consisted of two immiscible layers: flocculated oil at the top, and water/surfactants/residual FOG beneath. This treated water constituted the influent water needed for the experimental studies and what eventually was placed in the 3000 gallon reservoir tank. A sample of water was removed from this tank for pH testing and also sent for analytical testing for FOG, COD, Biological Oxygen Demand (BOD), Total Suspended Solids (TTS), Total Dissolved Solids (TDS), and Al, Fe, Ni, Cu, and Zn.

5.2.4 Sampling Schedule

Permeate and retentate samples were collected at specific points during the testing. Table 5.1 below depicts the general schedule followed for the three test units. The 'Batch' refers to the water held in the supply reservoir tank:

Table 5.1 Sampling Schedule for Filtration Testing

Time	**pH**	**FOG/TPH**	**COD**	**BOD**	**TSS**	**TDS**	**Metal Ions**
T=0	Feed	Feed	Feed	Feed	Feed	Feed	Feed
T=50% of Batch processed	Permeate, Retentate	Permeate, Retentate	Permeate, Retentate	Permeate, Retentate	Permeate, Retentate	Permeate, Retentate	Permeate
T=100% of Batch Processed	Permeate, Retentate	Permeate, Retentate	Permeate, Retentate	Permeate, Retentate	Permeate, Retentate	Permeate, Retentate	Permeate

5.2.4.1 Polymeric Membranes:

This membrane unit was tested for approximately seven weeks in five separate trials. The influent water from the reservoir tank was transferred to the unit into a 120 Liter holding tank local to the unit. A float valve in the local holding tank ensured that the water level did not overflow. The water was pumped through the tubular membranes. The transmembrane pressures for was kept relatively constant at 3.5 bar. The pressure on the other side of the membrane was atmospheric level or 1 bar. The temperature of the process was not controlled and varied with the external ambient temperature and the internal recirculation heat from 22 – 48° C. Flowrate was not controlled at any time. The retentate was recycled back to the reservoir holding tank, and the permeate stream was discharged to a local drain. Flux rates, pressure, and temperature were recorded every hour during process operation. Initially, during the night, the system was placed into a recycle mode, which caused the fluid temperature to increase over time. When the unit was switched back to process mode, the fluid temperature returned to ambient temperature. During the latter stages of testing, the unit was run continually for 24 hours, thus eliminating the temperature spikes in the fluid.

Initially, three different types of polymer membranes were tested simultaneously upon the vendor's request. Samples of both permeate, for all three membranes, and retentate were collected for analytical testing. The frequency of sampling was based on the overall processing rate for the water in the 11,400 L reservoir tank. The sampling schedule followed corresponds to the one outlined in Table 5.1.

After the first two weeks of testing, based on flux data and analytical test data, membrane 1.3 was evaluated as the most promising. Thus, permeate samples were only collected for this membrane. In addition, the hollow fiber membrane unit was installed and tested. However, due to poor flux rates and temperature limitations, it was decided to conduct the remainder of the testing with the tubular membranes, and specifically, membrane 1.3.

Cleaning cycles consisted of a caustic detergent wash, followed by an acid wash, followed by rinsing with water and a clean water flux reading. During each stage, a device that simulates the action of a 'pigging system' was used to further clean the system. The device, called a 'sponge-ball' consisted of a soft material that deformed under extreme pressure, but also, absorbed water and adsorbed dirt onto its surface. The device was placed into the system upstream of the tubular membranes and was pushed through the system by the supply pump. The device attempted to remove the superficial layer of organic material that adheres to membrane surface. The device was not designed to remove any material that might be plugging the membrane pores. The cleaning cycle was repeated if the reading was not at least 204 Liters/m^2*hr, then the cycle was repeated until the flux readings converged on this number.

The membranes were cleaned when the flux rate either dropped below 51 Liters/m^2*hr or 1 week had expired, using the aforementioned process. In addition, during some of the process runs, the sponge-ball devices were used to remove the superficial gel-layer that had accumulated on the membrane surface. The flux rate subsequently improved, but not to its initial level at the beginning of that trial. Over time, the flux rate eventually decreased over time, thereby necessitating either another run with the sponge-ball device, or a full-scale cleaning cycle.

5.2.4.2 Ceramic Membranes

Similar to the polymer membrane unit, the ceramic membrane system was self-contained and consisted of a 114 L process tank, feed pump, and temperature and pressure gauges. In addition, the unit was equipped with a shell & tube heat exchanger with no control system, a frequency inverter drive for the pump motor (0-60 Hz), and an air backpulse system. The system was operated 24 hours a day during process runs, and the permeate stream was sampled along the general guidelines given in Table 5.1. However, based on the vendor's request, only the permeate stream was sampled for analytical testing. The operating temperatures ranged from 17° C to 71° C. The heat exchanger was used intermittently to heat the feed water to these higher temperatures. Transmembrane pressure was usually kept at 1.5 bars..

Cleaning cycles consisted of a caustic detergent wash (supplied by vendor) followed by a nitric acid wash, and then rinsing, and then a clean water flux. The membranes were cleaned when flux rates dropped below 51 Liters/m^2*hr or when one week had expired.

5.2.4.3 Stainless Steel/Titanium Membranes

Similar to the polymer membrane unit, the SST membrane system was self-contained and consisted of a feed pump, a recycle loop with its own pump, temperature and pressure gauges, and the membranes. In this system, permeate and retentate streams were continuously discharged to the drain. Thus, the system continuously rejected both purified and concentrated oily wastewater. Both pumps were kept at a constant speed, and the transmembrane pressure was controlled by several manual valves throughout the system. The vendor recommended keeping the pressure upstream of the membranes at 6.1 bar, and the pressure downstream of the membranes at 4.8 bar. The system was operated 24 hours a day during the process runs and the permeate was sampled along the general guidelines given in Table 5.1. However, based on the vendor's request, only the permeate stream was sampled for analytical testing. The operating temperatures could not be controlled and 29-62 ° C and the transmembrane pressure was usually maintained at 5.4 bar.

Cleaning cycles consisted of a caustic detergent wash (supplied by the vendor), followed by a nitric acid wash, and then rinsing. The membranes were cleaned when flux rates dropped between 34-51 Liters/m^2*hr, or when 1 week expired.

5.2.5 Analytical Testing

Analytical testing was performed a third-party source, Alloway Labs (Lima, OH) for the duration of the experiment. With the exception of pH, which was measured in-house with simple color strips, all other parameters were measured by Alloway. Samples bottles, glass bottles for FOG/TPH, and plastic bottles for all other parameters, were supplied by Alloway. The test methods employed for each parameter were as follows:

1. pH – color test strip
2. FOG – EPA Method 1664
3. Total Petroleum Hydrocarbons (TPH) – EPA Method 5520F
4. Chemical Oxygen Demand (COD) – EPA Method 410.1
5. Biological Oxygen Demand (BOD) – EPA Method 405.1
6. Total Suspended Solids (TSS) – EPA Method 160.2
7. Total Dissolved Solids (TDS) – EPA Method 160.1
8. Metal Ions:
    8.1. Al – EPA Method 202.1
    8.2. Cu - EPA Method 220.1
    8.3. Fe - EPA Method 236.1
    8.4. Ni - EPA Method 249.1
    8.5. Zn - EPA Method 289.1

Additional information can be found about these test methods at the EPA's official website, www.epa.gov. This concludes the discussion related to the experimental methods employed for conducting the tests. The next chapter presents the actual results and relevant analysis.

CHAPTER 6 RESULTS AND ANALYSIS

As discussed previously, the wastewater testing was performed in two different phases: the Ford Research Labs and the Lima Engine Plant. The text below presents, discusses, analyzes, and summarizes the findings.

6.1 Phase I – Preliminary UF testing/Organoclay Testing

6.1.1 Filtration Testing

The data generated from the laboratory -scale testing is given below in Table 6.1:

Table 6.1 FOG/TPH and COD Levels from Laboratory Scale Filtration Testing

Filter Size (MWCO)	*FOG (mg/L)*	*TPH (mg/L)*	*COD (mg/L)*
0.45 μm filtered water	36	35	260
500	< 5.0	< 5.0	69
1000	< 5.0	< 5.0	147
3000	< 5.0	< 5.0	123
10,000	< 5.0	< 5.0	73
30,000	< 5.0	< 5.0	64
100,000	23	22	167

Smaller pore sizes required significantly longer processing times. The 500 MWCO filter needed 5 hours to create 300 mL of permeate. In comparison, the 100,000 MWCO required only 5 minutes to create the same volume of permeate. The remaining pore sizes required filtration times between this range, with the absolute magnitude corresponding to the pore size, or MWCO. This qualitative effect is consistent with equations 4.1, where flux is proportional to D_p^2.

Except for the 100,000 MWCO filter, all of the filters were able to reduce FOG/TPH levels below 5 mg/L. These results indicated that ultrafiltration technology was capable of purifying water below the 17 mg/L threshold level.

Thus, the initial test data indicated that the critical MWCO needed to achieve FOG levels below 17 mg/L was below 100,000 MWCO. This information was relayed to the filtration vendors. Unfortunately, all vendors indicated that they would not be able to meet this MWCO (or pore size) stipulation. The polymeric membrane vendor indicated that the smallest MWCO for pilot-size polymeric membranes was 100,000 MWCO. Although not ideal, we decided to continue with the filtration tests at LEP and evaluate the resulting data.

6.1.2 Clay Adsorption Isotherm Testing

A detailed discussion regarding the adsorption testing can be found in the study reported by Mueller et al. From the various species of organoclays tested, the most promising could be represented by the following correlation:

$$X = 0.0437*C_{Eq}^{2.06} \qquad \text{Eqn. 6.1}$$

Where X = the amount of adsorbate (FOG) adsorbed per unit mass of adsorbent (mg/g)

C_{eq} = equilibrium concentration of adsorbate (mg/L).

Assuming an average FOG influent and effluent concentrations of 30 mg/L and 15 mg/L results in an approximate adsorption capacity of 11.6 mg FOG/g clay adsorbate. This number was used to determine the amount of clay needed to purify a given volume of wastewater, in the following section on cost analysis.

In addition to FOG removal, the study found that the organoclays had no preference towards removing non-oily organics, which contribute to overall COD levels. In fact, the adsorbents actually had a preference towards removing oily compounds over non-oily compounds, as seen by the increases in the ratio of COD/FOG in the final wastewater effluent.[17]

6.1.3 Biological Systems:

As mentioned, this technology was not tested in any of the trials. However, a quotation for a large-scale industrial sized unit indicated that the levels of FOG and BOD (from which COD

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[17] Mueller et al, "Removal of Oil and Grease and Chemical Oxygen Demand from Oily Wastewater by Adsorption", Ford Research Laboratory, Ford Motor Company, Dearborn, MI.

can be inferred from), and TSS are well below the EPA proposed limits. Given that this technology is well understood, installed, and operated throughout the world, and the vendor was highly recommended by personnel at Ford, this quote was deemed reasonable in regards to water effluent quality.

6.2 Phase II – Lima Engine Plant

Before proceeding any further, it was important to understand if each of the proposed membrane technologies was capable of meeting the EPA proposed regulations for wastewater effluent. The data from the analytical tests conducting during the tests is given and discussed below. As mentioned previously, the biological wastewater technology was assumed to be able to meet all water quality requirements. Laboratory results indicated that clay was capable of meeting the water quality specifications, so the only technology that was tested at the plant was the membranes.

6.2.1 FOG/TPH

The data on FOG/TPH levels in the permeate samples is summarized below in Table 6.2.

Table 6.2 FOG Levels (mg/L) for all Permeate Samples

Membrane	*# of Samples*	*Initial FOG (mg/L)*	*% FOG < 17 mg/L*	*% < MDL for FOG**
Polymer, 1.3	19	46, 14, 25, 106, 26, 89, 27, 26	95	84
Ceramic	7	56, 24, 50	100	71
SST	5	56, 24, 50	100	40

*Minimum Detectable Limit (MDL) was 5 mg/L.

It is of interest to note that the regular wastewater effluent at LEP currently discharged to the environment has been consistently below 17 mg/L for some period now. For the purposes of this experimental study, the regular chemical treatment process was modified such that the treated wastewater had FOG levels > 17 mg/L.

A histogram for the FOG measurement in the permeate stream is presented below in Figure 6.1:

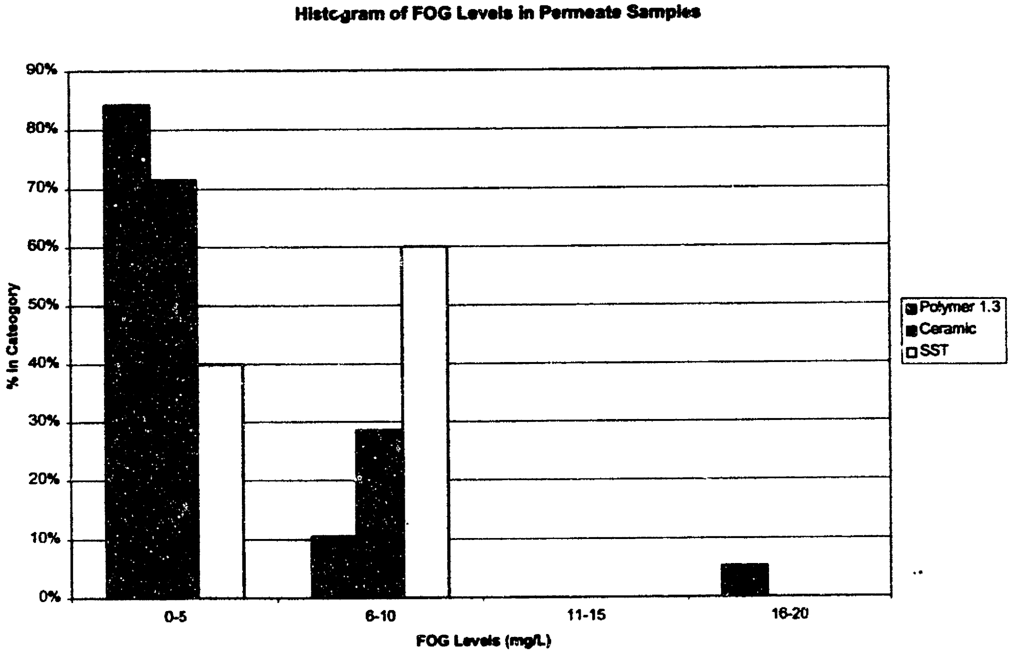

Figure 6.1 FOG Levels in Permeate Stream for Different Membranes

From the table and the histogram above, it is apparent that all of the membranes were able to reduce FOG levels from initial levels greater than 17 mg/L to well below the threshold proposed by the EPA. Furthermore, a majority of the samples had FOG levels that were below the Minimum Detectable Limit (MDL), 5 mg/L, which is well below the 17 mg/L threshold limit. This fact significantly reduces the chance that the true values of FOG levels are > 17 mg/L, due to experimental error associated with the analytical technique. Thus, irrespective of the membrane technology employed, all membranes are quite capable of reducing FOG levels well within the current proposed EPA limits.

Figure 6.2 depicts before and after samples of the water processed through the membranes:

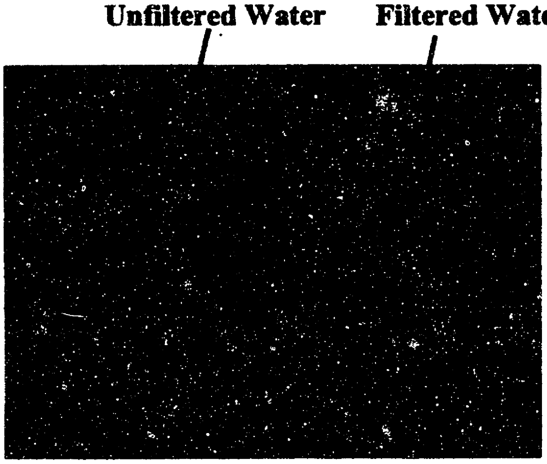

Figure 6.2 Unfiltered and Filtered Water using a Ceramic Membrane

To help confirm the validity of the test results, several of the permeate samples were tested by another analytical test vendor (Tri-Matrix Labs, Grand Rapids, MI). No inconsistencies between the results were found, thus, validating all test results.

There are some interesting points to note regarding these results. In the previous study by Kim et al regarding oily wastewater treatment with ultrafiltration using polymer membranes, primary effluent was treated from initial levels of FOG > 200 mg/L to final FOG levels ranging from 30-100 mg/L in the final effluent. Thus, based on these results, it might be possible to use two ultrafiltration units in series to reduce FOG levels below 17 mg/L, and completely eliminate chemical treatment. This might be a possible treatment solution for the complete treatment of oily wastewater, but this area deserves further investigation.

6.2.2 COD Results

COD data for the various membrane streams was collected in parallel with the FOG data. Table 6.3 below summarizes the COD data for all of the membranes. Additional details can be found in Appendix C.

Table 6.3 COD Levels for All Membranes Tested

Membrane	*Influent COD (mg/L)*	*Average Effluent COD (mg/L)*	*% Reduction*
Polymer 1.3	271	139	49%
Polymer 1.3	238	208	13%
Polymer 1.3	277	210	24%
Polymer 1.3	800	277	65%
Polymer 1.3	475	303	36%
Polymer 1.3	440	287	35%
Polymer 1.3	378	264	30%
Polymer 1.3	406	294	28%
Ceramic	400	244	39%
Ceramic	983	256	74%
SST	400	233	42%
SST	983	224	77%

From the above data, the most obvious conclusion is that with the exception of one case, all of the membranes were unable to reduce COD levels below 200 mg/L, irrespective of initial influent COD levels. Although each membrane significantly reduced COD levels in the water, presumably through FOG reduction, the 200 mg/L threshold was not surpassed (except for one case). One possible explanation is that the surfactants and other small, dissolved organic compounds easily pass through the membrane. Indeed, each vendor expressed significant concern that their membrane would not be able to remove surfactants and dissolved organics, because of their relatively small particle sizes.

This hypothesis was confirmed by the relatively constant Total Dissolved Solids (TDS) concentration for each permeate stream, irrespective of membrane. The greatest reduction in TDS for any of the membranes was only 10%, and on average, significantly less than this. Thus, although the membranes were effective at reducing FOG levels below 17 mg/L, they were not as effective at removing dissolved organic compounds from the water. Although not relevant today, this information might become pertinent if the EPA plans to use COD as a parameter to monitor and regulate wastewater effluent in the future.

In regards to the clay technology, the study by Mueller et al concluded that the adsorption media tended to adsorb FOG preferentially over dissolved organics. Thus, although COD was reduced through FOG removal, this technology would not be recommended to reduce COD levels in wastewater.

6.2.2.1 Metals and Inorganics:

The concentration of various metal ions were also measured both in the influent and final samples. The project team decided that the relevant metals to test for were aluminum, copper, iron, nickel, and zinc. Chromium and cadmium were not tested because wastewater from engine plants does not typically contribute to increasing the quantities of these parameters. Out of the metals tested, after the chemical treatment process, only aluminum and iron surpassed the proposed EPA limits. Thus, the membrane technologies were attempting to remove only these two metals. Although they were all successful at removing iron, none of the membranes were able to consistently reduce aluminum levels below the EPA proposed limit of 1.0 mg/L. Table 6.4 below gives the Al concentrations, and additional data can be found in Appendix C:

Table 6.4 Inorganic Metal Levels in Permeate Stream

Membranes	*Influent Al (mg/L)*	*Effluent Al (mg/L)*
Polymer 1.3	2.1	0.35
Polymer 1.3	2.3	2.5
Polymer 1.3	4.1	4.1
Polymer 1.3	3.9	1.4
Polymer 1.3	2.1	0.95
Polymer 1.3	2.1	1.2
Polymer 1.3	2.1	1.4
Ceramic	5.9	4.9
Ceramic	6.2	6.2
SST	5.9	4.6
SST	6.2	4.7

From the data above, except for a couple of instances, in general, the Al limits exceed the proposed limit. In fact, in some cases, the Al present in the effluent stream exceeds the influent level. This could be explained either by experimental error or by concentrating aluminum hydroxide in the retentate tank. This precipitant might actually convert back into its ion form in the retentate tank, and then, pass through into the water permeate stream. Nevertheless, all of the membranes seem incapable of reducing aluminum levels below the threshold limit of 1 mg/L. This fact implies that additional downstream processing would be required to reduce aluminum levels to the proposed standard. On a side note, the variation of Al levels in the influent stream are indicative of the daily variability in both raw influent water from the plant, as well as the overall chemical treatment process.

Similarly, the clay adsorption media showed a poor affinity for metal ions, such as aluminum. Thus, this type of system would not be recommended for this specific application.

In conclusion, the data gathered from both the laboratory and the plant studies was insightful. Although the membrane technologies easily remove oil and grease from the water to a level well below the proposed standard, they are incapable of removing aluminum below the EPA proposed limits, implying additional downstream processing would be needed. In addition, although the membranes are capable of reducing the overall COD levels, total dissolved solids, such as surfactants, were not reduced. Similarly, although the clay is capable of reducing FOG levels below 17 mg/L, the adsorption capacity is quite low. In addition, the clay's affinity for metals is quite low, thereby making it an unattractive solution for this application. This data must be taken into account into a final decision regarding the type of waste treatment technologies to employ for this waste treatment application.

6.2.3 Membrane Performance – Flux Data

Now that technical capabilities for the membranes have been discussed, it is now appropriate to assess the overall capacity performance, or flux rate, of each membrane technology. This analysis will influence the direct capital investment required for each technology, and thus, affect the overall economic analysis of each technology. The discussion below begins with how to evaluate flux rates.

6.2.4 Membrane Flux Rates

Because temperature and transmembrane pressure varied significantly between different membranes, and flux is strongly correlated with temperature and a direct function of pressure, it is important to normalize all of the data to one temperature and pressure before any comparisons can be made. Following the work by Kim et al, oily wastewater flux rates can be shown to vary with temperature in the following manner:[18]

Relative Flux : $$\frac{J(T)}{J(r)} = \frac{\mu(r)}{u(T)}$$ Eqn. (6.2)

where J_T = permeate flux at temperature T
J_R = permeate flux at a reference temperature chosen
μ_R = viscosity of water at this reference temperature
μ_T = viscosity of water at temperature T

This assumes that parameters such as ε, d_p, Δx do not vary with temperature and that Δp is equivalent in each case. The relationship between temperature and viscosity of water can be represented as:[19]

$$\ln(\mu) = -1.5668 + 230.298/(T-146.797)$$ Eqn. (6.3)

Where T = temperature (K)

To compare all data at the same reference point, all of the flux data taken for the polymeric, ceramic, and stainless steel membranes were normalized to 30° C (303 K) using equations 6.2 and 6.3 and the original data.

As far as pressure, Kim et al[20] showed that for various ultrafiltration membranes, flux varied linearly with transmembrane pressure. Thus, the following relationship can be used to normalize flux to a specific pressure:

$$\frac{J_1}{\Delta p_1} = \frac{J_o}{\Delta p_0}$$ Eqn. (6.4)

where

J_o = flux at reference pressure
Δp_o = reference transmembrane pressure
J_1 = measured flux at a specific pressure
Δp_1 = operating pressure correlating to J_1

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[18] Kim et al, "Evaluation of Commercial Ultrafiltration Systems for Treating Automotive Oily Wastewater", Water Environment Research, Vol, 70, No. 7.

[19] Kim et al, "Evaluation of Commercial Ultrafiltration Systems for Treating Automotive Oily Wastewater", Water Environment Research, Vol, 70, No. 7.

[20] Kim et al, "Evaluation of Commercial Ultrafiltration Systems for Treating Automotive Oily Wastewater", Water Environment Research, Vol, 70, No. 7.

Using relation 6.4, all of the flux data was normalized to the transmembrane pressure measured for the polymeric membranes, 3.4 bars. Table 6.5 below summarizes some of the more salient points about the overall flux data for each membrane:

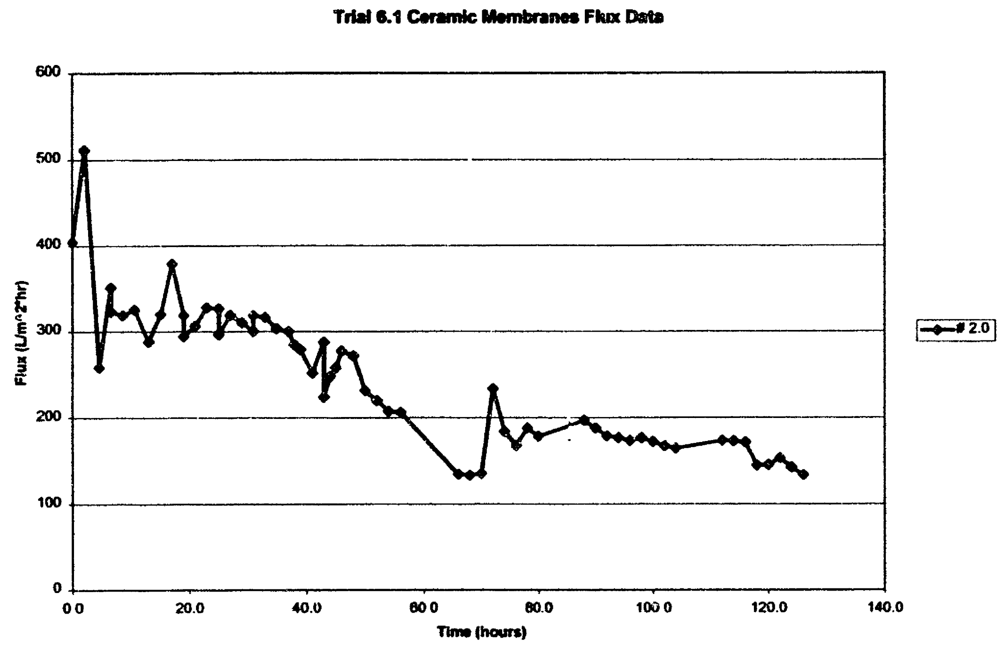
Table 6.5 Normalized Flux Data for Filtration Membranes

Membrane Type	*Max (L/m²*hr)*	*Min (L/m²*hr)*	*Average (L/m²*hr)*
Polymer 1.3	412	54	82
Polymer 1.3	242	53	105
Polymer Hollow Fiber	NA	NA	NA
Polymer 1.3	175	46	104
Polymer 1.3	212	33	80
Polymer 1.3	268	59	132
Ceramic 2.0	511	134	245
Ceramic 2.0	530	82	273
SST 3.0	76	15	34
SST 3.0	28	11	16

From the above data, overall, the ceramic membranes achieved and maintained the highest flux rates. On average, the flux rate for the ceramic membranes was 259 L/m^2*hr. However, these numbers above only give a brief snapshot of the entire data through time. Thus, flux vs. time curves would be useful in evaluating overall performance.

6.2.5 Ceramic Membranes

Figures 6.3 and 6.4 below illustrate the flux vs. time behavior for the ceramic membranes:



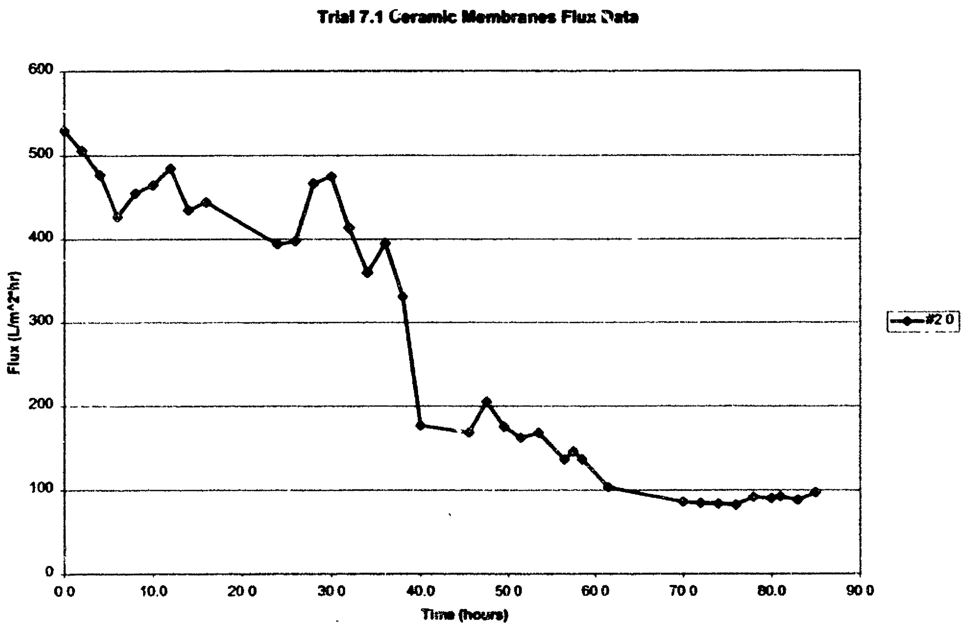


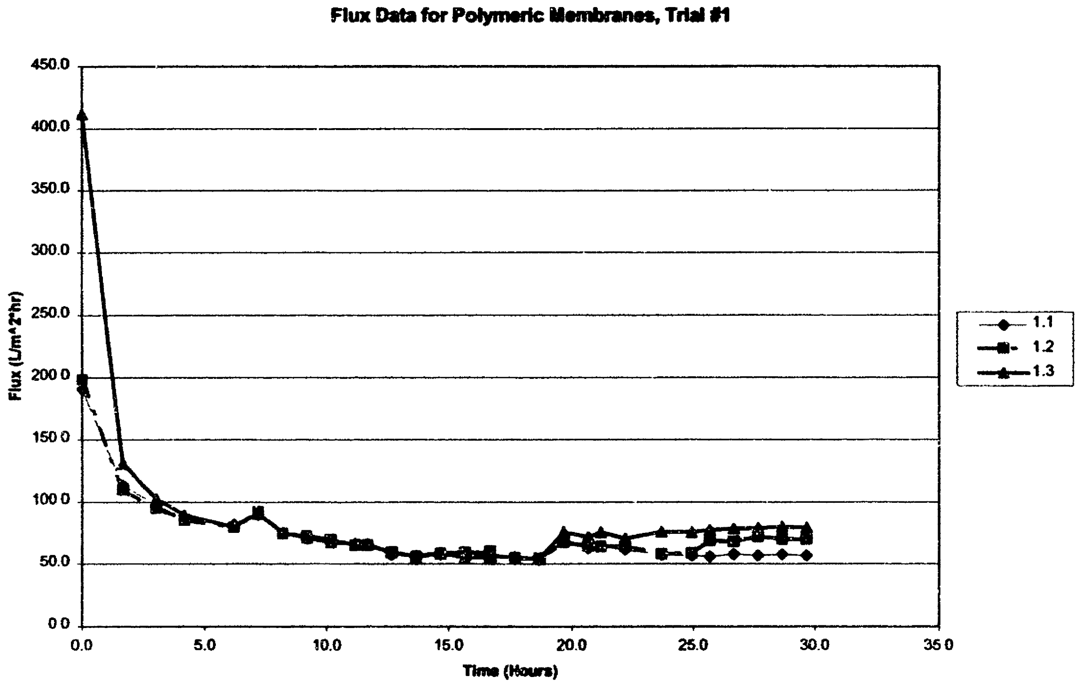
Figure 6.3 and 6.4 Normalized Flux Data for the Ceramic Membrane, #2.0

The general behavior for each flux curve follows an exponential decay of flux over time. The physical mechanisms underlying this behavior can be explained as follows. As the solute begins to accumulate on the membrane surface, the overall flux rate begins to decrease. This fouling layer, otherwise known as Concentration Polarization (CP) layer, quickly accumulates and causes flux rates to decrease over time. Over time, this fouling layer increases in thickness and eventually, results in the flux rate decreasing below recommended operating levels. However, from the figures above, the flux rate spikes to increases level during certain portions of the runs. These points are usually associated with increases in temperature. Because the flux curves were already normalized with temperature, these rapid flux spikes indicate that increasing the fluid temperature has a more profound effect on flux rate than simply reducing the fluid viscosity. One possible explanation might be that the increased fluid temperature disrupts the CP layer that formed on the membrane surface. This would result in an immediate increase in flux rates, followed by an exponential decay again, as seen in the figures. Thus, one possible conclusion is that the optimal operating procedure increases temperature periodically to help increase flux rates and reduce the frequency of membrane cleanings.

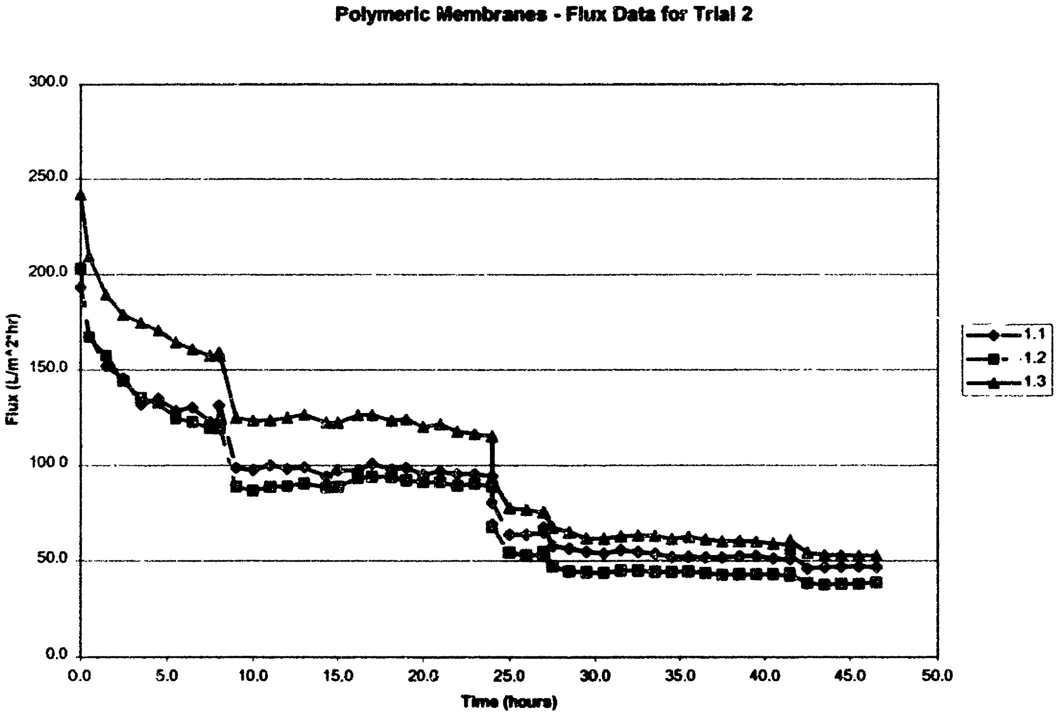
A possible explanation in regards to why the ceramic membranes performed significantly better than other membranes may lie in the air back-pulse operation. During operation, once a minute, the permeate fluid was pressurized in the reverse direction through the pores of the membrane back into the retentate stream. This action helps to reduce plugging and fouling in the membrane, and thus, keeps the flux rates higher. Because of the way the ceramic membrane is constructed, it is able to handle the high pressures needed to back-pulse fluid in the reverse direction through the pores. Other membranes, such as asymmetric polymer tubular membranes, are not able to backpulse fluid through the membranes.

6.2.6 Polymeric Membranes

As described previously, three different types of polymer membrane surfaces were tested simultaneously throughout the set of experiments at LEP. After analyzing all the initial data, it was seen that membrane 1.3 consistently performed the best. In general, flux rates for membrane 1.3 were on average 10-20% or greater than the flux rates of the other the polymer membranes, 1.1 and 1.2. Figures 6.5 and 6.5 illustrate flux rates vs. time for all three membranes:



Flux Data for Polymeric Membranes, Trial #1



Polymeric Membranes - Flux Data for Trial 2

Figures 6.5 and 6.6 Flux Data for Polymeric Membranes 1.1, 1.2, and 1.3

As can be seen in the graphs above, membrane 1.3 consistently performs at a higher flux rate than 1.1 or 1.2. Thus, to reduce analytical test costs, a decision was made to exclusively sample only this membrane's permeate stream for analytical testing for the remainder of the trials.

As seen from Table 6.5, the flux rates for the polymeric membrane 1.3 were significantly lower than the ceramic membrane. When normalized for temperature and pressure, average flux rates for the polymer membrane were at best, 40% less than the ceramic membrane. The flux vs. time curves in Figures 6.7-6.9 show that both initially and throughout the run, the flux rates with the polymer membrane were consistently lower than the ceramic membrane:

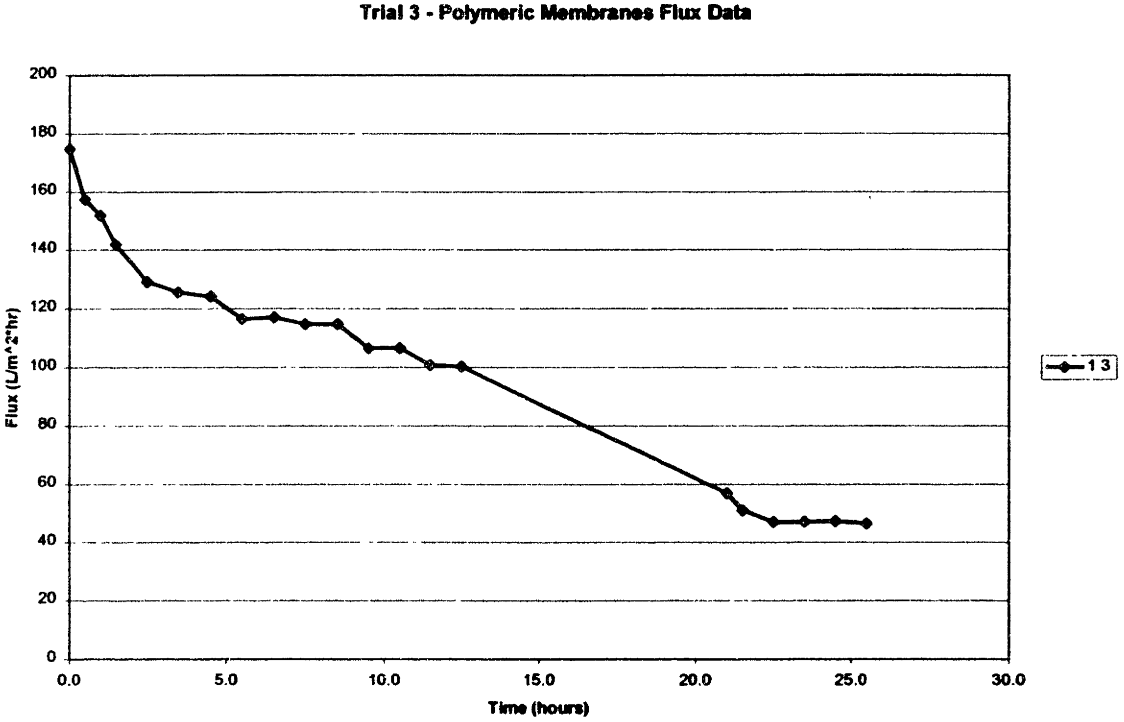


Figure 6.7 Flux vs. time for Trial 3, Polymer Membrane 1.3

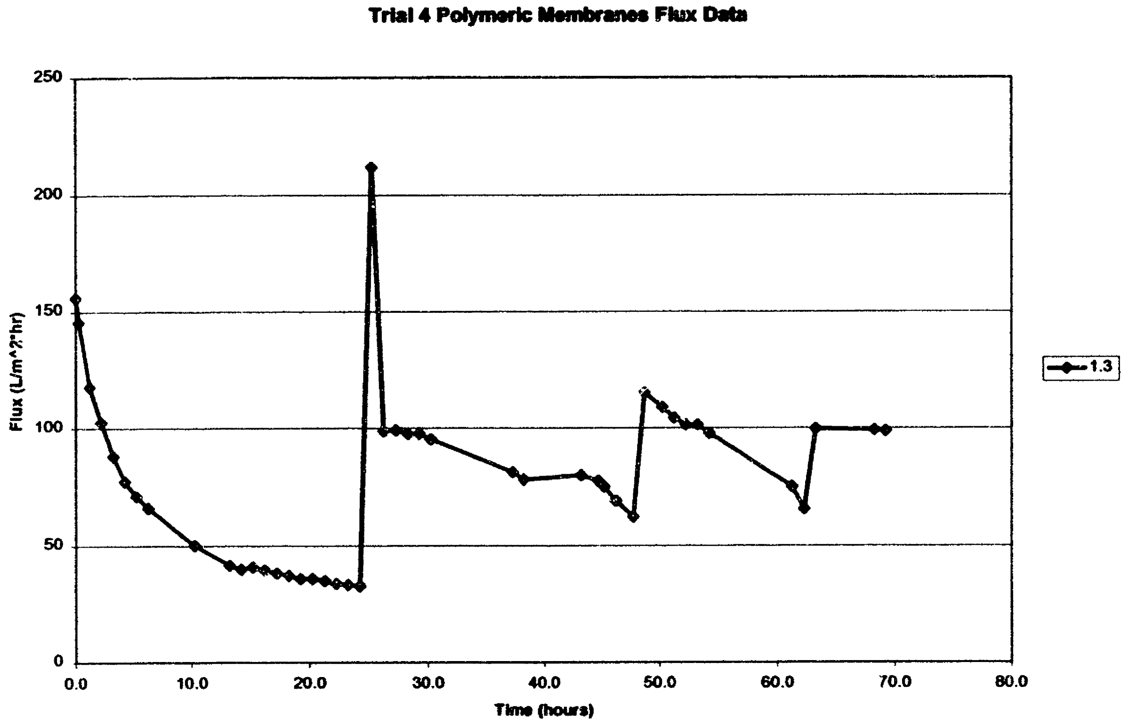


Figure 6.8 Flux vs. time for Trial 4, Polymeric Membrane 1.3

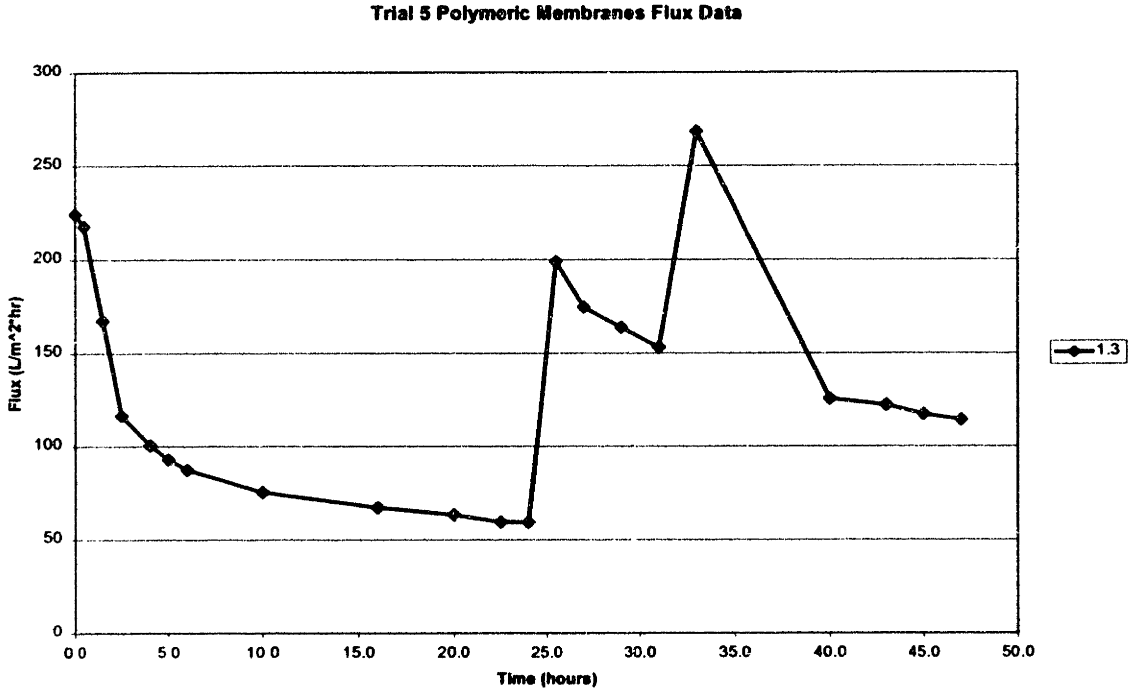


Figure 6.9 Flux vs.time for Trial 5, Polymeric Membrane 1.3

In addition to overall lower flux rates, the curves also show some unusual spikes in flux rates during Trials 4 and 5. Initially, the flux rate decreases exponentially as time increases, similar to the other trials. However, at certain points, the flux rate seems to instantaneously spike to a higher level, and then again, begins to decrease in an exponential manner. However, there is no defined periodicity to this behavior. The primary reason for these step-level increases flux was because of the use of the sponge-ball device for intermittent cleaning. Again, the effect was to reduce the thickness of the CP layer that had formed on the membrane surface. Immediately after using the device, the flux rates increased significantly, and in Trial #5, even surpassed the initial flux rate observed at the beginning of the trial. Thus, using the sponge-ball device emulates the effect of the back-pulse device on the ceramic membrane, but with less frequency. However, because the sponge-ball device is only used periodically, its effect is much more pronounced and easily detectable, as seen from the graphs. Given the way the polymer membrane is constructed, it was not possible to use a back-pulse device during operation in lieu of the sponge-ball device. Finally, it is difficult to evaluate which device, either the sponge-ball or the back-pulse, is more effective at keeping the membrane surface clean from the data observed during these trials.

6.2.7 Stainless Steel Titanium Membrane

From Table 6.5, it can be seen that the SST trials had the poorest performance in regards to flux rates. When normalized for temperature and pressure, average flux rates were at best, 14% of those obtained on the ceramic membrane. Figures 6.10 and 6.11 below illustrate the flux rates with respect to time:

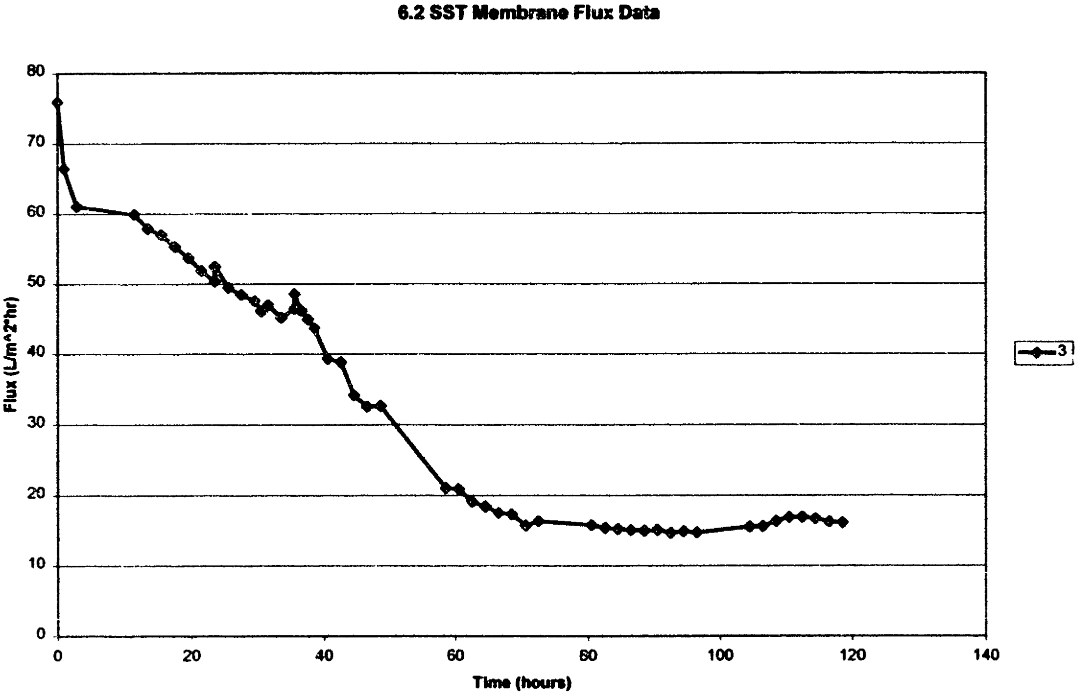


Figure 6.10 Flux data for Trial 6.2, SST Membrane

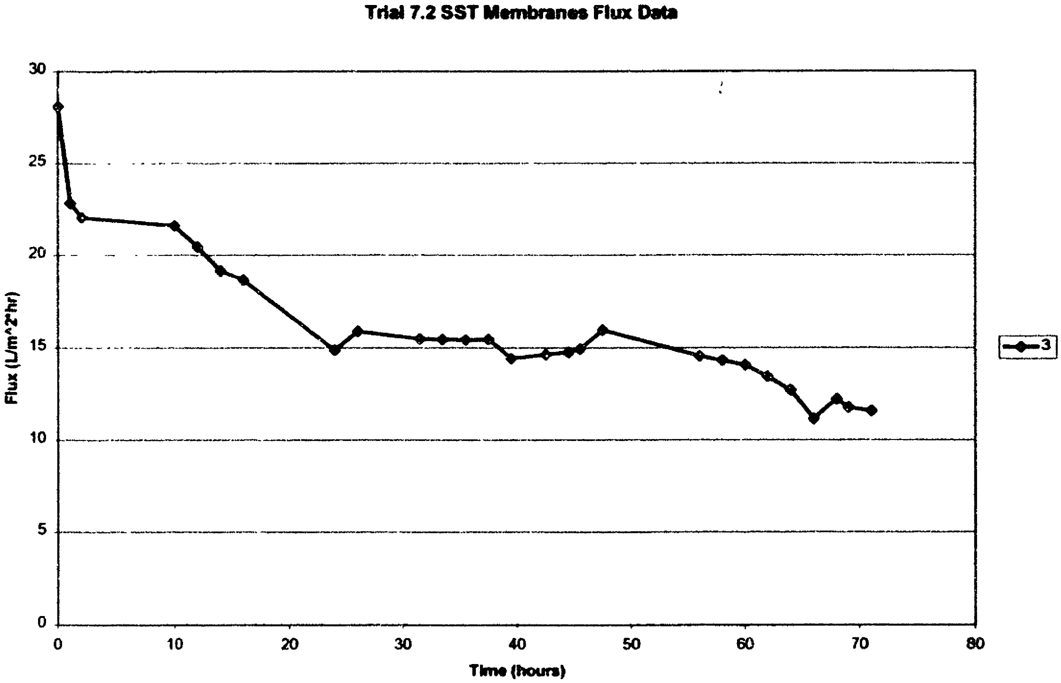


Figure 6.11 Flux data for Trial 7.2, SST Membrane

As seen above, both flux rate curves follow an exponential decay pattern, without any unusual spikes. The temperature of the system was generally above 40° C because of the high rate of internal fluid recirculation in the system. The majority of the fluid pumped to the membrane was composed of retentate fluid, and thus, accumulated energy in the form of heat as it was recirculated multiple times. Thus, there was not an opportunity to observe how flux rates would change with respect to sudden changes in temperature, as was possible with the ceramic unit.

The SST membrane is physically capable of using an air back-pulse system. Attempts to enable such a system were undertaken, but not successful. Thus, it is difficult to ascertain what the effect of 'continuous cleaning' would have been. However, it is likely that the backpulse unit would not have made up for the significant difference in flux rates observed between itself the other membrane units.

6.2.3 Next Steps

All of the data gathered during the trials was given to the corresponding vendors to allow them to size an appropriate commercial size unit for a specific base case. A copy of the base case has been attached in Appendix A. The design and analysis process by each vendor was considered proprietary and was not available for general discussion in this forum. The membrane analysis given above was performed to better understand the performance capabilities and limits of each type of membrane, as well as some intuitive insight into the design proposals specified by each vendor.

6.3 Economic Analysis

It was hypothesized that the best way to obtain accurate costs estimates for the relevant technologies was to create a base-case scenario for waste treatment and allow outside vendors to bid on a system needed to meet the specified criteria. In the case of the membrane technologies, the experimental data gathered was sent to each respective membrane vendor for further analysis and a bid proposal. In the case of the biological systems, the needs and desired criteria were communicated to an appropriate vendor, recommended by personnel at Ford Motor Company. Finally, in regards to the clay adsorption technologies, a cost estimate was performed based on the analytical data gathered during the laboratory experiments. Detailed costs calculations are provided in Appendix B.

The cost estimates for each filtration treatment technology were taken from the vendors and the adjustments were made based on the scope and level of consistency with experimental data. Assumptions and methodologies for each technology are given below:

Primary Assumptions:

1. Each technology was evaluated over a 10 year life-cycle time
2. The analysis is divided into two portions:
   2.1. Fixed Capital Investment
   2.2. Annual operating costs, discounted to time zero
3. The discount rate used was 10%.
4. Capital Investment costs estimates include installation (except the clay technology)
5. Labor costs were not included in the above calculations because it is of the opinion that it would be identical regardless of the technology chosen

More specific assumptions for some of the specific treatment technologies were as follows:

For Filtration and Biological Treatment Technologies:

1. Infrastructure Costs: 50% of capital costs of the process technology.
2. Mechanical Installation: 25% of capital costs of the process technology.
3. Electrical Installation: 10% of capital costs of the process technology.
4. Heat Exchangers, Tanks, Compressors: Only added if necessary to meet the vendor's specifications.
5. Project Contingency Costs: 10% for all membrane technologies, 20% for biological waste treatment
6. Major equipment replacement costs were amortized over the expected equipment life.

6.3.1 Overall Summary

The results of the quantitative calculations on total life-cycle costs are given below in Table 6.6:

Table 6.6 Life Cycle Costs for Each Waste Treatment Technology

	Biological Systems	*Polymer Membranes*	*Ceramic Membranes*	*SST Membranes*	*Organoclay Media*
Fixed Capital Investment	$590,00	$660,000	$1,200,000	$1,200,000	NA
Annual Operating Costs	$30,000	$92,000	$171,000	$92,000	$280,000
Total Lifecycle Costs	$780,000	$1,200,000	$2,200,000	$1,800,000	$1,700,000

Figure 6.12 below graphically illustrates the cumulative costs, both fixed and operating, for each year during the 10-year project life.

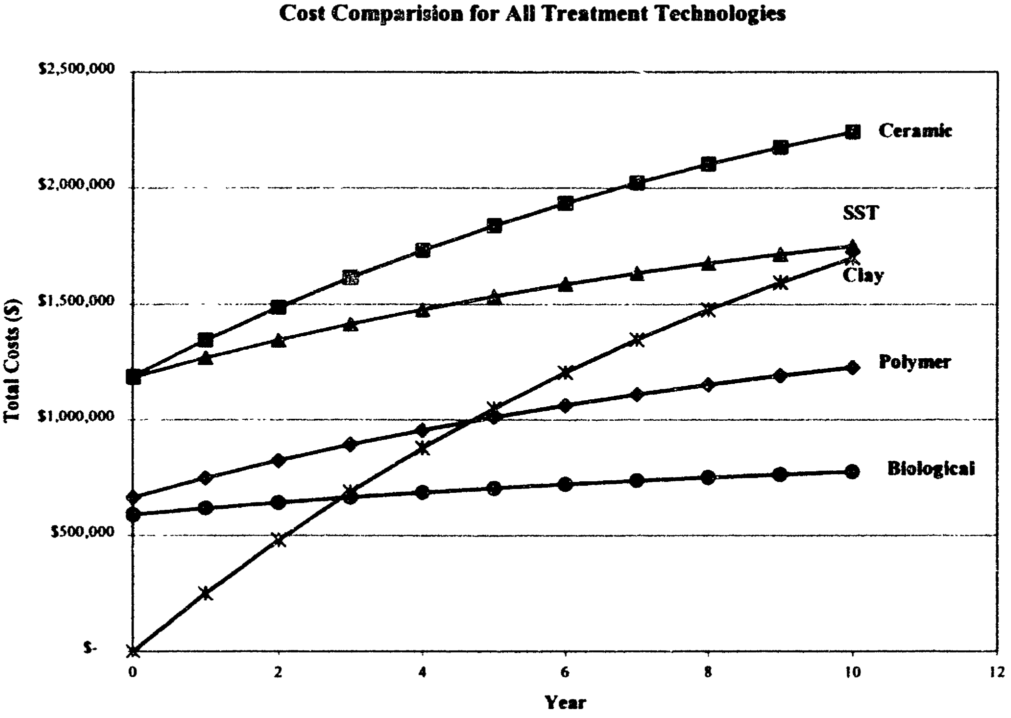


Figure 6.12 NPV Cost Comparison for Total Life-Cycle Tests for Each Treatment Technology (Discount Rate of 10%)

Note: Costs for the clay technology do not include equipment and installation costs and only reflect approximate operating costs.

As can be seen from the table and the figure above, the biological waste treatment system appears to be the lowest cost option over a 10-year project life, both in regards to the fixed capital investment and annual operating costs. Again, the fixed capital investment for the clay media was not considered in this evaluation. Other pertinent issues will be explored in the final recommendation section. A brief discussion about each section is given below.

6.3.2 Biological Treatment System

The cost of the biological treatment system was scaled using the bid quotation as well as actual historic data. The quotation for a feasible system was approximately $165,000. However, using past historical data for biological waste treatment systems at Ford, a cost/capacity curve was generated, and is given below:

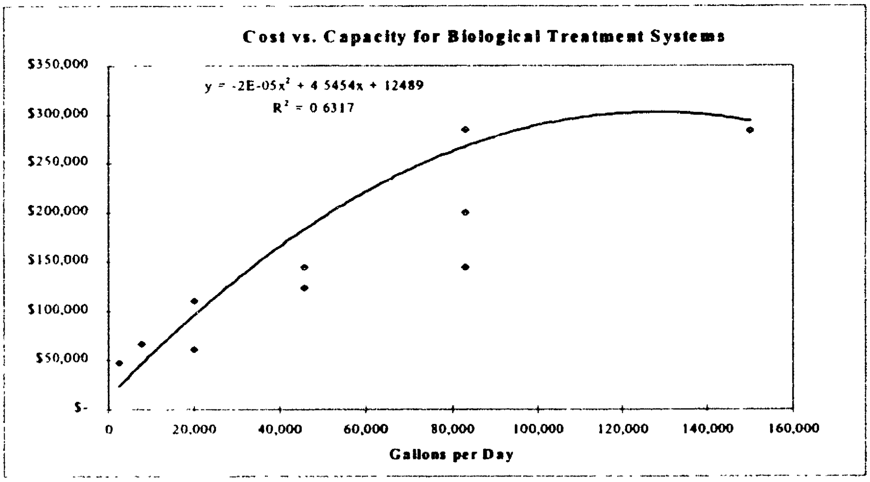


Figure 6.13 Cost/Capacity Curve for Various Biological Waste Treatment Systems at Ford Motor Company[21]

From the regression above, a system of the size of 100,000 gallons/day would require an initial capital investment of approximately $270,000, which is significantly larger than the $165,000 quotation from the vendor. Because there was a fair amount of uncertainty associated with the regression, it was appropriate to attach some engineering judgement to this number.

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[21] Data gathered from William Gaines, Environmental Quality Office, Ford Motor Company

After discussing the problem with an expert in waste treatment technology at Ford[22], the bid was increased by 10%, resulting in an estimated fixed capital investment of about $300,000. However, this number was inclusive of any additional infrastructure and related support needed to install and run the biological waste treatment technology that was not included in the original quotation. Given that the initial bid quotation almost 50% less than this number, there was a high degree of confidence that the $300,000 accurately estimated several of the unexpected costs associated with projects of this type.

Additional items such as a compressor, installation costs, freight, and project contingencies add to the initial $300,000 cost estimate. Also, to compensate for the lack of experimental data with this technology, the project contingency for this technology was placed at twice that of the membrane technologies, 20% vs. 10%.

Operating costs on an annual basis were calculated based on costs given by the vendor for sludge dewatering, utility expenses, and maintenance. The total expected operating costs were estimated at $30,000/year.

6.3.3 Polymer Membranes

The membrane costs and system specifications given by the vendor were deemed appropriate within the operating range that the vendor was promising. The vendor recommended a standard processing unit that has been used in similar applications. A similar unit was installed at a Ford engine plant in Canada, and has been operating according to design specifications for three years. Typical installation, infrastructure, and freight costs were added to the fixed investment amount. Operating costs were generated from estimated utility requirements and raw materials (water, detergent) needed to maintain normal operations. Because polymeric membranes have been in use for a number years, the typical materials and processing are well-defined and inexpensive, relative to more exotic materials, such as ceramics, or sintered metals.

6.3.4 Ceramic Membranes:

The membrane unit costs and system specifications given by the vendor were deemed accurate within the operating range that the vendor was promising. The vendor recommended a very conservative solution to the base case, given the experimental data generated in the plant, so the numbers given are taken with greater confidence. In addition, the vendor has installed similar

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[22] Personal communication with William Gaines, Environmental Quality Office, Ford Motor Company

units in various types of applications and has a strong reputation throughout the industry for delivering successful solutions. Typical installation, infrastructure, and freight costs were added to the fixed investment amount. Additional heat exchangers were needed because of both process and cleaning requirements. Operating costs were generated from estimated utility requirements and raw materials (water, detergent) needed to maintain normal operations. The higher capital costs for this technology reflects the additional costs, relative to polymeric membranes, incurred when manufacturing the actual ceramic membrane.

Although ceramic membranes are considered more durable than polymeric membranes and have a longer life, its higher initial costs weighed unfavorably in its overall cost cycle. In addition, the vendor recommended a very conservative solution, despite the high flux rates seen during the experimental trials in Lima. The vendor's solution assumed average flux rates on the order of 100 L/m^2*hr, despite flux rates of over 200 L/m^2*hr observed in the plant. Combined with the higher initial capital costs for the membranes, this approach resulted in a more expensive solution relative to the polymer membranes.

6.3.5 SST Membranes

Because of some uncertainty associated with the actual membrane surface area for the SST pilot system, the cost of the total unit was modified. This uncertainty stemmed from a discrepancy between the SST technology vendor and the original membrane manufacturer. To be conservative, the amount of membranes needed was doubled and the associated process equipment scaled-up by 50% in costs. Membrane surface area were doubled from $55,000 to $110,000 and an additional $35,000 was added to equipment skid costs for pumps, valves, and other associated equipment. Tank prices were already included in the original quotation and not added again. Typical installation, infrastructure, and freight costs were added to the fixed investment amount. Operating costs were generated from estimated utility requirements and raw materials (water, detergent) needed to maintain normal operations. The higher capital costs for this technology reflects the additional costs, relative to polymeric membranes, incurred when manufacturing the actual sintered stainless steel membrane. Although the sintered stainless steel membrane is considered more durable than polymeric membranes, and has a longer life, its higher initial costs weighed unfavorably in its overall cost cycle.

6.3.6 Organoclay Media

Based on a oily wastewater flowrate of 100,000 gpd, FOG composition of 30 mg/L, and an overall FOG loading factor for the clay of 10 mg/g adsorbent (based on isotherm data), the total amount of clay needed during one operating year was calculated. Because the experiments for the clay adsorption isotherms were conducted over a range of 0-30 mg/L FOG, it was appropriate to modify the FOG level of the influent water from the base-case to 30 mg/L from the 80 mg/L used in the other cases. The clay vendors gave rough cost estimates of approximately $1/lb for the clay. Given this information, the total annual operating costs were estimated to be on the order of $300,000/year. These operating costs did not take into account spent clay disposal costs or any capital equipment costs needed to use the clay media. However, given the high annual operating cost for the clay itself, the long-term life cycle costs become less attractive when compared to the other, less expensive treatment technologies. Thus, further design calculations regarding the capital investment costs were not conducted, based on the unfavorable operating costs.

Based on all of the technical and economic data and analysis above, final recommendations and conclusions were created in regards to the next steps for Ford. Details of the recommendations are presented in Chapter 7.

CHAPTER 7 CONCULSIONS AND RECOMMENDATIONS

7.1 Conclusions

The major conclusions from this thesis project are given below:

- Biological wastewater treatment promises significant advantages as a solution for use as a secondary wastewater treatment step to remove oil and grease compounds and metal ions from chemically treated wastewater. The technology appears to have the lowest overall costs relative to other treatment technologies. As an alternative, ultrafiltration with polymeric membranes should be considered as a viable option. Although overall costs are expected to surpass biological treatment, nevertheless, it is a feasible solution for removing oil and grease from chemically treated wastewater.
- Optimal capital investment decisions should be made with relevant and current information, supplemented with the most probable outcomes for the future. Thus, although the polymeric membranes are quite capable of removing oil and grease from treated wastewater and meeting currently proposed EPA water standards, it is desirable to further investigate biological wastewater treatment as a potential solution. Biological water treatment also has the potential to reduce both FOG and COD levels in water significantly. Although COD is currently not regulated by the EPA, it might become the metric of choice in future environmental legislation.
- When conducting experimental work in a plant or operational environment, the key driver for which plant should be the quality of the workers and their willingness and attitude to cooperate. By far, these attributes will have a profound impact on potential success of the experiments.
- Environmental issues are often comprehensive and broad-based in scale and scope. Increasing operational efficiencies and reducing resource consumption are often consistent goals, and can be linked to specific business benefits. It is often more constructive to think of these problems from this holistic perspective rather than a simple waste treatment framework. Chapter 8 provides further details on this issue.

7.2 Next Steps

1. Set up a range of experiments to test the feasibility and effectiveness of biological wastewater treatment. In an effort to compare test results with this work on filtration and clay adsorption, it would be most useful to conduct the experiments at LEP, using partially treated wastewater as the feed influent with similar characteristics (COD > 500, FOG ≈ 100).
2. The biological wastewater treatment study should be expanded to testing at a transmission plant. The wastewater at these plants could vary significantly from an engine plant and it is important to characterize the capability of this technology in the various scenarios.
3. Begin to assess the feasibility of implementing a biological wastewater treatment system at some of the key Ford Powertrain plants.
4. Develop a long-term strategic implementation plan based on the projected passing of EPA regulations.

Given all of the data and analysis above, it was appropriate to conclude the project with recommendations and next steps. There were several parameters and issues that became relevant during such an analysis:

1. Technical feasibility
2. Life-cycle costs
3. Operational complexity
4. Waste generation and sustainability
5. Long-term regulatory issues

The best choice of technology that meets the desired objectives and overall needs of Ford is biological wastewater treatment. However, it is important to understand the implications of this decision in regards to the issues raised above. The following text attempts to compare and contrast the two most feasible solutions, biological waste treatment, and polymeric membranes.

7.3 Technical Aspects

Based on the previously outlined assumptions and knowledge about biological treatment systems, it was believed that a system would be capable of reducing both FOG and any relevant metals from the water. The FOG and other residual organics would be converted to water and carbon dioxide, while the residual metals like Fe and Al would find their way into the sludge that is created from the dewatering process. This sludge is a rich organic material that could be reapplied to the plant grounds for use in landscaping. This type of reuse would eliminate sludge disposal costs as well as reduce the overall waste generated by the plant. This practice would be subject to meeting specified EPA land application criteria regarding metals (40 CFR Part 257).

In contrast, the filtration technologies are not fully capable of meeting currently EPA proposed limits for water effluent. Although the technology is effective at removing oil & grease, it was unable to remove aluminum to the levels proposed by the EPA. Thus, if the regulations are passed as they are given today, this technology option would require a supplemental unit operation to further purify the water.

In regards to the organoclay technology, the adsorption isotherm testing showed that the media is physically capable of removing FOG as well as the metal ions. However, the more relevant question then becomes how much clay is needed. This will be addressed in a later section.

7.4 Life-Cycle Costs

From an overall cost perspective, biological wastewater treatment is by far the lowest cost solution with a cumulative expected cost of $800,000 at present value. The next best solution, the polymeric membranes were estimated to cost $1.2 million, or 50% more than the biological treatment. Because the biological waste treatment solution utilizes standardized technology that incurs extremely low operating costs, it needs significantly less capital to install and maintain. As the next best alternative, the polymer membranes seem to provide the required performance at a reasonable price. However, an additional processing unit (possibly a smaller filter) would have to be used in conjunction with the polymeric membranes to remove Al to the necessary levels.

One additional point to consider when comparing the two solutions is the differences in physical infrastructure requirements. The biological wastewater treatment system could be placed outdoors and does not need dedicated physical building for its operation. However, the technology will require a significant amount of physical space, relative to the filtration technologies. In contrast, a filtration technology would have to be place indoors, but would require less overall space. These considerations might be very important at a specific plant site, depending on its physical space needs and availability.

7.5 Operational Complexity

This term refers to all of the knowledge required to operate and maintain a system as well as the overall chance for inherent instability in the system. Because biological systems are relatively complex, operators must take care not to shock the system. Examples include rapid changes in either organic or inorganic materials in the feed stream. Once the biological system is compromised, it must be carefully regenerated through a culturing process that requires significant time and effort.

In addition, biological systems are somewhat sensitive ambient conditions, such as temperature. How would the oscillations between summer and winter affect the overall performance of the unit? What about periods such as plant shutdowns? How would the systems be operated during this period to maintain their current steady-state conditions? Also, the operators would have to be trained in the entire sludge dewatering process. The vendor indicates that there is a substantial amount of operator intervention required to ensure proper operation, often consisting of manual labor. Thus, as can be seen, operating biological systems is somewhat involved and requires extensive training and effort.

In comparison, a process such as ultrafiltration with polymeric membranes is relatively simple and easy to operate. Based on the past experiences during the test trials, the operators readily learned this new technology and were proficient within 2 weeks of initial startup. The process was able to run 24 hours without supervision and required little intervention, if any. In addition, although not completely impervious to upstream shocks, operation of a UF system can be recovered in the event that changes in wastewater influent or chemical treatment adversely affect the system. One notable exception is the irreversible fouling of the polymer membranes by exposure to high levels of cationic polymer. In this case, depending on the severity of the fouling, the membranes might have to be replaced.

7.6 Environmental Sustainability

One appealing aspect of biological waste treatment is the concept of environmental sustainability and reuse. Because the residual effluent is quite low in oil and grease and registers a low COD, it could be possibly reused in the plant either directly or indirectly. Further processing might be required, but it is possible to send the water back to the plant as a raw material. In addition, the sludge generated from the treatment process can be dispersed throughout the plant grounds, thereby eliminating solid disposal costs. If disposal limits set by the EPA (40 CFR Part 257) are not exceeded, then this becomes a viable solution. Based on current water costs at LEP in Lima Ohio, this amounts to a potential $140,000/year savings.

The UF system, in contrast creates a concentrated waste stream that must be dealt with separately. The retentate stream is collected over time and segregated from the permeate water. Eventually, this retentate water must be sent either for retreatment in the main batch tanks, or sent out of the plant as a concentrated waste stream, which usually incurs a waste disposal charge. Although the overall volume of retentate water generated is quite low (5% of initial feed water), it still increases the overall operating costs for the plant.

7.7 Regulatory Issues

Currently, the EPA's proposed regulations attempt to limit the amount of FOG that certain industries are allowed to discharge to the environment. The EPA has based this proposal on their belief that many organic pollutants have an affinity for the oil phase rather than the water phase. Thus, regulating FOG levels will effectively reduce the amount of organic pollutants discharged to the environment. However, there is currently some discussion that other parameters such as COD are a far better measure of the amount of organic compounds present in the water. As environmental regulations continue to become more stringent, in the future, the EPA may decide that the COD of wastewater effluent streams is a better parameter than FOG to monitor. Thus, given the possible regulatory outcomes in the future, the optimal solution for FOG removal should also reduce COD levels.

However, in this specific situation, the lowest-cost technology also seems like the most capable in regards to both FOG and COD reduction. The vendor for biological wastewater treatment systems estimates that the effluent would be essentially free of oil and grease and have a COD level of approximately 30 mg/L, based on the BOD levels in the effluent water. In these types of applications, COD is usually 2x-3x of BOD.[23] On an absolute scale, this COD level is quite low and most likely below any future COD regulations that the EPA would consider mandating. Thus, biological wastewater treatment is both a comprehensive and effective treatment technology that has the potential to help Ford meet both pending and future EPA wastewater regulations.

In comparison, although the polymer membrane system fully exhibited the capability of removing FOG levels below detection limits, it had a less significant effect on reducing COD levels, based on COD testing. Because UF is not able to remove surfactants and other small dissolved organics, based on TDS testing, the membranes are not a viable solution for reducing COD levels below 100 mg/L in wastewater effluent. Thus, although polymer membranes might help Ford meet pending EPA regulations, it may not address issues brought forth by future legislation.

7.8 Remaining Issues

Although we have assumed that the biological treatment system would be capable of processing the wastewater effluent generated at the Ford Engine plants, it is prudent and imperative to conduct further experiments both in the laboratory and plant to verify these assumptions. This will provide additional data and insights into the feasibility and effectiveness of this treatment technology and help improve the chance of success with this solution.

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[23] Personal Communication with William Gaines, Environmental Quality Office, Ford Motor Company.

CHAPTER 8 ENVIRONMENTAL PROJECTS AT AN AUTOMOTIVE COMPANY – ANOTHER PERSPECTIVE

As multinational companies face ever-increasing pressure in regards to their impact on the global environment, they are actively taking on programs to reduce their raw material consumption and emissions to the environment. They have been actively trying to reduce their total impact through various programs and initiatives. However, currently, many companies still evaluate environmental initiatives more by their pubic relation's value, rather than their total impact on the business operation. In particular, this was typically the attitudes and views expressed by certain personnel at Ford. However, much of this problem is due to the lack of well-developed metrics that would attempt to quantify the associated positive benefits of environmental initiatives. This chapter seeks to explore what other companies and industries are attempting in regards to these issues, understand what is currently done at Ford, and finally, various options for developing better ways to address this problem at Ford.

8.1 Established Environmental Metrics and Industry Benchmarking

Companies in other industries have begun to devise accounting standards and systems that would help quantify the business benefit any environmental issues. One example is Novo Nordisk, a Danish biotechnology/pharmaceutical company.

Novo Nordisk has published an annual environmental report regarding its manufacturing operations for the last 6 years. In this report, the company details how it has created new metrics that evaluate each of its plant's environmental performance during the year. These metrics are used to gauge the effectiveness of each plant's efforts to reduce resource consumption and meet annual environment performance objectives. This index, called the Eco-Productivity Index, or EPI, is defined as follows:

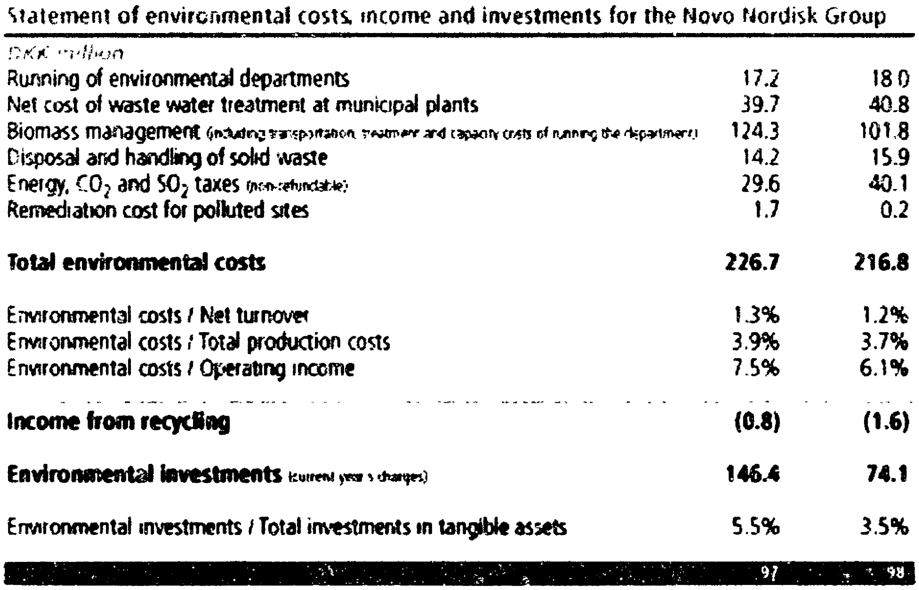
EPI = Turnover of Enzyme Business/Resource Consumption
(The year of 1990 was baselined as 100)

When first created, this metric was reported as an aggregate number of all of the company's operations. However, this metric was not able to monitor individual plants and their overall progress each year. To better understand how each site/operation contributed to this metric, a revised EPI was created last year:

EPI_{site} = [Actual amount of product recovered/
consumption of resource (water, electricity) for Current Year] *
[Consumption of Resource/
Actual Amount of Product Recovered for Previous Year]

The goal of this new metric was to understand each site's environmental performance and determine if it was making progress towards its specific goals and objectives. In addition, Novo Nordisk hopes that the EPI metric can provide a quick link between environmental performance and financial performance. In their environmental report, Novo Nordisk outlines the amount of money saved each year due to resource conservation, including water and energy. Figure 8.1 below is a sample of Novo's report:

Figure 8.1 Environmental Report from Novo Nordisk



Statement of environmental costs, income and investments for the Novo Nordisk Group

DKK million		
Running of environmental departments	17.2	18.0
Net cost of waste water treatment at municipal plants	39.7	40.8
Biomass management (including transportation, treatment and capacity costs of running the department)	124.3	101.8
Disposal and handling of solid waste	14.2	15.9
Energy, CO_2 and SO_2 taxes (non-refundable)	29.6	40.1
Remediation cost for polluted sites	1.7	0.2
Total environmental costs	**226.7**	**216.8**
Environmental costs / Net turnover	1.3%	1.2%
Environmental costs / Total production costs	3.9%	3.7%
Environmental costs / Operating income	7.5%	6.1%
Income from recycling	**(0.8)**	**(1.6)**
Environmental investments (current year's charges)	**146.4**	**74.1**
Environmental investments / Total investments in tangible assets	5.5%	3.5%
	97	98

After further research, it was learned that the company has attempted to try and link compensation incentives to non-traditional metrics such as the EPI[24]. This has helped to reinforce

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[24] Information obtained from the following web-site: www.novo.dk.

the fact that managers, leaders, and workers are going to be strictly judged not only by their specific unit's business performance, but also, by its environmental performance. These incentives drive changes in overall behaviors at the company in the right direction. In addition, these metrics allow management to quickly ascertain whether a manufacturing operation is making any progress towards its annual environmental objectives.

Because resources in Europe are extremely expensive relative to the US, corporations and businesses in Europe are extremely sensitive to these types of issues and take an active approach to reduce overall resource consumption. In an effort to be pro-active, Novo has implemented these environmental metrics to help meet these objectives. The program allows Novo to promote itself as a responsible corporate citizen that improves the communities it operates in. More importantly, these programs have a direct impact on the bottom line of the business. Thus, Novo Nordisk has viewed environmental issues as viable method to improving overall business results and as a model for other industries.

8.2 Analysis at Ford Powertrain:

Given the current background information and relevant work in this area, some investigation into the current practices at Ford was undertaken. This led to the following questions:

1. Rather than create the wastes in the first place, what measures can be taken to reduce the overall generation of wastewater? What are the current incentives for doing so?
2. Is there any benefit to purifying the water more than the regulated standard set by the EPA and local municipalities?

Before addressing these issues, it was important to understand the current systems that are in place. All of the information used in the analysis was obtained from the Lima Engine Plant. Although the information is specific to this plant, personnel indicated that the general accounting systems are standardized across many of Ford's Powertrain plants.

Because the plant produced engines for internal Ford customers, the facility is treated solely as a cost center. Thus, the overall goals and incentives each year are to reduce overall costs per unit engine produced. Within the plant itself, each operating division is grouped with many others and placed under a number of area managers. At Lima, wastewater operations are placed in Central Support Services for the plant. This area manager is held accountable for all of the budgets and expenses in a number of different groups throughout the plant. He has an annual budget that is allocated at the beginning of the fiscal year and is based on a target derived from previous performance and future expectations.

Although waste treatment costs are an explicit function of upstream waste generation, the annual operating budget is fixed and does not vary to changes in composition and volume of wastes. However, the area manager is usually evaluated on how well he/she is meeting the planned budget for the year, independent of upstream operations. Thus, the person responsible for wastewater operations has no formal organizational authority to enforce changes in policy that directly affect his operations.

In turn, because the people and operations that are creating the wastes have no incentives to reduce the amount of chemicals that are consumed. Although they may be asked to the amount of raw materials used in the plant, there is no formal mechanism to ensure that they are actively reducing the amount of wastewater created.

One way to alleviate this deficiency is to modify the accounting principles used for cost allocations. In theory, a better way to represent costs would be to charge each group in the plant a variable amount based on the aggregate amount of overall wastewater generated in the plant. Because it is literally impossible to fairly assess how much water is used in each part of the plant, it is simple and more equitable to allocate the costs to each section, based on the number engines they each produced (these statistics are already compiled). An example of this metric is as follows:

Water Charge = Total costs incurred for treating wastewater (including labor): X
Cost/engine = Water Charge/# engines produced: C
Department Cost = # engines produced*C

However, this charge should not be considered profit that is accumulated by the department head responsible for wastewater. His department is still treated like a cost center, where costs minimization remains the objective function. However, his overall budget is funded by the waste treatment charges incurred by the various departments throughout the plant. To ensure non-partiality, the internal accounting staff would be responsible for creating and maintaining the metrics used in this system. In addition, incentives would be needed to be devised to reward or penalize the various managers based on their overall performance regarding wastewater creation and costs savings.

Thus, this system would provide the financial metrics and appropriate incentives to track and reduce overall wastewater costs in an appropriate matter. It also helps to provide the economic justification for projects that would either lower wastes generation or improve overall operating inefficiency.

The above text addresses the first question regarding defining metrics that address true wastewater costs and how to track and reduce them. However, there still remains the question of what exactly is the benefit of purifying the water beyond the usual regulatory limits. Given today's current incentive structures, there is none. Local water municipalities charge a fixed rate of some $/gallon amount for water that is used by the plant. It does not charge a different set of rates based on the quality of the water discharged by the plant. The only exception is when the plant discharges water that does not meet local/EPA codes. Thus, the system is configured in a binary manner: compliance or non-compliance.

Thus, the only benefit for purifying water beyond the local code is to go to extreme: total water reuse. Thus, the water is purified to the level of where it can be reused again in the plant as a raw material feed. Thus, the plant becomes a zero-discharge facility. As noted in the previous chapter, based on water costs in Lima, this would amount to an estimated costs savings of $140,000/year. Technology to meet this level of water purity is readily available, such reverse osmosis or ion exchange. However, the capital investment required for additional processing will increase the overall operating costs associated with wastewater treatment. However, the costs will be eventually be reconciled by the amount of water saved in the plant. At an estimated cost of about $1 MM for a reverse osmosis or ion exchange system, this results in a payback of about 8 years.

In addition, by implementing a zero-discharge system, the plant has an opportunity to drive overall resource consumption down even further and operating efficiencies higher. These higher unit operating costs would be passed on to the individual groups throughout the plant.

Thus, again, the total plant would have an incentive to reduce overall water usage, to mitigate higher operating costs.

The above thoughts and ideas represent only one perspective on environmental issues and how they relate to business and industry. Although this might be one way to approach the issue, there are several others that deserve further discussion. The hope is that companies, businesses, governments, and citizens will continue to explore and actively debate these ideas and strategies, and most importantly, implement the best solutions.

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Alan Seiler, Mitco Chemicals
Richard Rower, LEP, Ford Motor Company
Byung Kim, Ford Research Laboratories, Ford Motor Company
William Gaines, Environmental Quality Office, Ford Motor Company

Web Sites:

www.novonordisk.de
www.epa.gov
Ford Intranet internal sites

APPENDIX A BASE CASE FOR ECONOMIC ANALYSIS

Base Case:

Volume of Water: 378 m^3/day (100,000 gallons/day)
Operating Constraints: 24 hours/day, 365 days/year
Operating temperatures and pressures: Flexible
Influent Feed: Pretreated oily wastewater, with the following characteristics:

Parameter	*Influent (mg/L)*	*Desired Effluent (mg/L)*
FOG	80	<15
TPH	60	<15
COD	500	<400
BOD	70	<70
TSS	100	<36
TDS	2000	<2000
Al	4.0	<1.0
Cu	<0.008	<0.60
Fe	1.5-2.5	<1.3
Ni	0.01	<0.50
Zn	0.15-0.30	<0.40
pH	8-9	8-9
Cationic polymer	N/A	N/A
Anionic polymer	N/A	N/A

Additional general evaluation criteria are as follows:

1. Total Fixed Capital Investment
   1.1. All associated equipment
   1.2. Installation and start-up costs
2. Operating Costs
   2.1. Utilities
      2.1.1. Water
      2.1.2. Chemicals/detergents
      2.1.3. Electricity
      2.1.4. Steam/Hot Water
      2.1.5. Air
   2.2. Equipment replacement costs
   2.3. Any other miscellaneous costs
3. Physical Dimensions
   3.1. Spatial Constraints
   3.2. Infrastructure requirements (water drains, concrete pad, etc.)
4. Estimated spare parts (speed controller, pump speeds, etc.)

Please state all assumptions used to devise a bid proposal.

APPENDIX B COST ANALYSIS

Technology Cost Evaluation

Base Case 100,000.00 gallons/day

Technology

UF:	Polymer	1.3
	Ceramic	2
	SST	3
Biological		B
Clay		C

Fixed Capital Investment				1.3	2	3 B	C*	
	Engineering Unit			275000	525000	563400	300000	
	Main Process Tank(30,000 gallons, P&T, p. 539)			50000	50000	0		
	Heat Exchanger			5000	20000	5000		
	Air Compressor						75000	
	Infrastructure/Buildings*							
		% of investment	50%	137500	262500	281700		
	Utilities	(assume all of these are present at the relevant plant) equipment costs included in infrastructure						
	Equipment Installation							
		Startup Expense		10000	10000	0		
New O&G Analyzer		Instrumentation and Controls		5000	5000	5000		5000
		Mechanical Installations						
		% of investment	25%	68750	131250	140850	75000	
		Electrical Installations						
		% of investment	10%	27500	52500	56340	30000	
		Utility Services		0	0	0	0	
		Land		0	0	0	0	
		Engineering and Supervision		0	0	0	0	
		Structural/Building construction		0	0	0	0	
				0	0	0	0	
		Freight		25000	25000	25000	50000	
		Contingencies						
		% of investment	10%	60375	108125	107729	$ 60,000	
Totals:				**$ 664,125**	**$ 1,189,375**	**$ 1,185,019**	**$ 590,000**	

Assume new building needs to be built for the UF units (25% of fixed capital costs, I averaged the highest and lowest together)
* Clay technology will only be evaluated in regards to operating costs

Operating Costs			1.3	2	3 B	C*	
Fixed							
	Labor	Already accounted for in normal plant operating costs					
Variable							
	Utilities						
		Air	$ 72	$ 720	$ 1,800		
		Steam	$ 70	$ 15,284	$ 70		
		Electricity	$ 17,535	$ 88,750	$ 44,302		
		Water	$ 188	$ 450	$ 188		
		Liquid Disposal Costs	$ 16,875	$ 24,526	$ 13,175		
	Chemicals						
		Soap	$ 5,000	$ 9,300	$ 9,850		
		Caustic	$ 5,248		$ -		
		Acid	$ 637		$ 1,750		
		Other					
	Spare Parts						
	Replacement Costs						
		Total Life	5	7	10		
		Total Costs	$ 180,000	$ 155,000	$ 110,000		
		Cost/year	$ 46,000	$ 32,143	$ 21,000	(includes maintenance costs for other parts of systems)	
Total			$ 91,625	$ 171,172	$ 92,134	$ 30,000	$312,630

10-year project assessment

Total Operating and Investment Costs

Discount rate: *10%*

Year	Polymer	Ceramic	SST	Biological	Clay
-	$ 664,125	$ 1,189,375	$ 1,185,019	$ 590,000	0
1	$ 747,420	$ 1,344,986	$ 1,268,777	$ 617,273	$ 284,218
2	$ 823,143	$ 1,486,451	$ 1,344,921	$ 642,088	$ 542,584
3	$ 891,882	$ 1,615,055	$ 1,414,143	$ 664,606	$ 777,484
4	$ 954,583	$ 1,731,968	$ 1,477,072	$ 685,086	$ 991,019
5	$ 1,011,455	$ 1,838,253	$ 1,534,280	$ 703,724	$ 1,185,143
6	$ 1,063,175	$ 1,934,875	$ 1,586,287	$ 720,659	$ 1,361,619
7	$ 1,110,193	$ 2,022,713	$ 1,633,587	$ 736,053	$ 1,522,051
8	$ 1,152,937	$ 2,102,537	$ 1,676,548	$ 750,048	$ 1,667,899
9	$ 1,191,795	$ 2,175,180	$ 1,715,622	$ 762,771	$ 1,800,468
10	$ 1,227,120	$ 2,241,155	$ 1,751,143	$ 774,337	$ 1,921,023
Total Accumulated Costs:	**$ 1,227,120**	**$ 2,241,156**	**$ 1,751,143**	**$ 774,337**	**$ 1,921,023**
% difference (relative to lowest one)	**58%**	**189%**	**126%**	**0%**	**148%**

All references for equipment costs were taken from Peters and Timmerhaus, Unit Operations in Chemical Engineering

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