Implementation of Enhanced On-Site Wastewater Treatment Systems in Toledo

Urban Affairs Center
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Executive Summary

Effective wastewater treatment is an important ecological and economic issue, especially in industrial areas along the Great Lakes. In Toledo more than 100 firms discharge 300,000 gallons of industrial wastewater a day. Most (88) firms have some type of on-site wastewater pre-treatment and meet the City's pollutant discharge limits. Given a weak economy and competition in the manufacturing sector, the potential benefits of modern, on-site wastewater systems have been overlooked by firms and under-considered as economic and ecological policy issues. This study examines 7 local firms to demonstrate the ability to degrade the organic wastes and also produce value-added chemicals that will add extra profit to the companies.

This study found:

- Most pre-treatment systems in Toledo and the vicinity areas are more than 10 years old and many are using ineffective or no wastewater treatment techniques. Often, the wastewater from Toledo companies can be degraded more effectively through system modification and improvement. High BOD, COD, and heavy metals are not properly treated on-site in most Toledo companies tested. .
- The companies can take advantage of the value-added byproducts, such as methane, ethanol, organic acids, and hydrogen—an alternative energy--generated in the improved systems, which will bring about the extra profits to the firms as well as reduced costs to the City.
- As Toledo industry grows, the discharge of organic/inorganic pollutants will increase, and better treatment systems are needed to meet the environmental regulations.
- Tests in UT's Microbial Biotechnology Lab show that enhanced on-site wastewater treatment of the by-products of Toledo industry degrades organic chemicals more efficiently and in cost-effective manners.

Therefore, we recommend:

1. A survey of wastewater pretreatment systems in all Toledo area companies.

2. The City should identify opportunities where investments in new wastewater pre-treatment systems, might render mutual benefit to the City and company, and potentially be willing to offer the financial benefits of a system to firms as part of an enticement package to encourage more effective treatment of industrial waste.

3. The City, manufacturing community, and University should form a consortium to:
    a. Explore the technical feasibility, legal issues, and mutual economic benefits to the City and firms,
    b. Create pilot projects showing cost effectiveness of new systems and the benefits of secondary product sales including hydrogen for fuel cells.
    c. Secure appropriate funding to assist in the implementation of such systems, including creating fiscal incentive for companies.

Introduction

The project has initiated in fall 2002 in order to improve the industrial wastewater treatment systems in Toledo. Effective wastewater treatment is an important issue in the industrialized Toledo region and the Great Lakes in general. More than 100 companies in the City of Toledo discharge 300,000 gallons of industrial wastewater a day. While most (88) firms have on-site wastewater pretreatment, many of these systems are not the most modern nor cost-effective. Improvements in bio-technology and changes in the demand for various products may have also created for secondary market opportunities for the salvaging and sale of industrial waste bi-products. This study examined five local firms to explore whether there is an opportunity to create mutual benefit to firms, government agencies, and the public.

In order to support the proposed ideas, experiments have been performed in the Microbial Biotechnology Lab at The University of Toledo. In these experiments, the industrial organic wastes are biologically degraded and at the same time value-added chemicals such as propionic acid or hydrogen that can be used as an alternative energy source, have been produced. Such insights beg the question; How large and widespread is this unrealized opportunity? To answer this, we need a more extensive examination of the wastes of local firms, and to lay the groundwork for a collaborative to mobilize resources to take advantage of these unrecognized opportunities for mutual benefit.

Research Questions

The research question that have guided this project is:

1. Can state-of-the-art pre-treatment of industrial waste be applied to local industrial firms create opportunities for increased firm profitability and reduced costs of treatment for the local governmental agencies?

Toledo has unique industrial structure in a sense that it encompasses an unusually wide variety of industries within the city boundaries. Unlike many other cities where most manufacturing factories are spread outside the city, Toledo has many factories concentrated within and near the city boundaries ranging from food to heavy machinery and oil refinery companies. Each company produces different chemicals and each chemical needs to be treated in specific ways depending on the chemical characteristics. Improper treatment of these industrial wastes can be a threat to the environment and city life. Currently the City's wastewater treatment facilities must take a heavy burden of terminal treatment of organics and heavy metals to reduce their concentrations before discharging the wastewater to the Lake. The terminal treatment at the City facilities is becoming more challenging due to the many number and high concentrations of different chemicals.

In order to reduce the rising impacts of industrial wastes on the environment, each manufacturing site will have to operate an on-site wastewater pre-treatment system that is specifically designed for the wastes that each company produces. The more effective pre-treatment is used, the better will it help the City reduce the burden of treating the number and concentration of chemicals.

Thinking further about question #1, we have to recognize that the answer at each firm is unique to its operations. So, to address the question, we have to examine the chemical- and site-specific pre-treatment systems existing, and those that might be created for each company. That question has two parts: technology and the cost. Laboratory research must be carried out to analyze the wastes and to design and operate a system specific to the chemical conditions of the waste. Once the design specifications are determined, a replacement system could be proposed, and cost estimates for creation and operation can be estimated. Obviously, the cost must be reasonable for the companies to be willing to accept the proposed new system.

This research and its findings beg the question; how to get more companies involved in this project. If the company is committed to improve its on-site wastewater treatment system, it has to support the cost for the research for system development and for the installation of a system. In the current economic conditions, it is hard to motivate the companies to commit the support for the project. In Methodology part below, we have suggested an approach that can motivate the companies.

Methodology

In order to address the research question, experiments and interviews with firm executives were undertaken.

1.- Lab experiments
Although there are many different chemical species in the wastewater to be treated, these chemicals can be largely categorized into three groups: 1) Organic chemicals, 2) Inorganic chemicals, 3) Heavy metals. Initially, we focused on organic chemicals because of their high discharge rates, low removal efficiency, and their considerable impacts on the environment. Compared to organic chemicals, inorganic chemicals and heavy metals are low in the discharge amount and relatively easily treated on-site, for example, using **adsorption** techniques. Organic chemicals are especially attractive for research analysis because the value-added chemical byproducts can be produced during the pre-treatment processes.

There are many companies that produce organic chemical wastes in Toledo. The organic compounds these companies produce are high in polysaccharides, protein, organic acids, and oils. Currently these organic compounds are not pre-treated in most companies. Where they are pre-treated, it often is through precipitation, neutralization, sedimentation, or filtration, which are not appropriate methods for organic compounds.

An experimental system has been set up in the Microbial Biotechnology Lab at The University of Toledo *to demonstrate that these wastes can be more effectively degraded and simultaneously produce useful chemicals*. In our anaerobic digestion system, various organic wastes are processed to produce value-added chemicals, methane, or hydrogen during biological degradation. As a model case, a food processing waste from a milk company has been successfully processed to produce propionic acid and hydrogen. Propionic acid is an important component in many chemical processes, especially in pharmaceutical industry. Hydrogen can be used as a cost-effective alternative energy source.

1.1 Analysis of wastewater

Prior to the experiment, untreated wastewater samples were collected from 7 local companies for chemical analysis. The biological oxygen demand (BOD), chemical oxygen demand (COD), pH, and concentrations of organic and inorganic chemicals, and heavy metals were our primary concern. These were measured using GC, HPLC, and TOC located in the Department of Chemical and Environmental Engineering. The results are summarized in Table 1. Company names are not revealed consistent with a commitment between the companies and the PI.

All the companies tested were discharging various high BOD and COD wastewaters ranging from 52 mg/L to as high as 8670 mg/L for BOD, and from 113 mg/L to 12,800 mg/L for COD. Because biological and chemical contaminants directly affect the contamination of the ecosystem, high BOD and COD must be handled properly. According to our analysis, most companies are not practicing proper treatments for BOD and COD. Further, our analytical data indicate that all the samples tested, except one (Company D), involved discharges that included various heavy metals. These heavy metals are easily accumulated in the ecosystem and can be toxic even at trace levels. Therefore, although the current discharge concentrations are below the city limits, a more thorough or proper treatment is required if the City is to meet its goal of protecting the water resources from heavy metal contamination.

A wide range of pH was also observed in the company samples from acidic (pH 4.6) to basic (pH 9). The wastewater pH balance must be controlled at the manufacturing site because the pH imbalance affects the biological activities and causes corrosion in the on-site (?) water/wastewater transport systems.

The other hazardous chemicals including phenol, benzene, and sulfides, were also detected at low concentration levels in some samples.

Table 1- Chemical Analysis Results of the Wastewater Samples

Major Manufacturing Activities	Untreated Wastewater Conditions	Chemical Compounds and Heavy Metals Detected
Company A Kitchen Utensils	pH = 4.6 – 6 BOD =1200 mg/L. COD = 4000 mg/L	Oils = 260 mg/L Heavy Metals: Nickel 0.03 mg/L
Company B Oils & Filters	pH = 7.87 BOD = 52 mg/L COD = 336 mg/L	Oil & Grease 30.3 mg/L Phenols = 1.48 mg/L Benzene = 2.4 mg/L Heavy Metals: Cadmium < 0.002 mg/L Chromium = 0.007 mg/L Lead = 0.009 mg/L Mercury = < 0.0002 mg/L Nickel = 0.05 mg/L
Company C Leather	pH = 7.7 – 8.9 BOD = 2000 mg/L COD = 2100 mg/L	Oil and Grease = 12.7 mg/L Heavy Metals: Copper = 0.05 mg/L
Company D Milk	pH = 5.2 BOD = 8,670 mg/L COD = 560 mg/L	Oil & Grease = 7.9 mg/L Phenol = 0.132 mg/L Sulfide = 0.45 mg/L Heavy Metals: not detected
Company E Pickling	pH = 5.29 BOD = 264 mg/L COD = 560 mg/L	Phenols = 0.44 mg/L Sulfide = 0.47 mg/L Heavy Metals: Chromium = 0.1 mg/L Copper = 0.7 mg/L Nickel = 0.2 mg/L
Company F Metal Polishing	pH = 7.74 BOD = 48 mg/L COD = 133 mg/L	Heavy Metals: Chromium, hexavalent = 0.8 mg/L
Company G Polymers	pH = 7.3-9 BOD = 150 mg/L COD = 250 mg/L	Sulfide = 0.02 mg/L Heavy Metals: Cadmium = 0.001 mg/L Chromium = 0.01 mg/L Copper = 0.012 mg/L Lead = < 0.004 Mercury = < 0.0002 Nickel = < 0.02 mg/L

In Table 2, the current status of the pre-treatment system of each company and the problems are summarized. Company A manufactures kitchen utensils. This company uses a large amount of organic solvents and inorganic compounds for surface treatment and coating generating a great amount of organic chemical wastes. Despite high BOD and COD levels, which indicate severe organic/inorganic chemical contamination, Company A practices no proper pre-treatments other than neutralization. Although neutralization helps reduce the pH imbalance of the wastewater, the wastewater discharge with high BOD and COD still severely contaminates the water resources. There is also a high discharge of oils that may damage the ecosystem.

Table 2. Tests Results, City Limits, and Problems of the Current Systems

Firm & Sector	Test Results (mg/L)	City Limit (mg/L	Current on-site Pre-treatment	Problems
Company A Kitchen Utensils	pH = 4.6 – 6 BOD =1200 COD = 4000 Oils = 260 Heavy Metals = Yes	 <300 <600 <250 under city limits	Neutralization/pH control	➢ High BOD indicates high biodegradable organic compounds & major water contamination. ➢ High Oil concentration. ➢ Although< limits, heavy metals are detected.
Company B Oils & Filters	pH = 7.87 BOD = 52 COD = 336 Oil/grease=30.3 Phenols=1.48 Benzene=2.4 Heavy Metals - Yes	 <300 <600 <250 under city limits	Neutralization/pH control Activated sludge Oil separation Sedimentation Sedimentation sedimentation	➢ The active sludge process is outdated. ➢ Sedimentation processes for chemicals and heavy metals are outdated.
Company C Leather	pH = 7.7 – 8.9 BOD = 2000 COD = 2100 Oil/grease = 12.7 Heavy Metals = Yes	 <300 <600 <250 under city limits	**No Pretreatment**	➢ High pH. Caustic. ➢ High BOD & COD. ➢ Although < limits, heavy metals are detected. ➢ No Pretreatment.
Company D Milk	pH = 5.2 BOD = 8,670 COD = 560 Oil/grease = 7.9 Phenol = 0.132 Sulfide = 0.45 Heavy Metals= not detected	 <300 <600 <250	**No Pretreatment**	➢ Low pH. Acidic. ➢ High BOD & COD. ➢ Toxic chemicals – phenols & Sulfides. ➢ No Pretreatment
Company E Pickling	pH = 5.29 BOD = 264 COD = 560 Heavy Metals = yes	 <300 <600	Neutralization/pH control	➢ High BOD & COD ➢ Heavy Metals present
Company F Metal Polishing	pH = 7.74 BOD = 48 COD = 133 Heavy Metals = yes	 <300 <600 under city limits	Neutralization/pH control Chemical precipitation	
Company G Polymers	pH = 7.3-9 BOD = 150 COD = 560 Heavy Metals -= yes	 <300 <600 under city limits	**No Pretreatment**	➢ High pH: Caustic ➢ High BOD & COD ➢ Heavy Metal Present

Company B is an oil refinery company. This company, among the 7 tested companies, seems to be the only company that is the most properly practicing the pretreatment. It practices the activated sludge process to reduce biodegradable organics (i.e., BOD) and sedimentation for removing the chemicals and heavy metals (i.e., COD and heavy metals). However, their current activated sludge process must be significantly updated to improve the degradation efficiency and to produce value-added chemicals. In addition, the current sedimentation process uses both chemical precipitation and adsorption. The chemical precipitation introduces chemical precipitants that are another form of contaminant in many cases. The chemical precipitation needs to be replaced with a physical adsorption process that can effectively remove the chemicals and heavy metals without introducing toxic chemicals.

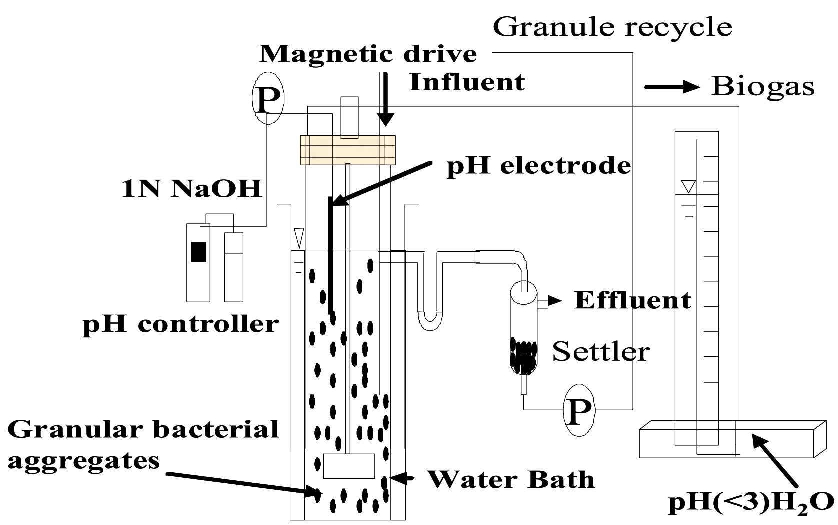
Companies C, D, and G have no pretreatment systems. These companies produce a large amount of both organic and inorganic chemicals, and wastewater is acidic (company C, pH 5.2) and basic (company D, pH 7.7 -8.9 and company G, pH 7.3 - 9). These companies need a pretreatment system for neutralization, and the removal of chemical compounds and heavy metals.

Company E is similar to Company A. The wastewater has high BOD and COD, but no specific pretreatment is performed for the chemicals. Heavy metals are detected, but no pretreatment is performed for heavy metals either. Again, the neutralization is not a decontamination process, but a mere adjustment of acidity.

1.2 Acids and hydrogen production form the wastewater

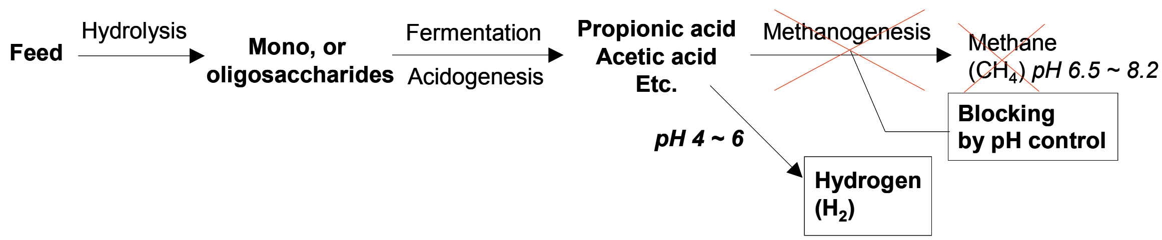
Food processing wastes were collected from Company D in order to demonstrate the possibility of producing value-added chemicals from the wastes. The wastes were transported to the Microbial Biotechnology Lab in the Department of Chemical and Environmental Engineering (Figure 1) for anaerobic digestion.

Figure 1. Schematic of the anaerobic digestion system for food processing waste



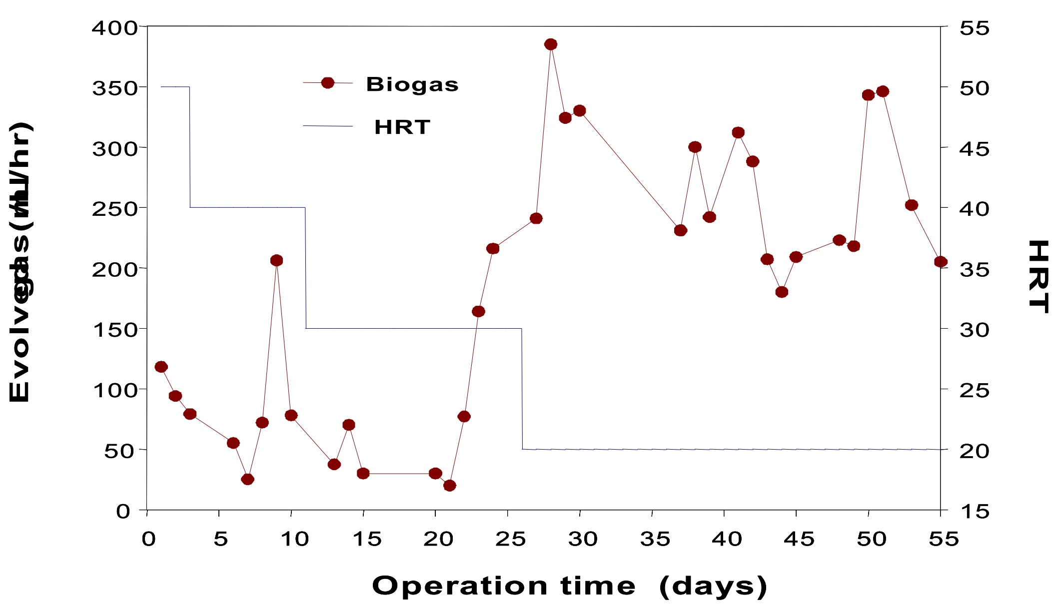
The anaerobic reaction for the acids and hydrogen production proceeds as shown in Figure 2. Acids (acetic acid, propionic acid, butyric acid, etc.) were produced through fermentation. Without the pH control, methane is produced from the acids through methanogenesis. The pH in the reactor was controlled at 4 – 6 to suppress the methanogenesis and to enhance hydrogen production.

Figure 2. Acids and hydrogen production by pH control



The optimum conditions for acids and hydrogen production were determined. During the course of reaction, the pH of the reactor was maintained at pH values of 5 – 5.3 for optimum hydrogen production. The concentrations of acetic acid and propionic acid were measured. The produced gas was collected and analyzed once a day for two months. Figure 3 shows the total gas produced from the reactor in terms of operation time. The gas production began to increase rapidly 20 days after the beginning of the reaction. The maximum gas production rate was observed at 385 mL/L/hr. In average, the hydrogen production rate was 4.4 L H_2/L/day, which is *sufficient for 1 – 2 kW fuel cell operation.*

Figure 3. Biogas production rate



In Table 3, the experimental results are summarized for acids and hydrogen. Acetic acid was produced predominantly, and the biogas consisted of hydrogen and other gases such as CO_2 and ammonia. The hydrogen concentration was between 41 – 63 %. Methane was not detected.

As the commercial value of propionic acid is high compared with acetic acid in the areas of fine chemical manufacturing and pharmaceutical industry, a large production of propionic acid can lead to the extra economic benefits. In order to increase the production of propionic acid over acetic acid, two different approaches were attempted using a 500 ml anaerobic reactor. First of all, the enzyme inhibitors were added into the system to deactivate the enzymes that produce acetic acid. Reduction of acetic acid was thought to help redirect the metabolic energy fluxes toward the propionic acid production.

Table 3. Summary of the production of acids and hydrogen

Time (Day)	Acetic acid (mg/L)	Propionic acid (mg/L)	Biogas (ml/L/hr)	H_2 rate (ml/L/hr)	H_2 %
29	372	0	300	183	61
37	1014	0	216	116	54
43	1448	117	206	84	41
50	1499	608	341	214	63

Secondly, the reactor pH was maintained at 7 to suppress the byproduct inhibition and the biogas (hydrogen, methane, CO_2, etc.) production. The acid production stops when the pH value reaches around 4.5 at which the cell metabolism is inhibited by the low acidity in the reactor. By maintaining the pH at 7, it was thought that the acidic byproduct inhibition might be prevented, so that more acids (preferentially propionic acid) are produced. Furthermore, by suppressing the gas production, more propionic acid would accumulate before it was converted to the biogas. Consequently, as the production of acetic acid and biogas reduced, the propionic acid production was expected to increase.

Lactose was fed into the anaerobic reactor, and the production rates of the acids were measured. At the beginning of reaction, 0.3 mM of benzoate was added into the system. Benzoate is known to inhibit the acetic acid-producing enzymes. In the first run, the pH was not controlled. Without control, pH was observed to decrease from 7 to 4.5 during the exponential growth phase. The acid production stopped in about 20 hours from the beginning of the experiment due to the acidity of the reactor. During the course of experiment, the concentrations of the both acids were measured every 4 hours (Figures 4 and 5).

As shown in Figures 4 and 5, both the production rate and final concentration of acetic acid reduced with 0.3 mM benzoate, while the production rate of propionic acid increased as we expected. The slop of the curves representing the production rate of acid became steeper with 0.3 mM benzoate, which indicates the increase of production rate of propionic acid.

Although the production rate of propionic acid successfully increased with the addition of benzoate, the total (or final) amount of propionic acid remained the same at 3.5 g/L as in Figure 5. The production of propionic acid discontinued due to the acidity in the reactor, which is called "product inhibition." In order to increase the final concentration of propionic acid as well as its production rate, the reactor pH was controlled at 7 with 0.3 mM benzoate. As shown in Figure 6, it turned out that the acetic acid production increased, while the propionic acid production decreased—an outcome opposed to our expectation.

Figure 4. Decrease of the acetic acid production rate with 0.3 mM benzoate

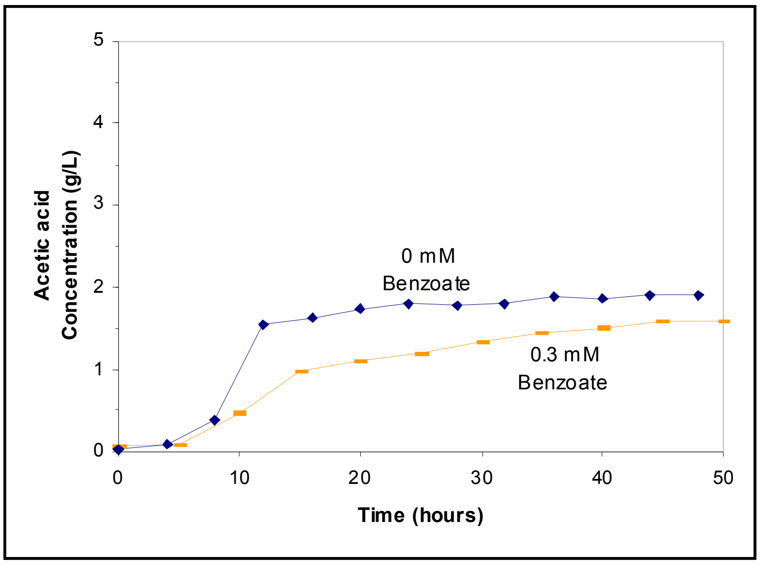
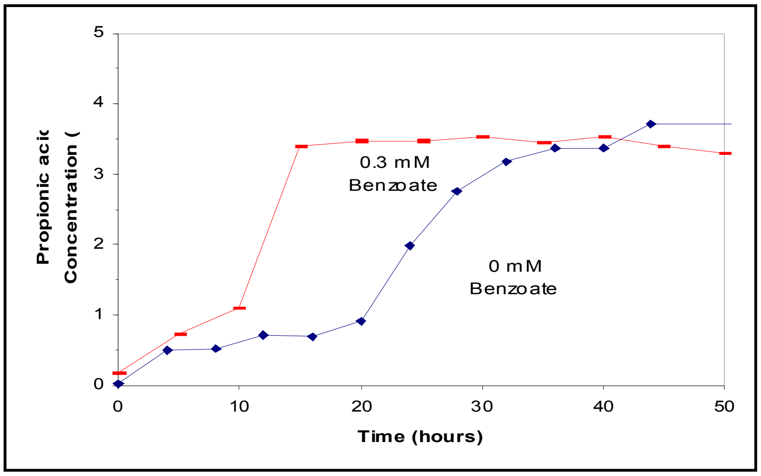


Figure 5. Increase of the propionic acid production rate with 0.3 mM benzoate



As shown in Figures 6 and 7, when the pH was controlled at 7 with 0.3 mM benzoate, both the propionic and acetic acid productions decreased beneath those without benzoate. Regardless of the presence of benzoate (0 mM or 0.3 mM), the acid concentrations at pH 7 turned out to be lower than those with the uncontrolled cases. With pH control, it appears that the effect of enzyme inhibition for acetic acid reduced and also the overall cell metabolism decreased compared to the pH-controlled cases. It indicates that benzoate did not inhibit the acetic acid producing enzymes at pH 7 as much as it did when the pH was lower than 7. More in-depth study is needed to increase the final amount of propionic acid.

Figure 6. Acetic acid production under pH-controlled conditions

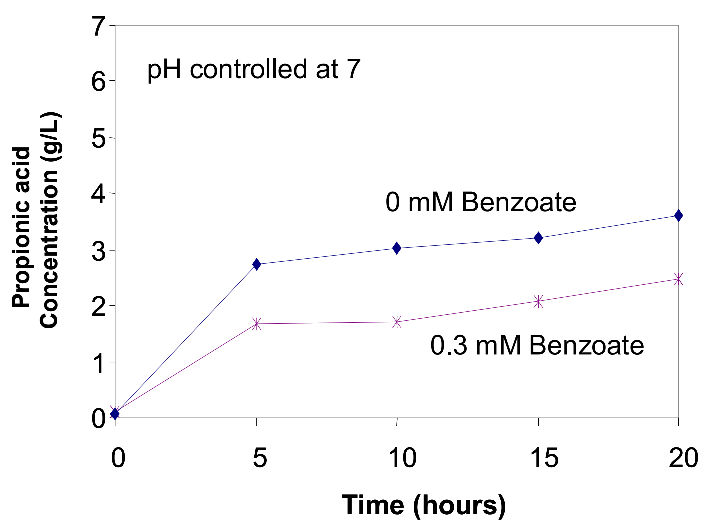
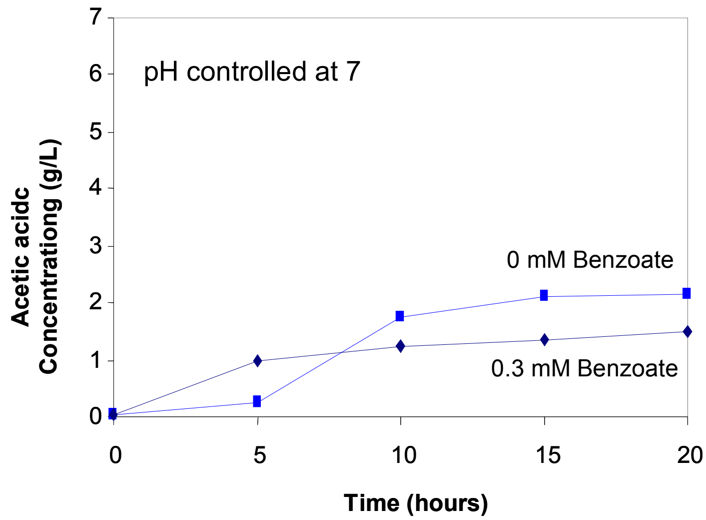


Figure 7. Propionc acid production under pH-controlled conditions



In Table 4, the final concentrations of acetic acid and propionic acid are summarized for pH controlled and uncontrolled cases. The final concentration of propionic acid was observed to marginally increase only in the pH uncontrolled and with 0.3 mM benzoate case.

Table 4. Comparing acid production for pH controlled and uncontrolled cases

PH condition	Acids	Amounts	Change
PH uncontrolled	Propionic Acid Acetic Acid	3.5 g/L 1.5 g/L	0.85% increase 12% decrease
PH controlled	Propionic Acid Acetic Acid	2.1 g/L 1.2 g/L	45% decrease 40% decrease

Consequently, the production rate of propionic acid was successfully increased with 0.3 mM benzoate without pH control, but the pH control for increasing the final propionic acid concentration appears to be unsuccessful. More in-depth study is necessary to increase the total production of propionic acid.

2. **Company interviews**

The results of these analyses were shared with company officials. While there clearly is a need for more thorough and modern pre-treatment efforts by these firms, executives report being reluctant to the investment for improving the current systems or installing a new system due to the tight economic situation. This suggests that if effective pretreatment is to occur, attractive incentives must be presented in order to get the companies involved more actively in this project.

The firm executives also noted that although the experimental results shown above are promising, the system was too specific and the production rates of hydrogen or propionic acid were not high enough to motivate the companies to invest. More in-depth study is necessary to make the system more effective. Before firms invest they would require demonstrations of a small-scale system (as opposed to experimental activities) to show how effectively such systems could degrade the organic wastes and also produce value-added chemicals that will add extra profit to the companies. Demonstrating the effectiveness of the technology and the cost-benefits of such activities, is a logical precondition to motivating the companies to update of their systems.

Findings

- Many companies in Toledo are using ineffective or no wastewater treatment techniques.
- In many cases, the wastewater from Toledo companies can be degraded more effectively through system modification and improvement.
- High BOD, COD, and heavy metals are not properly treated on-site relative to contemporary standards in most Toledo companies tested in this project.
- Local companies are reluctant to improve their systems or install a new system.
- The lab-scale improved wastewater pre-treatment system effectively degraded organic wastes, and produced propionic and acetic acids and hydrogen that can be used for chemical industry and fuel cell operation to generate electricity.
- Demonstration of a small-or pilot-scale system treating the industrial wastes and operating a fuel cell will be needed to motivate more companies towards the system improvement.

Policy Implications and Recommendations

A logical precursor to advocating corporate and environmental change or reform is to demonstrate the existence of a problem, and where possible to perform the experiments and analysis that indicates a potential solution to that problem. In the best of situations, one may identify a potential policy solution that can render mutual benefits for the firm, the governmental jurisdiction, and its citizens. This study indicates that potential to create effective social, economic, and ecological policy. What is needed next is the creation of political will to encourage and to help fund further work specifying the size of the economic opportunities suggested by these experiments.

The experiments described above suggest that there are more effective ways to treat industrial waste than partial pretreatment on site and then “socializing” the cost of remaining treatment by dumping waste into the public sewer system for the City and its citizens to remediate. The key to this transition would be the create incentives to industry—through secondary products and perhaps through governmental incentives. A small-scale or pilot system is necessary to demonstrate the economic benefits of secondary products to the firms. For the government to provide incentives, it is necessary to determine the economic benefits to the City of a reduced chemical load at the sewage treatment facility, and to be willing to share those benefits with firms.

Therefore, we recommend:

1. A survey of wastewater pretreatment systems in all Toledo area companies.

2. The City should identify opportunities where investments in new wastewater pre-treatment systems, might render mutual benefit to the City and company, and potentially be willing to offer the financial benefits of a system to firms as part of an enticement package to encourage more effective treatment of industrial waste.

3. The City, manufacturing community, and University should form a consortium to:
    a. Explore the technical feasibility, legal issues, and mutual economic benefits to the City and firms,
    b. Create pilot projects showing cost effectiveness of new systems and the benefits of secondary product sales including hydrogen for fuel cells.
    c. Secure appropriate funding to assist in the implementation of such systems, including creating fiscal incentive for companies.

The PI has taken two steps toward the creation of such a consortium and pursuit of the above noted agenda. In concert with Mr. Dave Beck at EISC (Center for Innovative Food Technology, 2600 Dorr St., Toledo, OH 43607) and Mr. Dan Birmingham at SOFCo (Fuel Cell and Processor Solutions, 1562 Beeson St., Alliance, OH 44601), he has discussed the development of a waste treatment system that produces hydrogen for fuel cell operation. In this system, organic wastes are degraded by bacteria and hydrogen or methane is produce as a byproduct in our anaerobic digester. The produced gases are further processed to a reformer and separator to produce pure hydrogen. The produced hydrogen will be used for a fuel cell to generate electricity. It is expected that the cost saving from more effective degradation of wastes and the benefit of electricity from the waste will be a good incentive for the companies. One small-scale system is expected to generate 2-6 kW of electricity.

As a second step, a proposal for developing a demonstration unit was written by UT (Dr. Martin Abraham, Dr. Dong-Shik Kim, and Dr. Maria Coleman), Mr. Dave Beck at EISC, and Mr. Dan Birmingham at SOFCo, and submitted to State of Ohio's Third Frontier Action Fund in July 2003. While these are limited initial steps, they demonstrate the potential for collaboration and the opportunity to build a more effective and profitable manufacturing community, and to create new economic opportunities for that community and the citizens of the region.

Conclusion

This work suggests that there is an opportunity to create multiple and mutual benefit to industrial firms, the City, local citizens, and the environment. Improving the wastewater pre-treatment systems is necessary for both economic and environmental reasons. As the Toledo industry grows and the discharge of hazardous materials increases, the demands for improved systems is increasing. It is appropriate to further investigate and demonstrate the extent to which improved systems can degrade the pollutants better and also provide extra benefits of value-added chemicals and electricity through a fuel cell. More in-depth research is necessary to develop the systems that fit the uniqueness of Toledo industry, but the opportunities for environmental improvement and increased economic development identified herein can only be ignored or overlooked at our own peril.