

# The Aerobic Biological Treatability Of A High Strength Mixed Petrochemical Industrial Sludge

By

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B.A.Sc., McGill University, 1993

A Thesis Submitted In Partial Fulfilment Of

The Requirements For The Degree Of

Masters Of Applied Science

in

The Faculty Of Graduate Science

(Department Of Civil Engineering)

We accept this thesis as conforming  
to the required standard

The University Of British Columbia

October, 1995



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### **Abstract:**

Investigations were performed on the aerobic biological degradation potential of a high-strength, industrial sludge from the Chatterton Petrochemical site in Delta, BC. The sludge was located at the bottom of one of the wastewater treatment equalization lagoons. The lagoon was used to store process water and on site drainage from the Phenol processing plant operations. The plant had been in operation from 1961 to 1991. The sludge contained high concentrations of: Phenol, Diphenyl, Diphenyl Ether, Diphenyl Methane and Xylene and had a Total COD of over 250 000 mg/L. It also contained over 1000 mg/L of copper and cobalt.

Treatment was initially attempted using a Modified Batch Process (MBP). Nine batches were run, to determine the best initial sludge loading level in the treatment system and to assess the degree of treatability of the waste mixture. In each set of experiments, a control was run to determine the degree of volatilization of the organic compounds from the waste. Twenty litre batches, having been diluted up to ten times, were run for more than forty days. In later batches, due to microorganism growth problems, both ammonia and phosphorus were added to the system; phosphorus was needed both for the growth of microorganisms and the precipitation of dissolved copper. The performance of the systems was monitored using Total COD, Total

BOD<sub>5</sub> and the concentration of selected target organics present in the mixture.

The most notable batch data resulted from a reactor loaded with an initial Total COD of approximately 30 000 mg/L. All the organic compounds of the sludge were removed from the mixture to below the detection limit of the Gas Chromatograph and the Total BOD<sub>5</sub> was reduced to a negligible concentration. The success of the run was attributed, in part, to the high concentration of phosphorus present in the system. The concentration was 100 mg/L higher than the nutrient requirements of the culture and the elevated nutrient loading apparently resulted in the precipitation of much of the dissolved copper present in the reactor.

The control showed that when the system was run under ideal conditions, the loss due to volatilization could be limited to less than 5%, based on Total COD.

The system was then modified to operate as a True Batch Process (TBP). Treatment was attempted by keeping 75% of the previous run's final product in the reactor, while inputting a new load of sludge and dilution water to make up the volume difference. Results from the run indicated that treatment kinetics of the new system were three time faster than the best batch run based on Total BOD<sub>5</sub> degradation. All of the organic compounds had been

removed to below the detection limit of the Gas Chromatograph in the end product sludge. However, questions remained about the accumulation of copper in a true batch treatment system.

Pretreatment of the sludge to remove copper may be necessary to achieve the high Total BOD<sub>5</sub> removal rates seen in the true batch system.

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### **Acknowledgments:**

The author would like to thank those people who without their assistance this thesis would not be possible.

Firstly, Professors Atwater and Mavinic who provided advice, guidance, technical review and most of all encouragement.

To Corky, who always supported me and understood why I always had to be at the computer on sunny Sunday afternoons.

To Susan, Paula and Jufung who always provided advice and helped analyze sludge samples no matter how revolting they looked.

To Dean, who always provided technical advice and solutions that would turn a problem into easy solutions and also for making those long days in the environmental lab a lot more exciting then they should have been.

Finally and most of all, thanks to Mom, Dad, Big, Bam and the wonderful recent additions to the family Nick, Craig, Corky, Mr. Max, Mr. Riley and miss mufette; who always believed I could succeed.

## 1. Introduction:

The Chatterton Petrochemical site is located along River road in Delta, British Columbia. It sits on the banks of the Fraser River. A phenol processing plant originally owned by Dow Chemical was in production on the site from 1961 to 1991. In 1981, the plant was sold to a conglomerate of companies including B.C. Sugar.

Two Lagoons were constructed on the site in order to treat and store contaminated water, groundwater and sludges generated during the process plant's operations. The lagoons were part of the on site wastewater treatment plant system.

The first lagoon was used to store and dewater waste biomass from the biological oxidation treatment plant.

The second was a wastewater equalization lagoon. It insured a constant flow into the treatment plant. This lagoon is located in the north west corner of the Chatterton Petrochemical site. It was designed with a 0.45 metre compacted silt liner extending across the base and up the impoundments. It could hold up to two million US Gallons ( $7570 \text{ M}^3$ ) of process water. The lagoon has a rectangular shape of 55 M by 70 M. The total depth of the lagoon is approximately 3 M and the sludge area is in the order of  $3\,500 \text{ M}^2$ . The lagoon originally received process water and on

site drainage. On some occasions it has been reported that it received some sludges from the sumps and catch basins.

In 1991, the Chatterton Petrochemical Corporation shut down the phenol processing plant. Many of the building and holding tanks are presently being dismantled and disposed of. The site is being remediated in order to be sold. The treatment plant is still in operation, treating groundwater. The second lagoon is presently used to store groundwater when the plant is not in operation or not discharging effluent.

During the thirty years of operation of the treatment system, there has been an accumulation of sludge at the bottom of the second lagoon. It has been found to contain large concentrations of organic chemicals and heavy metals.

In 1994, Golder Associates Inc. investigated the lagoon and determined the volume of sludge at the bottom of the lagoon to be approximately  $1\,750\text{ M}^3$ , based on an average sludge depth of 0.5 M and surface area of approximately  $3\,500\text{ M}^2$ . Analytical testing of the sludge was performed by Golder and had previously been tested by the Chatterton Petrochemical Corporation.

Table 1.1 shows the extreme concentration and diversity of organic chemicals and heavy metals contained in the sludge.

The Chatterton report in 1992 attributed the high BTX (Benzene, Toluene and Xylene) concentrations in the sludge to the heavier

than water organics such as phenol, diphenyl, methyl diphenyl and diphenyl oxide, forming heavier than water oily

Parameter:	Golder Study (1994)*:	Chatterton (1992)**:
Moisture Content(%):		
Range	73.3 - 88.4	
Mean	84	89.9
Standard Deviation	6	
Copper (mg/Kg):		
Range	4 500 - 58 400	
Mean	19 700	9300
Standard Deviation	19 900	
Cobalt (mg/Kg):		
Range	3 700 - 12 100	
Mean	6 610	6900
Standard Deviation	2 980	
Phenol (mg/Kg):		
Mean	4 630	3700
Standard Deviation	2 060	
BTX Mean (mg/Kg):		
Benzene		13 000
Toluene		92 000
Xylene		18 500

**Table 1.1 : Comparison Sludge Characteristics. \* Golder Associates Inc. (1994) \*\* Chatterton Petrochemical Corporation (1992).**

globules which would trap the BTX. It was observed that an iridescent slick floated to the surface when the bottom of the lagoon was stirred. Therefore, there was little chance for the organics to escape through volatilization.

Golder obtained five core samples of the lagoon using a boat dragged across the water/sludge surface. The samples were obtained using a hand coring device.

The variability of the results of the sludge show the non uniformity of the mixture. There exists many distinct pockets in the sludge with different concentrations of organics and metals. Each sample is independent and the standard deviation should not be looked on in terms of accuracy, but in terms of showing the diversity of the sludge.

The sludge is considered a Special Waste under British Columbia environmental regulations due to the high organics and metal content. It cannot be legally disposed in British Columbia. Therefore, a final disposal site would have to be found in the United States. This would incur high transportation and tipping fees in the neighbourhood of 1000 dollars a tonne.

In March of 1994, a project proposal was presented to Professor Atwater of the Civil Engineering Department of the University of British Columbia. It proposed looking at the possible aerobic biological treatment of the sludge. The hope was to degrade the organic content of the sludge and enable the final product to be disposed of in an industrial landfill and the effluent released to the river.

The first step was to perform preliminary analysis of the sludge in order to confirm the findings of the Golder report. Five grab samples were taken, each consisting of 100 ml. The samples were taken from the northwest end of the lagoon. The water level was

low so it was possible to go 1 meter into the lagoon. The samples were taken at various places along the north west edge of the lagoon. The following table shows the preliminary results of the analytical investigation of the sludge.

Parameter:	U.B.C. Initial Sludge Analysis
Moisture Content (%):	96.9
COD (mg/L):	239 959
Copper Concentration (mg/Kg):	536
Cobalt Concentration (mg/Kg):	276

**Table 1.2: Initial investigation of the Chatterton Petrochemical sludge**

Table 1.2 shows that the analytical results obtained differed considerably from those of both Golder and the initial Chatterton Petrochemical study. This can partially be explained due to the sampling differences. The earlier studies used a boat and a core auger to retrieve samples from the middle of the lagoon. However, the U.B.C. study used a shovel and samples were taken very near the sides of the lagoon. It also further reemphasises that the composition of the sludge is quite variable.

The analysis gave a preliminary indications of the Chemical Oxygen Demand of the mixture. It ranged from 180 000 to 260 000 mg/L.

The waste was a high strength mixed waste and it's potential degradation would be hampered by the high concentration of both

copper and cobalt. Nothing present in the literature search indicated that such a treatment was possible.

## 2. Literature Review:

The literature review is generally used to present an account of background research which has been performed relating to the study in question. The project then goes on to add to the body of knowledge in that particular area. In the case of this research, it was not possible to located any investigation which had dealt with a remotely similar waste. The range of the Total COD, metals and specific target organic compounds are significantly higher than any study presented in the literature. Since no directly related previous research can be presented, the literature review is composed of a blueprint of the options available when treating a hazardous waste and some of the history and theory behind the processes demonstrated in this study.

When faced with the clean up of a contaminated industrial site many remediation options are available. They are most commonly considered as: physical, chemical, thermal and biological approaches (Prince 1993).

Physical solutions simply transfer the contaminated material from one medium to another without providing a permanent solution. Chemical treatment usually exploits a chemical property of the waste such as acidity and precipitation potential. Often this procedure results in toxic by products and it usually increases the total volume of the waste by dilution. The contaminants are

not eliminated but are simply entrapped within a matrix. Thermal techniques such as incineration are effective but are often quite expensive when dealing with large amount of waste material (Prince 1993).

Biodegradation is defined as the break down of organic compounds by microorganisms. The degree of alteration varies and is either typically defined as mineralization or biotransformation (Prince 1993). Mineralization is the complete breakdown of the original organic matter to carbon dioxide and biomass (Autry 1992). While biotransformation is the partial degradation of a parent compound to one or more daughter compounds which may or may not be less toxic than the original compound (Prince 1993).

Bioremediation has been gaining popularity recently due to it's high public acceptance, relative to other alternatives such as incineration. The technique also provides potential savings of time and money. Bioremediation provides the opportunity to treat on site, thus saving transportation costs and liabilities (Jespersen 1993). It also provides a permanent elimination of the waste, reducing long term liability risks (Prince 1993).

There are many bioremediation treatment technologies which include: land treatment, bioventing and bioreactor treatment. Bioreactor treatment is the physical movement of the waste into a reactor. This treatment process increases the separation of many

contaminants from soil and results in a fast, effective destruction of the contaminants. The drawbacks are that the waste must be physically moved and that treated solids must be dewatered. Thus, high mobilization and demobilization costs can be incurred for small projects (Jespersen 1993).

Most wastes will eventually biodegrade naturally unless they are exposed to extreme pH or toxicity. This natural degradation may be too slow to be of value. In controlled biodegradation, the growth conditions are provided to optimize the process (Bradford 1991). The process utilizes naturally occurring bacteria to degrade the waste. In a recent study, acclimatized bacteria were added to the site of a petroleum contaminated soil (Autry 1991). The bioaugmentation did not significantly alter the biodegradation rates for the compounds. This implies that bacteria capable of hydrocarbon degradation are in the soil from this site and in sufficient numbers to carry out effective degradation of the waste. Other authors have indicated that the use of naturally occurring bacteria are preferred due to the regulatory difficulties in releasing genetically engineered organisms in the environment. None of the over 100 EPA site involved in bioremediation currently uses genetically engineered microorganisms (Prince 1993).

The success of bioremediation relies on the controlling of the following rate limiting factors:

1) The toxicity of the waste itself: The presence of a compound in large concentration can lead to the poisoning of the system and the complete inhibition of bioactivity (Rebhun 1988).

2) The type and complexity of waste itself, because bacteria break down different wastes at different rates (Pitter 1975): The ease of biodegradation of compounds decreases for highly branched compounds (Prince 1993). As a general rule, the more complex the compound, the more difficult it is to degrade (Autry 1991).

3) The concentration of the waste components: Phenol concentrations over 1500 mg/L and as low as 200 mg/L have been reported to interfere with the treatment process (Vipulanandan 1993; Rebhun 1988; Rozich 1984; Parker 1994). High concentrations of heavy metals, toxic organic compounds and or inorganic salts can inhibit microbial growth (Prince 1993). Many compounds are inhibitory to their own degradation at high concentrations (Grady 1990).

4) The temperature, since reaction rates tend to be slow below 18 degrees Celsius (Bradford 1991): most studies on mixed hazardous waste degradation were conducted around room temperature. Twenty to twenty six degrees Celsius is the preferred temperature range

for optimum degradation (Beltrame 1979; Beltrame 1980).

Temperature affects the biodegradation application in two ways. Both the specific growth rate of the degrading organisms and the activity of the enzymes responsible for contaminant oxidation are largely temperature dependent (Autry 1992).

5) The degree of agitation: Chemical Oxygen Demand kinetics in a batch reactor have been showed to be affected by the degree of agitation and impeller submergence. Increased agitation increases the surface area for mass transfer between the bulk liquid and the biological cells and from the gas phase to the bulk liquid. Agitation also improves the performance of the reactor by dissipating excess heat and gaseous inhibitors. However, excess agitation has been shown to physically damage cells and reduce efficiency (Deepak 1994).

6) Acclimation of microorganisms to a contaminant can enhance the extent and the rate of degradation: Many studies have shown that the degradation rate of compounds significantly increase through exposure of the bacteria to the substance. An original microbial culture was only able to reduce the Total BOD of a benzene waste by 49%. However, the third subculture degraded the compound to below the detection limit of Gas Chromatography and to a negligible Total BOD concentration. (Patterson 1981; Kinannon 1983; Tabak 1981). Acclimation normally occurs when bacteria are exposed to the waste. Bacteria that contain enzymes capable of

breaking down the specific waste reproduce faster than the other bacteria and the presence of the enzyme containing bacteria speeds up degradation (Brandford 1991). Two to five fold increases in the average degradation rates have been reported after only the second exposure in a batch reactor for some wastes (Lewandowski 1990). On the other hand, some compounds like benzoates, show no benefits of acclimation when monitored. However, the addition of another carbon source such as glucose increased the rate and the total amount degraded. (Haller 1978)

7) The rate of desorption from the contaminated media (Bradford 1991): In many cases the contaminants may not be available due to contaminant hydrophobicity, sorption onto the soil colloid, volatilization potential or dissolution into soil organic matter (Autry 1992). The rate is slowed by the solubility of the contaminant in water (Smith 1979).

8) The presence of nutrients and micronutrients: It is essential that both nitrogen and phosphorus be present in order for degradation to take place. The carbon:nitrogen:phosphorus ratio is waste specific. The general accepted C:N:P ratio for microorganism growth degrading sewage is 100:5:1 (Metcalf 1993). However, as the composition of the waste changes, so do the nutrients required for it's complete breakdown. In studies performed with low concentration phenolic wastes, the proposed ratio is 100:10:1. (Beltrame 1979, 1980). Sulfur and trace

nutrients (K, Mg, Fe, Na, Co, Zn, Mo, Cu and Mn) are also required (Prince 1993).

9) The optimal pH for growth lies between 6.5 and 7.5 (Jespersen 1993). However, it should generally be maintained between 5 and 9 (Bradford 1991).

The aerobic degradation of a waste is a fourth order reaction which can be described as follows:

$$WDR = KC_w C_o C_n C_p \quad (\text{Bradford 1990})$$

Where: WDR is the rate of waste destruction

$C_w$  is the concentration of waste

$C_o$  is the concentration of oxygen

$C_p$ ,  $C_n$  are the concentration of nutrients (nitrogen and phosphorus)

In most cases, the process can be reduced to a pseudo first order reaction. This is accomplished by insuring that the concentrations of oxygen and nutrients in the reactor are supplied to meet the needs of the bacteria and insuring that agitation is high enough that there are no micronutrient deficiencies present in the system. The equation can then be modified as follows (Bradford 1991):

$$WDR = KC_w$$

Therefore, the waste reduction rate is simply a function of the

concentration of the waste. The system should be designed to maximize the kinetic reaction rate (Bradford 1991).

The first approach when dealing with a waste is to perform batch lab scale studies, to determine the possible effectiveness of bioreactor treatment. There are several types of bioreactors that can be used from the simple beaker to the complex Truex reactor. The Truex reactor has been specifically designed for monitoring process dynamics during the biodegradation of volatile organics (Truex 1994). Treatability studies are relatively inexpensive, allow optimization of operating conditions and provide the design criteria for scale up (Bradford 1991). However, Grady warns that lab-scale reactors tend to overpredict the removal that will occur at the pilot and full scale of the same type of run with similar loadings. The reason for this that air stripping is more prevalent as a removal mechanism in a lab-scale aerated reactor (Grady 1990). Also, it is reported that excessive aeration rates increase cost and heat loss and tends to destroy microorganisms and hence lower MLVSS. High concentrations of dissolved oxygen tend to change the population dynamics which will not be optimum under heavy contaminant loading (Capps 1995).

Many studies have focused on the removal rates of organic priority pollutant compounds in the lab scale environment. Each study noted that many compounds resistant to degradation were easily degraded using an acclimatized culture of microorganisms

(Patersson 1981; Tabak 1981; Kincannon 1983). These studies focussed on the degradation of single pure compounds in concentration generally less than 10 mg/L. A mixed waste with many different chemical constituents can behave quite differently. Initial testing must be done on the waste to determine it's degree of degradability. The first step in determining the potential success of treatment is the examination of the COD/BOD ratio. Below a ratio of 2.5 the waste should be readily biodegradable in an activated sludge process. A ratio above 2.5 indicates that there are molecules which are refractory to degradation; but which might be degraded under a longer residence time (Capps 1995).

The initial concentration of the waste is critical in the success of the remediation. High concentration of such chemicals as phenol have been shown to induce a lag phase in the growth of the microorganisms. Some concentrations of phenol have created an inhibitory substrate for growth. The rate of biodegradation is dependent on the initial concentration of the waste (Vipulanandan 1993). As the concentration increases, the number and species of microorganisms changes. Too high a concentration leads to a less optimum mix of organisms (Tokuz 1991). It is unlikely that bacteria will have to be added to the waste since an active culture should already be present (Autry 1991).

Many researchers, in the past, have assumed that sequential

substrate removal will occur in a multicomponent media, with the easily degradable compounds being used first, followed by substrate progressively more difficult to use. In a mixed waste system, substrate tends to be used simultaneously, although at different rates. Simultaneous substrate removal prevails as the SRT of the system is increased, giving slower specific growth rates. However, there are exceptions as some compounds interfere with each other's removal due to the pathways required to attack them (Grady 1989). Grady further proposes that single substrate removal kinetic parameter models can be used to describe the removal of a single compound in a mixture. Many models have been proposed for the degradation rates of specific organic compounds (Kim 1979; Rozich 1984). These models will tend to be more conservative and over predict the effluent concentration present in a mixed waste (Grady 1989). Studies have been done with PCP, showing that the degradation rate increases in the presence of other contaminants. A mixed waste system will have a more diverse microbial population.

One important component of the lab scale research should be the establishment of a control to determine the fraction of organics which are being air stripped (Parker 1994). Copper sulfate can be used in this reactor as a biocide to prevent the growth of microorganisms (Lewandowski 1990). If copper sulfate is used as a biocide, the system must be closely monitored because microbial growth has been documented in systems with copper sulfate levels

up to 20 mg/L.

As the degradation of the waste proceeds, carbon dioxide will be produced and lower the pH through the formation of carbonic acid. The diminishing pH during experiments seems to influence the pattern of the growth curves. Microbial growth in phenolic waste degradation runs was slowed due to the inhibition of the biomass caused by the very low pH reached in the reactor. The decreasing pH was stabilised when the compounds were exhausted (Lallai 1989). This is not usually experienced at the full scale, since the accumulation of acid intermediates is negligible. (Chuboda 1990)

Another problem with a high organic loading rate, especially hydrocarbon, is that biofloc settleability is impaired. Some have hypothesised that the biofloc becomes coated by a hydrophobic layer, which affects it's physical property and biochemical performance (Rebhun 1988).

In the course of treatment, absorption by the microbial biomass is an important process in the removal of hazardous organic pollutants in biological treatment systems. The danger is that the process is fully reversible and desorption of the pollutants may occur further down the road (Bell 1987). Also, it has been shown that this process greatly affects the settleability of the biofloc (Stenstrom 1989).

In the degradation of a mixed waste, it is possible that one compound may need another compound to be present in order to be degraded. This is problematic because both compounds must be present in the right relative concentrations to each other in the waste mix. Many compounds can only be degraded when the other compounds induce enzymes that act gratuitously on the pollutant (Neufeld 1979).

To optimize the degradation process, a sequencing batch process is often used. Not only are the bacteria able to degrade the waste at a faster rate (since they have been acclimated to the waste mixture) but biomass with an increased sludge age has been shown to biodegrade refractory organics faster than a low sludge age biomass (Capps 1995). The initial lag phase is reduced as the bacteria are resistant to the shock loading effects of the waste addition. Thus, a higher initial waste loading rate can be used (Hsu 1986). A study, using an SBR, successfully treated a high strength mixed phenolic waste with initial phenol concentrations higher than 2000 ppm. The total COD of the mixture was 7 500 mg/L. This was seen as a major step since authors had long proposed that a phenol concentration higher than 100 mg/L was inhibitory (Brenner 1991). The author introduced anoxic periods to avoid bulking sludge, which was present in his earlier work. The presence of filamentous organisms and the bulking sludge were responsible for poor settleability of the sludge.

Many studies have been done on the treatability of mixed waste hazardous sludges in Canada and the United States. However, as the waste sludge from all these sites differ, so do the results and success of treatment (Sloan 1987; Jespersen 1993; Capps 1995). None of the studies dealt with a sludge that had organic constituents as concentrated as the Chatterton Petrochemical site. Moreover, none have the added complexity of having cobalt and copper present in high concentration. Both compounds have been shown to be inhibitory to the growth of microorganisms in low concentrations. Dissolved copper concentration as low as 1.0 mg/L has been shown to reduce the rate of degradation present in a wastewater by 40 percent (Mowat 1976). However, as wastes vary, so does the ability of the microorganisms to perform under high heavy metal concentrations.

## 2.1 Objectives:

- 1) To determine the biodegradability of the Chatterton Petrochemical sludge.
- 2) To determine the optimum initial sludge loading rate for an efficient and effective treatment using a Modified Batch Process.
- 3) To establish the quality of the effluent and treated sludge which could be expected from the aerobic biological treatment process.
- 4) To modify the batch reactors to operate as true batch reactors and monitor and observe differences.

5) To determine the different rates of reaction for the True Batch Process vs the Modified Batch Process.

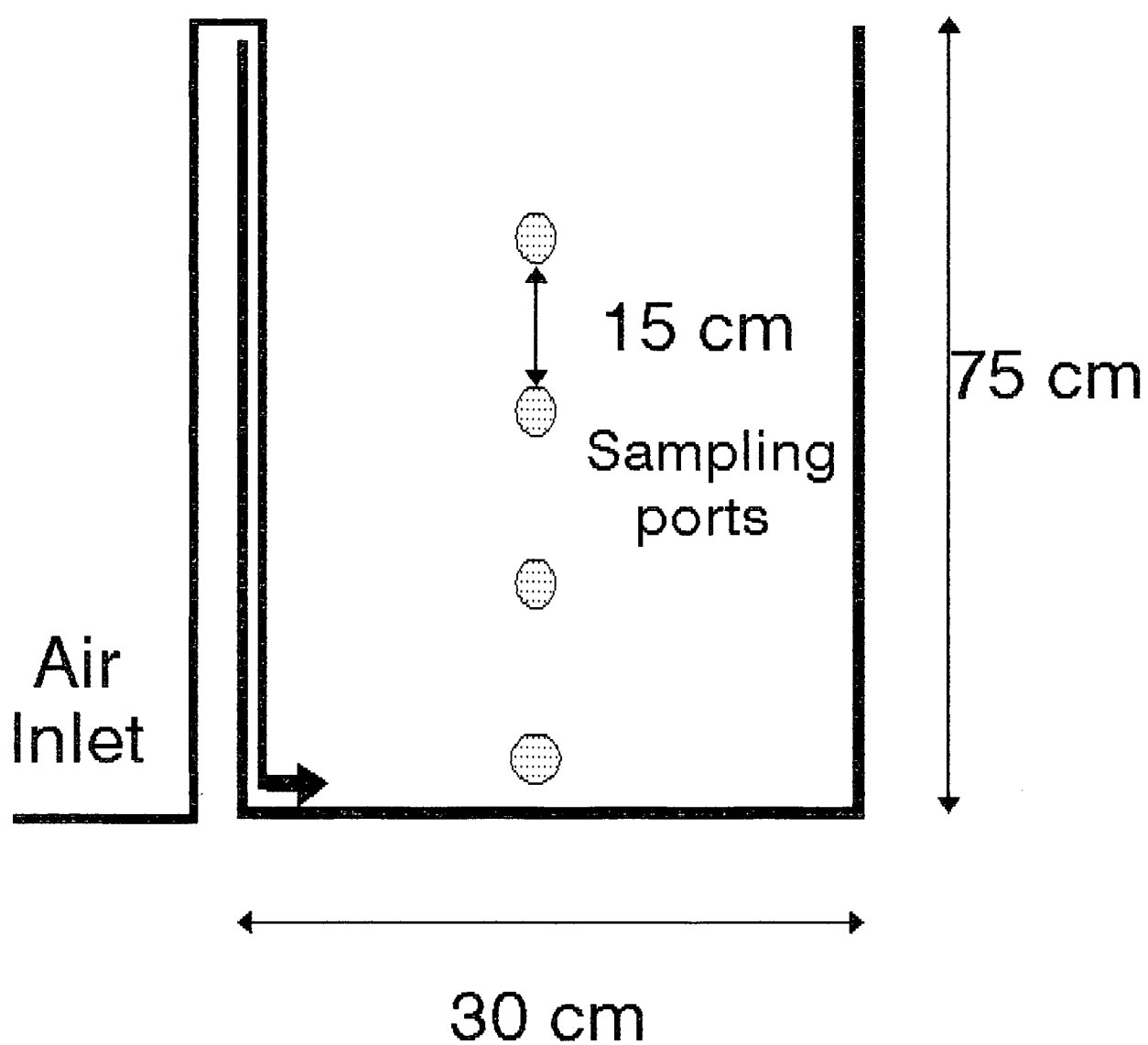
### 3. Materials and Methods:

#### 3.1 Reactor Design:

Four PVC reactors were modified to be used as batch reactors. They had previously used as lysimeters. The units were cut to 75 cm in height and had an internal diameter of 30 cm. The bottoms had previously been sealed and the top was open. Sampling ports were drilled and threaded every 15 cm, starting at 2 cm from the bottom. The bottom port was 3/4" in diameter in order to prevent clogging during sampling due to the high solids content of the mixture. The other ports were 1/2" in diameter as can be seen in Figure 3.1.1.

A steel frame was fabricated to encompass the four reactors. Dayton variable speed mixers were mounted onto the frame and mixing rods were extended into the middle of the tanks. The steel frame was covered by a wooden box which could easily be slipped on and off the steel frame. The box was fabricated from 2 cm thick plywood and extended 30 cm down the side of the frame as can be seen in Figure 3.1.2. The purpose of the box was to create a closed system. Since the waste that was being degraded was hazardous in nature, it was necessary to take precautions to insure that vapours were not vented into the general lab area during the aeration of the waste. To further prevent the loss of vapours, a sheet of plastic was velcroed to the end of the sides

Figure 3.1.1 Reactor Profile



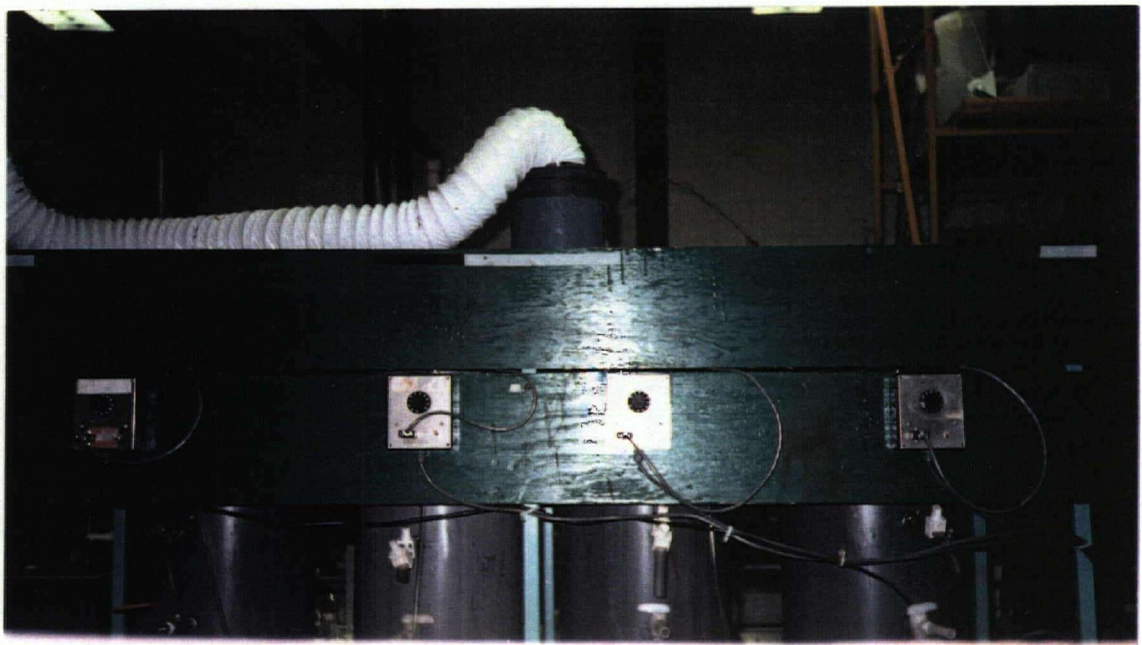


Figure 3.1.2 Picture of the reactors as set up in the laboratory



Figure 3.1.3 Picture of the laboratory reactor setup with protective plastic sheet in place

of the box and extended to the table level on which the reactors sat, thereby creating a tent like barrier. This can be seen in Figure 3.1.3. The plastic wrap could easily be removed and stored during sampling. In the middle of the top of the box, a 15 cm System Past constant speed fan was placed to remove all the vapours coming out of the reactors. The fumes were then piped through 5 cm (2") plastic pipe into a fumehood which vented outside.

The flow of air into the reactors was initially through a pressure regulator to guard against sudden pressure fluctuations. The air line was then split into two and carried through 1/4" Cole Palmer stiff plastic tubing. At this point, a Whitey needle point valve was used for pin point air control. Followed by Swage Lock quick fit connectors, which allowed a Cole Palmer variable output flow meter to be placed in the circuit, to set and measure the air flow rate using the ball valve. Prior to entry into the top of the reactor, the air line was once again split into two separate lines. The tubes were fixed onto facing sides of the vessel. The lines were adhered to the sides of the reactor with steel wire which would not corrode and taped high enough that it would not be in contact with the contents of the reactor. The fixing of the air line was necessary, since during operation, they tended to float and could potentially wrap around the mixers. At first, the airlines were weighed down with stainless steel rings but during aeration tests, it was noticed that the

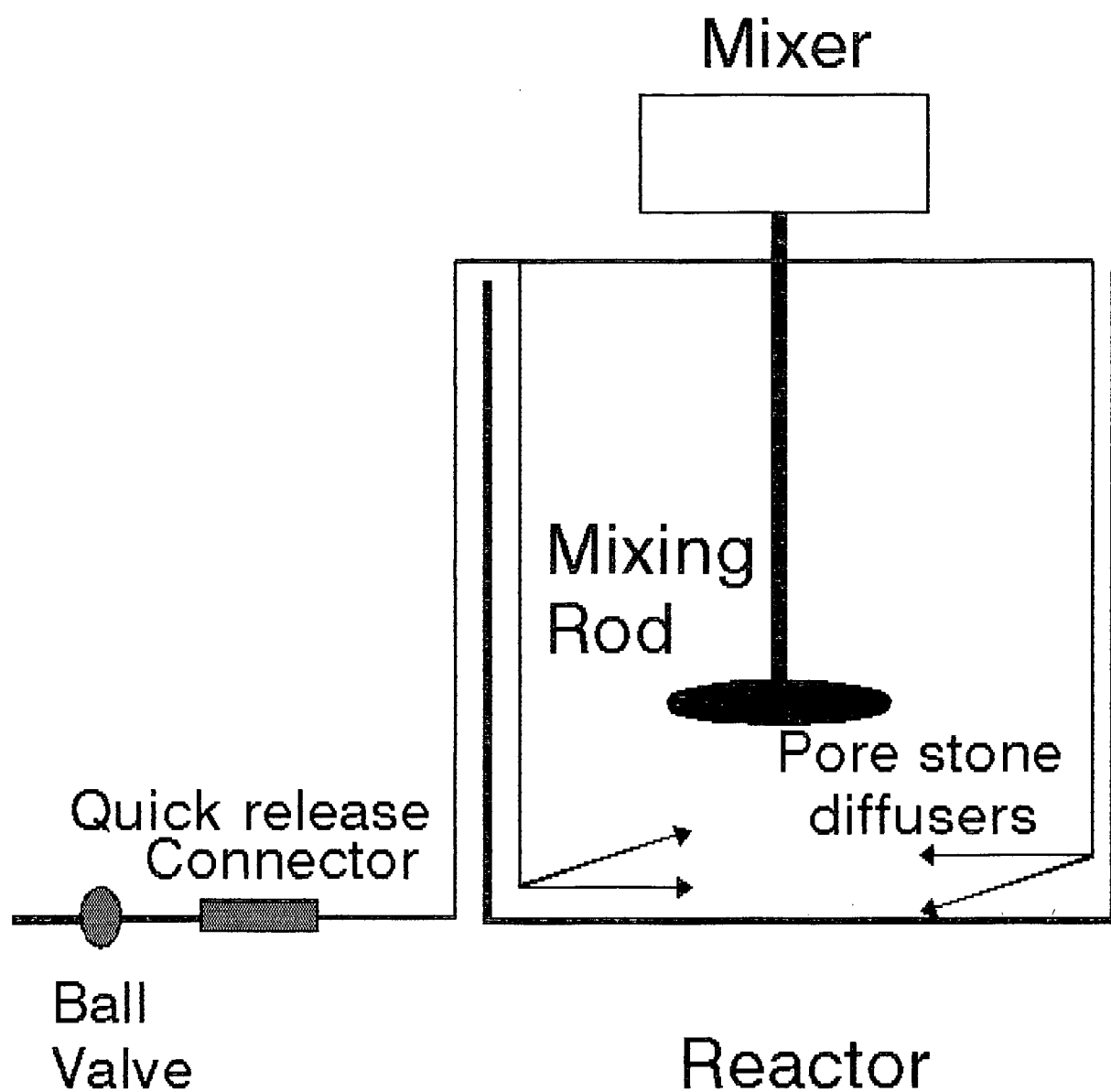
lines still floated considerably. On the floor of the reactor, each line was once again split into two. Aquarium pore stone diffusers were placed on the tubing outlets. The diffusers were obtained from a pet store and were intended to be used in fish aquariums. Four diffusers were used per reactors and thus 16 for the entire experiment. A schematic of the aeration system can be seen in Figure 3.1.4.

After the experiment's first run, the aeration stones degraded in the chemical sludge mixture. The glue which bound the stones together was not compatible with the chemicals found in the sludge. Thus, the entire set of stones were replaced with Cole Palmer laboratory grade diffusers.

### 3.2 Sampling:

Sampling was done twice per week during the batch runs. Usually, samples were taken on Mondays and Thursdays. At first, samples were taken from the lowest sampling port. An initial 500 ml sample was retrieved to flush out the valve and to insure a fully mixed sample was obtained. A 100 ml sample for analysis would then be taken. During the second batch run, a considerable amount of gravel was incorporated in the sludge added to the reactors. The gravel obstructed and plugged the outlet valves. Cleaning and flushing of the valves was not successful and all future samples were taken by removing the wood cover and immersing a beaker

Figure 3.1.4 Aeration system profile



directly into the tanks. This yielded a sample which was unmistakably fully mixed. The new sampling technique also created additional problems. When the wooden cover was removed, the experiment vented directly into the lab. Therefore, prior to sampling, the air was shut off. Also, a considerable amount of personal protective equipment had to be worn. Besides the obvious lab coat and glasses, shoulder length viton gloves and a respirator with organic vapour cartridges were worn. Prior to taking the sample, a 500 ml beaker was immersed several times in the sludge mixture. A 50 ml portion was then transferred to a plastic sampling bottle and the remainder was returned to the reactor. The following tests were routinely performed on the samples:

Test:	Frequency:
Chemical Oxygen Demand (COD):	2 per week
5 Day Biochemical Oxygen Demand (BOD <sub>5</sub> ):	1 per week
Solids; Total Suspended Solids (TSS): Volatile Suspended Solids (VSS):	2 per week 2 per week
Nutrients; Phosphorus (PO <sub>4</sub> ): Ammonia (NH <sub>4</sub> <sup>+</sup> ):	2 per week 2 per week
pH:	2 per week
Metals (total and dissolved); Copper (Cu): Cobalt (Co):	2 per week 2 per week
Gas Chromatography (GC):	1 per week

**Table 3.2.1: The type and frequency of analytical tests performed on the sludge.**

### 3.3 Analytical Procedures:

The following criteria were followed in the preparation and the performance of analytical tests.

1) Chemical Oxygen Demand (COD): the test was performed according to the Hack method as outlined in Standard Methods. Prior to analysis, the original samples were diluted between 10 and 100 times since the range of the test is 50 - 1000 mg/L. The total COD of the running reactors was between 2000 - 100 000 mg/L depending on the run in progress. Two samples were analyzed; a total sample and also a supernatant sample which was centrifuged for 10 minutes at 3000 RPM. The supernatant was then removed using a glass pipette and diluted. Two replicates were done in order to provide more accurate results.

2) 5 Day Biochemical Oxygen Demand (BOD<sub>5</sub>): The test was performed according to the specifications in Standard Methods. Both total and supernatant samples were tested in duplicate. Most times, samples were diluted prior to addition into BOD bottles. However, when the anticipated BOD was low, straight sludge addition was done.

3) Solids: Precautions had to be taken when performing the TSS and VSS tests on the sludge since the samples contained high concentration of volatile and carcinogenic compounds. The drying oven in the environmental lab vented directly into the general

lab environment. Thus, it was not feasible to use it for these samples. An oven was installed in a fumehood in the material's lab which was used to initially fire the samples. Also, due to the high solids nature of the sludge it was not possible to determine the solids content using glass fibre filters and a vacuum apparatus as recommended by Standard Methods. This procedure was initially attempted. However, even when the samples were diluted up to ten times, the sludge clogged the filter. Thus, another solids determination procedure was designed. Porcelain dishes were used and fired overnight prior to sampling. The dishes were then left to cool in a decanter for one hour. The dishes were then initially weighed, sludge was added to the dishes and the final weight was recorded. The samples were then fired overnight at 103 degrees Celsius. The next day the dishes were removed from the oven, placed once again in the decanter and let cool for one hour. Once they had been weighed, the samples were fired in the furnace at 550 degrees Celsius for 30 minutes. The samples were then again left to cool and the final weight was recorded.

4) Nutrients: The running reactors and the control were tested for both Ortho-Phosphate ( $\text{PO}_4$ ) and Ammonia ( $\text{NH}_4^+$ ) using the Quickchem AE model Lachate Analyzer. The samples were first diluted, filtered through Whatman #4 filters and acidified to a pH of 3 with a ten percent  $\text{H}_2\text{SO}_4$  solution in order to preserve them prior to analysis.

5) pH: The pH of the mixed liquor was determined using a Cole-Palmer Chemcadet Model 5986- 60 pH meter. The meter was routinely calibrated with 4, 7 and 10 pH standards.

6) Metals: The samples were analyzed for both total and dissolved copper and cobalt. The total samples were diluted and then digested with nitric acid according to Standard Methods. The samples were then filtered with Whatman #4 filters. To obtain a dissolved sample the sludge was first diluted and then was filtered through cellulose nitrate Sartorius 0.45 micron filters using a vacuum apparatus. Both sets of samples were then analyzed according to Standard Methods using the Video 22 model, Thermo Jarrell Ash Atomic Spectrophotometer.

7) Gas Chromatography: To monitor the organic constituents of the waste mixture the GC was used. 5 mls of raw sample was mixed with 5 mls Methylene Chloride and shaken for 5 minutes. The test tubes were then centrifuged for 10 minutes at 3000 RPM. The solvent was then removed using a Pasteur pipette and stored. Another 5 ml of Methylene Chloride was added to the sample and it was shaken, centrifuged and the solvent was once again removed. Sodium hydroxide was added to the total solvent sample to remove any water. Using a Pasteur pipette, part of the solvent was removed and placed in a GC vial. The sample was then analyzed for the presence organic compounds with the Hewlett Packard 5890 Series II GC.

A J & W Scientific DB-1 column was used. It was 30 meters in length, had an internal diameter of 0.32 mm and a film thickness of 0.25 micron. Helium was used as the carrier gas at a flowrate of 20 cm/s and nitrogen was the makeup gas at 60 ml/min. The initial oven temperature was 45 degrees Celsius for 2 minutes. The temperature was then increased 10 degrees Celsius/minute, until it reached 290 degrees Celsius. The oven was then maintained at that temperature for 16 minutes. The entire GC run lasted a total of 41 minutes and used a Flame Ionization detector.

8) Mass Spectrometer: The Hewlett Packard 5830A GC/MS was used to identify the major organic constituents of the waste mixture. Using the instrument, the various specific peaks on the GC could be identified, quantified and monitored during the course of the experiment. The GC/MS was also used to analyze a head space sample taken from the top of the reactor to determine the various components which would potentially be venting into the general laboratory area.

### **3.4 Experimental Procedure:**

A series of Modified Batch Process (MBP) experiments, referred to as batch tests in this thesis, were initially run to determine the most effective initial sludge loading rate range for the system. In the MBP system, each run consisted of a set of

reactors, each individual reactor was filled with a combination of virgin sludge, dilution water and seed. The reactors were then aerated and mixed until the sludge was degraded. At this point, the set of reactors was completely emptied and they were once again filled with a combination of virgin sludge, seed and dilution water. On some occasions, the same initial sludge concentration was repeated in two consecutive runs, to determine if the success of a previous run could be replicated. The progress of the various runs was monitored using the HACH COD test. In later runs, the BOD<sub>5</sub> and the concentration of certain target organics were used to follow the progress of the run, since they provided more insight into the degree of treatment accomplished.

Since little was known about the degradation of the sludge and there was little information present in the literature, the first run's initial sludge loading concentration was an educated guess. From that point, different initial sludge concentrations were attempted to optimize the degradation process. Different nutrient conditions and aeration rates were attempted to determine the effect on the degree and rate of treatment of the waste.

A control was established to determine and minimize the loss of organic constituents due to volatilization. It contained the same amount of sludge as the other reactors, but a dose of Javex brand bleach, containing 5.25% sodium hypochlorite was used to kill the

microorganisms present. Plate counts would be performed to monitor if bacteria were still present in the control.

After the most effective initial sludge loading concentration was determined, the Modified Batch Process (MBP) was converted to a True Batch Process (TBP). In the TBP system, 75 % of the previous runs final product were kept in the reactor. Depending on the desired initial concentration for the run, the remaining volume was made up of a combination of virgin sludge and dilution water. The reactor was aerated and mixed until the organic compounds had been degraded. At that point, the aeration was discontinued and the reactor was let settle for 2 hours. One quarter of the volume was removed and replaced with a combination of virgin sludge and dilution water. Aeration and mixing was then resumed.

#### 4.Results and Discussion:

In total, 11 different sludge degradation runs were attempted. Each individual run had a specific goal and in turn led to the formation of specific objectives for the next run.

What follows is a detailed run by run description of all the experiments which were attempted. The rationale behind each run is explained and the information obtained from the experiments is analyzed and presented.

The initial characteristics of the sludge on the bottom of the equalization lagoon at the Chatterton Petrochemical site as analyzed at U.B.C. in the spring of 1994 were as follows:

Parameter:	Result:
Total COD (mg/L)	240 000
BOD <sub>5</sub> (mg/L)	60 000
Metals:	
Total Copper (mg/L)	550
Total Cobalt (mg/L)	110
pH	6.7
Solids	3%

**Table 4.1: Initial characteristics of the Chatterton Petrochemical sludge as analyzed at U.B.C..**

As shown in Tables 4.1 and 4.2, the sludge is composed of a varied amount of chemical constituents. Due to the high concentrations of copper and the various organic compounds

present, the sludge would have to be greatly diluted in order to be biologically treated, thus reducing the Total COD and BOD<sub>5</sub> to levels which could be handled in a aerobic biological system.

Organic Constituent:	Amount (ppm):
Phenol	1 790
Diphenyl	95 900
Diphenyl Ether	219 000
2-Phenyl Toluene	34 200
3-Phenyl Toluene	11 800
4-Phenyl Toluene	4 440

**Table 4.2: Initial organic constituents of the sludge on February 23 , 1994.**

The sludge was earthy in colour and had a distinct chemical, overpowering odour. An iridescent film could be seen floating on the surface of the liquid.

Determining the best initial concentration of sludge for treatment was difficult, since little was present in the literature about treating such a concentrated and complex waste mixture. Also, no research had been performed in this area in the Environmental Engineering Department at the University of British Columbia to this point. However, the treatment plant on the Chatterton Petrochemical site had been treating groundwater and surface runoff for BTX. The treatment plant therefore had an active culture of microorganisms which were conditioned to treat a similar, yet less concentrated waste. The mixed liquor from the

treatment plant was used to seed the reactors, to provide an active and partially acclimatized microbial population. It was hoped that this would avoid a lag in the growth of the bacteria during the beginning of the experimental run.

The goal of the first experimental run was to determine the physical conditions of the system required to treat the sludge. Also, it was desired to learn more about the needs of the bacteria in order to degrade the waste. Through the running of the first phase, some basics would be learned about the sludge, the experimental set up and the monitoring and testing requirements of the system. All four reactors could not be used for the first run since leaks had been detected in two of the vessels. To complicate matters, the glue used to seals the reactors was not compatible with the sludge and created an even larger problem. The reactors had to be emptied, dried off and a new binding agent was selected.

#### **4.1 The Initial Runs:**

##### **Run #1**

Two reactors were used for the initial batch test run. The batch process was selected because it would yield considerable information on degradation of the sludge. The problem with performing batch runs was that it usually resulted in an

acclimatization period for bacteria at the beginning of the experiment. The presence and length of this acclimatization period would depend not only the type and concentration of the waste, but also the type and concentration of microorganisms. After knowledge was gained using the batch system, it was hoped to convert the process to a true batch system to improve the degradation rates of the bacteria and produce a better quality endproduct in a shorter time frame.

Parameter	Reactor 2	Reactor 4
Sludge Volume (L)	3.0	3.0
Activated Seed Vol. (L)	1.5	1.5
Dilution Water Vol. (L)	5.5	5.5
Total Volume	10	10

**Table 4.1.1: Contents of the two running reactor for the first batch trial.**

Parameter:	Reactor 2	Reactor 4
Total COD (mg/L)	75 514	80 452
BOD (mg/L)	n/a*	n/a*
pH	6.7	6.8
Solids:		
TSS (mg/L)	5 900	9 000
VSS (mg/L)	4 000	7 000

**Table 4.1.2: Initial analytical analysis of the sludge in the running reactors for run 1. \* Due to dilution problems the BOD of the reactors was not determined.**

As can be seen in Tables 4.1.1 and 4.1.2, although the same volume of sludge was used in each reactor, the Total COD differed

by about 6%. This was due to the non uniformity of the sludge in the lagoon. The sludge was taken from the same area in the lagoon and was mixed prior to addition to the reactors. It was very difficult to reach a target COD in a running reactor, since the chemical makeup (and thus the Total COD in the lagoon) varied greatly, both horizontally and vertically.

The concentration of both copper and cobalt were not monitored in the first runs because it was felt that with the large degree of dilution, the metal concentration would be low and as such, insignificant.

The initial BOD for the run is unavailable due to dilution problems. The samples were either too diluted or not diluted enough to achieve an accurate reading.

As with any new experiment, equipment problems had to be overcome and modifications had to be performed right from the start. Firstly, upon the activation of the mixers, the air diffusing stones in Reactor 4 "floated" and the airline wrapped itself around the mixing rod. The line was fixed to the side of the reactor once again with tape and wire. However, the following day the same problem recurred. The mixer was then shut off for the remainder of the run and the air flowrate was increased. The air was set to a rate which produced 7.5 mg/L of dissolved oxygen in the tank. This was higher than literature advised but produced a

thoroughly mixed unit (Brenner 1992).

The second problem was the aeration supply. Due to the demand from new experiments in the environmental lab, the main compressor had trouble meeting these new needs. Twice during the first week the main compressor failed overnight and the emergency compressor did not come on line. Thus, the experiment did not receive air for an extended period of time. After the second failure, an airline was installed from the analytical room compressor and was used until the main system could be used with confidence.

The length of the experiment in each test reactor was different. Reactor 2 was run for a period of 30 days while Reactor 4 was in operation for 20 days.

As can be seen in Table 4.1.3, the batch run was able to reduce the Total COD of the waste mixture by almost 90 percent in a short amount of time. As shown in Figure 4.1.1, most of the reduction in terms of Total COD occurred in the first few days for Reactor 2. This seemed to contradict the notion that a lag phase for the bacteria to adapt to the waste mixture would be required. However, a lag phase is clearly apparent in the Total COD concentration graph for Reactor 4. The difference in the two reactor could be due to the difference in the initial

Parameter	Reactor2	Reactor4
Total COD (Inn.) mg/L	75 514	80 452
Total COD (Final) mg/L	7 986	8 661
% Total COD reduction	89.4	89.2
Supernatant COD (Initial) mg/L	3 909	8 847
Supernatant COD (Final) mg/L	2 431	2 083
Supernatant COD reduction %	37.8	76.5

**Table 4.1.3: Total and Supernatant COD reductions during run 1.**

sludge dose. Although similar amounts were dosed into each reactor, the chemical components of the sludge mixture were possibly different. It is also possible that Reactor 2 received a more active/acclimatized population of microorganisms.

For the first 6 days of the experiment, the Total COD concentration remained the same and actually increased slightly in Reactor 4. The increase can be attributed to the extra mixing which resulted from the increased aeration rate (thereby indicating that the first sample was not fully mixed). After the short adaption phase, the degradation was rapid. Early indications from the data seem to infer that a high degree of treatment was possible in a short amount of time. However, many questions about the quality of treatment remained to be answered. More specifically: which specific chemicals remained at

FIGURE 4.1.1 TOTAL COD CONCENTRATION VS TIME FOR RUN 1

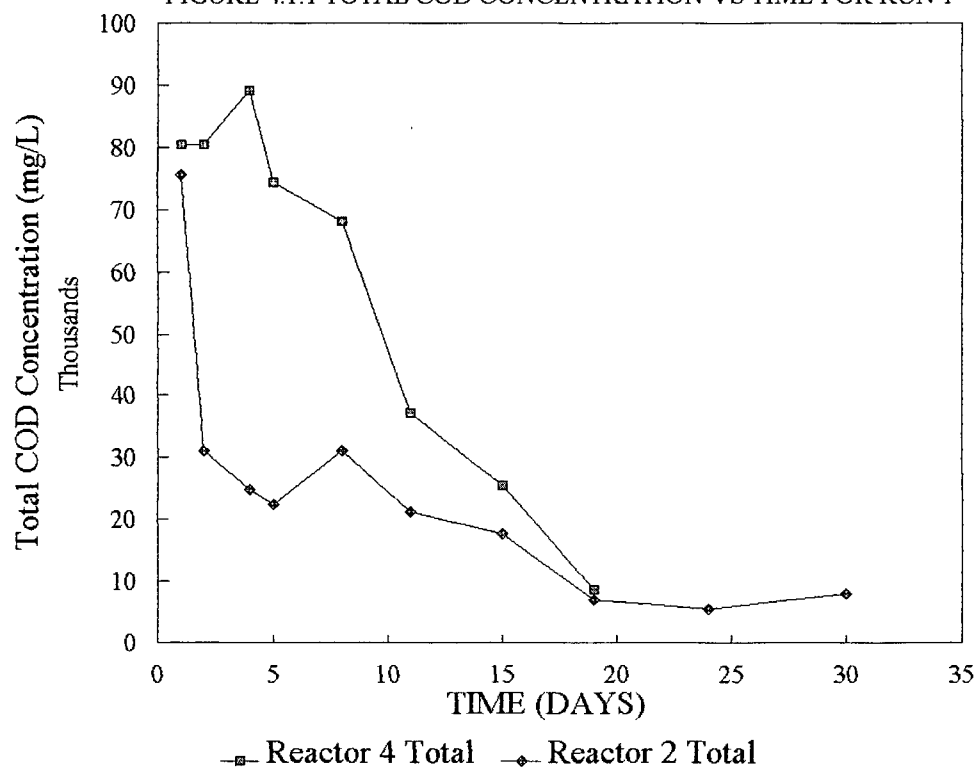
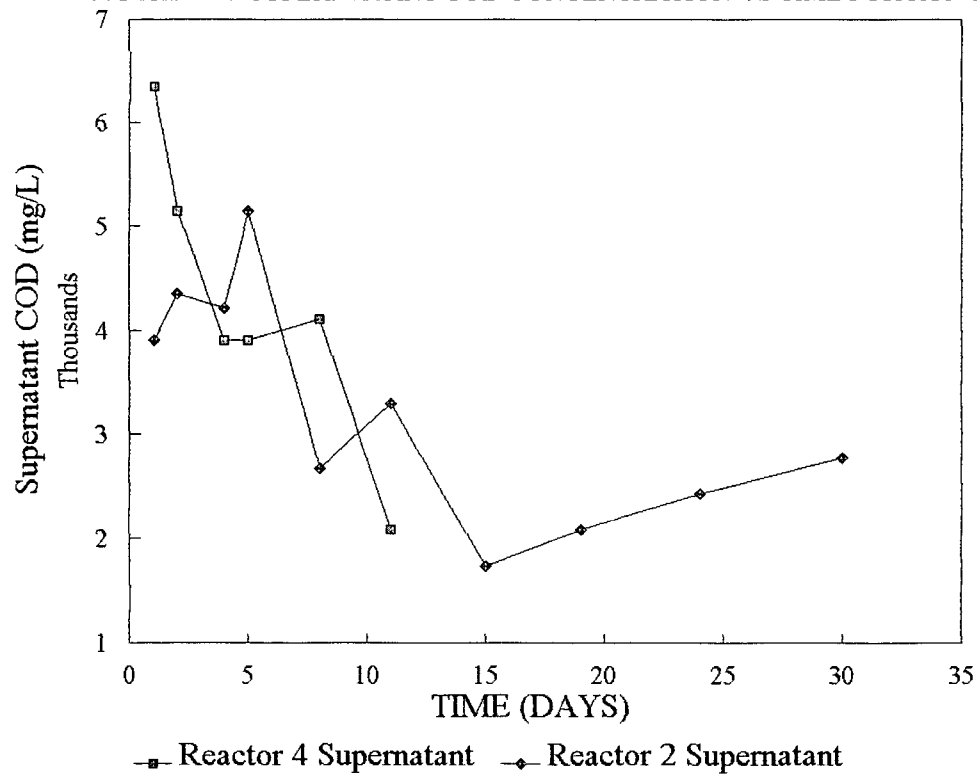


FIGURE 4.1.2 SUPERNATANT COD CONCENTRATION VS TIME FOR RUN 1



the end of the treatment period, which chemicals were resistant to degradation and the rates of degradation.

Since this was the first run, many problems with data collection and analysis were encountered. Starting with the previously mentioned BOD analysis problem. Discounting the importance of the presence of dissolved metals in the reactors was also a significant error. It is possible that the lag observed in Reactor 4 was due to the acclimatization of the bacteria to the high metal concentration and not the high organic content. Nutrients were not monitored since the sludge was believed to be nutrient rich. Chatterton Petrochemical believed that the sludge contained sufficient nutrients and that additions were not necessary for complete degradation. However, it was learned that significant additions of Ammonia and Phosphorus were being done at the on site treatment plant treating the groundwater. Further investigation would be necessary to determine if the system was running under nutrient limited conditions.

Due the varied chemical make up of the sludge, standards for most of the chemicals in the mixture were not yet available. Therefore, the Gas Chromatography trace could not be quantified. Thus, it was not possible to determine the exact degradation in terms of specific organic compounds.

The degree of treatment and the rate of treatment were

impressive. For this reason and to insure that actual treatment was occurring, a control was established for the next run. This reactor would contain the same sludge as the other treatment vessels but would not contain any activated biomass from the on site treatment plant. It would also contain a dose of bleach to kill all the microorganisms present. The control would serve as a guide to indicate the amount of organics which were being volatilized and would be used to determine the best level of aeration which supplied the needs of the microorganisms but did not facilitate the volatilization of the organic constituents of the waste mixture.

The positive results observed in this first run indicated that the aerobic biological treatment of the sludge seemed possible.

## **Run #2**

The first run was designed mostly to test the reactors and equipment and set up a sampling schedule and procedure. It also served as a guide in determining the optimum loading rate for the biological system.

In the second experimental run, all four reactors were used.

The need for nutrients, the aeration of the waste and the success of the degradation process were all questions which were addressed in this second run.

Parameter	Reactor 1 (Control)	Reactor 2 (Nutrients)	Reactor 3 (Nutrients)	Reactor 4 (No nutrients)
Sludge Volume (L)	3	3	3	3
Seed Water (L)	none	1	1	1
Dilution Water (L)	17	16	16	16
Total Volume (L)	20	20	20	20
Nutrients	none	N=850 mg/L P=170 mg/L	N=850 mg/L P=170 mg/L	none

**Table 4.1.4: Initial content of the reactors for the second run of the degradation experiments.**

A control (see Table 4.1.4) was established with the same solids and organics load as the test reactors, but without the addition of activated biomass and with 500 ml of bleach. Since no microorganisms were present, any reduction in the organics load would be attributed to volatilization, a process which was not an acceptable form of treatment.

Reactors with and without nutrient additions were used to observe the differences in the growth and response of the microorganisms to the different environments. It would test the theory that nutrients additions may not be required to treat this sludge. The nutrients were added to the two reactors, based on the theoretical relationship C:N:P of 100:5:1. The BOD<sub>5</sub> of the sludge was estimated as being approximately 50 000 mg/L; in the reactor, the content was diluted by a factor of 3. Therefore, the

approximate BOD<sub>5</sub> in the reactor was assessed at 17 000 mg/L; as such, 850 mg/L of nitrogen as N and 170 mg/L of phosphorus as P were required.

The actual Total COD of the reactors in the second run are shown in Table 4.1.5:

Reactor:	Initial COD (Mg/L):
1	2 563
2	5 955
3	6 973
4	2 139

**Table 4.1.5: Initial COD of the reactor for the second run.**

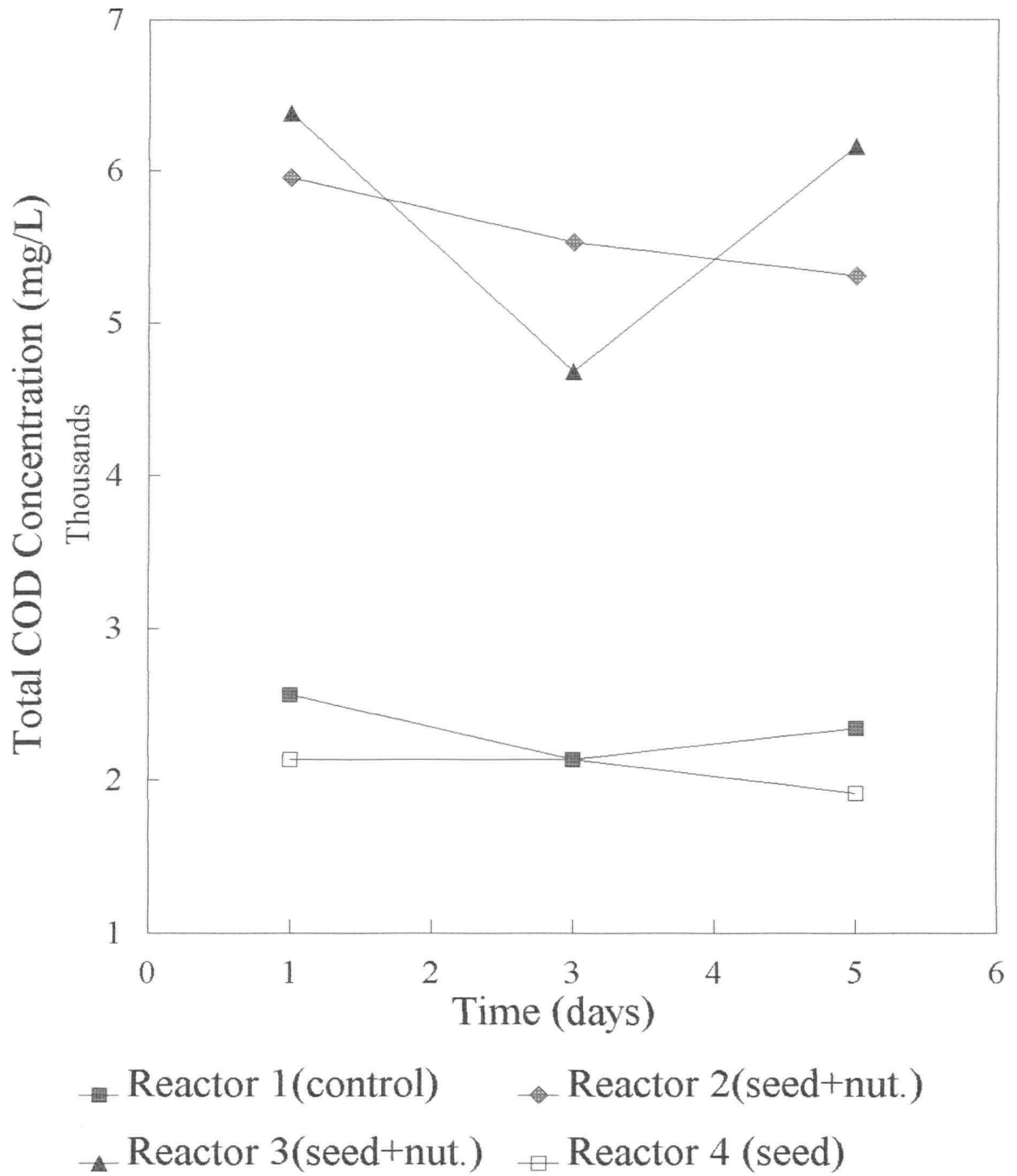
Table 4.1.5 indicates that the Total COD of the running reactors were much lower than expected, based on the sludge loading in Table 4.1.4. Although more dilution water was used than was the case in the initial run, the total COD in the running reactors should have been around 35 000 to 40 000 mg/L. The concentration in the reactors were out by a factor of almost 10. The Total COD values are further emphasised in Figure 4.1.3.

The "sludge strength" problem originated in the sludge collection method from the lagoon. In the first run, the sludge was collected in mid June when there was no water on the surface of the sludge. The sludge could be seen and easily collected. However, the second visit to the Chatterton Petrochemical site occurred in mid August, when the on site treatment plant had not been operating for several months. The plant treats surface water

and ground water during the spring, fall and winter. In the summer, the water is collected and stored in the lagoon. Therefore, the water level rises and covers the sludge during the summer months. The sample had to be taken without being able to see the sludge. The sample collected was not representative of the sludge and contained large amount of gravel and coarse material. The experimental run lasted four days before the source of error was determined. The reactors were then emptied in order to begin a new run with the representative sludge sample to be treated.

After emptying out the reactors, it was noticed that more damage was done than the obvious wasted effort and time delay by the sludge collection error. The sludge used had a very different texture and consistency. It was very granular and contained some large gravel. Samples of the reactors were taken through the sampling ports; in so doing, pieces of gravel became lodged in the valves. The valves then plugged. The reactors had to be emptied by bailing the contents out of the top of the units. The valves were then flushed but to no avail. Subsequently, sampling and emptying of the reactors was done from the top. The up side to this dilemma was that sampling from the top insured that a fully mixed sample was being obtained. Also, an examination of the contents of the reactors i.e. aeration rate and foam production were made on sampling days and problems in the operation of the units could easily be observed. None of the

FIGURE 4.1.3 TOTAL COD VS TIME FOR RUN 2



questions posed by the first run were answered in this venture but an important lesson was learned about the care needed in the collection of on site samples!

#### **Run 3:**

Run 3 was aborted due to analytical problems.

#### **Run 4:**

The results from Run 2 were disappointing. The sampling ports were clogged and the data did not reveal anything about the potential treatability of the mixed waste. It was hoped that this set of experiments would put the research back on track. The main points investigated by this phase was the effect of the aeration rate on the degree of treatment achieved and the effect of added nutrients on the success of treatment by the microorganisms.

Prior to the start of this phase of the study, 250 ml of Javel brand bleach was added to Reactor 1; this would serve as the control vessel for the remainder of the experiments.

The aeration rate in all the reactors was tested with an air calibrated submersible dissolved oxygen probe. The reactors oxygen content originally ranged from 7 to 10 mg/L. The valves were then slightly shut, in order to obtain a D.O. reading in the tanks of between 2.5 and 3.0 mg/L; this would be an adequate level of aeration for the growth of the culture, while avoiding

the needless volatilization of the organic constituents of the waste (Grady 1990).

As can be seen in Table 4.1.6, the reactors were loaded to a much higher extent than was the case in the first run. After the success exhibited in the first run, the question of the upper concentration of treatability surfaced. The more concentrated the mixture, the less treatment batches would be required on site. Thus, finding the maximum level of treatability of the waste, without exposing the bacteria to a toxic level was a priority. However, it was quite possible that this organic load was too concentrated for the organisms to handle.

More parameters were monitored during this batch than the previous one, in order to get a better understanding of the treatment occurring. COD, pH, TSS and VSS were monitored twice per week and metals, BOD<sub>5</sub> and GC traces were studied at various intervals during the process. The COD and BOD<sub>5</sub> tests became a problem during this batch due to the high concentration of sludge present in the test reactors. To perform a COD test, the samples had to be diluted to between 200 and 1000 mg/L, which is the range for the COD HACH procedure. This meant diluting the samples up to 100 times it's original concentration. Taking a sample which was not fully mixed would incur a large error, since that small error would be magnified 100 times. Also, the day to day

Parameter:	Reactor 1	Reactor 2	Reactor 3	Reactor 4
Contents	Sludge, water, bleach. (Control)	Sludge, water, nutrients, seed.	Sludge, water, nutrients, seed.	Sludge, water, seed.
Sludge Vol. (L)	5	6	6	4
Dilution water (L)	10	9	9	11
Nutrient load (mg/L)	None	N= 1 332 P= 267	N= 1 332 P= 267	None
Initial Total COD (mg/L)	96 350	113 849	113 849	64 840
Initial Supernatant COD (mg/L)	8 543	9 856	6 138	3 513
pH	5.98	8.67	8.63	6.20

**Table 4.1.6: Initial conditions at the start of the fourth test run.**

variability in the COD had to be examined carefully due to the lack of precision of the HACH test. It would be possible for treatment to be occurring at a lower rate than the test could monitor.

Looking at the Total COD graph and Supernatant COD vs time for the process, Figures 4.1.4 and 4.1.5, the first observation is the general variability of the day to day samples. To try and overcome this problem, two samples were taken and the average of the result was used. In terms of the Total COD graph, the lowest overall variability can be seen in Reactor 4, which proceeds from it's initial Total COD value of about 60 000 mg/L to below 20 000 mg/L at the end of the batch.' Looking at the first two samples,

those on day 1 and day 3, all the reactors show a general downward trend, thereby giving the impression that no lag phase or bacterial acclimatization period occurred. However, the batch still had to be run for 85 days and the resultant treatment does not appear favourable in terms of Total COD reduction. This is especially true when taking into account that the control appears to be one of the best performing units in terms of Total COD reduction. The reason for the extremely long batch was there seemed to be little or no progress in terms of Total COD removal. There was a general downward trend in the Total COD of the reactors up to day 40 but total COD of the reactors still remained quite high. Another problem was that the Total COD of the control was also decreasing. This seemed to indicate that there was considerable volatilization and that minimal treatment was occurring in all the experimental vessels. In fact volatilization appeared to be the leading treatment for the run. The volatilization process appears to have been slow since the aeration rate low and because most of the sludge consisted of high molecular weight organics which were resistant to volatilization.

To examine this concept further, at day 40, stained slides were prepared of the bacterial cultures in reactors 1 and 2. It was quite possible that organisms were present in the control which would account for the reduction in Total COD. Although bleach had

FIGURE 4.1.4 TOTAL COD CONCENTRATION OVER TIME FOR RUN 4

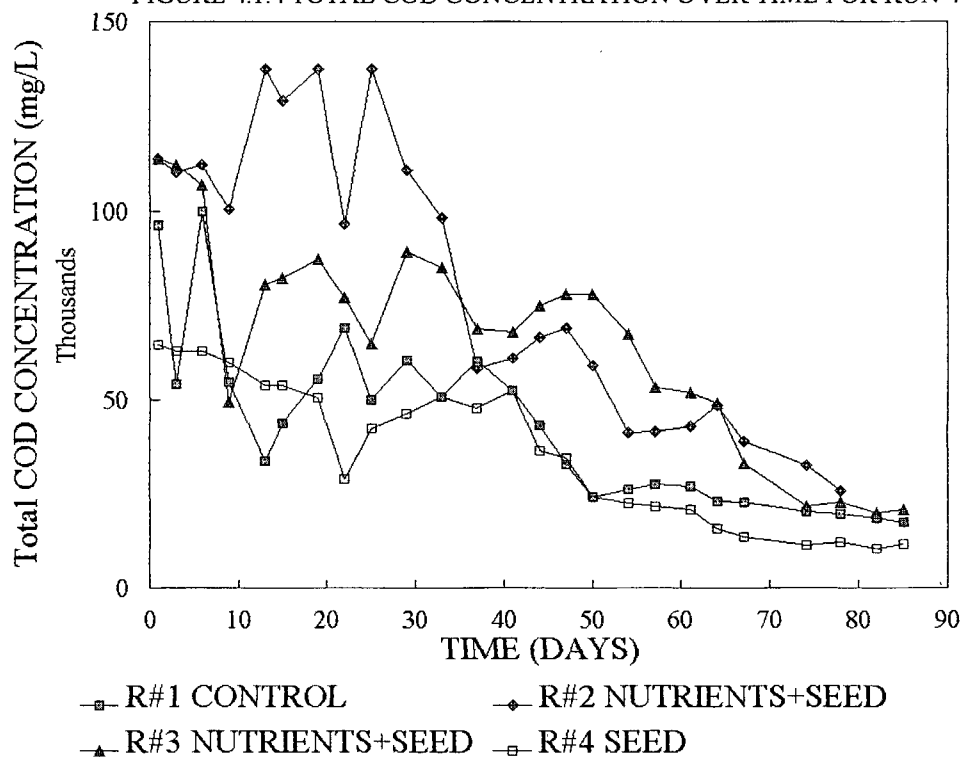
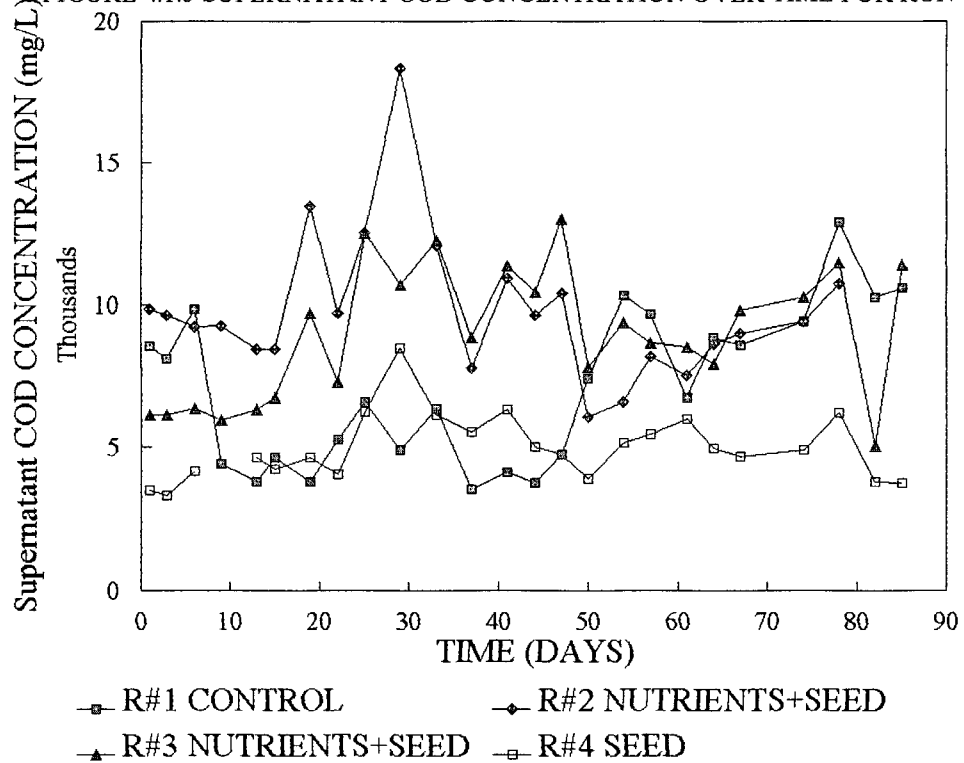


FIGURE 4.1.5 SUPERNATANT COD CONCENTRATION OVER TIME FOR RUN 4



originally been added to the control, it is possible that this simply slowed the hardier organisms and did not kill them. The slides revealed a small number of microorganisms were present in the control. However, it was difficult to differentiate the active bacteria from the organic matter present. The results of the slide from Reactor 2 were also inconclusive.

Since the Total COD degradation after day 27 in the Reactor 2 seemed stalled and the presence of an active microbial culture was in question, the reactor was reseeded with activated sludge from the on site treatment plant and dilution water was added to the reactor. The purpose was to try and enrich the culture present in the reactor. The manoeuvres did not affect the treatment occurring, since the decrease observed in the Total COD could simply be attributed to the dilution.

On day 37, three days after the seed addition, an oxygen uptake test was performed to determine the level of biological activity in Reactor 2. The rate of oxygen uptake was  $0.33 \text{ mg O}_2/\text{L min}$ , which indicates that the microorganisms were metabolically active. However, looking at the pH profile of the run, it can be observed in Figure 4.1.6 that the pH in the running reactors over the run was fairly stable. Past experience and literature indicated that a pH drop would incur, as the organic degradation proceeds in a non buffered system such as this one (Lallai 1989). As the organic compounds are broken down,  $\text{CO}_2$  will be released

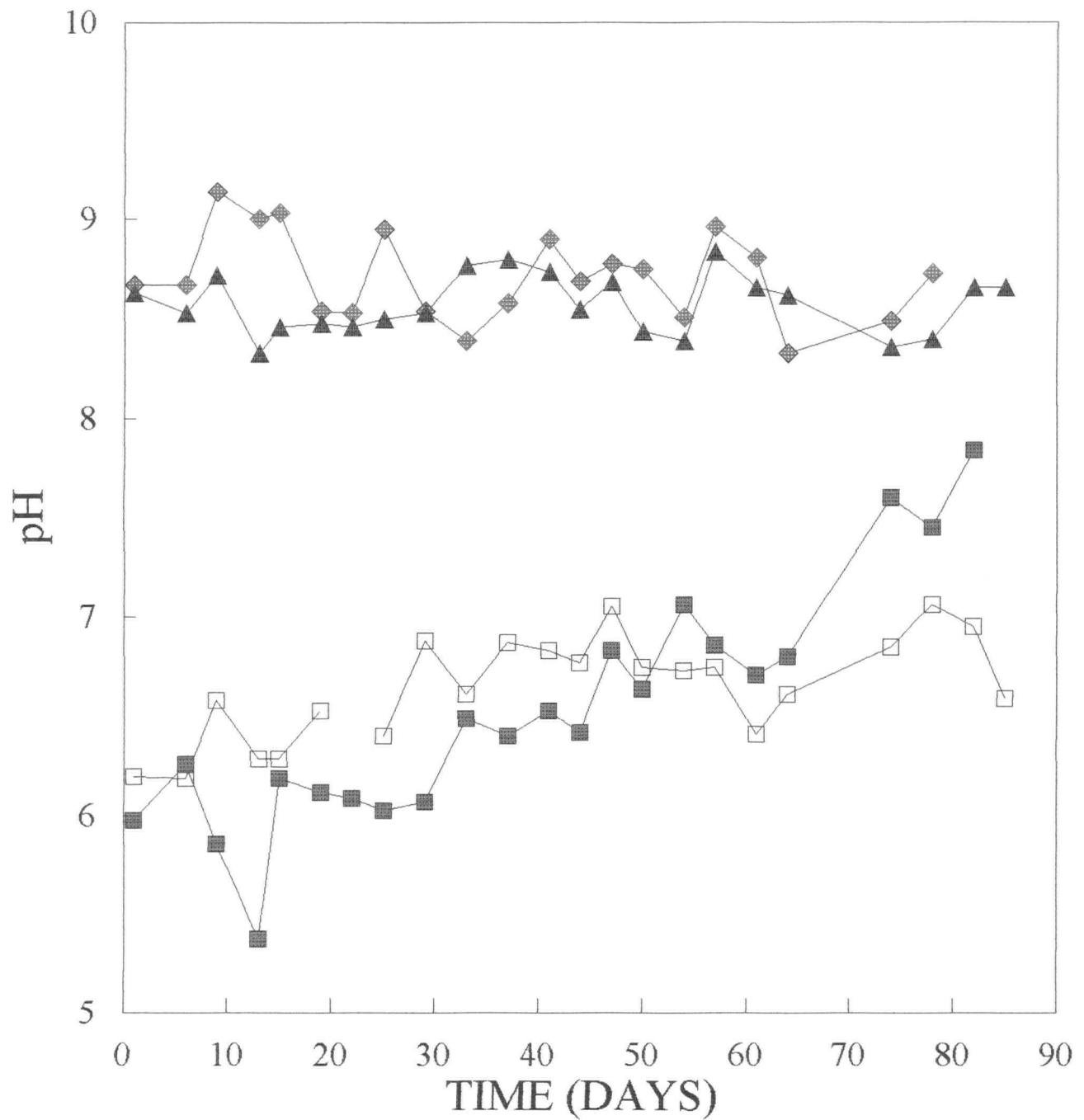
into the solution. Since the reactors have little or no buffering ability the pH would decrease with the formation of carbonic acid. Since this process was not occurring, it was another indication that the degradation process was occurring at quite a slow rate.

On day 47, more tests were run to try to quantify the level of microbial activity. Oxygen uptake tests were performed on each reactor, even the control, and microbial plate counts were performed on Reactor 1 (the control) and Reactor 3. The reason for choosing Reactor 3 was that it had the highest oxygen uptake rate and therefore seemed to have the most active biomass.

The most striking information provided by Table 4.1.7 was that there was considerable biological activity in the control. This created a significant problem since the control was supposed to be used to monitor losses due to volatilization. All the losses in terms of Total COD could no longer simply be attributed to volatilization. The rate of oxygen uptake shows that biological activity was occurring, although at a significantly lower rate than in the test reactors. The presence of a considerable culture of microorganisms was confirmed in the plate count.

Bacteria were present on the 4th or the 10000 th dilution; while in Reactor 3 bacteria were present on the 6th or 1 million th dilution. It thus appears that the control had been contaminated and thus, the results were not valid.

FIGURE 4.1.6 PH OVER TIME FOR RUN 4



■ REACTOR 1 - CONTROL      ◆ REACTOR 2 - SEED+NUT.  
 ▲ REACTOR 3 - SEED+NUT.    □ REACTOR 4 - SEED

Reactor:	Oxygen Uptake Rate: (mg O <sub>2</sub> /L min)
1 (Control)	0.15
2	0.27
3	0.43
4	0.3

**Table 4.1.7: Oxygen uptake Rate determined in the reactors on Day 47 of the fourth run.**

On day 50, to correct the problem with the control, 1 cup of bleach was added to the reactor. Since Reactor 2 seemed stalled in terms of Total COD reduction due to the possible presence of an inhibitory compound, and the oxygen uptake rate was almost half that of Reactor 3, it was diluted and reseeded. 10 litres were removed from reactor 2 and replaced by distilled water. One cup of the contents of Reactor 3 was added to Reactor 2 in order to improve the microbial culture. The dilution aimed to reduce the concentration of the apparent inhibitory compound present in reactor 2 to a level which would not affect the growth of the culture. Seeding the reactor sought to improve the quality and diversity of the organisms present and the rate of degradation in the reactor. Although the concentration in the reactor had been reduced from a Total COD of 70 000 to 40 000 mg/L, no immediate effect was observed in the rate of degradation in the reactor. It was possible that the culture was not able to recover from the toxic effects of the inhibitory substance.

On day 57, two parameters were checked to examine if they were

interfering with growth. The nutrient level in the reactor was measured. A deficiency of nutrients would inhibit the break down of organics. Nitrogen and phosphorus were present in all test reactors in concentration in excess of 10 mg/L, thus eliminating nutrient deficiency as a factor.

Secondly, the concentrations of copper and cobalt in the reactors were measured. Total Copper was present in concentrations ranging from 40 to 50 mg/L in the reactors. However, the dissolved copper was not examined; this would have given a clearer indication of the direct effect of the metals on the culture.

The run as a whole was not a success due to all the problems encountered. The Total COD reduction was reasonable; however conclusions are difficult since the control was contaminated. The reduction of the organic constituents was impressive but even the contaminated control also showed a large reduction.

On day 78, a decision was made to abandon part of the batch and to design a new batch experiment. Reactor 2 was emptied and the remaining reactors were left to continue the run for another week. At that point, the remaining reactors were converted for the start of a new set of experiments.

Although a large reduction was observed in the Total COD of the test reactors, the quality of the sludge had not markedly

Parameter:	Reactor1	Reactor2	Reactor3	Reactor4
Initial Total COD: (mg/L)	96 350	113 850	113 850	64 850
Final Total COD: (mg/L) after 78 days	19 869	(57 483 mg/L reduction attributed to dilution)  25 982	22 926	12 227
% Difference:	79.4	26.7*	79.9	81.1

**Table 4.1.8: Reduction in Total COD during run 4 in 78 days.\***  
Treatment due to degradation alone, without effect of dilution.

improved (Table 4.1.8). The physical characteristics of the sludge had not changed greatly during the course of experiment. The sludge still had an earthy colour. It had a significant, yet less pronounced strong chemical odour and an iridescent film still floated on the surface of the sludge. Table 4.1.9 indicates that many of the target organic compounds were still present in large concentrations. These were all indications of an incomplete degradation process. Sludge settling problems were also experienced. Even when left for a period of twenty four hours, the sludge would not settle. The literature indicates that the problem with a high organic matter loading rate, especially hydrocarbon, is that biofloc settleability is impaired. Some have hypothesised that the biofloc becomes coated with a hydrophobic layer, which affects its physical and biochemical performance (Rebhun 1988). Another possible cause for the problem, in this case, is the presence of fly ash in the sludge. The presence of

Compound:	Reactor1	Reactor2	Reactor3	Reactor4
Xylene	100	100	100	100
Diphenyl	82.1	90.6	96.9	71.1
Diphenyl Ether	66.0	48.4	84.0	73.1
Diphenyl Methane	47.9	26.6	68.7	0
Benzene, 1,1' Methylene Bis (4-methyl)	25.4	22.6	66.3	0
1,2-Dimethyl-4 Benzyl Benzene	100	88.1	94.2	100

**Table 4.1.9: Percent reduction in the 6 target organic compounds for run 4 in 78 days.**

these small molecules impedes the timely settling of the sludge. It is quite possible, however, that if the organic components in the sludge were totally degraded, these problems would not occur. Future runs would be used to prove this hypothesis.

Considerable information had been acquired from this unsuccessful run. Firstly, the rate of aeration was very important. The main purpose was to satisfy the requirements of the bacteria. However, on some occasion, the aeration system had been used for mixing the contents of the reactor. This process would be discontinued since any excess air simply leads to the unnecessary volatilization of the organic constituents of the sludge. The mixers would be used to produces a uniformly mixed culture. Mixing is one of the most important parameters required for

growth. It assures the distribution and availability of nutrients and oxygen to the growing bacterial cells (Deepak 1994).

Studies analyzing the degradation rate of sewage sludge emphasize that the presence of heavy metals greatly affects the rate of biodegradation. The concentration of dissolved metals are said to directly interfere with the growth of the bacteria and thus prevent the degradation of the sludge. A dissolved copper concentration of 1 mg/L has been shown to decrease the rate of Total BOD<sub>5</sub> degradation of sewage sludge by 40 percent (Mowat 1976). However, since the mixture of organisms found in the reactors differs greatly from those found in a system degrading sewage sludge, it is quite possible that the microorganisms in the reactors are more hardy or can adapt more readily to high dissolved copper concentration. Therefore, it is quite possible that the inhibitory copper level in this type of system is considerably higher than in a system degrading sewage sludge. However, there is no information in the literature to indicate inhibitory heavy metal levels in a concentrated chemical industrial waste. The monitoring of both total and dissolved forms of copper and cobalt might shed some light on the problems surrounding the Total COD reduction. Constant monitoring might also identify when concentrations approached possible toxic limits and actions could then be taken to remediate the situation to insure the continuation of the batch.

The presence of nutrients is essential for the growth of microorganisms. The absence of either nitrogen or phosphorus would inhibit growth and cause a stall in the Total COD degradation. From this point, the monitoring of nutrients would be done on a continuous basis. Each sample taken would be tested for the presence of nitrogen and phosphorus. The utilization of the nutrients would also indicate the degree of activity of the bacteria. If nutrients were present, yet were not being utilized then this would indicate that some other agent was responsible for the growth inhibition of the culture.

The establishment of a reliable control was essential. However, in run 4, a high concentration of bacteria was present in the control reactor. Therefore, it is not clear whether degradation or volatilization was responsible for the change in the organic concentration. Monitoring and maintenance of a control was essential for accurate conclusions to be drawn about the process.

#### 4B. Results and Discussion (Continued): Batches With Metal Toxicity Problems.

The purpose of the following set of runs was:

- 1) To establish a representative control free from contamination.
- 2) To monitor more closely the nutrient and the metal concentrations in the running reactors.
- 3) To cut the length of the batch runs, while achieving a higher degree of treatment.

##### Run #5

A new reactor was established for this run, since the previous run was not terminated for all the reactors. Reactor 2 was stopped at 78 days, but the other three reactors continued for another week. Due to space limitations, the new control was a five litre bucket which could sit between the larger reactors. The contents of the running reactors for run 5 are shown in Table 4.2.1:

Parameter:	Reactor 2	Reactor 5 (Control)
Sludge volume (L)	2	0.5
Dilution Water (L)	13	4.5
Total Volume (L)	15	5 (including 100ml bleach)
Initial Total COD (mg/L)	19 885	19 121
Initial Supernatant COD (mg/L)	1 438	960
pH	8.73	7.06

**Table 4.2.1: Initial conditions in the reactors at the start of run 5.**

The first observation to be made when looking at Table 4.2.1 is that only two reactors were being run for this batch: a test reactor and a control. The second point is the magnitude of the initial Total COD in the reactors. The lower starting concentration was chosen in order to decrease the initial concentration of the metals and the various organic compounds found in the waste mixture. The aeration system was tested and set in order to yield no more than 2.5 mg/L of dissolved oxygen in the reactors.

The run resulted in the most successful data to date, in terms of Total COD and organics degradation. Looking at Figure 4.2.1, the Total COD over time graph shows that there was almost a 50 % decrease in the concentration of the running reactor in the first three days. The reduction in Total COD cannot simply be attributed to volatilization, since there is little overall change in the Total COD of the control. Further evidence of treatment can be seen in the changes of the pH and the VSS/TSS ratio over time.

The pH vs time graph, Figure 4.2.3, shows a considerable decrease over the first twenty days, followed by a period of levelling off. The rapid decrease in the pH indicates that considerable organic matter degradation was probably occurring. As explained earlier, the degradation process leads to the accumulation of  $\text{CO}_2$  in the reactor and normally results in a reduction of the pH.

FIGURE 4.2.1 TOTAL COD CONCENTRATION VS TIME FOR RUN 5

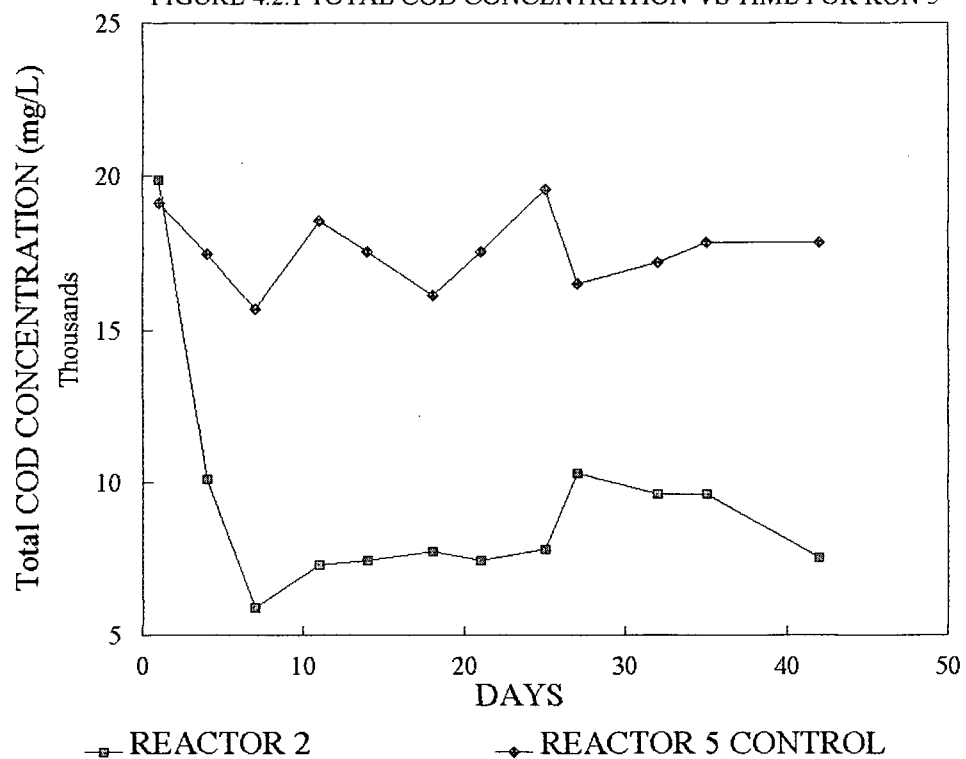


FIGURE 4.2.2 SUPERNATANT COD CONCENTRATION VS TIME FOR RUN 5

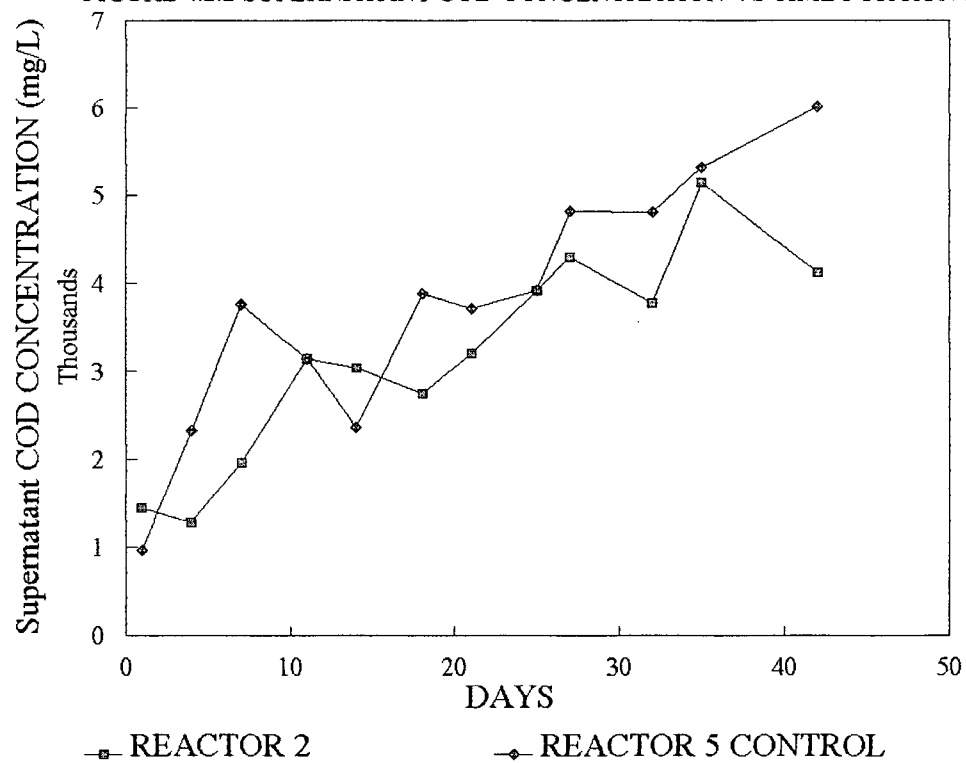


FIGURE 4.2.3 PH vs TIME FOR RUN 5

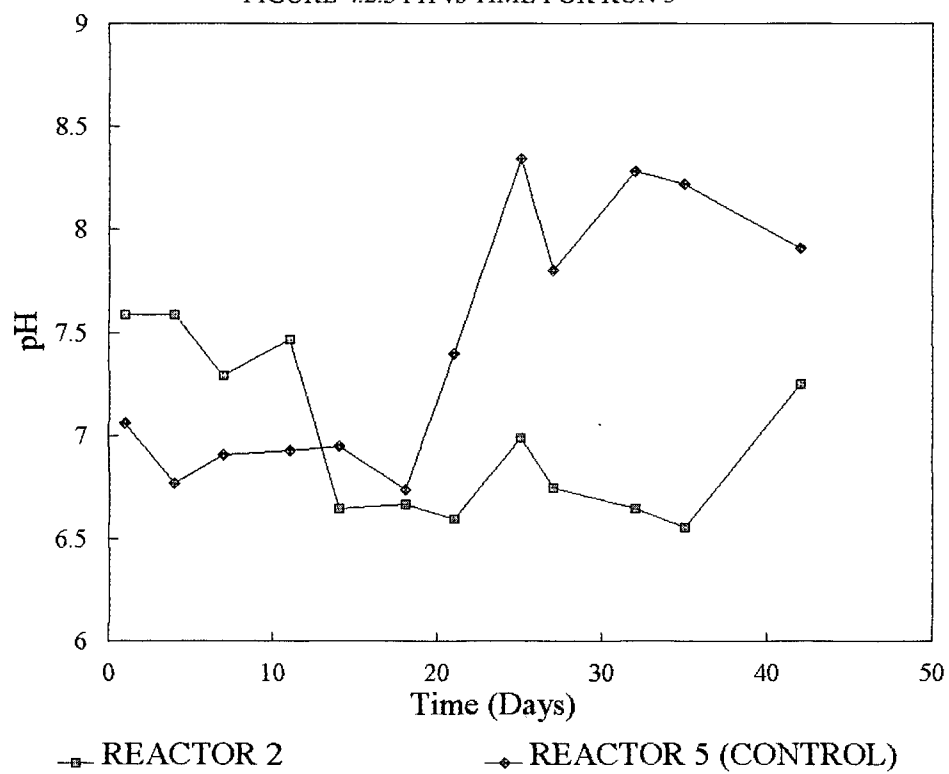
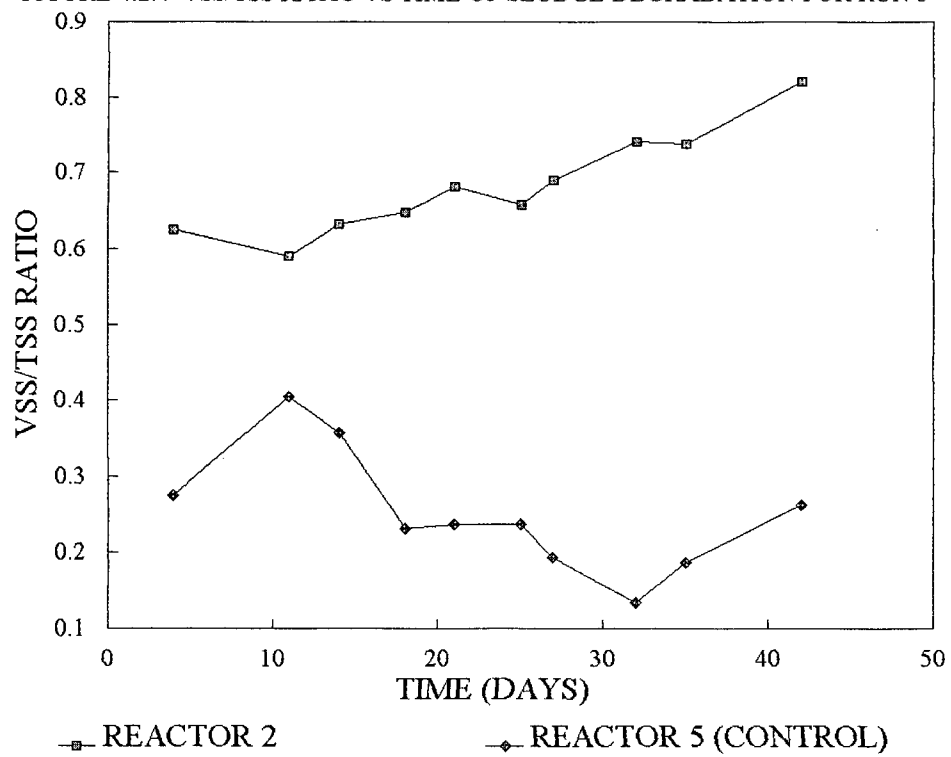


FIGURE 4.2.4 VSS/TSS RATIO VS TIME OF SLUDGE DEGRADATION FOR RUN 5



The VSS/TSS graph, Figure 4.2.4, shows a slight increase in the ratio as the experiment proceeds. This parameter is used to monitor the changes in biomass concentration in the reactor. An increasing biomass indicates that an increasing population of viable microorganisms are utilizing the organic contents of the reactor as a food/carbon source.

The presence of nutrients during the run can be observed in Figures 4.2.5 and 4.2.6. The phosphorus concentration graph vs time shows the constant presence of abundant residual phosphorus in the reactor. However, the ammonia vs time graph indicates a different situation. On day 18, ammonia was absent from the system. This is due to the fact that ammonia is used by the system at a higher rate than phosphorus was. However, both were added in the same proportion for this run. With constant monitoring, the problem was recognized and quickly corrected.

It is difficult to determine the effect that the deprivation of the essential nutrient had on the system. The Total COD vs time graph, Figure 4.2.1 does not show any effect. All the degradation in terms of Total COD occurred in the first 10 days of the experimental run. There is a slight change in the VSS/TSS ratio graph over the starvation period though, but nothing conclusive. The lack of nitrogen may have caused the metabolism of the cells to slow, thus reducing the rate of carbon usage.

The supernatant COD graph over time, Figure 4.2.2 shows some interesting results during the course of the run. The supernatant

FIGURE 4.2.5 PHOSPHORUS CONCENTRATION VS TIME FOR RUN 5

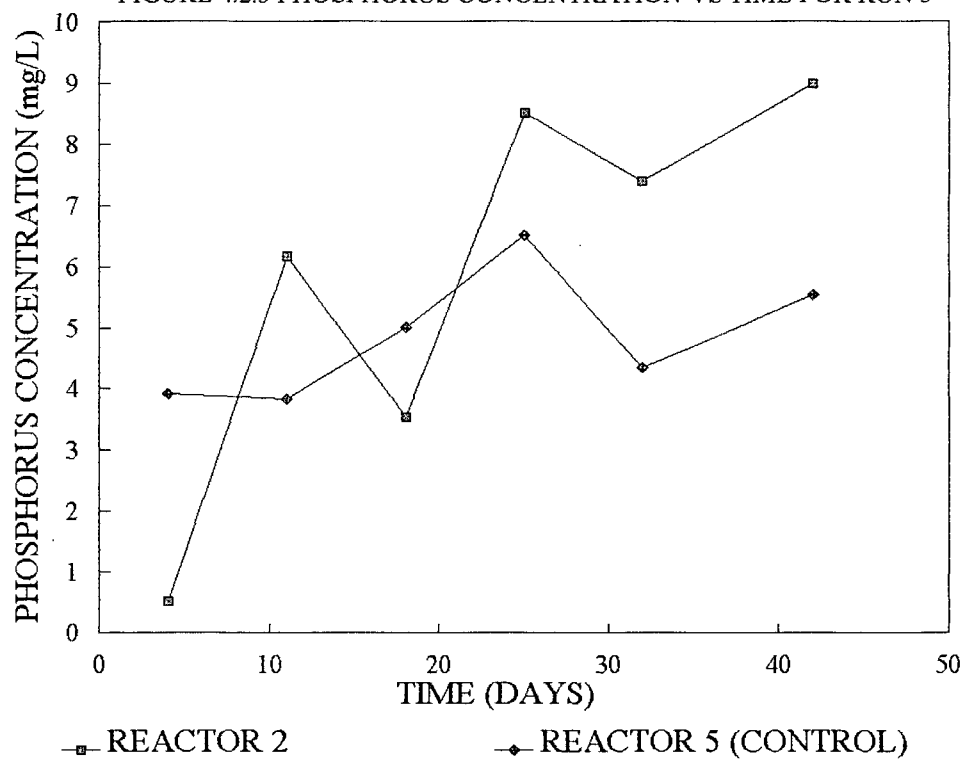
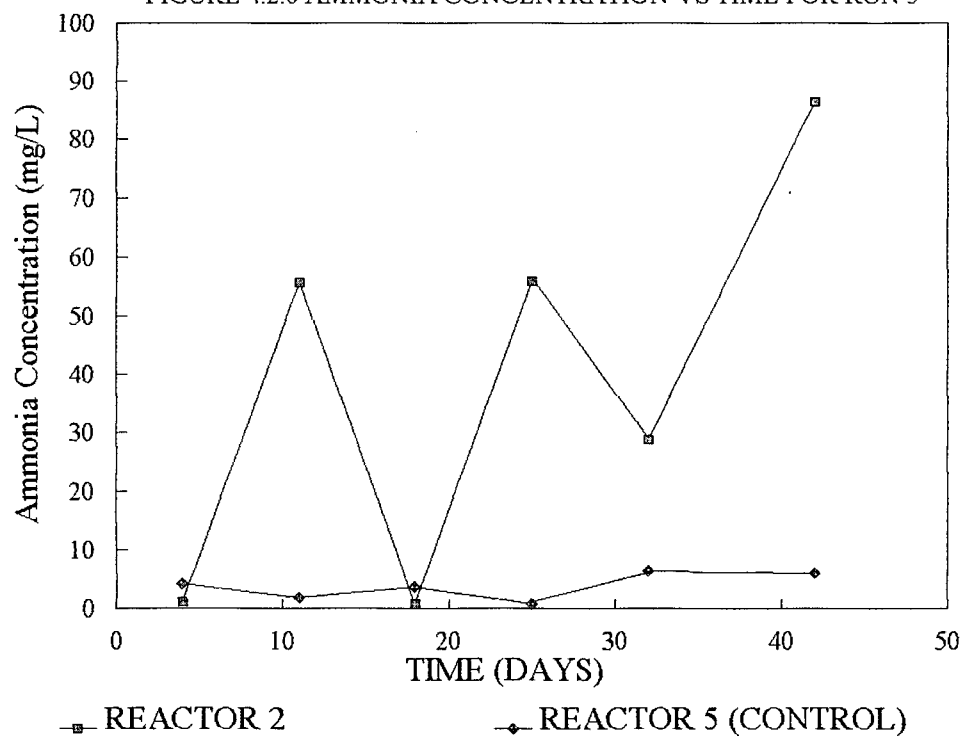


FIGURE 4.2.6 AMMONIA CONCENTRATION VS TIME FOR RUN 5



COD concentrations start off low but climb as the run proceeded. This indicates that components of the sludge were solubilizing as the run progressed. At the beginning of the run, the soluble COD concentration was 1 438 mg/L or 7.2% of the Total COD. At the end of the run, the soluble COD consisted of 4 118 mg/L or 54.6% of the Total. The organics appeared to be accumulating in the supernatant faster than the microorganisms usage rate in the mixed liquor.

As noted from Tables 4.2.2 and 4.2.3, the biological process was successful in degrading most of the target organic compounds in the sludge to below the detection limit of the GC in 41 days. Depending on the specific compound, the reduction can be partially attributed to volatilization. Compounds, such as Xylene, which are of low molecular weight, are more easily volatilized than heavier compounds. However, not all the Xylene reduction can be attributed to volatilization. From the GC trace, Xylene disappeared from the test reactor after 7 days; however, in the control, after 42 days there was still a residual concentration present. Therefore, quantifying the amount of volatilization is not as simple as the arithmetic difference between the concentration in the control and the test reactor after 42 days. It can be concluded that, if the waste mixture is aerated at a rate which produces 2.5 mg/L of dissolved O<sub>2</sub> in the reactor for 42 days, the Xylene contained in the waste would be volatilized. However, this is not what occurred. Most of the

Xylene reduction in the test reactor has to be attributed to degradation, since it disappeared from the reactor in one week. At that point, only 20% of the Xylene in the control had volatilized.

Parameter:	Reactor 2	Reactor 5 (Control)
Total COD (mg/L) (Initial)	19 885	19 121
Total COD (mg/L) After 41 days	7 548	17 850
% difference	62	6.6

**Table 4.2.2: Results of run 5 in terms of COD reduction after 41 days.**

Compound:	Reactor 2 Percent reduction	Reactor 5 (Control) Percent reduction
Xylene	100	94
Diphenyl	100	48.7
Diphenyl Ether	99.3	38.6
Diphenyl Methane	71.2	10.2
Benzene, 1', 1' Methylene bis (4- methyl)	100	48.7
1,2 Dimethyl 4 Benzyl Benzene	100	77.7

**Table 4.2.3: Percent reduction of the target organic compounds present in the sludge after 41 days.**

The major target compound of the waste mixture is Diphenyl Ether. It is present in the largest concentration and is the most difficult to degrade. Generally, when the concentration of this compound falls below the detection limit of the GC, the trace will be blank. Thus, it serves as a benchmark, indicating the

degree of treatment the sludge has received. In the case of this run, 99.3% of the original Diphenyl Ether was removed. Therefore, the treatment process was not quite complete, but was an improvement over past runs.

The waste was very difficult to analyze using Gas Chromatography due to it's varied chemical makeup. From week to week, the numbers obtained varied greatly. Due to this problem, for the remainder of the study, three sludge samples were analyzed on the GC and the average result was used.

Looking at the numbers as a whole, the residual Total COD must generally be composed of compounds which do not volatilize or extract under the analytical conditions, since no unidentified compound shows up on the final GC trace. These compounds are probably of low mobility and high molecular weight. The GC trace of the end product is significantly different from the initial trace, both in terms of the number and area of the peaks. On the initial trace, over 40 compounds could be seen in varying concentrations. However, on the final trace for the running reactor, only two peaks of significantly smaller area were present. The traces can be seen in Appendix B. The end product sludge contained a low concentration of Diphenyl Ether and Diphenyl Methane. The GC trace for the control is also slightly different with the disappearance of some lower molecular weight organics and the reduction in area of others. A key to the next

run would be to control the aeration rate in order to further reduce the volatilization. The Total COD loss in the control was 6.8% of the initial concentration, as compared to 66% in the test reactor.

Qualitatively, the end product sludge showed marked improvement. The sludge had a faint chemical smell and the iridescent hue on the surface of the sludge was less apparent. Also, the sludge settled a little better than in the past, but much of the solids remained in suspension. Although considerable progress had been made, the quality of the effluent still needed to improve.

Due to the progress and the apparent successfulness of the run in terms of Total COD removal, the heavy metal concentration in the reactors was not monitored closely. The heavy metals should not have been a factor due to the large initial dilution of the sludge. The total copper concentration in Reactor 2 was 52 mg/L. The initial dissolved concentration was below 1 mg/L, but by day 18, the dissolved concentration had reached 5 mg/L. Studies done on sewage sludge state that dissolved concentrations of copper as low as 0.5 mg/L have been found to inhibit growth. Apparently, the organisms in the reactor adapted to high copper levels, through exposure to the sludge or because the type of organisms present were more resistant to high copper concentrations.

Initially, the dissolved metal concentration was below the

detection limit and 18 days later it was quite high. This seems to indicate that, at first, the metal was bound to compounds in the sludge. As the organics degraded, the metal was released into the solution. The rate of the release seemed slow enough to enable the microorganisms to adapt to the increasing dissolved metal concentrations in the mixture.

The nutrient utilization for Reactor 2 are shown in Table 4.2.4:

Nitrogen Used (mg/L)	Phosphorous Used (mg/L)	Total COD Used (mg/L)
152.5	66.5	12 337

**Table 4.2.4: Nutrient utilization and the COD reduction for run 5.**

The C:N:P ratio of the run was 185.5:2.29:1. As mentioned in the literature review, the acceptable ratio for microorganisms growth in a low concentration phenolic waste system is 100:10:1, while in sewage sludge, the expected ratio is 100:5:1. The ratio for this run is not similar to either model proposed. This is not surprising since no work has been done in this area and the specific nutrient needs of the microorganisms may vary. Part of the reasons for the variance is due to the usage of Total COD as the amount of carbon used, rather than the traditional BOD<sub>5</sub>. However, due to the nature of the sludge, some BOD tests in the run were inconclusive and could not be used.

As can be seen in Table 4.2.5, the nitrogen to phosphorous ratio for most of the run was between 2 and 2.5. This is more than half

of the ratio necessary for bug growth, as predicted in the literature for sewage sludge (Metcalf 1991). This may be

Period of elapsed time:	N used: (mg/L)	P used: (mg/L)	N/P ratio:
7 days	15.9	6.6	2.4
7 days	54.9	26.5	2.07
7 days	30.3	6.7	4.52
7 days	27.1	11.1	2.44
10 days	24.3	15.6	1.56

**Table 4.2.5: Ratio of nitrogen to phosphorous utilization during run 5.**

attributed to phosphorous not only being used as a nutrient but as a reactant in the precipitation of dissolved copper. More information on the process would be required before conclusions could be made. However, it appeared that the dissolved copper, under the right conditions, could be removed from the solution by precipitation as copper phosphate.

This run provided a starting point for further analysis. It showed that the degradation of waste was possible and that the volatilization of organic compounds could be reduced and possibly eliminated. The control indicated that reduction in terms of Total COD was mostly due to the degradation by microorganisms, contrary to what had occurred in previous runs. However, the degree of treatment still had to be modified to produce a better quality end product. Also, the amount of organic matter being volatilized had to be further reduced. Many questions remained

unanswered, mainly focusing on the optimum initial sludge loading rate of the reactors and the effect of dissolved metals in the growth of the culture.

#### **RUN#6:**

This run sought to build on the progress of the previous run. Again, more careful analysis and monitoring would be necessary in order to determine the degree and quality of treatment obtained. For this run, three reactors were used, two test vessels and a control. The purpose of the run was to replicate the success obtained in run 5. The previous run had an initial Total COD of 20 000 mg/L, resulting in quite a successful run; a Total COD reduction of 66% and a removal of most of the organic compounds. The loading of the reactors for this run was as follows: one of the reactor would have the identical initial sludge loading as the running reactor in the previous run, to observe if the quality of the end product sludge could be improved, if the culture does not undergo a nitrogen deficiency. The other test reactor would have a concentration of 10 000 mg/L, to observe the differences in terms of the degradation kinetics. Table 4.2.6 shows the variability of the sludge from the lagoon and the difficulties in trying to reach a designed loading rate. Although Reactor 1 and 3 were seeded with the same amount of sludge, the composition differed greatly. The pH and initial Total COD indicate that the contents of the reactors were not identical.

Parameter:	Reactor 1 (Control)	Reactor 3	Reactor 4
Sludge Volume (L)	2.5	2.5	3.0
Dilution water Volume (L)	15.5	16	16
Total Volume	18 (including 500 ml of bleach)	18 (including 4 Litres of activated sludge)	19 (including 4 Litres of activated sludge)
Initial Total COD (mg/L)	16 909	14 878	31 802
pH	8.52	7.39	5.83

**Table 4.2.6: Initial conditions in the reactors prior to the start of run 6.**

The two test reactors, 3 and 4 were each seeded with activated sludge. Reactor 3 was seeded with the activated sludge from the on site treatment plant, while Reactor 4 was seeded with the supernatant from a reactor in the previous run. The purpose was to see the effect that acclimatised organisms would have on the rate of degradation, compared to the organisms which had not being exposed to the waste. Hypothetically, the lag or acclimatization phase should be decreased or eliminated in using the recycled seed and would result in a higher degradation rate. The other purpose was to conserve the culture, which was partially successful in degrading the sludge in run 4. This should explain the difference in the pH of the two test reactors, given the supernatant seed had a low pH and no buffering capacity.

Figures 4.2.7 and 4.2.8 are the Total COD and Supernatant COD vs

time graphs for the run. The Total COD graph is similar to the shape of the one in run 5. Initially, there was a quick decrease in the Total COD concentration of the test reactors, a process which has been exhibited in most successful runs to date. Following this initial degradation period, there was a certain degree of levelling off and a slight increase in the total COD. The length of the experiment was considerably longer than in run 5. The run was extended in order to try and reduce the Total COD further. However, as was the case in run 4 and 5, once the system stalled in terms of Total COD reduction it was difficult to restart. The halt in further Total COD reduction occurred earlier and more substantially than in previous runs. This could have been caused by lack of nutrients. However, Figures 4.2.9 and 4.2.10 indicate the presence of nitrogen and phosphorus during the entire run. As seen in Figure 4.2.10, on day 10 there was almost a nitrogen deficiency, but a quick addition remedied the situation.

The VSS concentration vs time graph, Figure 4.2.11, shows a slight dip in the amount of biomass in the reactor at that time. However, the graph shows a general increasing trend for most of the remainder of the run, indicating that growth resumed after the nutrient addition.

Around day 30, the biomass concentration was reduced drastically over 2 separate sampling periods (between day 30 and 40). During this period of time, nutrients were present in significant concentrations and the BOD was greater than 2000 mg/L

FIGURE 4.2.7 TOTAL COD CONCENTRATION VS TIME FOR RUN 6

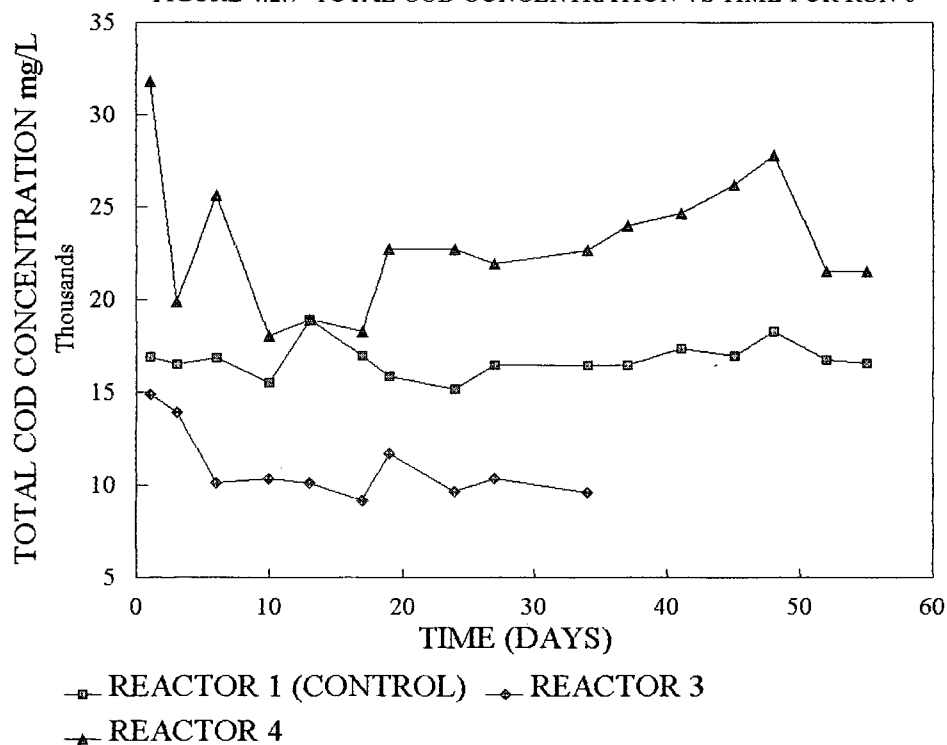
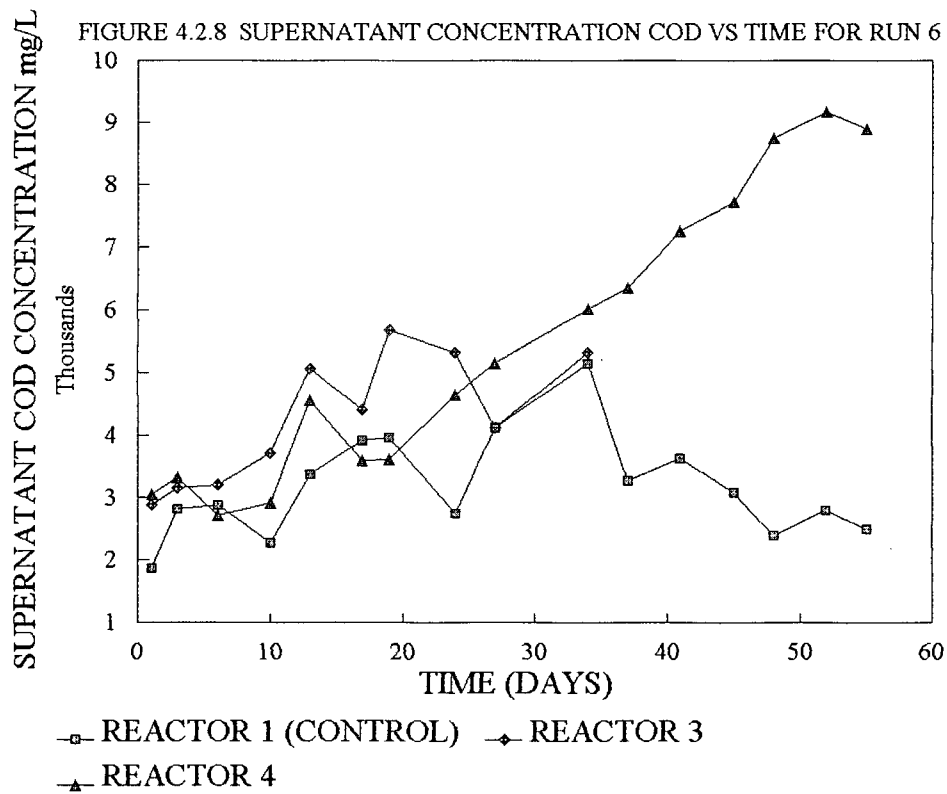


FIGURE 4.2.8 SUPERNATANT CONCENTRATION COD VS TIME FOR RUN 6



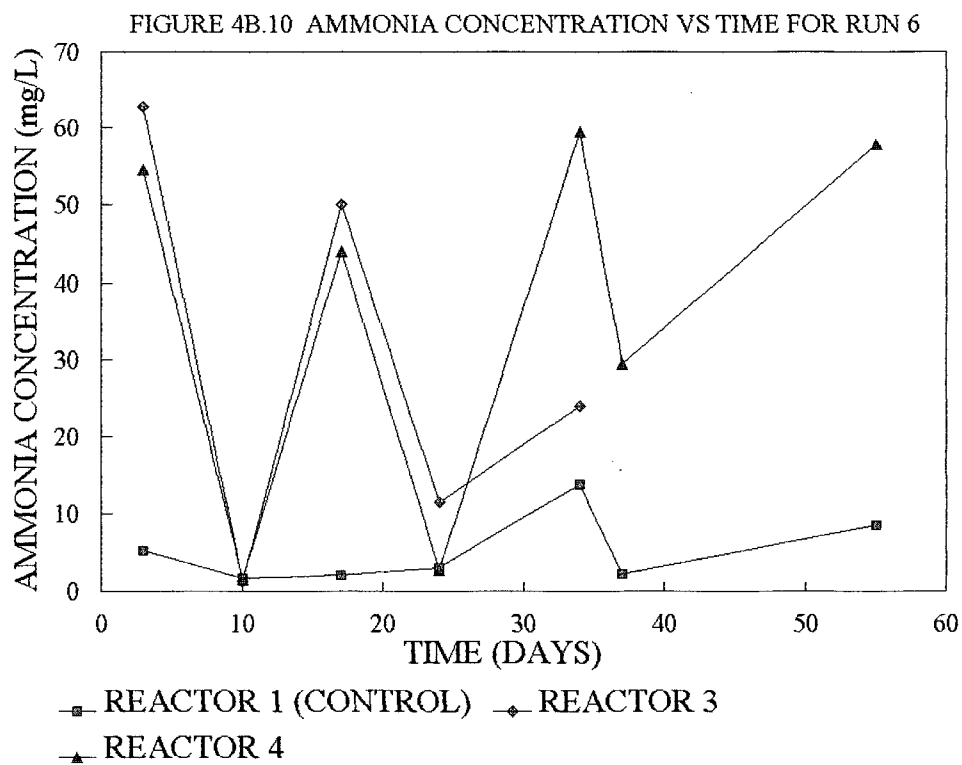
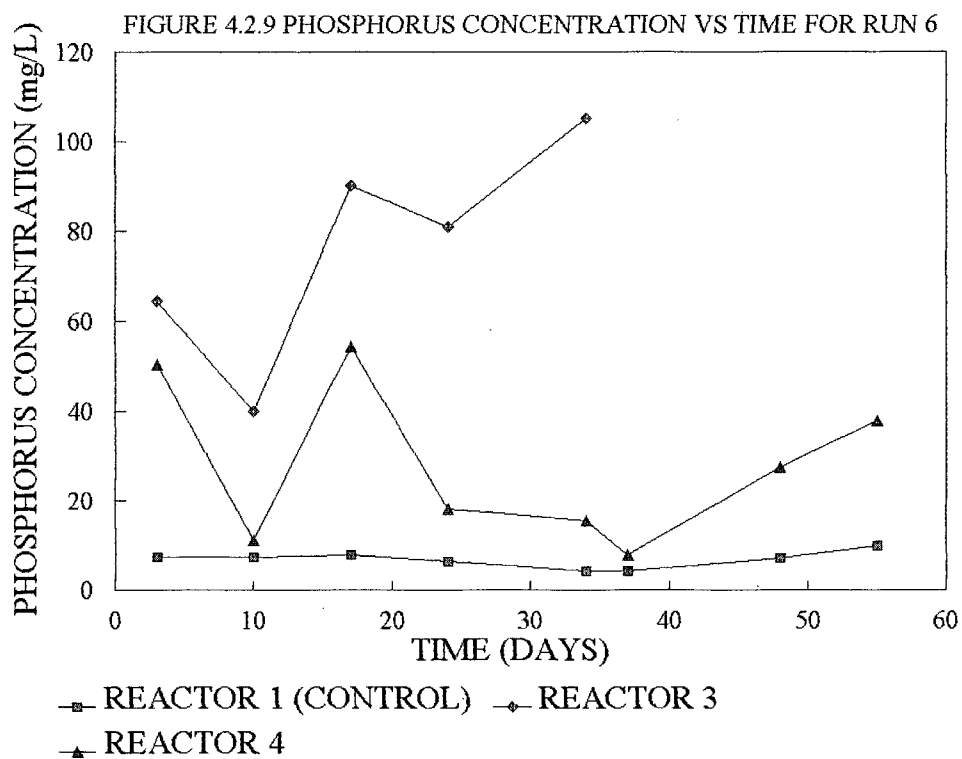


FIGURE 4.2.11 MLVSS CONCENTRATION VS TIME FOR RUN 6

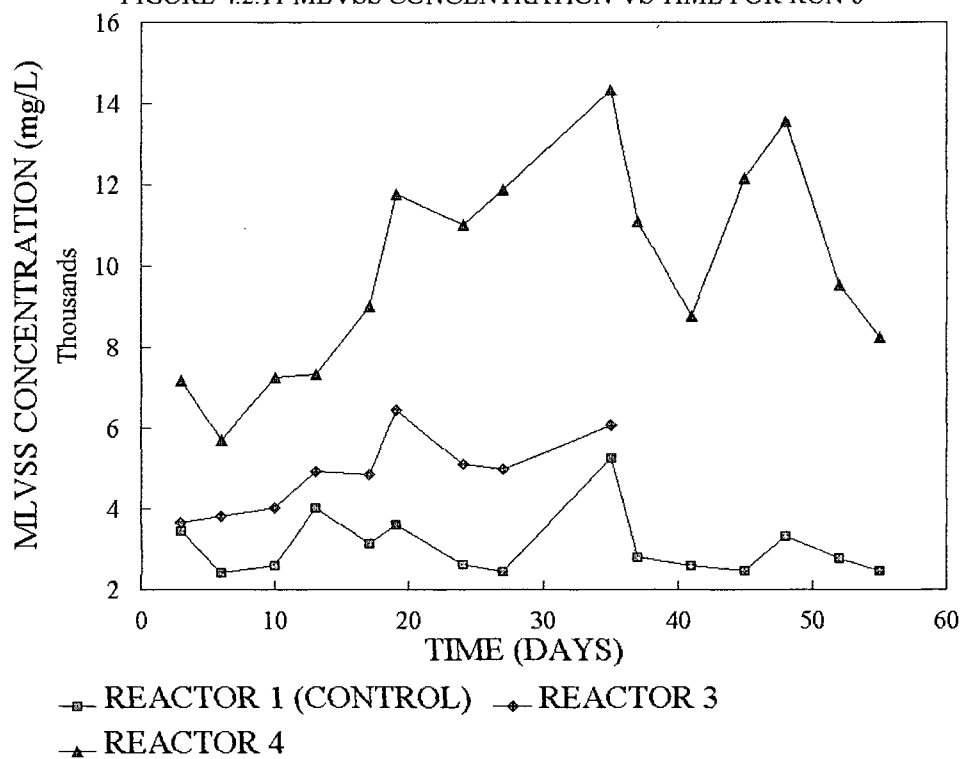
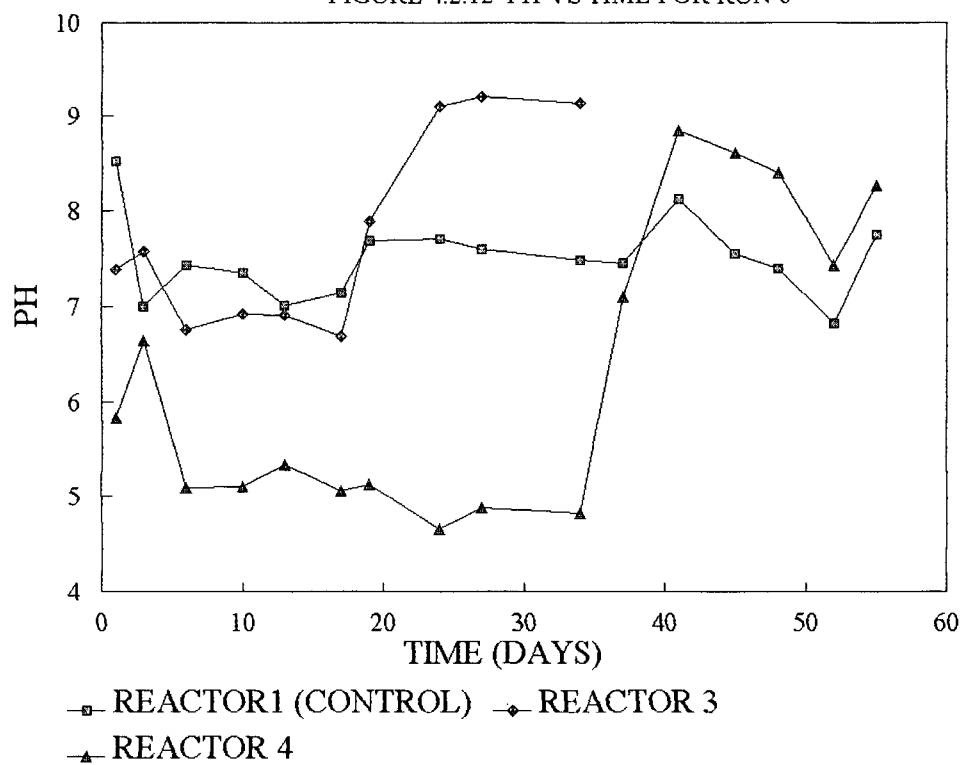


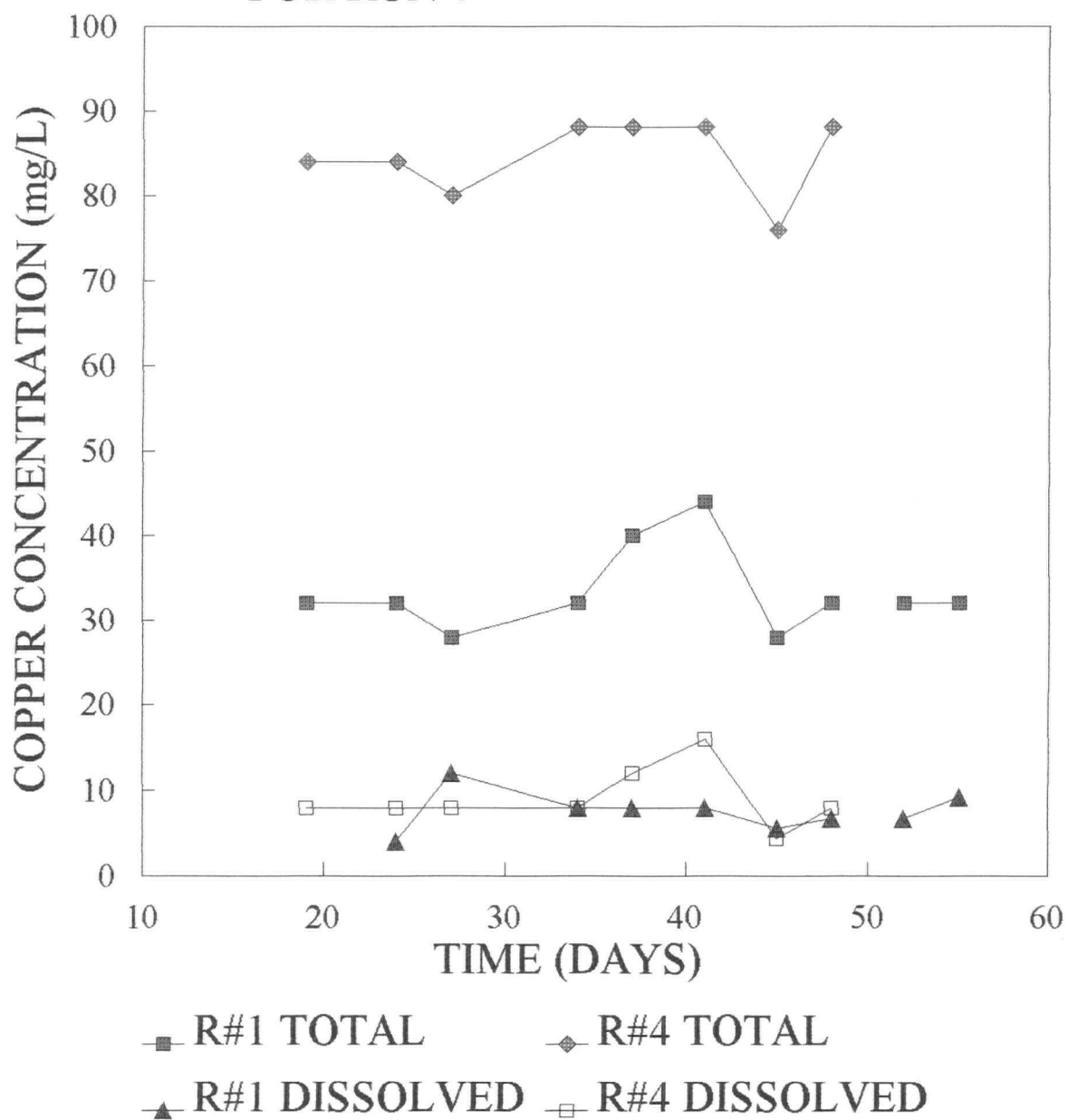
FIGURE 4.2.12 PH VS TIME FOR RUN 6



in the reactor. Thus, the basic essential requirements for growth were present. At first, it was thought that this was the result of low pH. Examining the pH over time, Figure 4.2.12, it shows that the pH dropped quickly at first and then levelled off to an average value of 5. For cell growth, the generally accepted pH range is between 6.5 and 8.5 (Beltrame 1979). The pH was adjusted with soda ash. After the addition, the pH was in the range of 9; this was slightly higher than desired and could have shocked the bacteria, due to the dramatic pH fluctuation. However, the growth in terms of VSS increased after the addition and the problem seemed to have been solved.

However, upon closer inspection, the system improved for only 2 sampling periods (1 week) in terms of VSS increase and then continued a downward trend. The pH at this time was within the accepted range for growth. Nutrients were plentiful and the BOD was still above 2000 mg/L. Examining the data more closely, it appears that the pH was not directly the cause of the growth problem but contributed to the problem. Looking at Figure 4.2.13, the total and dissolved copper concentration over time can be observed. The total copper concentration in Reactor 4 was above 80 mg/L. From the beginning of the run, the dissolved copper concentration was fairly constant, under 8 mg/L until day 35. At the same time, a reduction was seen in the VSS concentration. The dissolved copper concentration then rose to 14 mg/L.

FIGURE 4.2.13 COPPER CONCENTRATION (TOTAL AND DISSOLVED) VS TIME  
FOR RUN 6



This rise was attributed to the low pH in the mixed liquor, resulting in greater metal solubilization. Increasing the pH to 9 precipitated much of the dissolved copper, reducing it to a concentration of approximately 5 mg/L. The precipitation of the copper was also aided by the addition of sodium phosphate. Once the dissolved copper concentration in the reactor approaches toxic levels, recovery does not always appear to be possible; in this case the dissolved copper concentration continued to increase as the experimental run proceeded.

Reactor 3 was run for a shorter period of time than Reactor 4 but was more successful in terms of the degradation of the waste. The reduction in Total COD vs time for the reactor was not startling but resulted in the destruction of most of the organic constituents of the waste. The pH of the reactor was inconsistent as shown in Figure 4.2.12. Although there was a levelling off in Total COD degradation, the GC trace indicates that considerable treatment still occurred during this period; that is, that there was a reduction in the concentration of target organic compounds, even though there was no apparent change in Total COD. This indicates that examining the Total COD alone might not be the best way to monitor the progress of this type of system. A combination of data must be observed to understand the operations of the bioprocess.

The metal concentration was not of concern in this reactor, since

the initial concentration of the sludge was much lower than in Reactor 4. The run ended earlier than the was the case for Reactor 4, since the GC trace indicated that treatment was almost complete.

Through manipulation of the aeration rate it was possible to further limit the reduction of Total COD of the control due to volatilization. The Total COD level in the reactor for the length of the run was fairly stable.

Figure 4.2.8, is the graph of the COD of the Supernatant over time. It is similar to the one from the previous run. As the run proceeded, organic compounds were dissolved into solution. It is interesting to note that the reactor with the higher initial sludge concentration resulted in the accumulation of a higher supernatant COD concentration. This indicates that compounds were solubilizing into solution at a faster rate than can be used by the microorganisms. It is possible that this phenomenon was responsible for the cessation in the carbon degradation. The dissolved concentration of one of the compounds may have reached a toxic level in the supernatant and inhibited the growth of the microorganisms.

As Tables 4.2.7 and 4.2.8 indicate, Reactor 3 was more successful at treating the waste based on the removal of organics. This appears to be due, in part, to the fact that the initial

Parameter:	Reactor 1 (control)	Reactor 3	Reactor 4
Length of run (days)	55	34	55
Initial Total COD (mg/L)	16 909	14 878	31 802
Final Total COD (mg/L)	16 564	9 608	21 529
% difference	2	35.4	32.3

**Table 4.2.7: Comparison between the initial conditions and the end result of run 6 in terms of Total COD.**

Compound:	Reactor 1 (control) Percent removal	Reactor 3 Percent removal	Reactor 4 Percent removal
Xylene	100	100	100
Diphenyl	59.4	97.5	95.3
Diphenyl Ether	30.8	96.5	84.8
Diphenyl Methane	11.3	88.3	0*
Benzene, 1,1' Methylene bis (4 methyl)	7.8	78.9	22.7
1,2-Dimethyl- 4-Benzyl Benzene	77	100	86.2

**Table 4.2.8: Percent removal of the target organic compounds during run 6.\* No Diphenyl methane was removed from reactor 4.**

concentration of organics was lower. The control indicates that less volatilization occurred in this run than in the previous ones. However, the lower weight organic compounds were still easily volatilized, as indicated by the 100% removal of Xylene from all of the reactors. However, one must remember that this

does not indicate that the removal of Xylene from the test reactors was through volatilization, since the removal occurred much faster in the test vessels than in the control.

The GC data indicated that the initial Total COD loading of 32 000 mg/L in Reactor 4 might have been too high. The Total COD was reduced by almost the same percentage as in Reactor 3, but the percent removal of the organic compounds was quite different. A much lower degree of treatment, in terms of many of the target organic compounds, was achieved. This can be partially explained by the initial high organic loading rate, as well as the amount of dissolved copper present. The copper was not only present from the sludge, but also in the seed sludge from the previous run. The high dissolved metal concentration appears to have inhibited the growth of the bacteria and reduced the degradation of the waste. This initial sludge loading would thus serve as a benchmark for future runs. It was speculated that, if the pH were modified and buffered prior to the start of the run and that additional phosphorus were added to the system to precipitate dissolved copper, the results may have been quite different. More investigation into this area would be necessary.

The nutrient concentration over time for the run is summarized in Tables 4.2.9 and 4.2.10. The striking point about the ratios in Table 4.2.10 is that there seemed to be a high carbon content used for the microorganism growth. Again, it should be noted that

	Reactor 3	R#3	R#3 N/P ratio	Reactor 4	R#4	R#4 N/P ratio
Number of Days	P used (mg/L)	N used (mg/L)		P used (mg/L)	N used (mg/L)	
3	10.4	17.1	1.64	9.5	18.4	1.94
7	24.8	61.5	2.48	39.4	53.1	1.35
7	7.5	38.5	5.1	11.1	40	3.6
7	9.07	38.5	4.24	36.4	41.2	1.13
10	8.03	37.6	4.68	2.7	33.2	12.3
3				7.6	30.1	3.96
18				20.3	60.4	2.98
Total	59.8	193.24	3.23	137.1	280.2	2.04

**Table 4.2.9: Nutrient utilization for the two test reactors for run 6.**

Parameter:	Reactor 3	Reactor 4
COD:N:P	161: 3.23: 1	157: 2.02 :1

**Table 4.2.10: Total COD:N:P ratio for run 6.**

Total COD is not usually used in determining the ratio. Rather, Total BOD<sub>5</sub> should be used. The N:P ratio was still low, compared to the expected literature value of 5:1 and 10:1. This can partially be explained again by the complexing of phosphorus with copper and precipitating from the solution. Not all the phosphorus which disappears from solution was used for microorganism growth.

The highlight of this run was the stabilization of the control. Also apparent was the need for constant monitoring of the copper

concentration present in the reactors. During periods of low pH, dissolved metals are more prevalent. Therefore, there is a more pronounced effect on the growing culture. These periods can be identified by a "stalling" in the rate of degradation in terms of Total COD. The best action is prevention. A buffering of the system and high nutrient concentration is recommended to avoid similar problems. In this way, a higher initial concentration of waste can be effectively treated in the reactor.

#### **Run#7**

The purpose of the run was to have an initial high sludge COD loading level while avoiding the problems of the previous runs with dissolved metals. It was determined that the threshold of acceptable initial loading lay between 20 000 and 30 000 mg/L, unless the copper was reduced in some form of pretreatment. The previous run showed that it was not practical to overload the system, since initial rapid growth of microorganisms will be quickly slowed by the exposure of the bacteria to increasing copper dissolving into solution. The purpose was to replicate the relative success of run 5 while increasing the loading slightly; the target was 25 000 mg/L COD.

The initial conditions of the reactors at the start of run 7 can be observed in Tables 4.2.11 and 4.2.12. Although Reactors 2 and 3 contained the same initial sludge loading, the organic contents and thus, the initial BOD<sub>5</sub> differed slightly. The Total COD load

Parameter:	Reactor 2	Reactor 3	Reactor 5 (Control)
Sludge Loading (L)	3	3	0.75
Seed Vol. (L)	4	4	0
Total (L)	21.4	21.4	5 (including 100 ml bleach)
Initial Total COD (mg/L)	30 169	29 484	28 799
Initial Supernatant COD (mg/L)	1 378	1 207	1 035
Initial Total BOD (mg/L)	8 322	6 154	N/A
Initial Total copper (mg/L)	80	84	48
Initial Dissolved copper (mg/L)	0	0	0
pH	6.05	6.35	6.22

**Table 4.2.11: Initial loading of the test reactors and the control prior to the start of run 7.**

was slightly higher than the target but considered acceptable. The initial loading and concentration of organics once again reinforced the reality of the varied nature of the sludge.

The initial total copper loading was quite high and thus there was a concern that it could affect the degradation process, as it dissolved into solution. An effort was made to increase the phosphorus loading and keep it elevated to encourage the copper to precipitate out. Complicating matters was the low initial pH of the reactors. The pH ranged between 6 and 6.4 for the test

Compound:	Reactor 2: ppm	Reactor 3: ppm	Reactor 5: Control ppm
Xylene	243.4	245.7	205.6
Diphenyl	1 157.1	1 257.4	1 139.5
Diphenyl Ether	5 290	5 690	5 071
Diphenyl Methane	57.4	67.3	64.2
Benzene, 1,1' Methylene bis (4-methyl)	19	21.7	20.5
1,2-Dimethyl- 4-Benzyl Benzene	138.4	167.2	139.5

**Table 4.2.12: Initial concentration of the target organic compounds at the start of run 7.**

reactors. The lower the pH, the more copper that would be available in dissolved form. The system was not initially buffered, since prior attempts at modifying the pH had negatively affected the run. Close monitoring was selected and pH modification actions would be taken once other avenues had been exhausted.

Figure 4.2.14, the Total BOD<sub>5</sub> vs time curve, shows an initial high degradation rate for both reactors, for the first half of the experiment. At that point, day 19, the degradation rate shifted to a slow decline, until the end of the run, when the BOD<sub>5</sub> was below 100 mg/L. The drastic change in the degradation rate can be attribute to the elimination of easily degraded organics, initially, followed by the degradation of more complex

and resistant compounds; hence, these were degraded at a slower rate.

Figure 4.2.15, the Total COD vs time graph, has much the same shape as the BOD graph. There was, at first, rapid degradation in Reactor 2; in Reactor 3, a lag phase can be observed for the first three days, then rapid degradation occurred. The lag phase is difficult to explain since both reactors contained equal amount of the same sludge and seed. However, it is quite possible that the bacterial cultures differed and that Reactor 3 needed a lag phase for acclimatization. This is supported by the VSS Concentration vs Time graph, Figure 4.2.17, which indicates that Reactor 3 went through a period of increase in volatile solids levels.

In terms of Total COD, the degradation in Reactor 2 levelled off after 11 days, while degradation in the other reactor levelled off after 21 days. The tail end of the graph exhibited the same pattern as seen in previous runs but was less pronounced. Yet, there was still a certain amount of rising and falling in the tail end of the graph.

The control was quite stable in terms of Total COD for the run, with only a slight reduction over the length of the run.

The Supernatant COD vs time graph, Figure 4B.16, was more pronounced than in the past for Reactor 3. There was rapid solubilization of organics at first; then, starting on day 16,

FIGURE 4.2.14 TOTAL 5 DAY BOD CONCENTRATION VS TIME FOR RUN 7

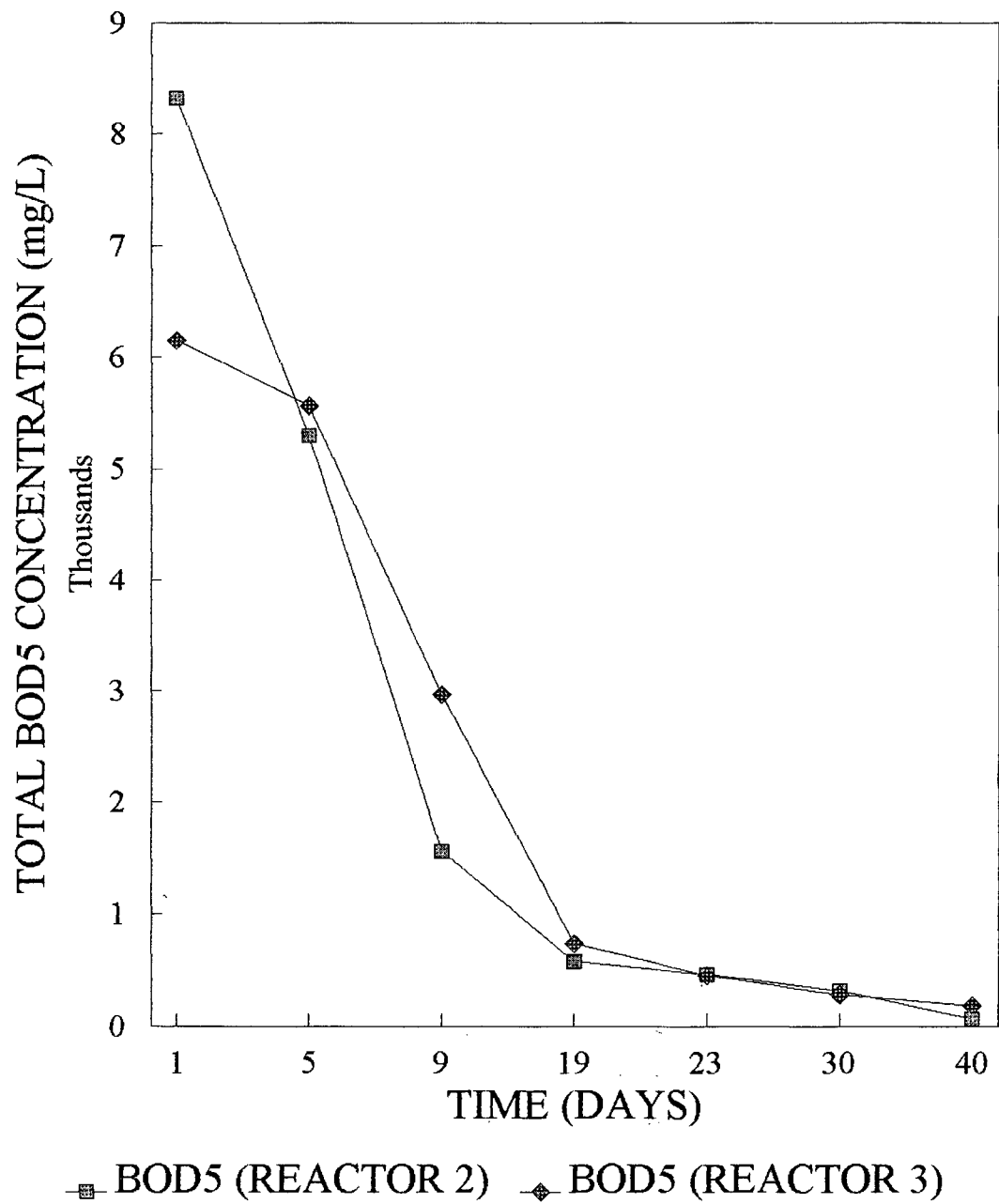


FIGURE 4.2.15 TOTAL COD CONCENTRATION VS TIME FOR RUN 7

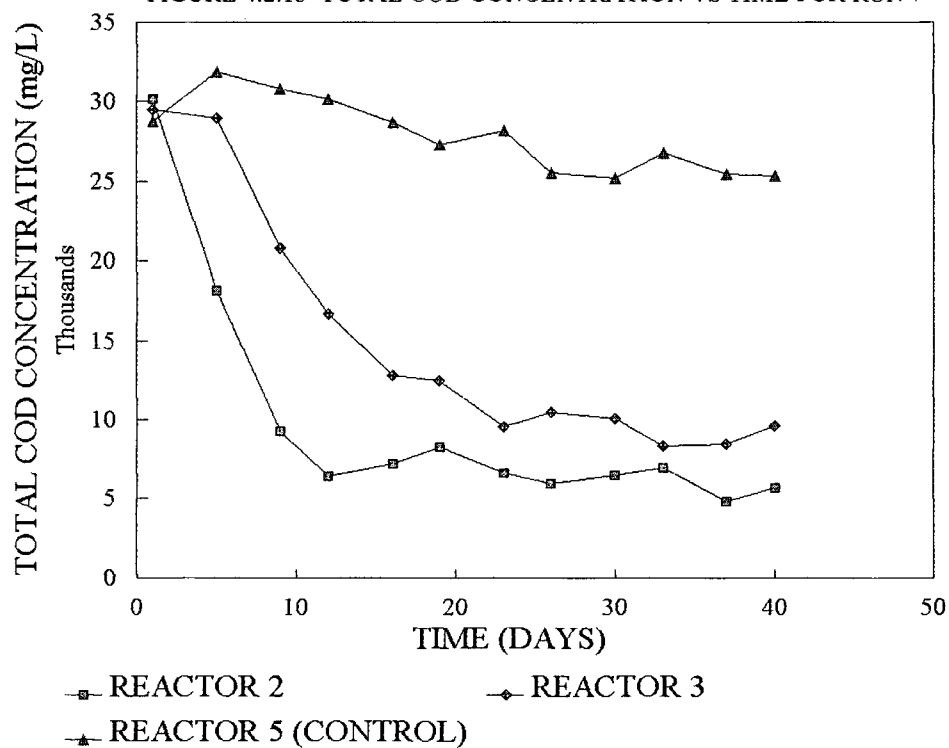


FIGURE 4.2.16 SUPERNATANT COD CONCENTRATION VS TIME FOR RUN 7

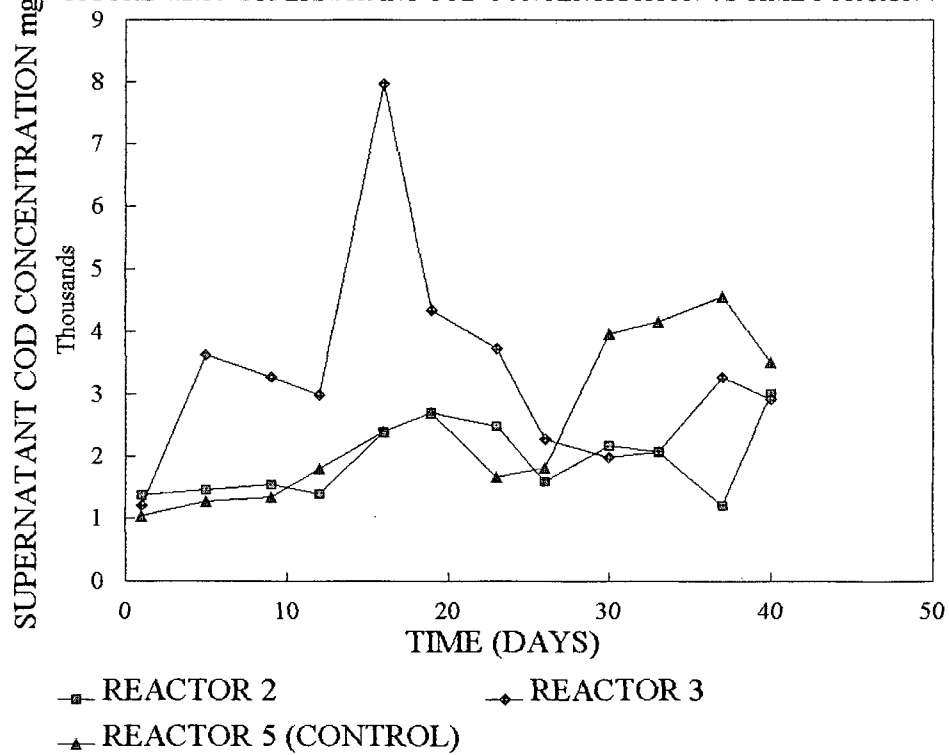


FIGURE 4.2.17 MLVSS CONCENTRATION VS TIME FOR RUN 7

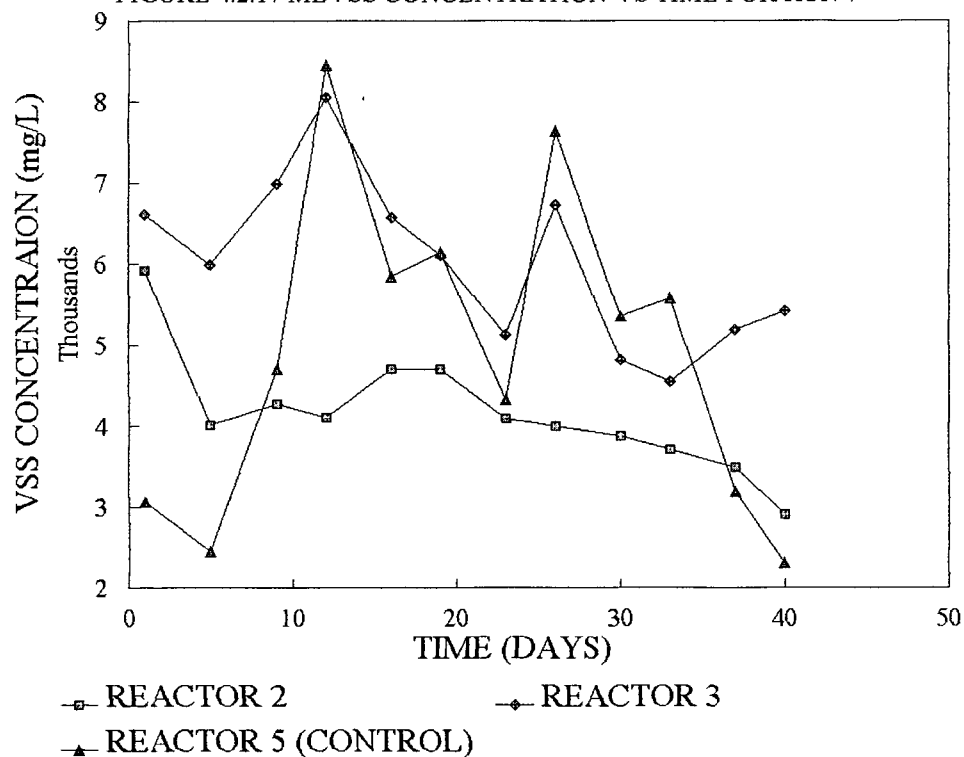
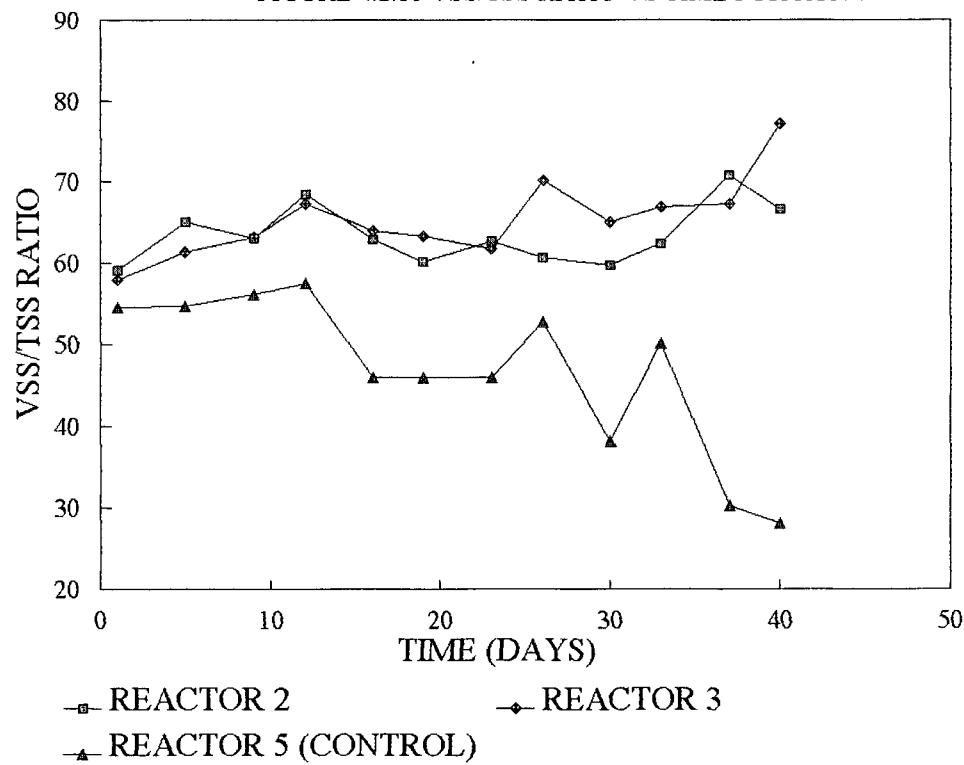


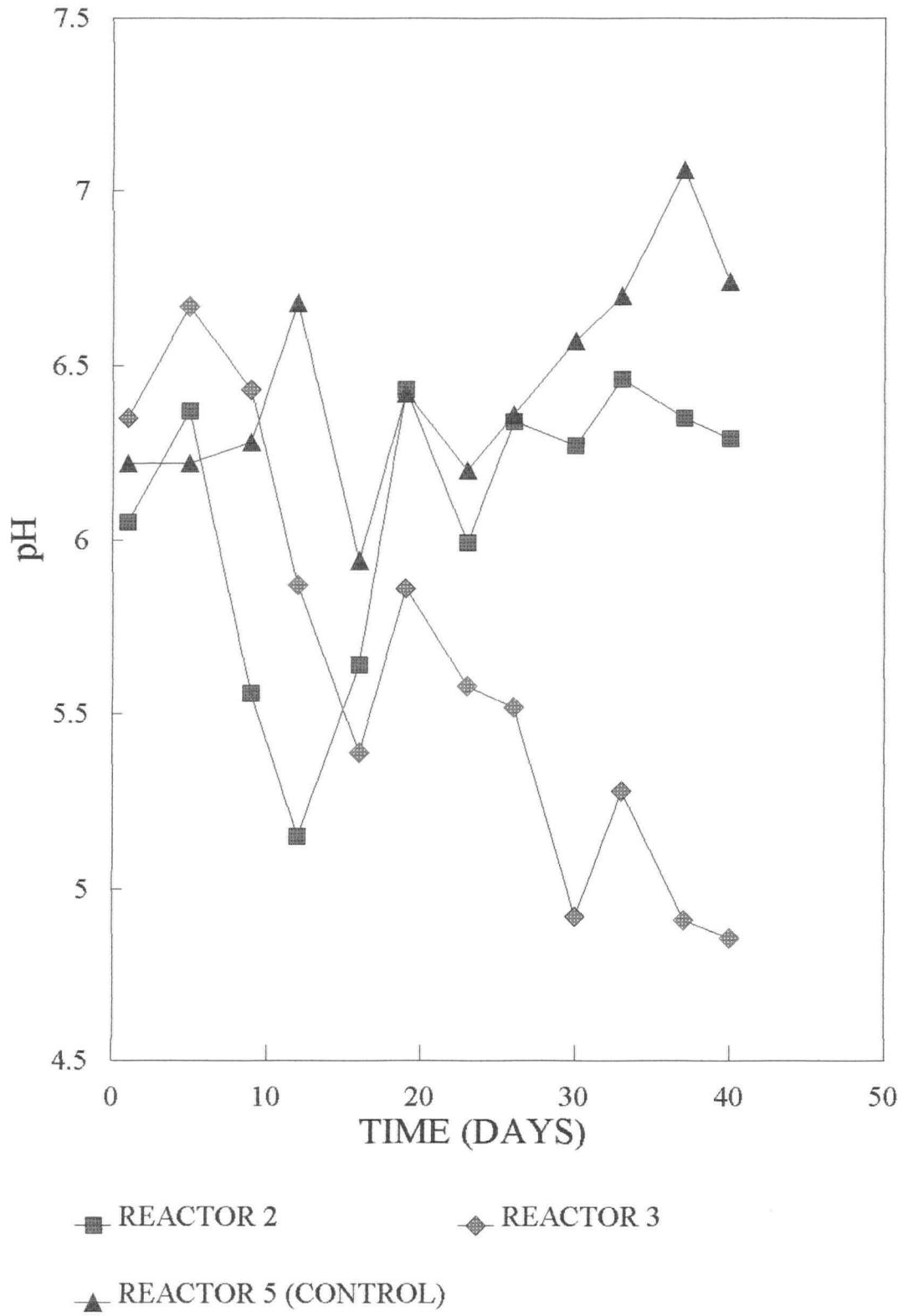
FIGURE 4.2.18 VSS/TSS RATIO VS TIME FOR RUN 7



the compounds were quickly removed from solution and reached the level found in Reactor 2. For Reactor 2, over the time of the experiment, there was a slight increase in the soluble COD concentration. The data indicates that, since there was little accumulation of compounds in the supernatant of Reactor 2, the compounds were solubilizing at a rate that the microorganisms could utilize them.

The pH was of concern during this run, as seen in Figure 4.2.19. Firstly, the initial pH was quite low for the two reactors. In the case of Reactor 2, it was below the favourable pH range for cell growth (Metcalf 1991; Prince 1993). On day 11, due to continued sludge degradation and thus CO<sub>2</sub> production, the pH had fallen to 5.15. Soda ash was added to raise the pH slightly. pH adjustments in the past had been troublesome and resulted in the "stalling" or end of the treatment process. The effect of the low pH was difficult to determine. The BOD<sub>5</sub> and the COD data indicated rapid degradation; however, the VSS vs time graph, Figure 4.2.17 was scattered but generally declined. The VSS/TSS ratio increase slightly during the run, indicating that there was an increasing population of viable organisms present in the reactor (Figure 4.2.18). Therefore, the low pH did not appear to be detrimental to the degradation process. The pH of reactor 3 was not modified to examine if an equilibrium point would be reached where the pH would level off. The data indicates that the pH will decrease as long as organic matter is being degraded.

FIGURE 4.2.19 PH VS TIME FOR RUN 7



The total copper levels in the reactors were quite high, as demonstrated in Figure 4.2.20, but the dissolved levels did not increase considerably during the run. In the test reactors, they did not go higher than 5 mg/L. This can possibly be attributed to the fact that the nutrient concentration in the reactors were kept at extremely high levels as seen in Figures 4.2.21 and 4.2.22. The high phosphorus concentration (close to 200 mg/L), due to an erroneous calculation, may have kept the dissolved copper below the toxic levels seen in previous experiments. The concentration of dissolved copper in the control did not increase because the pH was stable at around 6.5 for the course of the run. Studies have shown that a low pH increase the amount of metal found in dissolved form.

The first apparent conclusion from the data shown in Table 4.2.13 is the high degree of treatment which occurred in Reactor 2. There was a drastic reduction in terms of the Total BOD<sub>5</sub> and the Total COD, 99.1 % and 81.1% respectively. This resulted in the elimination of all but one of the target organic compounds to below the detection limit of the GC. Furthermore, the only organic present in the reactor was a small concentration of Xylene.

The change in terms of the concentration of specific organics can be seen in Table 4.2.14. Even the Diphenyl Ether, the most difficult organic in the mixture to degrade, was reduced to below the detection limit. Most of the compounds were degraded in the

FIGURE 4.2.20 COPPER CONCENTRATION (TOTAL AND DISSOLVED) VS TIME  
FOR RUN 7

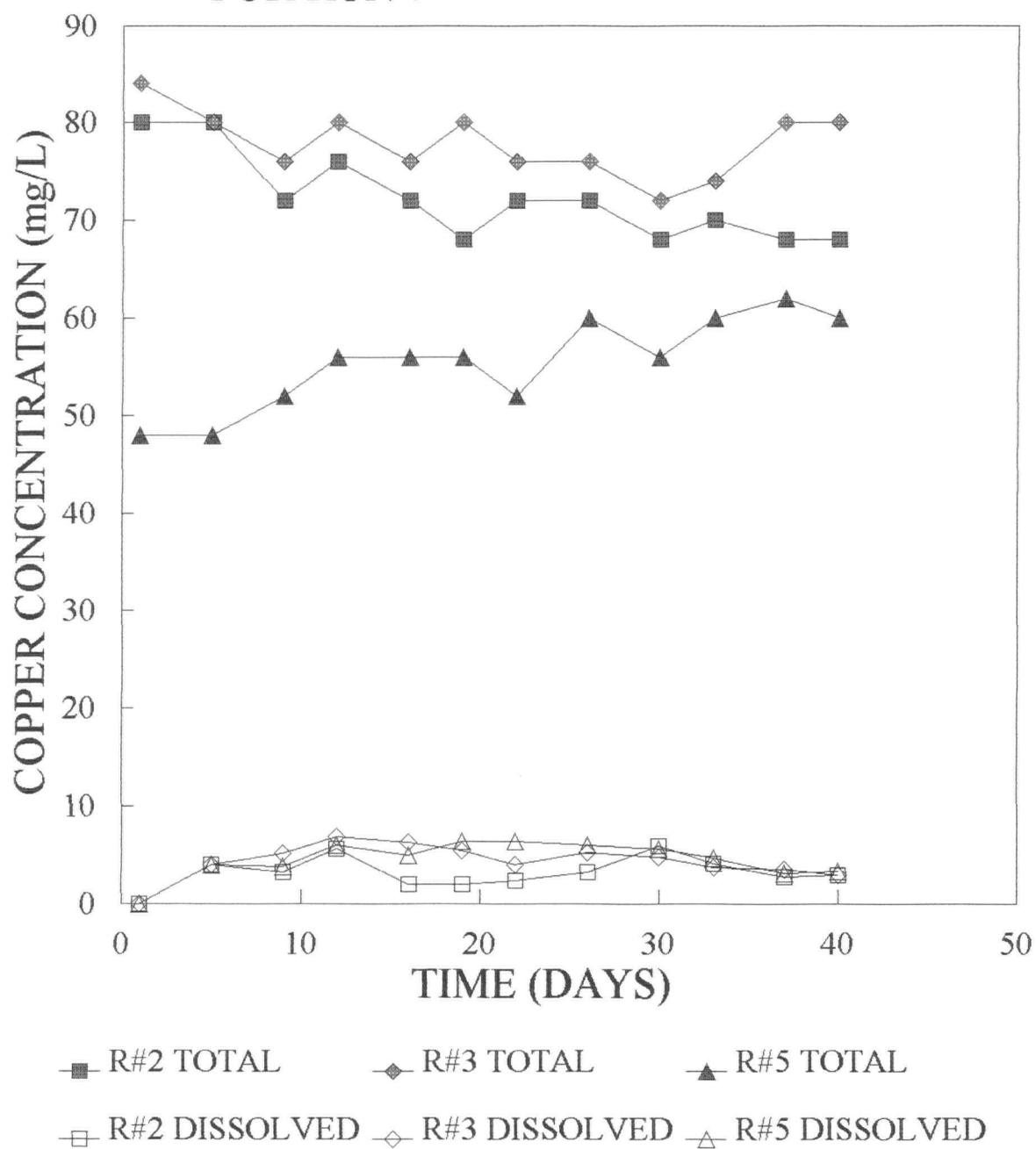


FIGURE 4.2.21 AMMONIA CONCENTRATION VS TIME FOR RUN 7

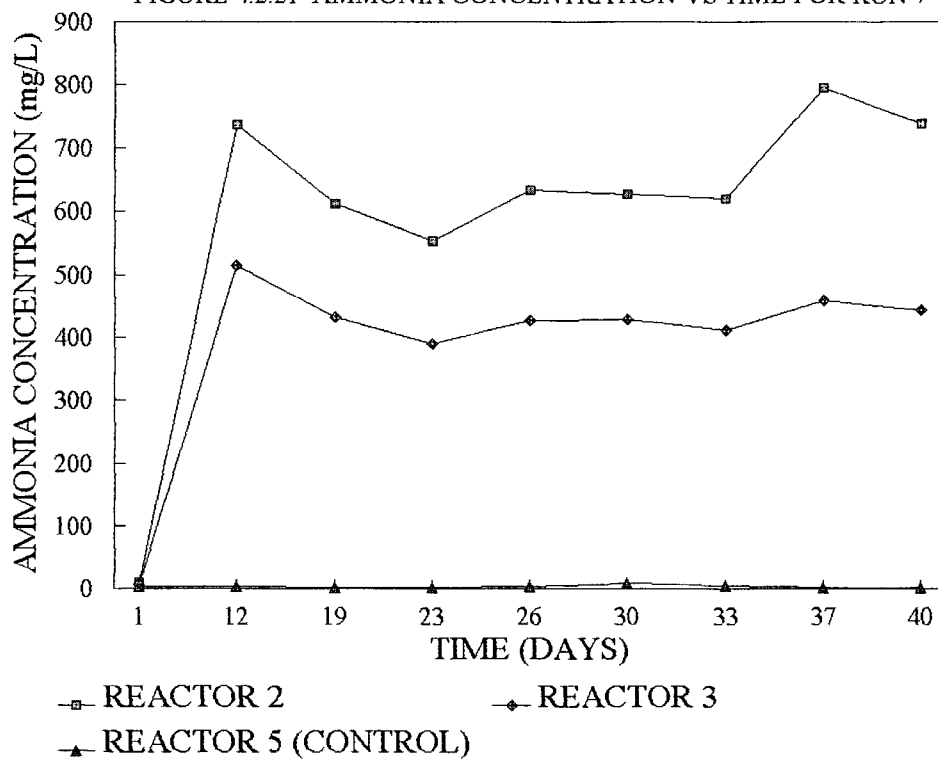
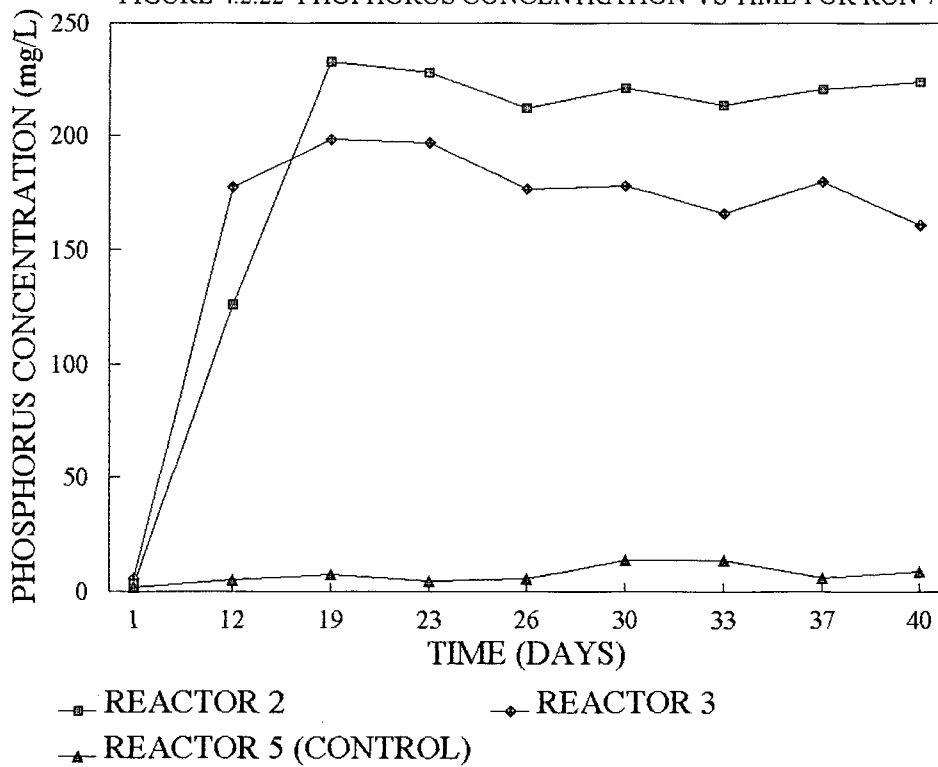


FIGURE 4.2.22 PHOPHORUS CONCENTRATION VS TIME FOR RUN 7



Parameter:	Reactor 2	Reactor 3	Reactor 5 (Control)
Initial Total COD (mg/L)	30 169	29 484	28 799
Final Total COD (mg/L)	5 710	9 592	25 350
% difference	81.1	67.5	12.0
Initial Supernatant COD (mg/L)	1 378	1 207	1 035
Final Supernatant COD (mg/L)	2 998	2 912	3 511
Initial BOD <sub>5</sub> (mg/L)	8 322	6 154	NA
Final BOD <sub>5</sub> (mg/L)	74	191	NA
% difference	99.1	96.9	NA

**Table 4.2.13: Final condition of the reactors at the end of run 7.**

first 12 days, in concert with the dramatic reduction in the BOD<sub>5</sub>. However, at that point the rate slowed and a further 30 days were required to achieve the final result. This remediation cannot simply be attributed to volatilization either. The change in the concentration of target organic compounds in the control was limited to less than 20 % for most compounds.

Qualitatively, the sludge also had markedly improved. The strong chemical odour, the iridescent hue and the settling problems had all disappeared. The end product sludge, when placed in a graduated cylinder, settled within one hour and the effluent had

the same quality and appearance as one centrifuged for 5 minutes at 3 000 RPM.

Compounds:	Parameter:	Reactor 2 (ppm)	Reactor 3 (ppm)	Reactor 5 (control) (ppm)
Xylene	Inn. Conc.	243.4	245.7	205.6
	Final Conc.	10.4	9.7	63.4
	% Degrad.	95.7	96.1	69.2
Diphenyl	Inn. Conc.	1 157	1 257	1 139
	Final Conc.	0	4.2	875
	% Degrad.	100	99.7	23.2
Diphenyl Ether	Inn. Conc.	5 290	5 690	5 071
	Final Conc.	0	24.9	4 067
	% Degrad.	100	99.6	19.8
Diphenyl Methane	Inn. Conc.	57.4	67.3	64.2
	Final Conc.	0	4.8	58
	% Degrad.	100	92.3	9.57
Benzene, 1, 1' Methylene bis (4- methyl)	Inn. Conc.	19.0	21.7	20.5
	Final Conc.	0	3.8	106
	% Degrad.	100	82.5	0
1,2- Dimethyl-4 Benzyl Benzene	Inn. Conc.	138.4	167	139.5
	Final Conc.	0	0	67.1
	% Degrad.	100	100	51.9

Table 4.2.14: Change in the concentration of the target organics at the end of run 7.

Compound:	Time	Reactor 2 Reaction rate	Reactor 3 Reaction rate
BOD <sub>5</sub> (mg/L Day)	Day 1-19	430.4	300.7
	Day 20-40	23.9	26.1
	Total	211.5	152.9
Xylene (ppm/day)	Day 1-12	22.1	22.3
	Day 13-42	-0.35	-0.32
	Total	5.68	5.76
Diphenyl (ppm/day)	Day 1-12	104.9	113.8
	Day 13-42	0.1	0.05
	Total	28.2	30.5
Diphenyl Ether (ppm/day)	Day 1-12	468.5	382.1
	Day 13-42	4.57	48.7
	Total	129	138.2
Diphenyl Methane (ppm/day)	Day 1-12	4.31	3.33
	Day 13-42	0.33	0.86
	Total	1.40	1.52
Benzene, 1,1' Methylene bis (4- Methyl) (ppm/day)	Day 1-12	1.1	1.11
	Day 13-42	0.23	0.19
	Total	0.46	0.44
1,2 Dimethyl-4- Benzyl Benzene (ppm/day)	Day 1-12	12.6	15.2
	Day 13-42	0	0
	Total	3.38	4.08

**Table 4.2.15: Straight line degradation rates of specific organic compounds during run 7 in the two test reactors.**

The straight line degradation rates shown in Table 4.2.15 further emphasize the information provided by the Total COD and BOD<sub>5</sub> vs

time graphs. The straight line degradation rate is the slope of the line connecting the concentration of a compound over two specific sampling days.

By the first 12 days, the majority of the organic compounds had been degraded. The reaction rates were quite high, as compared to the next 30. Comparing both systems, it becomes apparent the effect that the short lag phase had on the contents of Reactor 3. The breakdown process started immediately in Reactor 2; however, Reactor 3 with the same initial Total COD, lagged for 3 days as the microorganisms adapted to the system. For this reason, the reaction rates for the removal of organic compounds were not as high as those found in Reactor 2. Conversely, the reaction rates for the next 30 days were slightly higher in Reactor 3, since there was a higher organic residual left in the system. The removal rates were also quite high in terms of Total BOD<sub>5</sub>. In Reactor 2, the Total BOD removal was 400 mg/L Day for the first 11 days, while in Reactor3, it was 300 mg/L Day for the same period.

In general, both systems were effective at remediating the sludge. The total degradation rates for the systems were almost identical. However, Reactor 2 was more successful at remediating the sludge as a whole. Reactor 3 could have possibly removed all the organic constituents (as Reactor 2) if it were run for an extra week.

As previously mentioned, the nutrients were erroneously added in large concentration to the reactors. Although, the results were favourable, the exact quantities used are difficult to determine. The data was quite scattered due to the high concentration and further hampered by the large dilution effect. As noted in Figures 4.2.21 and 4.2.22, the phosphorus concentration was kept above 200 mg/L in each test reactor. The ammonia concentration was kept above at least 500 mg/L. These high concentrations, did not appear to hamper treatment occurring in the reactors, ironically, it may have contributed to the most successful run in terms of carbon removal and low dissolved copper concentrations through co-precipitation.

Time	Reactor 2	Reactor 3
	BOD/COD Ratio	BOD/COD Ratio
1	0.28	0.21
5	0.29	0.19
9	0.17	0.14
19	0.07	0.06
23	0.07	0.047
30	0.049	0.028
40	0.013	0.02

**Table 4.2.16: The BOD/COD ratio over time for run 7.**

Table 4.2.16 shows the BOD/COD ratio which was exhibited in the two test reactors during run 7. The table clearly shows the differences in the duplicate test reactors. Reactor 3 originally had a lower proportion of BOD than did Reactor 2; this could have been a factor in the slow start of the degradation process. The

interesting result in Reactor 2 was that, although there was an initial large reduction in BOD, the ratio actually increased slightly. This indicates that, originally, compounds removed from the system exhibited a COD demand but not a BOD demand. It could also be that some of the material was biological degradable, but would not degrade during the standard BOD<sub>5</sub> standard test.

The largest reduction in the ratio occurred from day 5 to 19 in both reactors; after this point it decreased. This is due to the slower kinetics resulting from the presence of harder to degrade organic material. Most simple organics were removed in the first part of the run, i.e. up to day 19. However, as Grady (1990) indicated with his work on low concentration mixed organic compound wastewaters, some of the larger more complex compounds are also removed during this period, but at a slower rate. This decrease in the ratio echoes the slowdown in the BOD removal graph, Figure 4.2.14.

This was the most successful run to date, partially due to the error in the supplying of the nutrients. The dissolved copper concentration was kept under control and all the organics were removed from Reactor 2, except for 10 ppm of Xylene. The remainder could have been easily degraded under right operating conditions. Reactor 3 displayed slower kinetics, but also resulted in a high degree of treatment. Lengthening the run by one week would have probably resulted in the same level of

treatment as Reactor 2. Most organic compounds were removed by more than 99.5% in Reactor 3. The success of treatment is best exhibited by a physical examination of the sludge itself. The process converted a strongly odoriferous chemical waste, with a distinct iridescent hue, to a product with a slight earthy smell and colour and one which easily settled. The next objective would be to replicate the success of the run and identify if a higher initial organic load could be tolerated.

#### 4.3 Results and Discussion (Continued): Overcoming The Problem Of High Dissolved Metal Concentrations.

##### Run#8:

Although the previous runs had been successful in degrading the organic content of the sludge, many questions remained about the process itself. It was puzzling that the Total COD of the run decreased, while the supernatant COD increased almost constantly for the length of the experimental run. An effort was made to understand this phenomenon through the analysis of the supernatant on a twice weekly basis, using Gas Chromatography. It was important to understand which compounds were dissolving into solution and possibly reaching toxic concentrations in the reactor.

The success of the previous run was not known at the beginning of this run. The initial organic loading of run 8 was low to avoid problems with dissolved copper. This run was started two weeks after the start of the previous run. They were running simultaneously for a period of time. The targeted initial loading for this run was a Total COD concentration of 15 000 mg/L. This experimental phase consisted of two reactors: a test reactor, Reactor 4 and a control, Reactor 1.

The initial starting point in terms of Total COD was lower than desired, as can be seen in Table 4.3.1. However, it would serve

as a baseline level, to follow the changing composition of the supernatant without having to deal with extremely large concentrations.

Parameter:	Reactor1 (Control)	Reactor4
Sludge Volume (L)	1.5	1.5
Total Volume (L)	21 (Including 1 cup of bleach)	21
Initial Total COD (mg/L)	11 178	12 419
Initial Supernatant COD (mg/L)	1 245	831
Initial Total BOD <sub>5</sub> (mg/L)	NA	3 353
pH	6.35	6.54

**Table 4.3.1: Initial conditions of the reactors at the beginning of run 8.**

Compound:	Reactor 1 Total (Control) ppm	Reactor 1 Supernatant (Control) ppm	Reactor 4 Total ppm	Reactor 4 Supernatant ppm
Xylene	127	14.6	150	18.4
Diphenyl	463	6.9	520	7.63
Diphenyl Ether	2281	36	2552	46.5
Diphenyl Methane	22	0	26.4	0
Benzene, 1, 1' Methylene bis (4-Methyl)	14.8	0	17.3	0
1,2-Dimethyl- 4-Benzyl Benzene	55.5	0	81	0

**Table 4.3.2: Initial total and supernatant concentration of target organic compounds in the reactors of run8.**

Table 4.3.2 shows the concentration of the target organics in terms of total and supernatant concentration which were present in the reactors prior to the start of run 8. Only the smaller, less complex organics were present in the supernatant. The concentrations in the supernatant were quite small, when at all present. A record was kept over the length of the run, enabling the compounds which were solubilizing and affecting the supernatant COD, to be identified.

A concern at the beginning of the run again focused on the low initial pH. A decision was made to let the system reach it's own equilibrium in terms of pH. If the system was successful in treating the sludge, there was no reason to modify the pH. It would also serve as an indication of the pH range which still enabled a culture of microorganisms to function in this environment.

Examining the run in terms of Total COD, Figure 4.3.1, the trend which was present in other runs is evident again. Initially, there was a quick Total COD reduction in the test vessel; the majority of this reduction, occurred by the twentieth day. After that point, the COD concentration rose to a level of 8 000 mg/L, having been as low as 6 000 mg/L. There was significant variability in the Total COD concentration of the control, as well, but the end result was that the initial and the final concentrations did not differ greatly.

FIGURE 4.3.1 TOTAL COD CONCENTRATION VS TIME FOR RUN 8

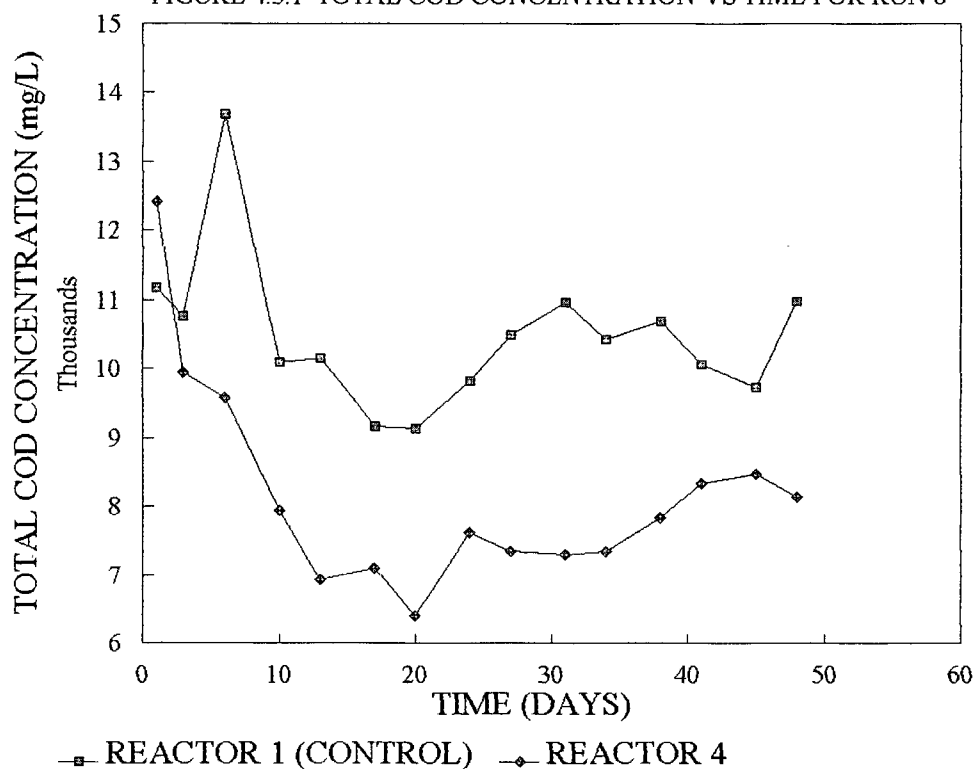
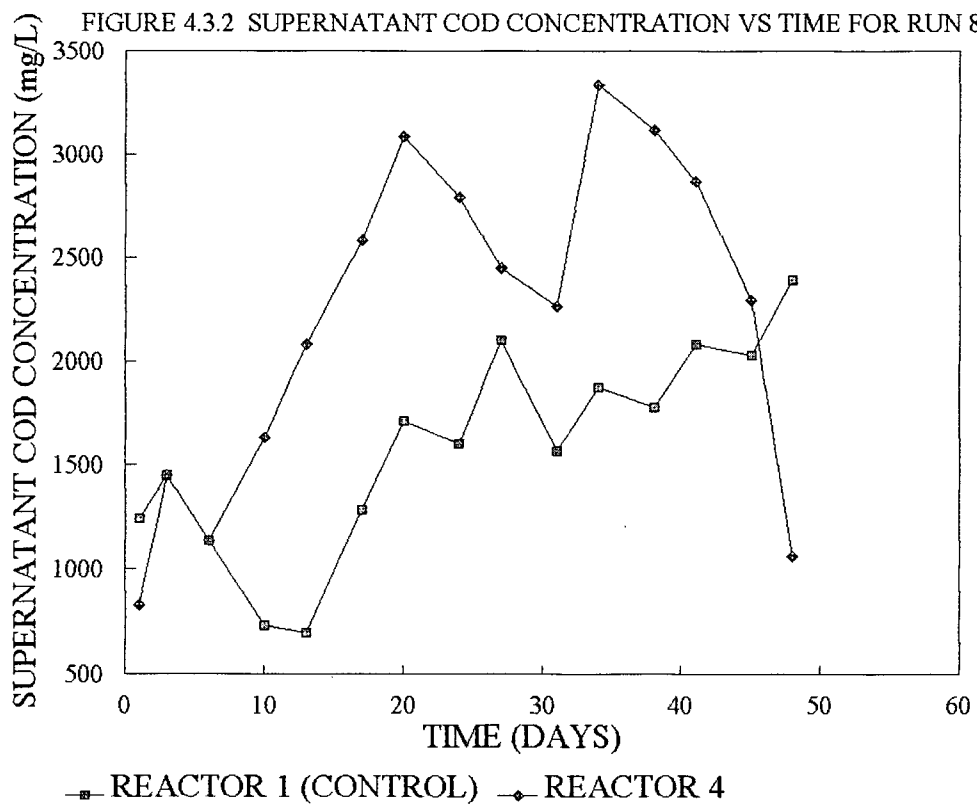


FIGURE 4.3.2 SUPERNATANT COD CONCENTRATION VS TIME FOR RUN 8



Between these readings, there was considerable up and down fluctuations. The concentration was as high as 13 800 and was low as 9 100 mg/L. Generally, the GC results from these samples show the same variability. Although three separate samples on any day were taken and analyzed, the results differed greatly from one sampling period to the next.

The supernatant COD graph, Figure 4.3.2, shows a pattern which has become quite familiar. The initial supernatant concentration was low; however, this concentration increased gradually, with time, for most of the run in the test reactor. The concentration reaches a maximum at day 20. As can be observed on the graph, the concentration then decreased for 3 subsequent sampling periods, only to increase again and then decrease back to the initial concentration at the beginning of the run. This was a new pattern. The concentration usually increased for the run or increased then decreased but does not generally fluctuate to such an extent. The overall total increase in the COD of the supernatant was negligible, attributable in part, to the low initial sludge loading rate. Reactor 4 had an initial concentration of less than half of the test reactor in the previous run. The reactor in the last run exhibited an increasing supernatant pattern in terms of Total COD. It was previously thought that when a high initial concentration was used, some organic compounds accumulated in solution at a faster rate than the bacteria could utilize them. In this case, however, although

the initial sludge COD concentration was low, the bacterial population must not have been healthy enough to effectively treat this waste. Therefore, they were not capable of using the compounds as fast as they were solubilizing, resulting in a considerable increase in the concentration in the supernatant.

Examining the run as a whole, many interesting details come to light. The pH vs time graph, Figure 4.3.3, can be used to identify the periods when most of the degradation occurred. Generally, the larger the pH drop in a non buffered system, the more degradation that has taken place. The most "active" period was from day 10 to 17; however, this does not match any large change in Total COD. During this period, the Total COD decreased slightly and then increased a little. On day 17, the pH seemed to level off, with no change in the value of the sample's pH from day 17 to day 20. There was then a slight increase in the next two samples. This indicated that the degradation process has slowed for some reason. A similar shift was seen in the values of the control, over the same period. Interestingly enough, the ammonia concentration vs Time graph, Figure 4.3.4, indicates that, for the period of pH stability, the reactor was running "nutrient limited".

Figures 4.3.4 and 4.3.5 show the concentration of nutrients present in the system. Little nitrogen was present in the system from day 17 to 27 (Figure 4.3.4). This result seemed to stall the

FIGURE 4.3.3 PH VS TIME FOR RUN 8

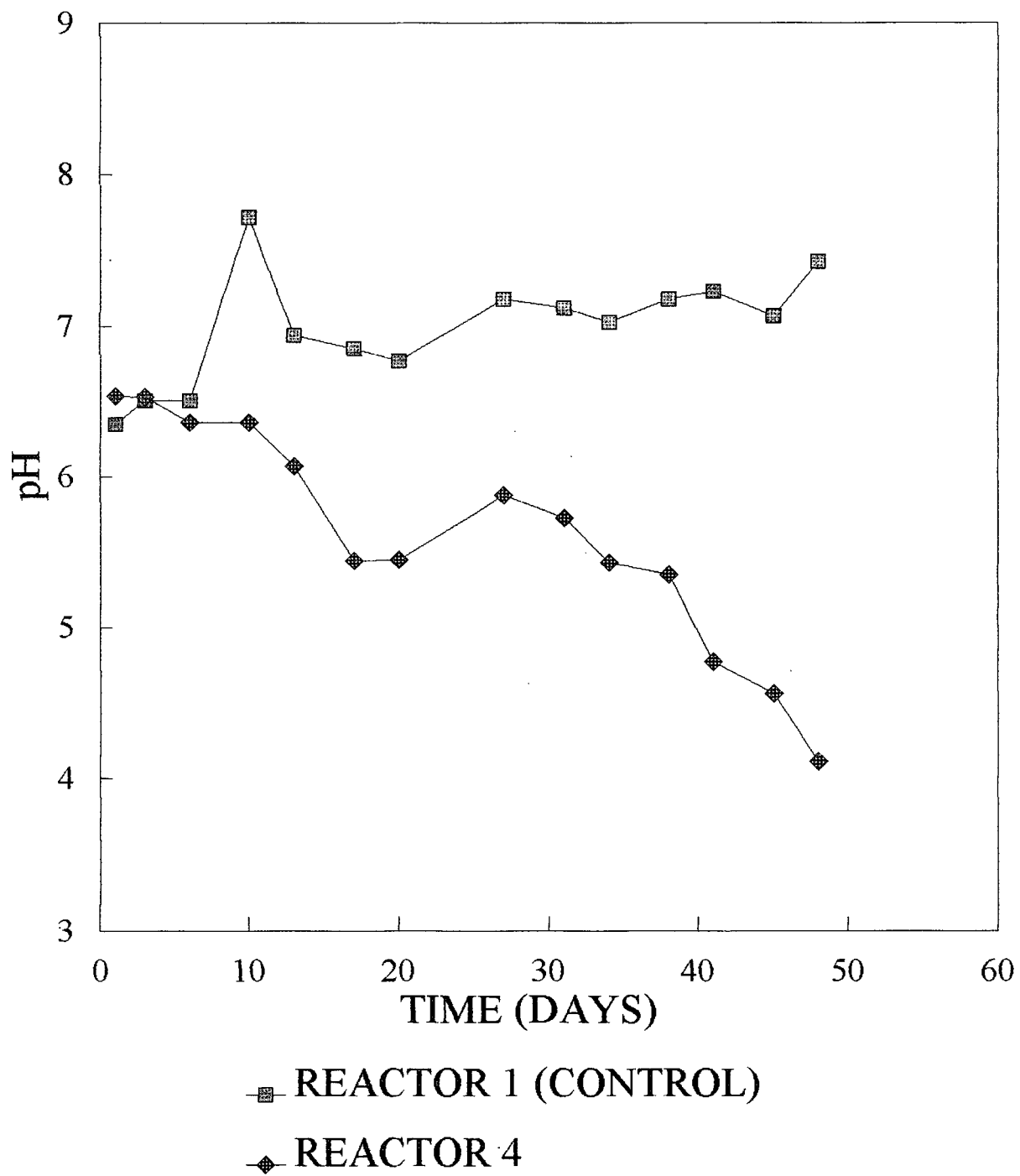


FIGURE 4.3.4 AMMONIA CONCENTRATION VS TIME FOR RUN 8

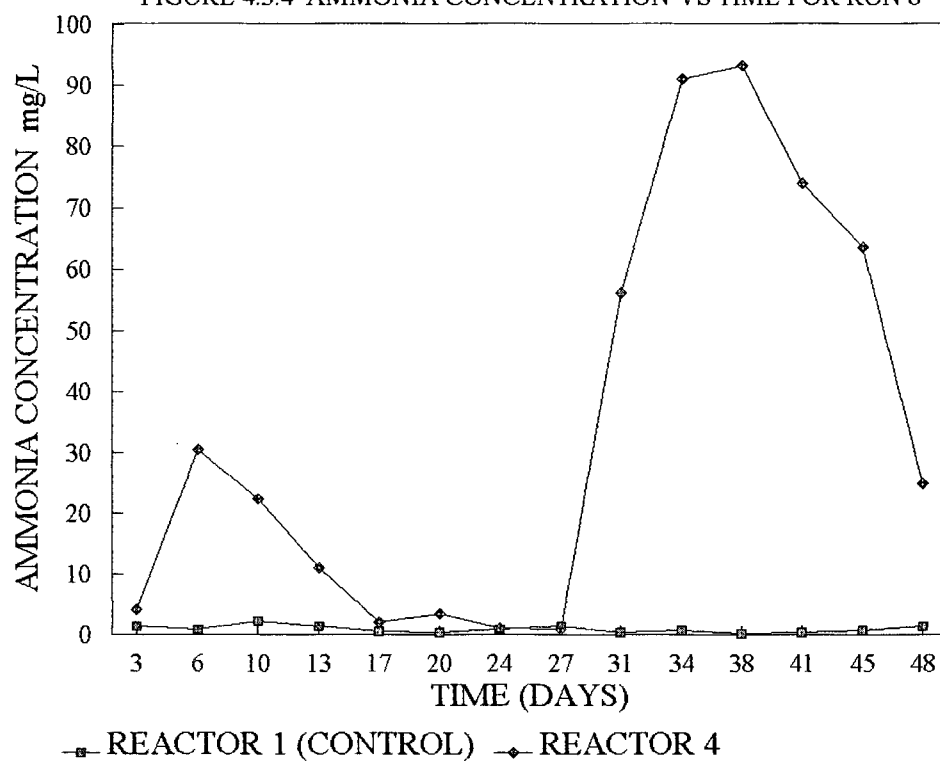
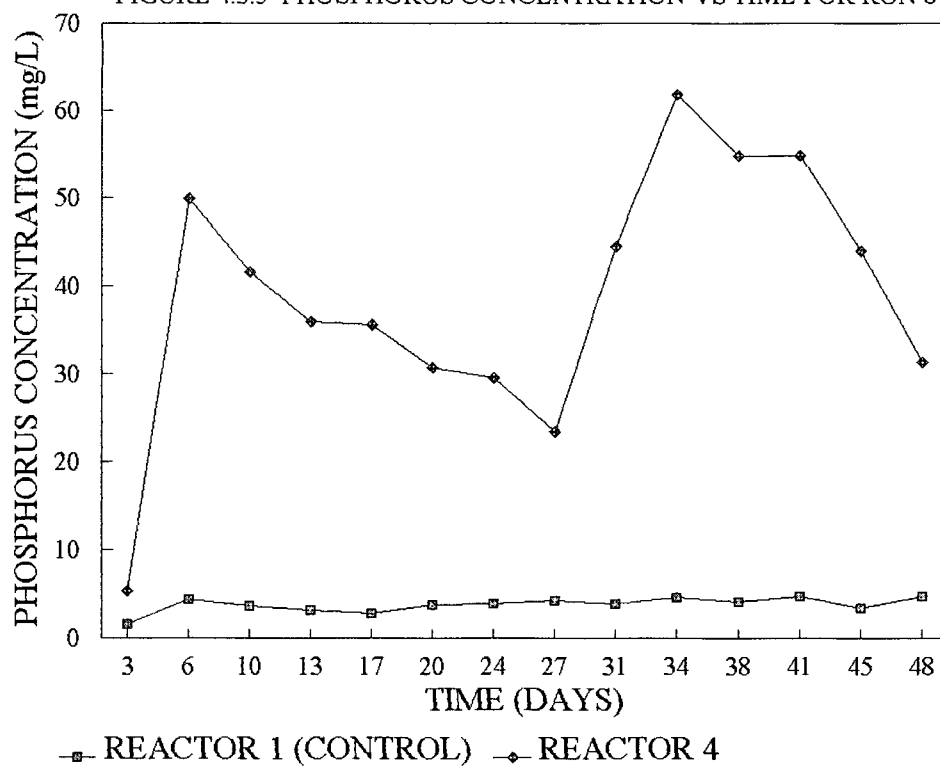


FIGURE 4.3.5 PHOSPHORUS CONCENTRATION VS TIME FOR RUN 8



system in terms of Total COD reduction. When additional nitrogen was added to the system, the pH continued a downward climb indicating increased bioactivity. Also, during this "starvation" period, the VSS/TSS ratio decreased as can be noted in Figure 4.3.6. On day 20, the ratio was at its highest point: 0.9. The ratio then continued to decline until additional nitrogen was present in the reactor. This was yet another indication of the necessity of on line monitoring, in this type of research. For this experiment, nutrient samples were taken twice weekly but were only analyzed on the Lachate Analyzer every two weeks. Often decisions had to be made without access to the most recent data. The decrease at the end of the VSS/TSS ratio was probably due to a nutrient limitation.

The MLVSS concentration during the run can be seen in Figure 4.3.7. It should be noted that on day 27, a significant decrease can be observed in the MLVSS concentration of the Reactor 4. This was exactly the same time that the concentration of dissolved copper in the reactor was approximately 10 mg/L. When the copper level was reduced by phosphorus addition, the MLVSS concentration increased slightly.

The dissolved copper concentration during the run was kept under control largely due to the low initial sludge COD loading level, as shown in Figure 4.3.8. The total copper concentration in the reactors was approximately 40 mg/L for the test reactor and

FIGURE 4.3.6 VSS/TSS RATIO VS TIME FOR RUN 8

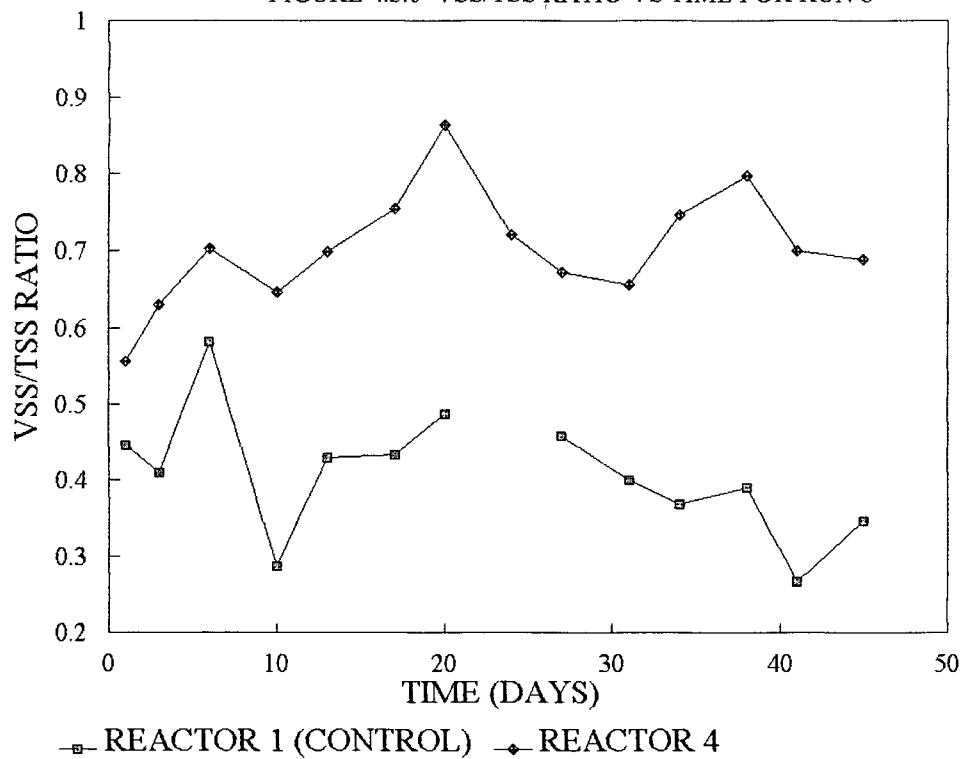


FIGURE 4.3.7 MLVSS CONCENTRATION VS TIME FOR RUN 8

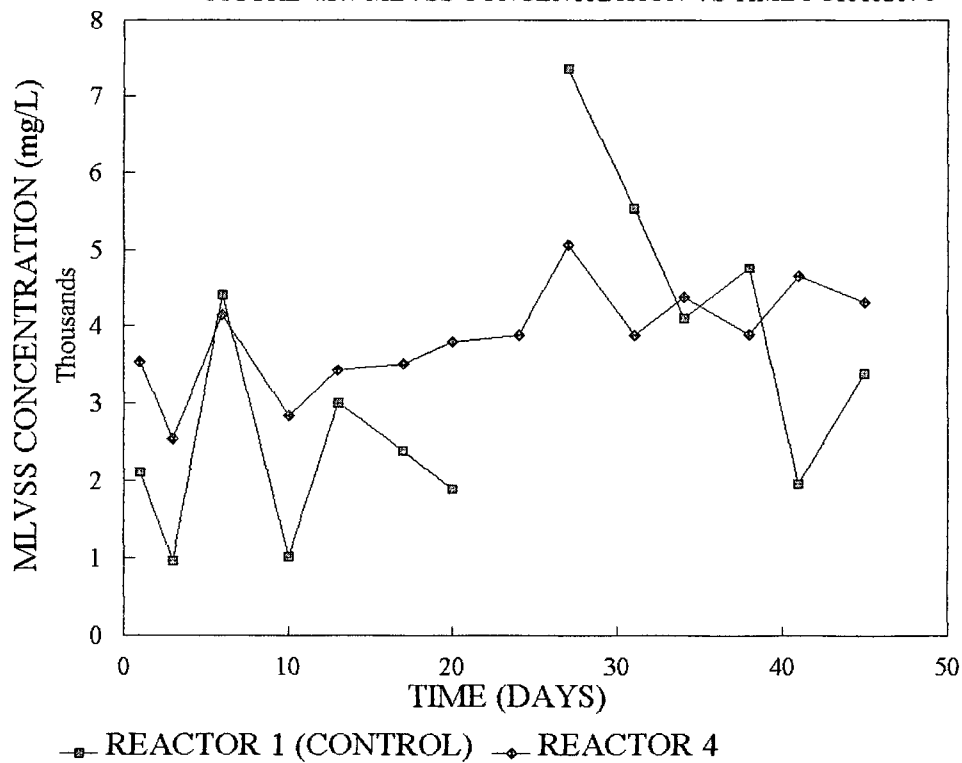
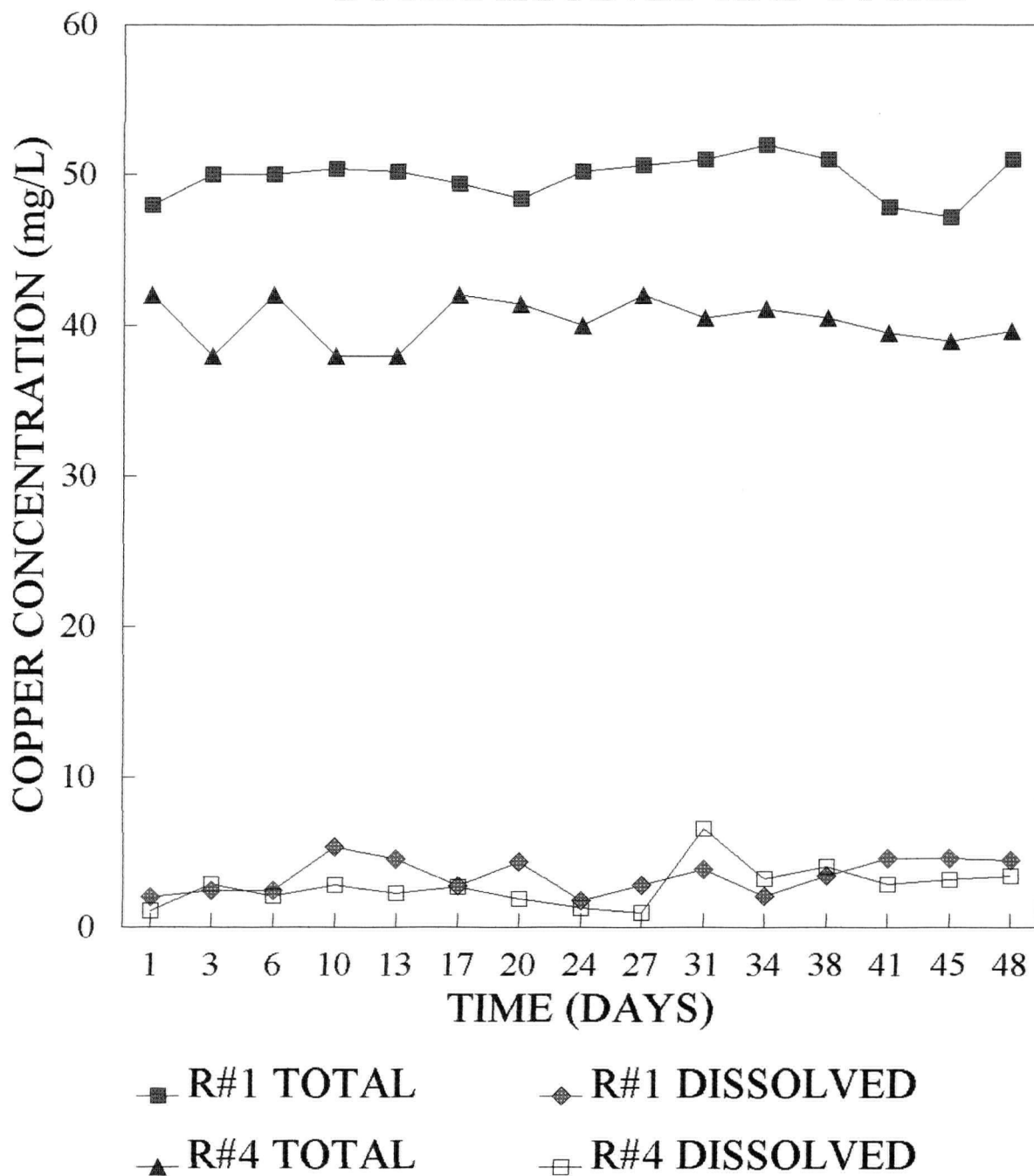


FIGURE 4.3.8 COPPER CONCENTRATION VS TIME FOR RUN 8  
BOTH DISSOLVED AND TOTAL



50 mg/L for the control. For most of the run, the dissolved copper concentration remained below the 4-5 mg/L threshold. However, on day 27, the concentration quickly rose to almost 10 mg/L. This was the apparent result of a relatively low concentration of phosphorus present in the reactor. Once this situation was recognized, addition phosphorus added to the system (see Figure 4.3.5). The situation was worsened by the low pH range under which the system was operating. After the phosphorus addition, the dissolved copper level in the reactor fell to below 5 mg/L. The data from Run 7 indicates that this level appears to be the upper limit for bacterial growth in this type of system.

The close monitoring of the supernatant, using the GC trace, yielded some interesting data. The first general observation was that the mixture of organics was less complex and concentrated than those observed in the Total samples. Two target compounds were present in the Total samples but never present in the supernatant, the two benzene derivative compounds. Diphenyl Methane was never present in the supernatant of the control but was present in small amounts in the test reactor. It is interesting to note that traces of some compounds were never found by the GC in the supernatant, although they were still degraded. This infers that, as soon as the compounds dissolved, they were utilized by the bacteria or that they were present in such small concentrations in the supernatant, as not to be detectable through the use of Gas Chromatography.

The purpose of the monitoring of the supernatant was to identify the compounds present in the supernatant and contributing to the COD, as seen in Figure 4.3.2 (and in previous runs). It was thought that several compounds were solubilizing in the reactor and causing a rapid increase in the concentration of the COD. Also, these compounds could be present in toxic concentrations thus explaining the "stalling" in the degradation experienced in some runs. There is little to explain the phenomenon present in the target organic data or the GC trace. During the run, there was a slight increase in the concentration of Diphenyl Ether but in no way drastic enough to explain the supernatant COD increase. One is left to consider the possibility that the increase was due to the solubilization of some refractory organic compounds, which are detectable by the COD test, but not by the GC.

The analysis of the components of the supernatant can be noted in Table 4.3.3. The Table clearly indicates that the change in the Supernatant COD was not as a result of the target organic compounds coming into solution in Reactor 4. Furthermore, the GC traces of both samples are quite different. The trace on day 20 showed only 3 peaks of small area. The GC trace from the day 6 sample was cluttered with small peaks. In total, there were 7 peaks of varying area. Both samples contained the Diphenyl Ether peak with the early sample having the larger peak. From the GC traces, it is clear that the Supernatant COD was increasing due to the presence of compounds not detectable by GC and likely

refractory.

Compound:	Day 6	Day 20
Supernatant COD (mg/L)	1 141	3 083
Xylene (ppm)	0	0
Diphenyl (ppm)	0	0
Diphenyl Ether (ppm)	89.3	79.6
Diphenyl Methane (ppm)	0	3.4
Benzene, 1,1' Methylene bis (4-methyl)	0	0
1,2-Dimethyl-4-Benzyl Benzene	0	0

**Table 4.3.3: Comparison of the trace organic concentration and the Supernatant COD concentration on two sampling days in run 8 in Reactor 4.**

Parameter:	Reactor 1 (Control)	Reactor 4
Initial Total COD (mg/L)	11 178	12 419
Final Total COD (mg/L)	10 984	8 149
% difference	1.7	34.3
Initial Total BOD (mg/L)	NA	3 353
Initial Final BOD (mg/L)	NA	623
% Difference	NA	81.4

**Table 4.3.4: Final conditions of the reactors after 48 days in run 8.**

The interesting results of this run was the inability of the system to reduce the BOD down to a negligible concentration (Table 4.3.4). The reduction in Total COD was also much less than

anticipated according to previous successful runs. The process, lasting 48 days, was longer than in run 7, although the initial sludge loading was lower. The problems observed in the run were monitoring and control problems. The delay in identifying both the nitrogen deficiency and the high dissolved copper concentrations ultimately inhibited the process and resulted in a less effective treatment. Although the Total COD results are suspect, due to the possible presence of refractory organic compounds, both the BOD and the target organic compounds data show an incomplete degradation process.

Table 4.3.5 clearly shows that there was negligible treatment in terms of target organic compounds in the control; as such, there was little volatilization of organic compounds in this run. This was the most stable control unit observed to date during the study, partially a result of a careful aeration procedure. Due to the high variability of the GC data, the confidence in the success of this run was low. There is a large residual concentration of target organics remaining at the end of the experiment, indicating an incomplete treatment process.

Compounds such as Diphenyl Ether were reduced by more than 98% of their original concentration; however, the residual concentration was quite high. It appears that the high metal concentration at the end of the run may have interfered with the treatment process.

Compound:	Sample:	Reactor 1 (control):	Reactor 4:
Xylene (ppm)	Day 1	127.4	150.1
	Day 48	59.4	0
	<b>% degradation</b>	<b>53.4</b>	<b>100</b>
Diphenyl (ppm)	Day 1	463.3	520.9
	Day 48	463	3.64
	<b>% degradation</b>	<b>0</b>	<b>99.3</b>
Diphenyl Ether (ppm)	Day 1	2281	2552
	Day 48	2280	40.5
	<b>% degradation</b>	<b>0</b>	<b>98.4</b>
Diphenyl Methane (ppm)	Day 1	22	26.4
	Day 48	22	9.8
	<b>% degradation</b>	<b>0</b>	<b>62.8</b>
Benzene, 1,1' Methylene bis (4-methyl) (ppm)	Day 1	14.8	17.3
	Day 48	14	8.1
	<b>% degradation</b>	<b>0</b>	<b>33.8</b>
1,2 Dimethyl-4-Benzyl Benzene (ppm)	Day 1	55.5	81.1
	Day 48	53	0
	<b>% degradation</b>	<b>4.6</b>	<b>100</b>

**Table 4.3.5: The difference in the target organic concentration at the beginning and the end of run 8.**

The overall BOD<sub>5</sub>:N:P ratio in this run was 35.8:1.51:1 (the N/P Ratios are shown in Table 4.3.6). Contrary to the previous run, the carbon consumption was quite low compared to the amount of phosphorous used. The overall COD:N:P ratio was 50.7:1.51:1. In previous runs, the COD consumed had always larger than the

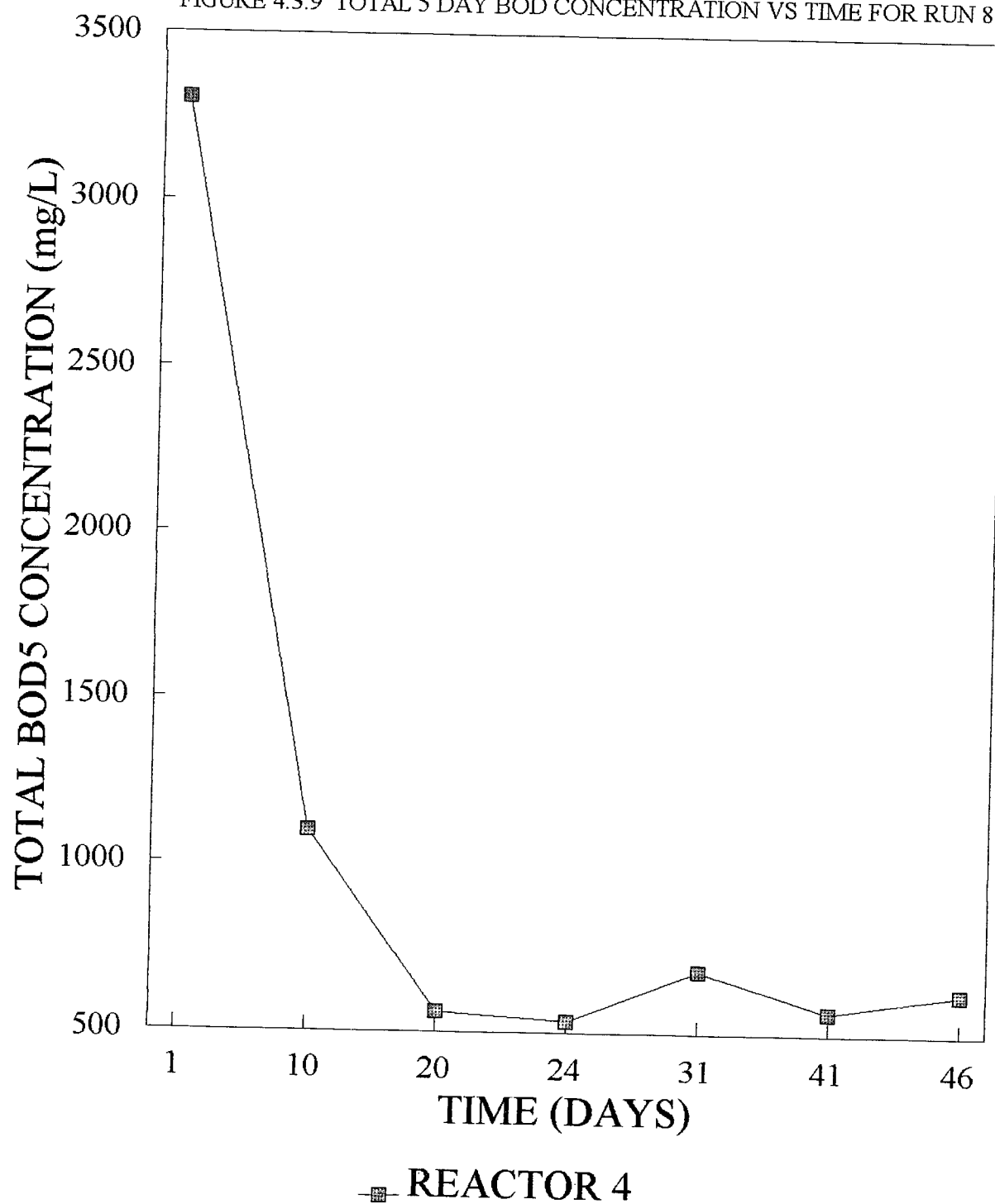
Days	Time (days)	N used (mg/L)	P used (mg/L)	N/P ratio
0-3	3	4.2	5.28	0.79
4-6	3	13.6	10.4	1.31
7-10	4	8.1	8.4	0.97
11-13	3	11.4	5.6	2.04
14-17	4	8.95	4.8	1.85
18-21	3	0	0.33	0
22-24	4	2.43	1.2	1.95
25-27	3	0.2	6.15	0.03
28-31	4	4.68	9	0.52
32-34	3	5.21	2.7	1.96
35-38	4	0	0	---
39-41	3	19.2	7	2.75
42-45	4	10.3	10.8	0.95
46-48	3	38.6	12.7	3.04
Total	48	84.3	127	1.51

**Table 4.3.6: Nitrogen/phosphorous ratios exhibited during run 8 in Reactor 4.**

theoretically specified 100. (Metcalf 1991; Beltrame 1979) As in the previous runs, the high P utilization was probably the result of the binding of phosphorus with dissolved copper, to form Copper Phosphate.

Examining the BOD<sub>5</sub> graph vs time, Figure 4.3.9, the first part of the graph seems to fit the pattern of a first order decay reaction quite well. The degradation pattern appeared to be a two step process. Initially, there was rapid degradation, followed by

FIGURE 4.3.9 TOTAL 5 DAY BOD CONCENTRATION VS TIME FOR RUN 8



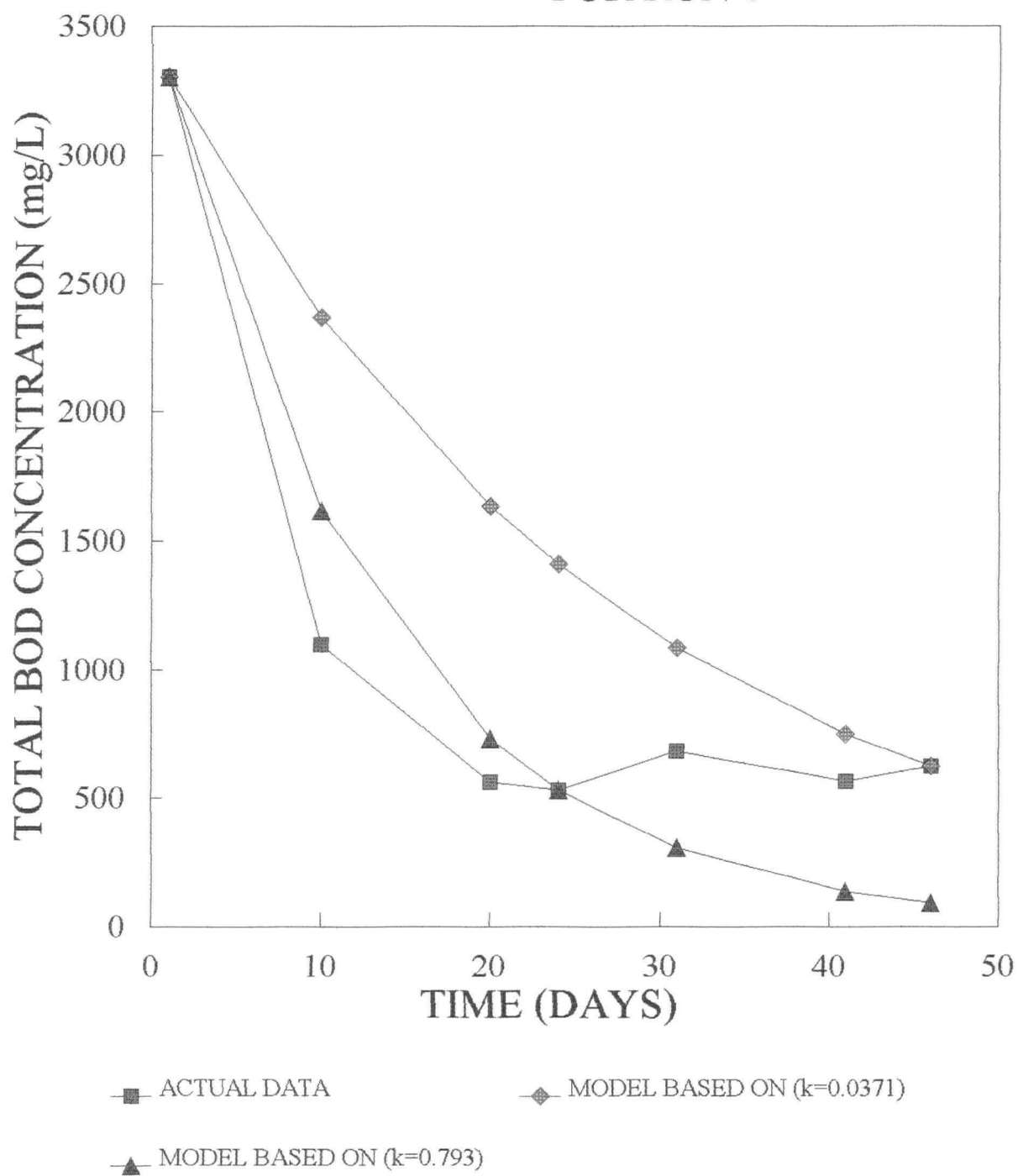
a levelling off. Based on first order decay equation of  $C/Co = \text{EXP}-(kt)$ , the constant  $k$  for the entire reaction was determined to be 0.036 Days<sup>-1</sup>. The quality of fit of this data is summarized in Table 4.3.7.

Days	Actual BOD5 Concentration (mg/L)	BOD5 Predicted using first order reaction for entire run (mg/L)	BOD5 Predicted using first order reaction up to day 24
1	3305	3305	3305
10	1100	2367	1618
20	561	1634	732
24	533	1409	533
31	685	1087	
41	566	749	
46	623	623	

**Table 4.3.7: Comparing the predicted BOD5 values for the models proposed.**

Examining Table 4.3.7 and the accompanying Figure 4.3.10, it is clear that the reaction fits the pattern of a first order decay for the first 24 days. At this point, the degradation process levelled off with little or no further reduction in BOD<sub>5</sub>. Two first order models are presented to model the BOD<sub>5</sub> degradation. The first model is based on the BOD<sub>5</sub> concentration on the last day of the run. The reaction rate constant for this model is 0.036 Days<sup>-1</sup>. It is clear from examining Figure 4.3.10 that the actual data does not fit this model. The BOD<sub>5</sub> degradation is more rapid than predicted and levels off near the end of the run. A second model is proposed, based on the BOD<sub>5</sub> concentration on day

FIGURE 4.3.10 ACTUAL AND FIRST ORDER MODEL PREDICTED TOTAL BOD VS TIME  
FOR RUN 8



24. This is the point where the degradation in the run levelled off. This model, with a reaction rate constant  $k$ , of  $0.793 \text{ Days}^{-1}$  fits the data more closely.

The data clearly indicates a problem in the biotreatment of this waste. The rapid, initial degradation was slowed after 20 days. A shift in the degradation rate was usually observed at the midpoint of the run, whereby the initial rapid degradation gave way to a slower process, due to the changing composition in the reactor. At first, simple organics were broken down; at the same time, some complex organics were slowly removed. The slow degradation of the tailend of the run enabled even the most complex compounds of the mixture to be broken down. The kinetics of the system changed, as noted previously. However, in the case of this run the rapid degradation gave way to a "stalled" system. There is no substantial degradation based on the Total BOD<sub>5</sub> of the reactor, after Day 20. The Total BOD<sub>5</sub> vs time graph (Figure 4.3.9) clearly indicates the problem with the run. Thus, it appears that the absence of nitrogen in the system had a greater effect on the treatment process than was originally thought.

Modelling the Diphenyl and the Diphenyl Ether breakdown can be seen in Figures 4.3.11 and 4.3.12, respectively. The Figures show how closely the first order models predict the degradation of the compound from the waste mixture. The reaction rate constants  $k$ , for the removal of Diphenyl and Diphenyl Ether are 0.40 and 0.11

FIGURE 4.3.11 Modeling the degradation of Diphenyl in run 8  
First order decay model

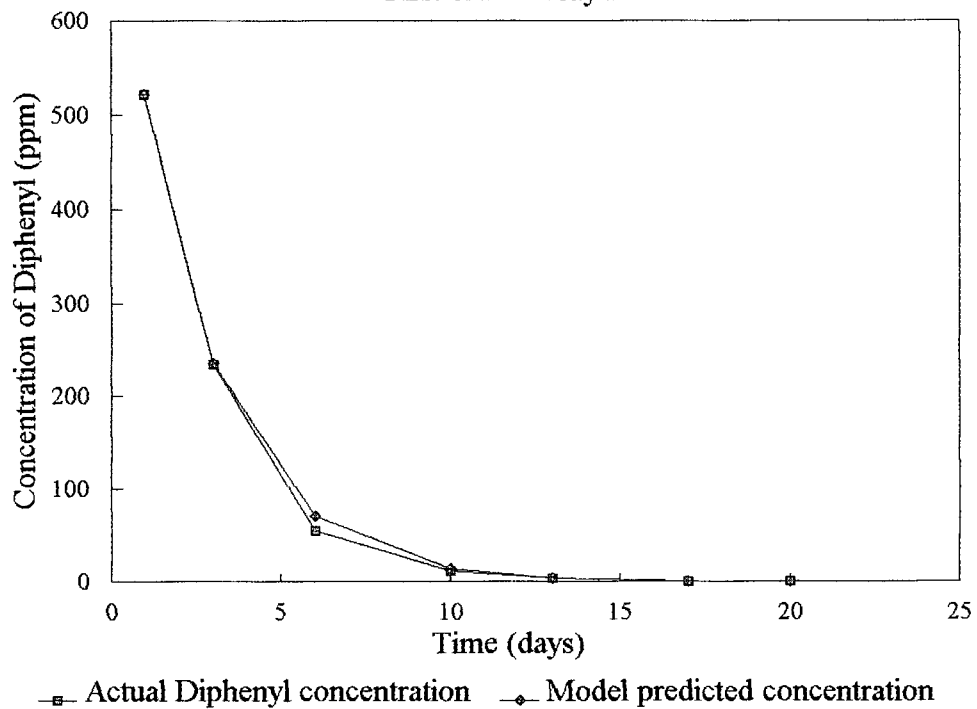
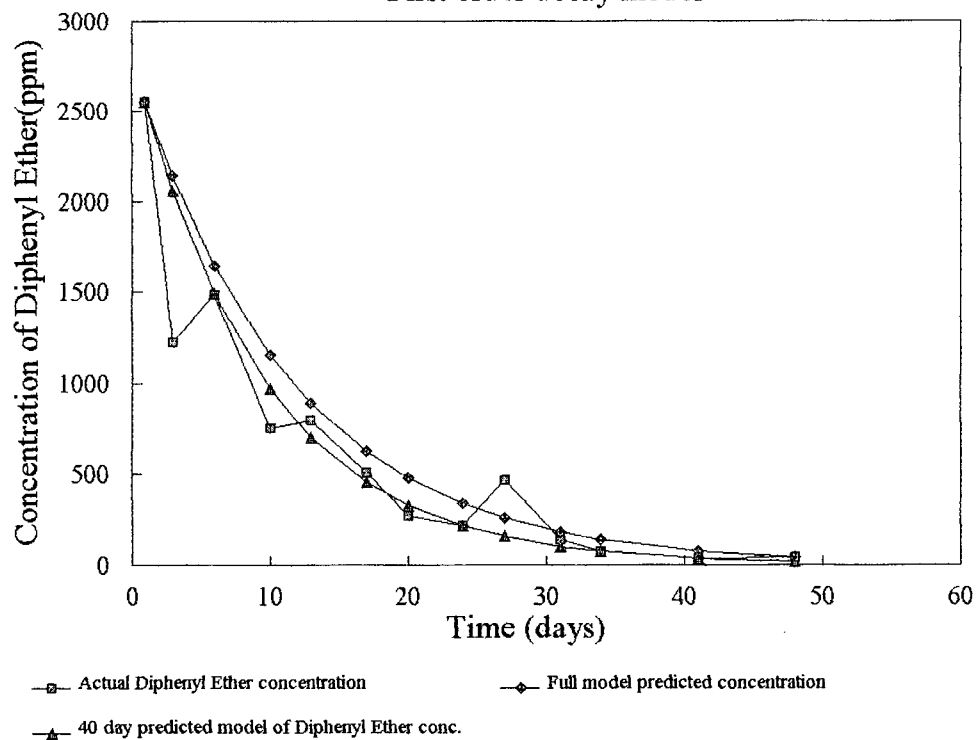


FIGURE 4.3.12 Modeling the degradation of Diphenyl Ether in run 8  
First order decay model



Days-1, respectively.

Overall, this run was not a success, based on the analysis of the final product. There remained a considerable BOD<sub>5</sub> and trace organics residual in the end product. Lengthening the run would not have provided any additional treatment, since the analytical results of the reactor had not changed greatly in the last 7 days of the run. It is probable that the failure was a combined result of the lack of nitrogen for a 7 day period and the high metal concentration. The phosphorus concentration was also not as high as in the previous run.

#### **Run#9:**

To continue the progress achieved in run 7 and to examine if a higher quality end product sludge and effluent could be obtained, the reactor contents at the end of run 7 were dosed with alum. The purpose of the alum was to reduce both the dissolved and the total copper levels to allow the microorganisms a better opportunity to treat the remainder of the organic constituents in the reactor. Jar tests with alum concentrations ranging from 200 to 1000 mg/L were performed on the treated sludge, to determine the dosage which would result in the best removal of copper.

Table 4.3.8 shows that the 1000 mg/L dosage removed the largest proportion of the original copper present. However, the dosage

Alum Dosage: (mg/L)	Resultant Total Copper Concentration (mg/L)
0	27.6
200	17.4
400	13.8
500	13.2
600	9.1
800	5.52
1000	4.53

**Table 4.3.8: Results of the jar test to determine copper removal.**

would not be practical on a large scale basis, due to the costs involved. Thus, if copper removal was desired at the full scale another method would have to be selected. The purpose here was to see if the bacteria would remove more of the Total COD if insitu copper levels were lower than in previous runs.

The contents of the Reactor 3, from run 7, were dosed with 1000 mg/L of alum in a separate clarifier. A 25 litre jug with an outlet on the bottom was used. 16 litres of the treated sludge (from run 7) were added to the clarifier and dosed with the alum. The pH was modified with sodium bicarbonate and sodium hydroxide, in order to fall within the range of 7.5 - 8.5. This modification was necessary, since the effectiveness of the alum depends on the pH and alkalinity of the solution. The contents were shaken for 10 minutes and allowed to settle. 12 Litres taken from the top of the vessel were collected and were used for the next run. This reactor would be known as Reactor 3.

Reactor 2 was loaded with a small concentration of sludge, to investigate the response of the system to a very low initial sludge loading. It was hoped that if the organic constituents and the metal concentration of the waste mixture were quite low the bio-kinetics of the system would improve. The objective was to observe the rates of reaction of an "under-loaded" system, compared to those of previous runs.

As can be noted in Tables 4.3.9 and 4.3.10, the target organic compounds were in quite low concentration in all the reactors. The waste mixture in Reactor 3 contained a less-diverse chemical makeup, when compared to the other reactors. This was expected, since the sludge was previously treated in run 7. At the end point of that run, the GC trace indicated that all the organic components had been reduced to below the detection limit. The origin of the organic compounds now present in this reactor would be from the wastewater seed utilised in this run. A seed was added to the system because it was feared that most of the original organisms had been removed from the system with the copper.

Reactor 2 was loaded with the lowest initial sludge loading rate to date. This was confirmed by both the Total COD and the concentration of target organics. This resulted in the lowest total copper level found in any run. The effect of this low level

Parameter:	Reactor 2:	Reactor 3: Alum Addition	Reactor 5: Control
Sludge loading vol. (L)	0.7	12 litres of alum treated sludge from final product of run 7 in Reactor 3	0.5
Seed water vol. (L)	3	3	0
Total vol. (L)	21	20	5
Initial Total COD (mg/L)	4 227	4 058	17 588
Initial supernatant COD (mg/L)	1 011	1 044	3 724
Initial Total BOD <sub>5</sub> (mg/L)	627	202	NA
pH	5.89	8.54	7.57

**Table 4.3.9: Initial condition in the reactors at the beginning of run 9.**

Compound:	Reactor 2 (ppm)	Reactor 3 Alum sweep (ppm)	Reactor 5 Control (ppm)
Xylene	108	18.4	68.4
Diphenyl	463.3	7.0	945.5
Diphenyl Ether	2 240	77.7	4 395
Diphenyl Methane	17.1	0	62.7
Benzene, 1,1' Methylene bis (4-methyl)	10.8	0	115.1
1,2-Dimethyl- 4-Benzyl Benzene	49.6	0	72.5

**Table 4.3.10: Concentration of target organics in the reactors prior to run 9.**

would be closely monitored and compared to previous runs.

Over the course of the run, a very small reduction in Total COD occurred in the two test reactors. The Total COD vs time graph, Figure 4.3.13, was not the typical shape which had come to be expected. There was an initial general, downward trend in the concentration of the Total COD; however, the tail end of the curve did not rise as it has in previous runs. The time frame for the run was quite different, since the reactors ran for less than 25 days (other runs lasted for as long as 48 days). The control did not exhibit the expected pattern either. However in this case, the control exhibited a general, slow rising trend but the overall trend was one of stability. Little overall change was exhibited.

The supernatant COD vs time graph was also rather uneventful, as shown in Figure 4.3.14. Reactor 2 displayed a slow decrease in concentration until the final days of the run. At this point, the degradation was more rapid. In the case of Reactor 3, there was a slight decrease in the concentration over time until the half way point of the run; this was followed by a slight increase, and then decreased until the end of the run. The end result was little change in the overall concentration. It appears that the initial Total COD concentration was the determining factor for the pattern found in the supernatant COD.

FIGURE 4.3.13 TOTAL COD CONCENTRATION VS TIME FOR RUN 9

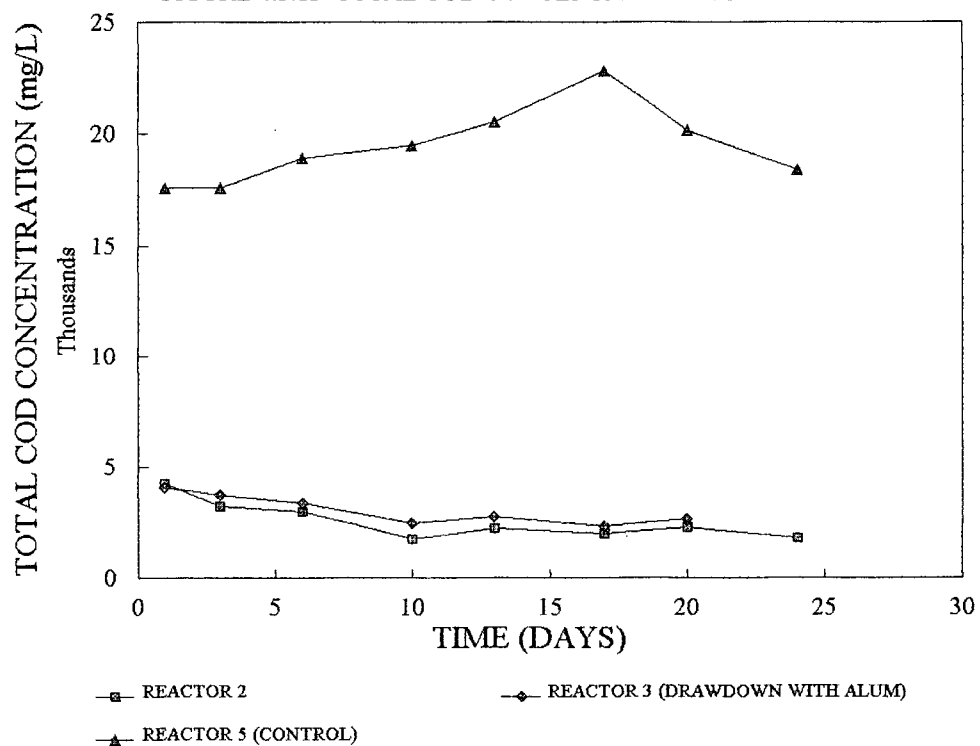
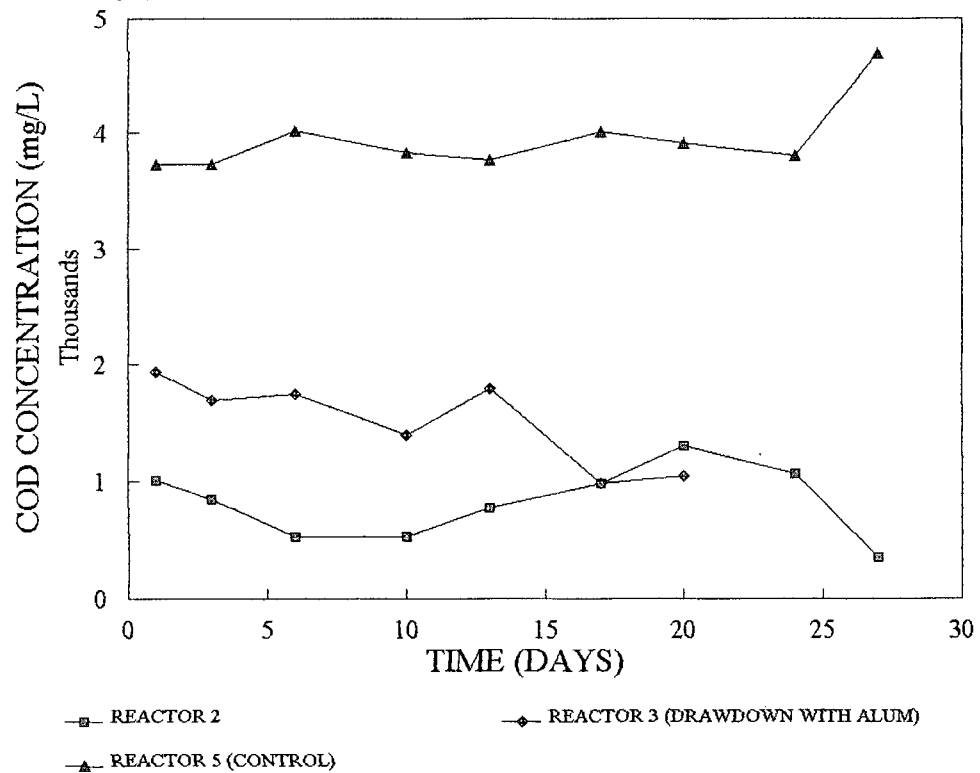


FIGURE 4.3.14 SUPERNATANT COD CONCENTRATION VS TIME FOR RUN 9



As discussed previously, there are two causes for the rise in the COD of the supernatant. Either the initial loading was too concentrated or the microorganisms were being inhibited from breaking down the material. When the initial loading is too high, compounds solubilize in the supernatant at a faster rate than the microorganisms can degraded them. Thus, there is considerable accumulation of compounds in the supernatant (evident from the rising value of the supernatant COD). The other possibility, as demonstrated in the last run, is that even though the initial loading was not high there can still be an accumulation in the supernatant if the bacteria are being inhibited through metal toxicity or nutrient deficiency. The result is the same; compounds will accumulate in the supernatant because the microorganisms are not able to actively degrade the waste. There was no noticeable rise in the concentration of the supernatant COD since none of these situations materialized. In this case, the lack of a significant increase in the supernatant COD was probably the result of the low initial concentration of the waste mixture added to the reactor.

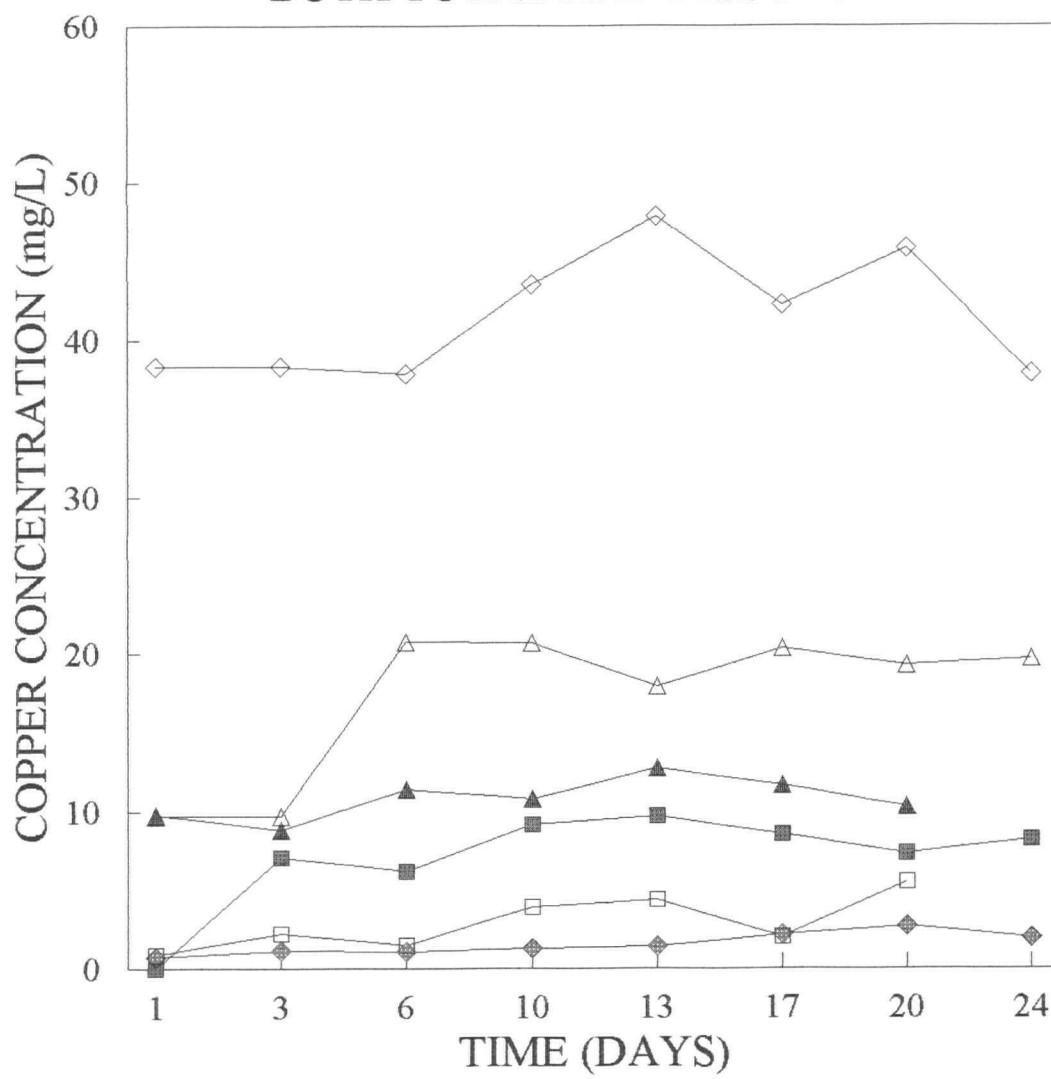
The total copper concentration in Reactor 2 was only 10 mg/L, as can be seen in Figure 4.3.15. The dissolved concentration in this reactor rose above 5 mg/L during the course of the experiment. This indicates that over half of the copper present was found in dissolved form. It also suggests that even using a low sludge loading rate does not necessarily guarantee that the run will

avoid possible copper toxicity problems. The total copper levels in Reactor 3 were slightly lower. However, the dissolved copper concentration in the reactor was considerably lower. This appears to be due to the fact that the phosphorus concentration in Reactor 3 was nearly 4 times the one found in Reactor 2 for most of the run, as seen in Figure 4.3.16. (Reactor 3 contained a significantly high concentration of phosphorus since a large amount had been added to this vessel in run 7 and it had not been utilised). This again indicates that phosphorus levels are instrumental in reducing the concentration of dissolved copper found in the reactors (also, previously demonstrated in run 7 which had considerable total copper level but little found in dissolved form).

There was little variation in the pH or MLVSS concentration over time. This was to be expected since the sludge COD loading was low and thus little degradation occurred.

As noted in Table 4.3.11, the alum addition was successful in producing a sludge in which further reduction in Total COD was possible. As seen in Figure 4.3.18, the BOD<sub>5</sub> was reduced to a small concentration and the GC trace was blank. This indicates that none of the organic compounds initially present were still there. The three step process was successful, but the method was not efficient since the sludge was already of "good quality" at

FIGURE 4.3.15 COPPER CONCENTRATION VS TIME FOR RUN 9  
BOTH TOTAL AND DISSOLVED



■ REACTOR 2 (TOTAL)    ◆ REAC 2 (DISSOLVED)    ▲ REACTOR 3 (TOTAL)  
 □ REAC 3 (DISSOLVED)    ◇ REACTOR 5 (TOTAL)    △ REAC 5 (DISSOLVED)

FIGURE 4.3.16 PHOSPHORUS CONCENTRATION VS TIME FOR RUN 9

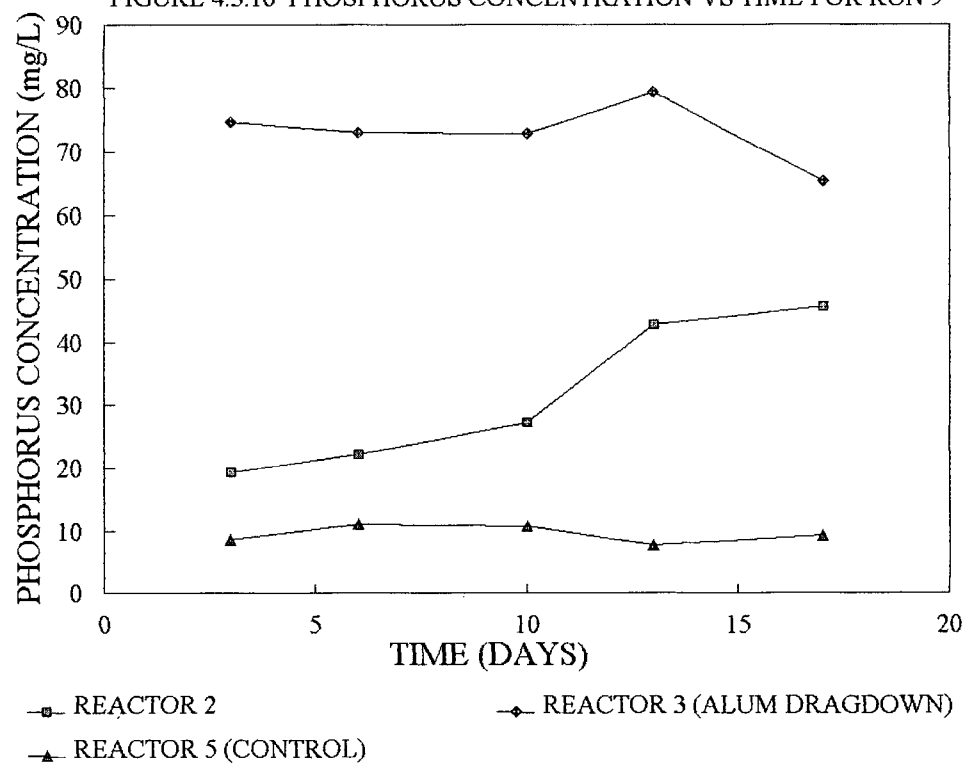
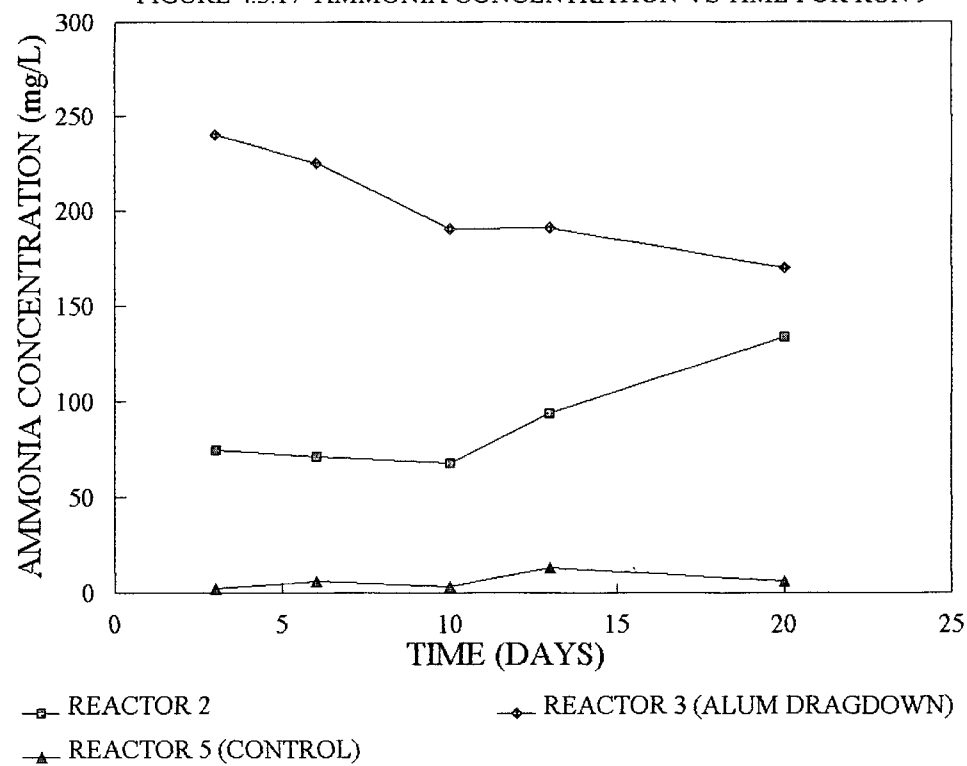


FIGURE 4.3.17 AMMONIA CONCENTRATION VS TIME FOR RUN 9



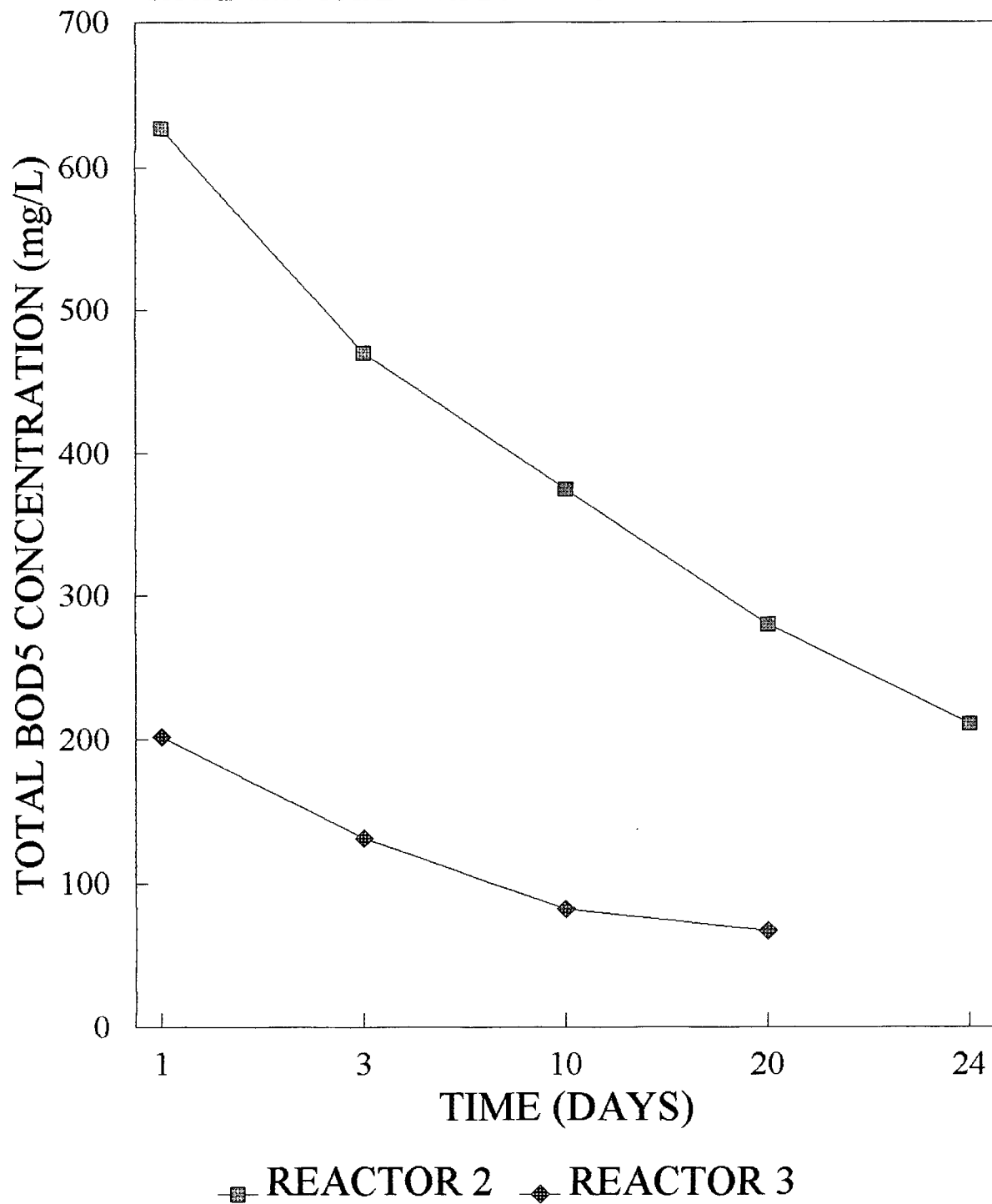
Parameter:	Reactor 2	Reactor 3 alum sweep	Reactor 5 control
Initial Total COD (mg/L)	4 227	4 058	17 588
Final Total COD (mg/L)	1 950	2 606	17 588
% difference	53.8	35.8	0
Initial Total BOD <sub>5</sub> (mg/L)	627	202	NA
Final Total BOD <sub>5</sub> (mg/L)	211	67	NA
% difference	66.4	70.0	NA

**Table 4.3.11: Final conditions in the reactors at the end of run 9.**

the end of the initial degradation process. It is questionable if the quality of the final sludge was increased with this slight reduction in Total COD. The only rationale for using this procedure would be to reduce the copper levels below the discharge limit or a reduction in refractory organics was necessary.

Reactor 2 was not able to eliminate all the target organics (see Table 4.3.12) from the initial sludge mixture. This was partly a result of the elevated copper levels as well as the short time frame of the experiment. The data from the previous runs indicated that Diphenyl Ether is always the last compound to be removed. Had the run been lengthened, it is quite probable that all compounds would have been removed to below the detection limit. The run was more successful than Reactor 4 in run 8, in terms of percent reduction of target organics, since it removed

FIGURE 4.3.18 TOTAL 5 DAY BOD CONCENTRATION VS TIME FOR RUN 9



Compound:	Parameter	Reactor 2 (ppm)	Reactor 3 alum sweep (ppm)	Reactor 5 control (ppm)
Xylene	Inn. Conc.	107.9	18.4	68.5
	Final Conc.	0	0	43
	% Reduction	100	100	37.2
Diphenyl	Inn. Conc.	463.3	7	945.5
	Final Conc.	11.2	0	730.7
	% Reduction	97.6	100	22.7
Diphenyl Ether	Inn. Conc.	2 240	77.7	4 394
	Final Conc.	78.3	0	3 298
	% Reduction	96.5	100	24.9
Diphenyl Methane	Inn. Conc.	17.1	0	62.7
	Final Conc.	0	0	47.3
	% Reduction	100	NA	24.7
Benzene, 1,1' Methylene bis (4- methyl)	Inn. Conc.	10.8	0	115.1
	Final Conc.	0	0	115
	% Reduction	100	NA	0
1,2- Dimethyl-4- Benzyl Benzene	Inn. Conc.	49.6	0	72.5
	Final Conc.	0	0	72.5
	% Reduction	100	NA	0

**Table 4.3.12: Concentration of the target organics in the reactors at the end of run 9.**

all of the target organic compounds, except for Diphenyl and Diphenyl Ether. A higher phosphorus loading could probably have produced a larger gradient for the formation of copper phosphate,

thereby further reducing the concentration of dissolved copper. The low organic loading did not improve the biological treatment rate, compared to the previous much higher loaded systems.

Reactor 5, the control, performed relatively well, showing little loss due to volatilization. The target organic compounds for the most part were reduced by less than 25% of their original value. Again, Xylene was the compound which exhibited the largest change in concentration. However, there was still considerable quantities left in the reactor at the end of the run. This compound was only reduced by 37.2%; however, it was a marked improvement over previous runs.

Comparing the two system in the run, it becomes clear that, in terms of BOD<sub>5</sub> reduction, Reactor 3 performed slightly better. Even though the reactor was loaded with a much lower organic load, the degradation constant  $k$  was larger for the process as can be noted in Table 4.3.13. This can be attributed to the fact that the phosphorus load was larger and resulted in a lower dissolved copper concentration. The other point to remember is that the organisms in the reactor were previous acclimatized to the mixture. The rate of bio-degradation was also larger than the last run, both in terms of the degradation constant  $k$ , but also in terms of a straight line decline.

Compound:	Parameter:	Reactor 2	Reactor 3 Alum sweep
BOD	Dx/Dt (ppm/d)	18.1	7.58
	k (day-1)	0.0474	0.0583
Diphenyl	Dx/Dt (ppm/d)	24.4	1.39
	k (day-1)	0.333	NA
Diphenyl Ether	Dx/Dt (ppm/d)	83.1	6.47
	k (day-1)	0.434	0.189
Diphenyl Methane	Dx/Dt (ppm/d)	0.90	NA
	k (day-1)	0.311	NA

**Table 4.3.13: Kinetic constants determined for the degradation in run 9.**

The low reaction rate constants in Reactor 3 for target organics are a likely result of the low organic loading and the lack of diversity of the waste mixture. Curve fitting using first order kinetics can be seen in Figures 4.3.19 to 4.3.22. The reaction rates for degradation of some compounds are reported to be dependent on the presence of other organic compounds in the mixture (Capps 1995)

A comparison of the previous three runs, to determine the best initial sludge loading can be seen in the Tables 4.3.14 and 4.3.15.

FIGURE 4.3.19 Comparing the actual data and model predicted values of Diphenyl vs time  
For reactor2 in run 9

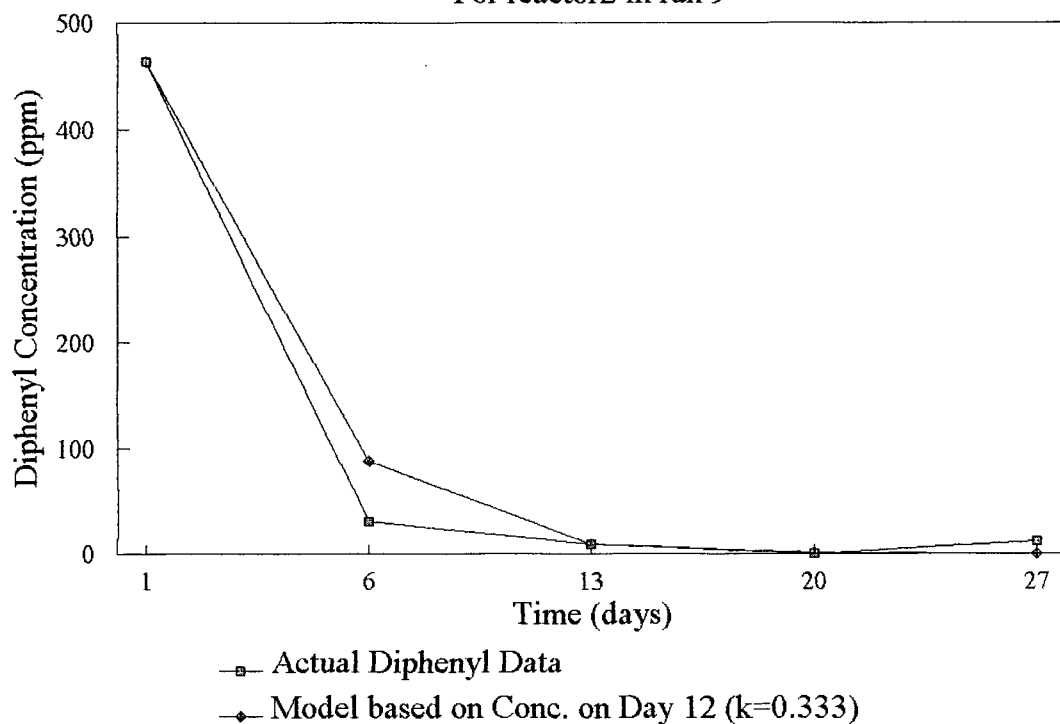


FIGURE 4.3.20 Comparing First Order Models and Actual Concentration of Diphenyl Ether vs Time  
For reactor 2, in run 9

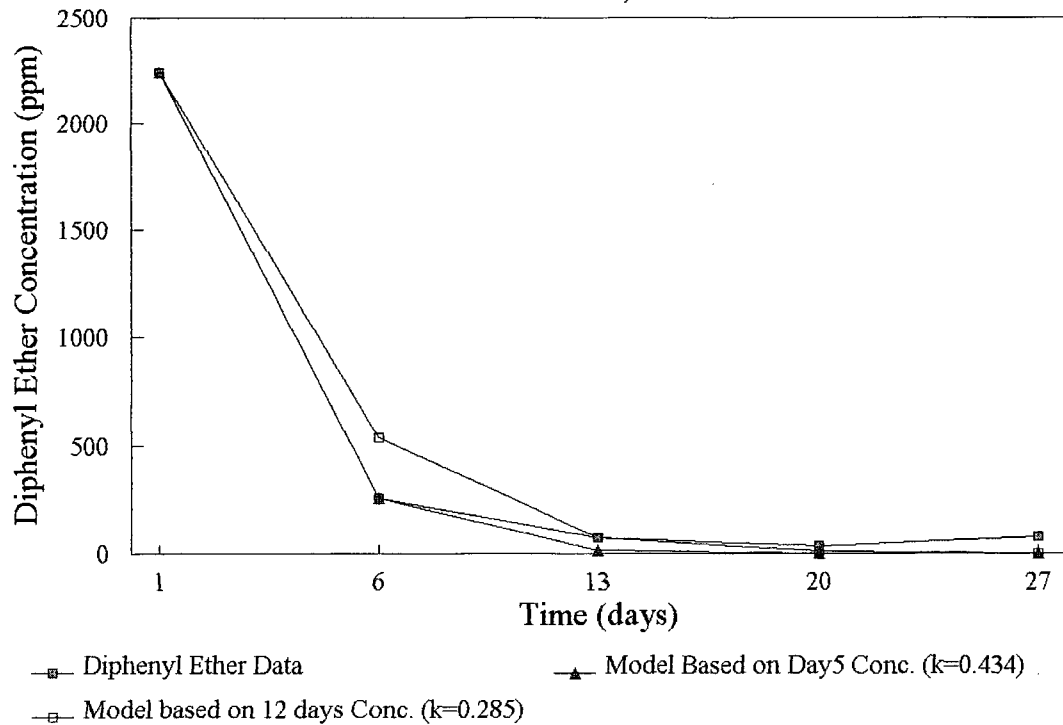


FIGURE 4.3.21 Actual Concentration and 1ST Order model of Diphenyl Methane vs time  
For reactor2 in run 9

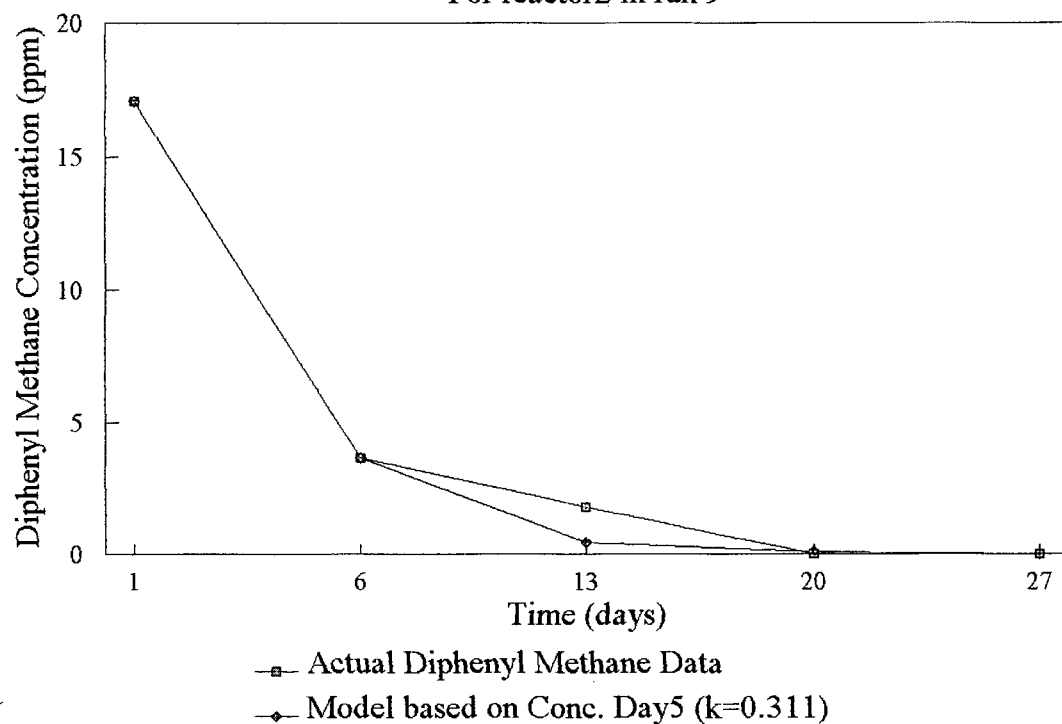
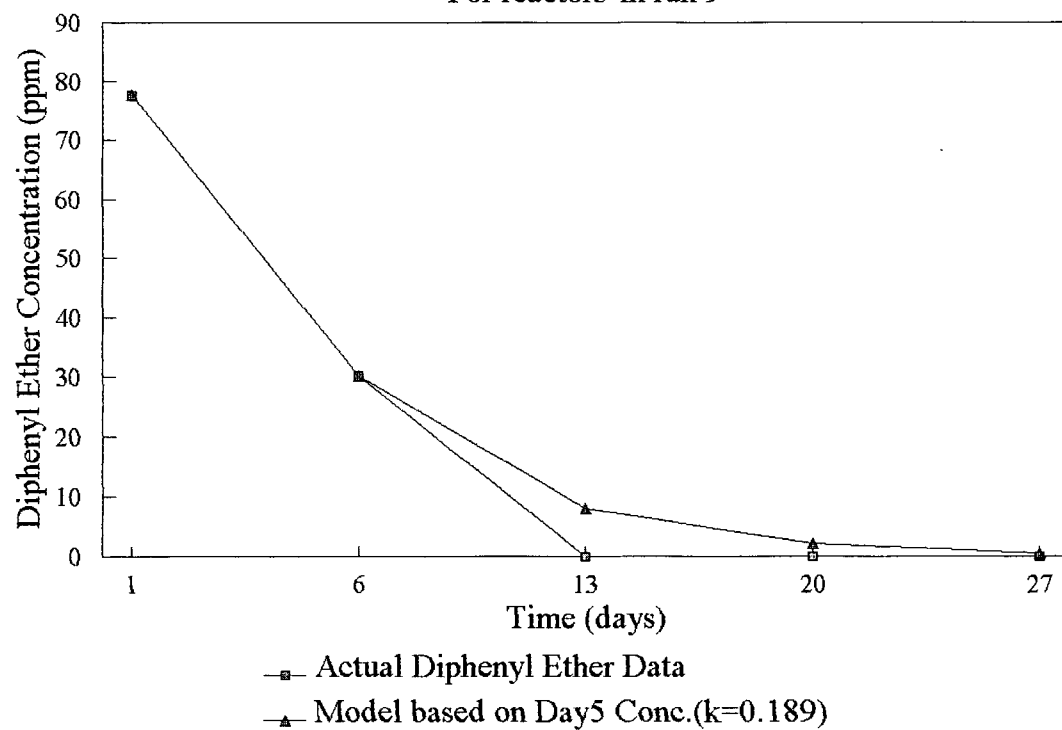


FIGURE 4.3.22 Actual and model predicted Diphenyl Ether Concentration vs Time  
For reactor3 in run 9



Parameter:	Reactor 2	Reactor 4	Reactor 2
Run	7	8	9
Length (days)	40	46	25
Initial Total COD (mg/L)	30 169	12 419	4 227
Initial Total BOD <sub>5</sub> (mg/L)	8 322	3 305	627.2
BOD <sub>5</sub> removal kinetics (mg/L day):			
Dx/Dt(1st half)	430.4	120.5	28.0
Dx/Dt (2nd Half)	23.9	0	11.71
Dx/Dt (Total)	211.5	59.6	18.1
Reaction rate constant k (Days <sup>-1</sup> )	0.121	0.0793	0.047

**Table 4.3.14: Comparison between the straight line BOD degradation rates and the reaction rate constant k for the past three runs.**

As the numbers in the Tables indicate, the largest proportion of the degradation, in terms of mass, occurred in the first part of the run. However, the second part was necessary to degrade the more complex organics and to create a clearly polished effluent. Examining the Diphenyl Ether degradation for run 7, in the first 20 days, the reduction rate average was over 100 mg/L Day but fell to below 0.1 for the remaining twenty days of the batch.

As Table 4.3.14 indicates; the underloaded systems were not as efficient at degrading the waste in terms of BOD<sub>5</sub> reduction. The system with a more concentrated waste mixture enjoyed a higher

degradation constant  $k$  and was thus capable of reducing the waste

Compound:	Parameter:	Period:	Reactor 2	Reactor 4	Reactor 2
	Run		7	8	9
Diphenyl Removal:	Dx/Dt(mg/L Day)	1st Half	104.9	21.7	37.8
		2nd Half	0.1	0*	0**
		Total	28.2	10.9*	24.4**
	$k$ (Day $-1$ )	Total	0.541	0.4	0.33
Diphenyl Ether Removal:	Dx/Dt(mg/L Day)	1st Half	468.5	97.3	180.5
		2nd Half	4.57	7.38	0
		Total	129	53.4	83.1
	$k$ (Day $-1$ )	Total	0.332	0.11	0.43

**Table 4.3.15: Comparison of the straight line degradation rates and reaction constants  $k$  for selected target organic compounds in runs 7,8,9.** \* Degradation rate 0 since none remaining. \*\* Degradation rate 0 due to the "stalling" of the degradation of this compound.

faster and to a larger extent than the other lower loaded systems. The best performing system, in terms of BOD<sub>5</sub> reduction rates was Reactor 2 in run 7. Achieving the highest possible loaded system capable of degrading the waste was a priority in this research, since it represents the most efficient and effective use of resources. Thus, the waste sludge can be treated in larger batches, resulting in less time to remediate the site, and thereby saving money to the owners of the site.

It is interesting to note that a high Total BOD<sub>5</sub> degradation constant  $k$  does not necessarily insure that the rate of

degradation of the specific target compounds will be high. As is the case run 9, the reactor with the lowest Total BOD<sub>5</sub> reaction rate constant  $k$  had the highest constant for the removal of Diphenyl Ether from the system. This can be attributed to a better sludge mixture, thus promoting the degradation of the specific compounds. However, even though Diphenyl Ether is efficiently removed from the system, there was still a considerable amount of organic material remaining at the end of the run.

The key to a successful run, in terms of a high degradation rate, appears to depend on the presence of dissolved copper. It alone seemed to be the largest deterrent to the growth of a prosperous bacterial culture. Even when the sludge loading rate was very low, as was the case in the Reactor 2 of run 9, the treatment was not successful. There was a residual Total BOD<sub>5</sub> and the target organic compounds were not completely degraded. Modifying the nutrient levels seems to be the most effective way of avoiding apparent copper toxicity problems. Removing the copper through alum addition is possible. However, this requires a three step process, increasing the cost and the complexity of the operation, considerably. Run 7, the most successful run to date, showed an increase in degradation rates and quality of the end product; however, phosphorus was added in 5 times larger quantities than required for cell growth. This step appears to be responsible for producing the highest degradation rates in any system observed,

almost twice as large as any other run in terms of Total BOD<sub>5</sub> removal.

#### 4.4 Results and Discussion (Continued): True Batch Runs

##### Run#10

This run presented the first attempt to deviate from the Modified Batch Process (MBP) treatment. The treatment system was converted to a True Batch Process (TBP), as outlined in the Materials and Methods section. Only 25% of the contents of the reactors at the end of the previous run was harvested, prior to the addition of more virgin sludge. The volume difference was made up with dilution water. It was hoped that this process would improve the system's biotreatment performance in employing adequately acclimatised organisms from the previous run.

A concern in switching to the True Batch Process centred around the potential problem with the accumulation of dissolved copper in the system. Usually, at the end of the treatment phase, the entire contents of the reactor were removed and the vessel was prepared for the new batch. However, in this case only a fraction of the endproduct sludge was removed. This meant that there could be a larger copper concentration, especially in dissolved form, in the reactor, prior to the dosing of new sludge into the units. The dissolved copper levels could potentially be much greater than any previously encountered. If, for example, one quarter of the contents of the reactor were removed, then, possibly, three quarters of the copper load remained in the system. Thus, the

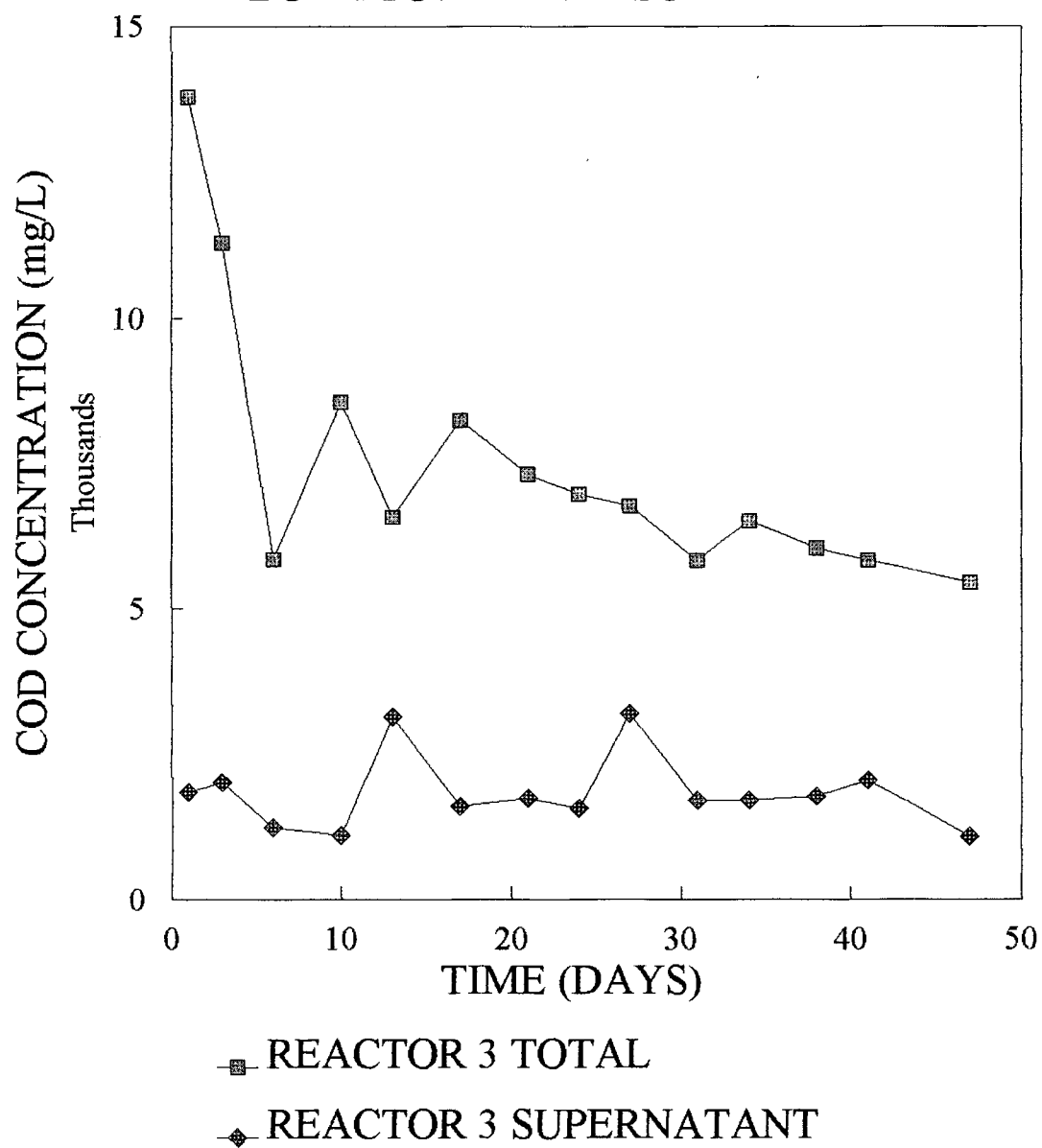
copper level of the next run would include three quarters of the copper load from the previous run and a full copper load from the incoming virgin sludge. This would definitely be an aspect of concern for the next phase of the study. However, because alum treatment had been used in run 9, to reduce copper levels, the concern with the initial copper concentration was considerably reduced.

Five litres of endproduct sludge were removed from Reactor 3 of run 9 and replaced with 1 litre of virgin sludge. Table 4.4.1 shows the initial conditions for this run.

The initial total copper load in the reactor was relatively low, as had been predicted; however, the total organic load was not as high as was hoped. It was hoped to replicate the success of run 7 but using the True Batch Process treatment system. However, the initial COD level was much less than the 30 000 mg/L experienced in run 7. Table 4.4.2 shows the initial concentration of target organics in run 10.

The Total COD vs time graph, is shown in Figure 4.4.1. The pattern is similar to the one that had been exhibited in previous runs, with one exception. There was an initial rapid degradation in terms of Total COD for the first six days; after that, the concentration varied but did generally decrease for the remainder of the run.

FIGURE 4.4.1 COD CONCENTRATION VS TIME FOR RUN10  
BOTH TOTAL AND SUPERNATANT



Parameter:	Reactor 3:	Reactor 5: Control
New sludge Volume (L)	1	1.5
Old Sludge (L)	12	None
Seed Volume (L)	2	None
Total Volume (L)	21.4	21.4
Initial Total COD (mg/L)	13 788	25 317
Initial supernatant COD (mg/L)	1 856	2 481
Initial Total BOD <sub>5</sub> (mg/L)	4 584	NA
Initial Total Copper (mg/L)	22.5	48.9
Initial Dissolved Copper (mg/L)	3.6	9.1
pH	6.58	7.15

**Table 4.4.1: Initial conditions in the reactor prior to the start of run 10.**

Compound:	Reactor 3 Initial Concentration (ppm)	Reactor 5 Control (ppm)
Xylene	78.3	187.1
Diphenyl	289.2	738.4
Diphenyl Ether	1 549	3 494
Diphenyl Methane	11.4	32.7
Benzene,1,1' Methylene bis (4- methyl)	7.71	28.8
1,2 Dimethyl-4- Benzyl Benzene	25.8	107.4

**Table 4.4.2: Initial concentration of the target organics prior to run 10.**

The endpoint concentration in terms of Total COD, was the lowest point in the entire run, a result not seen in earlier runs. Perhaps, a well acclimatised culture developed during this run,

enabled a breakdown of more refractory organics. As Grady (1990) indicated in his work with a low concentration phenolic wastewater, an increased sludge age of the biomass generally results in the degradation of more refractory organics. As noted from previous runs in this study, the tailend of the Total COD graph was usually characterized by a generally increasing concentration, not a decrease such as in run 10.

The supernatant COD over time, Figure 4.4.1, was very stable, this was also somewhat unusual. However, it should be remembered that the initial Total COD concentration of sludge was quite low. Previous runs indicated that, under these low COD loading conditions, there was little increase in the COD of the supernatant.

Examining the pH vs time graph, Figure 4.4.2, the pH drop was rapid and severe for the first 10 days. Over this time period, the pH fell more than 3 units from 7.15 to 3.68. At this point, action was taken to increase the pH. Soda ash was added to the reactor to raise the pH to 6.5. However, the resulting pH fell short of the target, at 5.88. It was hoped that in modifying the pH slightly, treatment "stalling" problems exhibited in previous runs would be avoided. Initially, the pH continued it's decline after the modification but after day 20, the pH was quite variable from one sampling period to the next. The net change after day 20 was insignificant.

FIGURE 4.4.2 PH VS TIME FOR RUN 10

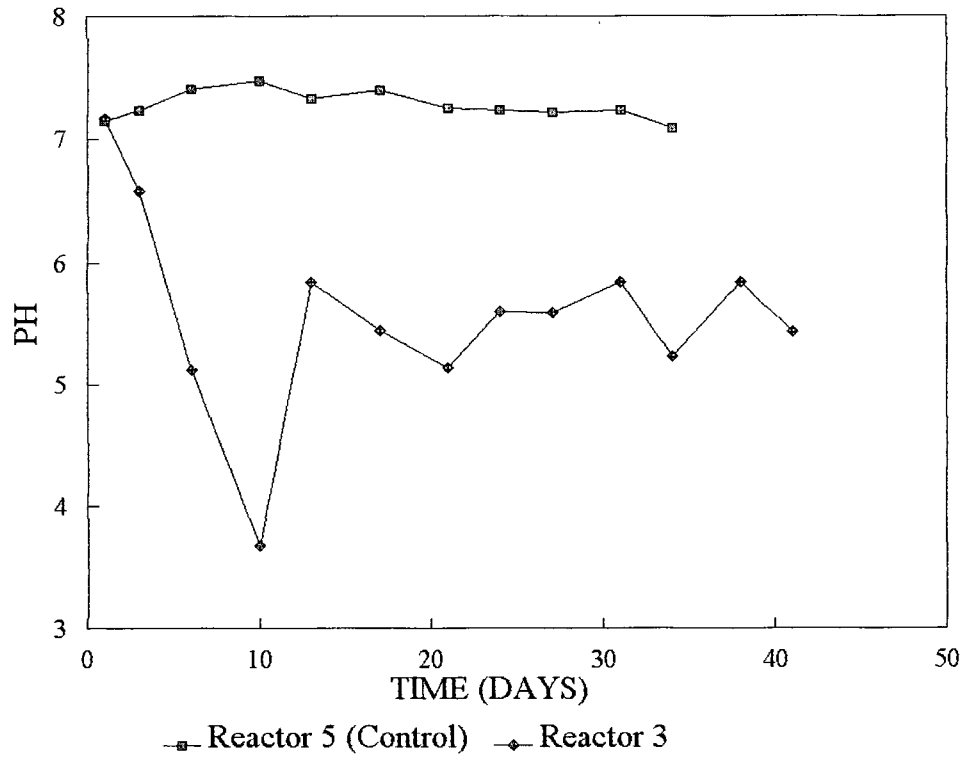
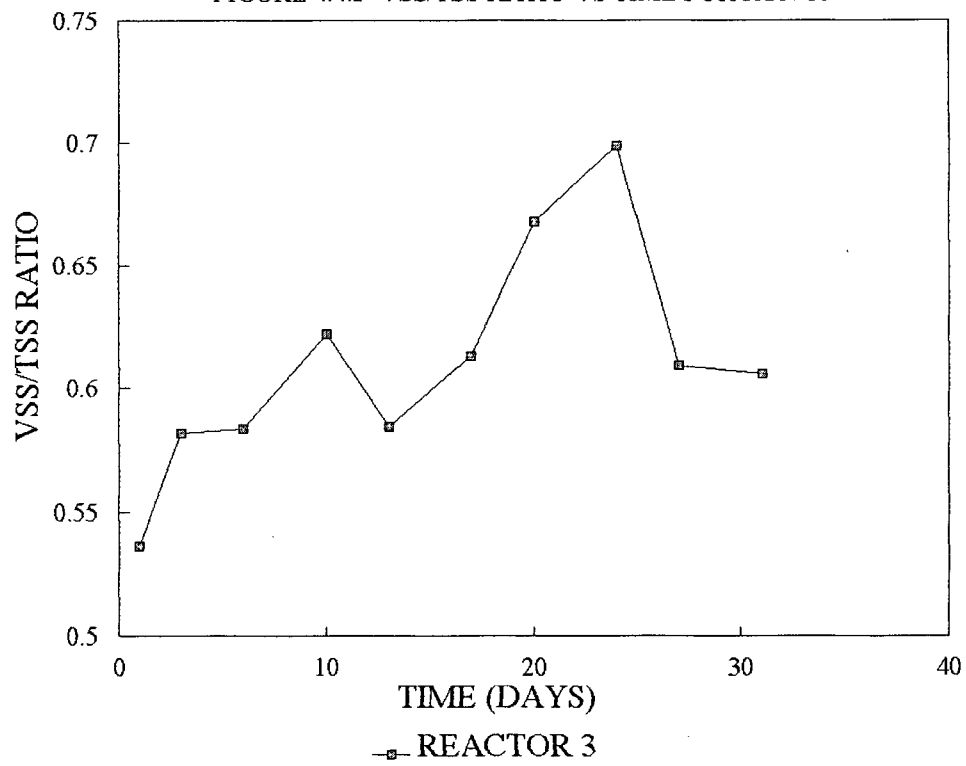


FIGURE 4.4.3 VSS/TSS RATIO VS TIME FOR RUN 10



The VSS/TSS ratio, Figure 4.4.3, reinforces the problems with pH modification. An increase in the VSS/TSS ratio can be observed during the period when the pH was not modified. Yet, when the pH was raised from 3.68 to 5.88, the ratio decreased, showing a possible decline in the viable biomass population. The bacteria actively degraded the waste under a low pH. However, when the pH was modified by more than 2 units, the Total COD degradation halted. Thus, it appears that the severe pH change negatively affected the bacteria as indicated by both the Total COD and the VSS/TSS Ratio (Figures 4.4.1 and 4.4.3).

No nutrient deficiencies were experienced during the run, as can be seen in Figure 4.4.4 and 4.4.5. However, the phosphorus concentration in the system, at some points, was lower than 20 mg/L. It has been shown that, in previous runs, the higher the phosphorus concentration, the lower the dissolved copper level. During the run, the dissolved copper concentration was initially 3.58 mg/L as Figure 4.4.6 shows. Usually, the concentration was initially low and increased as organic matter was degraded and released copper to solution. However, since this was a true batch attempt, much of the copper initially present in the reactor was found in dissolved form, since the sludge had been broken down in the previous run releasing copper into solution and the entire content of the reactor was not removed after the last run.

FIGURE 4.4.4 PHOSPHORUS CONCENTRATION VS TIME FOR RUN 10

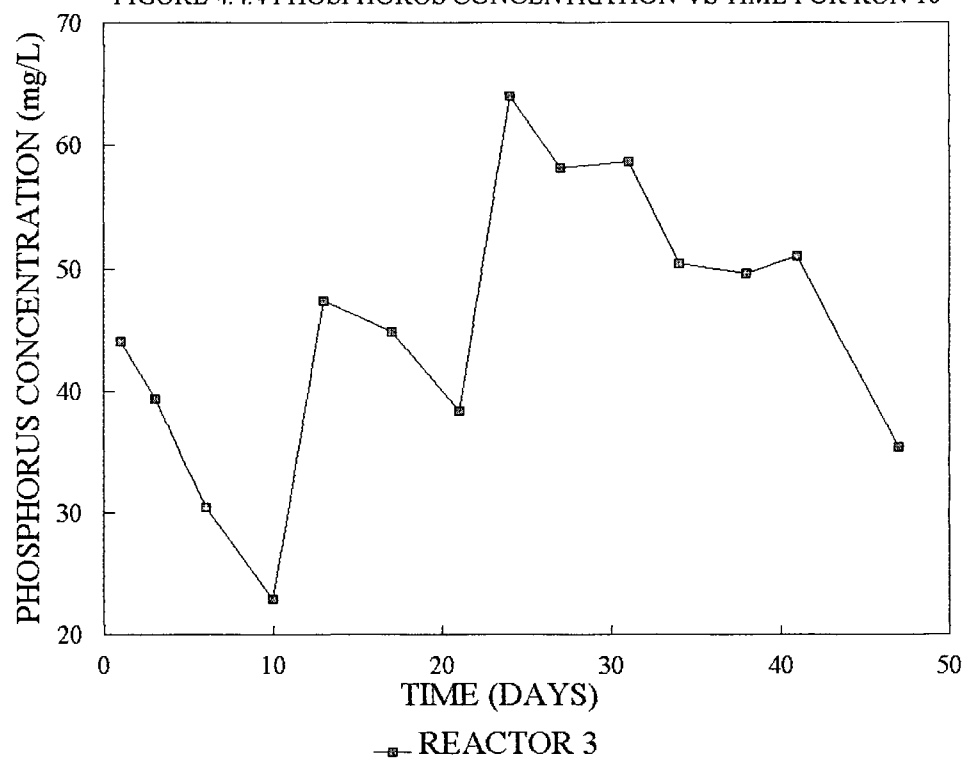


FIGURE 4.4.5 AMMONIA CONCENTRATION VS TIME FOR RUN 10

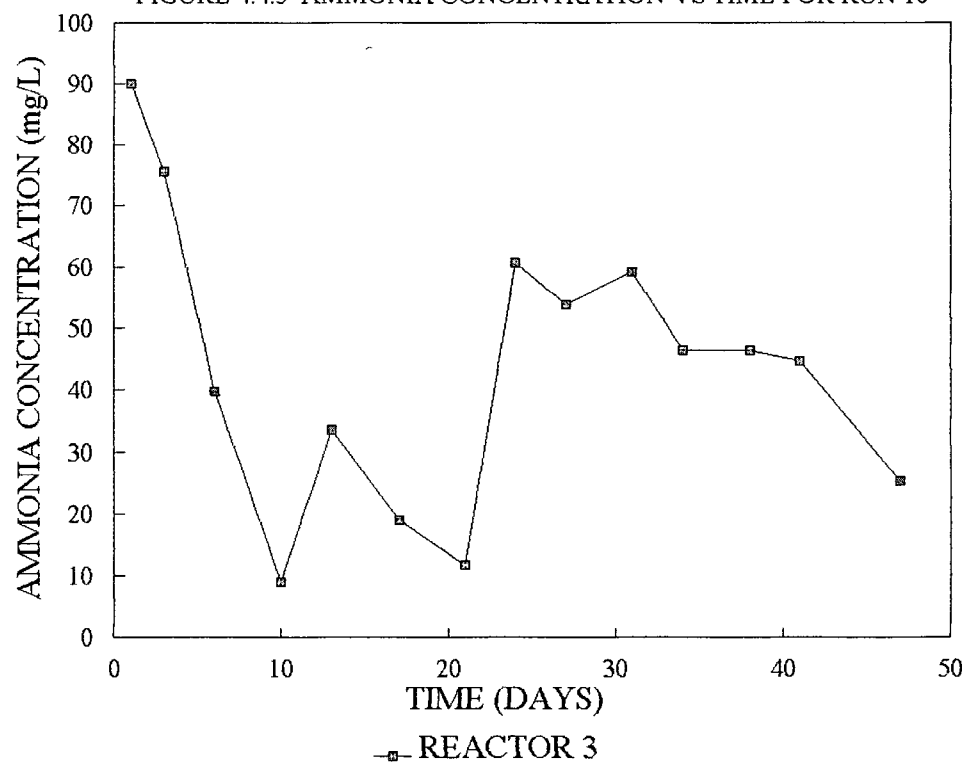
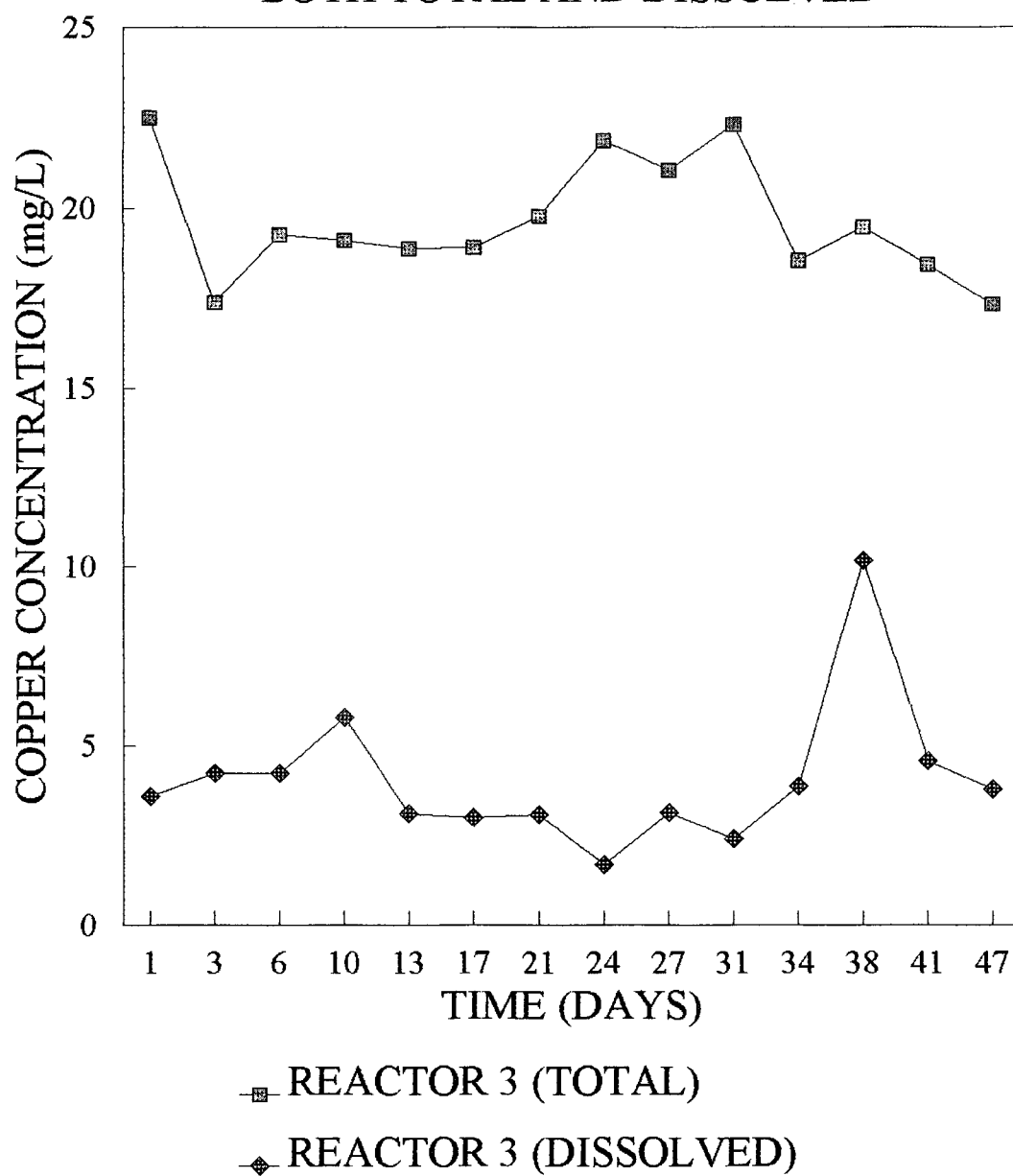


FIGURE 4.4.6 COPPER CONCENTRATION VS TIME FOR RUN 10  
BOTH TOTAL AND DISSOLVED



The dissolved copper concentration was rather stable for the entire run except for day 38, when it was measured at a concentration above 10 mg/L. This was probably an error in the preparation of the sample, since it was not in line with any other measurements. Also, the phosphorus concentration at this point should have been high enough at 50 mg/L, to precipitate the extra dissolved copper.

The BOD<sub>5</sub> was reduced to well below 100 mg/L, as can be observed in Figure 4.4.7, and in Table 4.4.3. The target organics were reduced to below the detection limit of the GC in 34 days (Table 4.4.4). The run was continued past this point in order to try and remove the residual Total COD.

Parameter	Reactor 3	Reactor 5 Control
Initial Total COD (mg/L)	13 788	25 317
Final Total COD (mg/L)	5 443	21 023
% Degradation	60.5	17.0
Initial Total BOD <sub>5</sub> (mg/L)	4 584	NA
Final Total BOD <sub>5</sub> (mg/L)	83.7	NA
% Degradation	98.2	NA

**Table 4.4.3: Final conditions in the reactors at the end of run 10.**

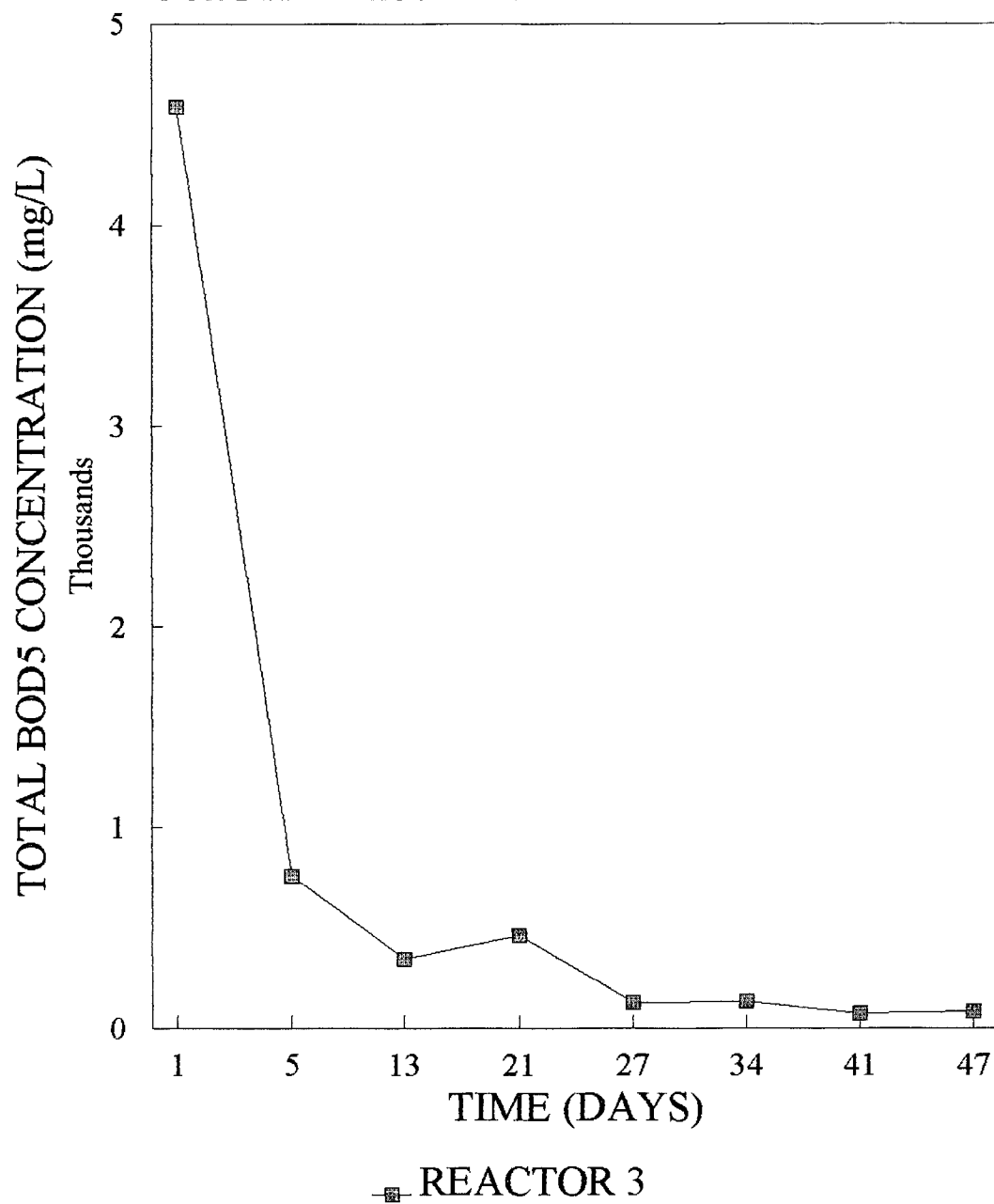
Tables 4.4.3 and 4.4.4 show that in terms of the degradation of the waste sludge, run 10 was quite successful. The interesting parameter is the length of time that it took for the degradation

Compound:	Parameter:	Reactor 3	Reactor 5
Xylene	Inn. Conc. (mg/L)	78	187
	Final Conc. (mg/L)	0	82
	% Degradation	100	55.8
Diphenyl	Inn. Conc. (mg/L)	289	738
	Final Conc. (mg/L)	0	738
	% Degradation	100	0
Diphenyl Ether	Inn. Conc. (mg/L)	1548	3493
	Final Conc. (mg/L)	0	3493
	% Degradation	100	0
Diphenyl Methane	Inn. Conc. (mg/L)	11.4	32.7
	Final Conc. (mg/L)	0	32.7
	% Degradation	100	100
Benzene, 1,1' Methylene bis (4- methyl)	Inn. Conc. (mg/L)	7.71	28.8
	Final Conc. (mg/L)	0	28.7
	% Degradation	100	34.7
1,2 Dimethyl-4- Benzyl Benzene	Inn. Conc. (mg/L)	25.79	107.4
	Final Conc. (mg/L)	0	74.9
	% Degradation	100	30

**Table 4.4.4: Degradation of the target organics during the 41 days of run 10.**

process. The entire process took less than 34 days, with most of the biotreatment occurring in the first five days. This seemed to indicate that there may be an advantage in using the True Batch Process, mainly in the apparent reduction in the length of time for the degradation process to occur. Also, the rate of the degradation improved in this run. The rapid reduction in the

FIGURE 4.4.7 TOTAL 5 DAY BOD CONCENTRATION VS TIME FOR RUN 10



BOD<sub>5</sub>, the reduction in target organics and the subsequent reduction in the pH, indicates that the rate was considerably more rapid than those established in previous runs with approximately the same COD loading level. These improvements were attributed to the production of a stronger, more acclimatized culture of microorganisms. This represented the first treatment attempt in which the bacteria were initially present in the reactor in large, acclimatized numbers, thus producing a more active and viable population. In the other runs, the culture would have taken time to establish itself and acclimate waste mixture. The specific degradation rates for the process can be seen in Table 4.4.5.

Compound:	Time	Reactor 3	Reactor 3
	Days	Dx/Dt mg/L day	Reaction constant k day <sup>-1</sup>
BOD <sub>5</sub>	40	112.7	0.334
Xylene	13	6.52	0.710
Diphenyl	24	12.6	0.565
Diphenyl Ether	34	46.9	0.310
Diphenyl Methane	34	0.345	0.143
Benzene, 1,1' Methylene bis (4- methyl)	24	0.335	No FIT
1,2 Dimethyl-4- Benzyl Benzene	5	5.15	1.963

**Table 4.4.5: Reaction rates and the degradation per day for the target organic compounds during run 10.**

Table 4.4.5 shows the reaction rates for the degradation of specific target organic compounds, as well as the Total BOD<sub>5</sub>. The

first order decay models fit some of the data perfectly. The degradation of most organic compounds follows the pattern established in the modified batch runs. Initially, a large reduction in the concentration of the organic compounds was observed, followed by a dramatic decrease in the rate of the degradation in the second part of the run. However, due to the slowing of the degradation in the second part of the run, the tail end often deviated slightly from a first order model.

Table 4.4.6 compares this run to the best batch run in terms of organic reduction.

Compound	Parameter	Reactor 2	Reactor 4	Reactor 3
	Run	7	8	10
	Setup	Modified Batch	Modified Batch	True Batch
Total COD	Initial (mg/L)	30 169	12 419	13 788
Total BOD <sub>5</sub>	Initial (mg/L)	8 322	3 305	4 584
BOD <sub>5</sub>	Reaction Constant k (days <sup>-1</sup> )	0.121	0.079	0.334
Diphenyl	Reaction Constant k (days <sup>-1</sup> )	0.54	0.4	0.565
Diphenyl Ether	Reaction Constant k (days <sup>-1</sup> )	0.332	0.108	0.31

**Table 4.4.6: The comparison of the reaction rate constant k for the several modified batch and the true batch runs.**

Table 4.4.6 shows the effect that the True Batch Process had on the treatment kinetics of the sludge. Run 10, is compared to an almost identically loaded modified batch system, run 8, and to

the most successful modified batch run, run 7. The True Batch Process had a relatively high degradation rate constant  $k$ , in terms of Total BOD<sub>5</sub> reduction, almost three times larger than the rate constant in the most successful modified batch run, and almost five times greater than the identically loaded modified batch system. Also, the degradation kinetics for the most prominent target chemical compounds in the mixture were almost identical to those observed in the best modified batch; however, the true batch system was likely underloaded in this case. The early results clearly indicated that True Batch Process could improve the degradation rates in the mixed liquor and produce a relatively high quality end product sludge in less time.

As can be observed in Table 4.4.7, the Total BOD<sub>5</sub> initially made up more than 33 % of the Total COD. The ratio decreased rapidly at first, as the easily degradable BOD<sub>5</sub> material was removed from the reactor. After day 13, the ratio was quite stable. As mentioned earlier, the run was lengthened to try and remove more refractory compounds. The ratio indicates that, in the end, some of the residual Total COD was removed while the BOD<sub>5</sub> removal was negligible, thus explaining the slight increase in the ratio. At the same time, the GC trace was blank, thereby producing an effluent free from the target organic compounds initially present. However, there is a possibility that the additional retention time could actually hinder the quality of the final

Day	BOD/COD Ratio
1	0.332
5	0.129
13	0.05
21	0.06
27	0.019
34	0.021
41	0.013
47	0.015

**Table 4.4.7: BOD/COD ratio during run 10.**

effluent by degrading the remain organic matter and releasing more copper into solution; this would effect the quality of the effluent.

The nutrient use during run 10 is shown in Table 4.4.8. The overall N/P ratio for the run was 2.51; once again the BOD<sub>5</sub>:N:P ratio at 63.5:2.51:1 was atypical (Metcalf 1992; Beltrame 1979). However, the overall ratio is in line with the one observed for run 9, thereby, further emphasizing the nutrient requirements of this specific culture.

The last six days of the experiment were quite interesting; there was a high use of nutrients, both nitrogen and phosphorus. However, there was little degradation in terms of Total BOD<sub>5</sub>. The VSS/TSS Ratio (Figure 4.4.3) does not indicate a great change in the amount of biomass. It is possible that, in the breakdown of

Time Days	Nitrogen used (mg/L)	Phosphorous used (mg/L)	N/P Ratio
2	14.6	4.75	3.08
3	35.7	8.9	4.01
4	30.9	7.5	4.1
3	23.0	5.73	4.01
4	14.6	2.5	5.83
4	7.2	6.56	1.1
3	6.43	4.55	1.41
3	6.91	5.83	1.19
4	4.62	0	NA
3	12.7	8.24	1.54
4	0	0.8	0
3	1.66	0	NA
6	19.55	15.51	1.26
Total	70.9	177.8	2.51

**Table 4.4.8: Nutrient use and the Nitrogen/Phosphorus Ratio over the length of run 10.**

some refractory organic material, the nutrients complexed with some of the released compounds.

Qualitatively, the sludge had improved markedly. The strong overpowering chemical smell was no longer present. The iridescent film floating on the top of the sludge had also disappeared. The sludge settled in less than 30 minutes while the endproduct sludge in run 7 took almost two hours to settle. Therefore, this appeared to be the best end product generated from all of the treatment phases.

The run as a whole was successful in showing that operating the system as a true batch could produce a more efficient and effective process for the remediation of the sludge. A cleaner end product, with a lower dissolved copper concentration, was obtained in less time using the true batch procedure. However, questions still arose about the process, namely the effect of higher dissolved copper levels and higher initial COD concentrations on the quality of the end product.

#### **Run #11**

This run, the last in a series, was also operated as a True Batch Process and sought to answer questions and problems which came up in the previous run. The starting COD concentration, would be increased to see the effect it would have on the quality of the final product and the degradation rates. Also, the reactors' content would not be pretreated with alum this time. Thus, this run would simulate expected conditions in the field and flag possible problems.

The run consisted of three reactors, two test reactors and a control. The first test reactor was to have a target organic load of approximately 30 000 mg/L, in terms of Total COD. This would enable direct comparisons to be made with the most successful modified batch run. Conclusions could be drawn on the rates of reaction and the quality of the end product. The second vessel would be loaded to a concentration of approximately 40 000 mg/L

COD. In all likelihood, the copper and organic concentrations would be too concentrated for the system to handle and the treatment should fail, although there was a possibility that the acclimatized organisms would enable the system to withstand these new operating conditions. Important information about the running of an on site full scale system would be learned from this step.

Reactor 2 was originally used in run 9. It was loaded with a low concentration of organic sludge in that particular run. At the end of the process, the sludge had low levels of organics and a total copper concentration of 10 mg/L remaining.

Reactor 4 was originally used in run 8. It was originally loaded with a 15 000 mg/L Total COD sludge, and total copper concentration of 40 mg/L. This reactor would be loaded to a Total COD of 40 000 mg/L. The copper originally present in the reactor combined with the added amount from the virgin sludge, was expected to effect the biotreatment performance, since the anticipated total copper concentration for this reactor would be between 80 and 90 mg/L. The initial loading of the reactors is shown in Table 4.4.9.

From Table 4.4.9, it is clear that the target organic loads were reached as close as can be expected. Reactor 2 was slightly higher than the projected 30 000 mg/L of Total COD but Reactor 4 reached the expected level of 40 000 mg/L. Table 4.4.10 shows the initial concentration of target organic compounds in this run.

Parameter	Reactor 1 Control	Reactor 2	Reactor 4
Original Sludge present from previous run (L)	0	14	12
New sludge added (L)	1.0	1.5	2.0
Total Volume (L)	25	25	25
Initial Total COD (mg/L)	25 317	32 153	40 356
Initial supernatant COD (mg/L)	2 481	1 712	1 712
Initial Total BOD <sub>5</sub> (mg/L)	NA	8 117	12 256
Total Copper Conc. (mg/L)	48.9	47.9	56.8
Dissolved Copper Conc. (mg/L)	9.12	6.04	5.56
pH	7.15	4.93	4.74

**Table 4.4.9: Initial conditions present in the reactor at the start of run 11.**

Compound:	Reactor1 Control (ppm)	Reactor2 (ppm)	Reactor4 (ppm)
Xylene	187	257	676
Diphenyl	738	949	2 334
Diphenyl Ether	3 494	4 425	11 016
Diphenyl Methane	32.7	37.4	105.6
Benzene,1,1' Methylene bis (4-methyl)	28.8	24.3	74.7
1,2 Dimethyl-4-Benzyl Benzene	107	64.1	341

**Table 4.4.10: Initial concentration of the target organic at the start of run 11.**

Initial concerns focused on the low pH and the high concentrations of dissolved copper. The pH in both test reactors

was below 5. This clearly demonstrates the result of not removing all the existing sludge from the reactors. The buffering capacity of the system was compromised due to the cycling. The dissolved copper concentration usually was below the detectable limit at first, and then grew depending on the sludge concentration. In this case, the concentration started off at higher than 5 mg/L in dissolved form. From previous runs, this was seen as the toxicity limit for any substantial growth of microorganisms.

In Reactor 4, the concentration of target organics was extremely high. Although the concentration of Total COD was not drastically different than the other test reactor, the Diphenyl Ether concentration in the reactor was 3 times larger than in Reactor 2. This again demonstrates the variability of the sludge from different points in the lagoon.

The Total COD vs Time graph, Figure 4.4.8, shows some interesting results. The control, as was the case in the past few runs was quite stable. Reactor 4 showed an initial rapid decline in the Total COD, but does not exhibit the pattern of increasing concentration near the end of the run. Reactor 2, the lower organically loaded vessel, did exhibit the classic pattern as expected from previous runs. Initially, there was rapid and almost constant degradation of Total COD in the reactor; however, after day 17, the pattern of fluctuating Total COD concentration, present in many previous runs, was demonstrated.

FIGURE 4.4.8 TOTAL COD CONCENTRATION VS TIME FOR RUN 11

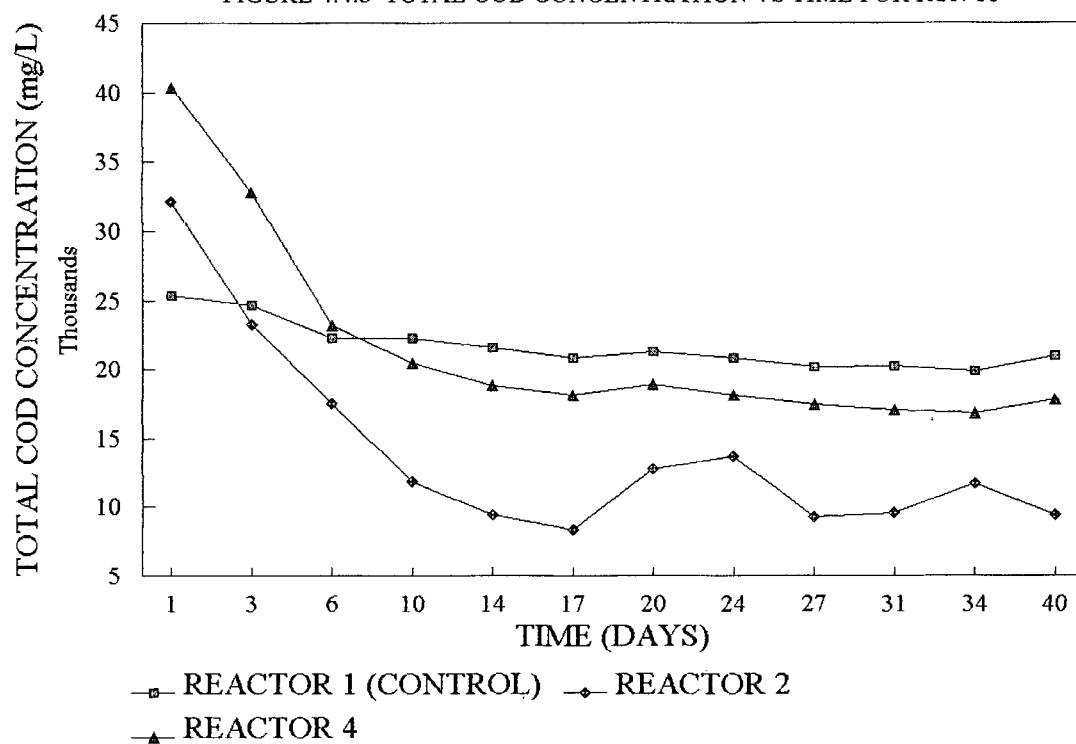
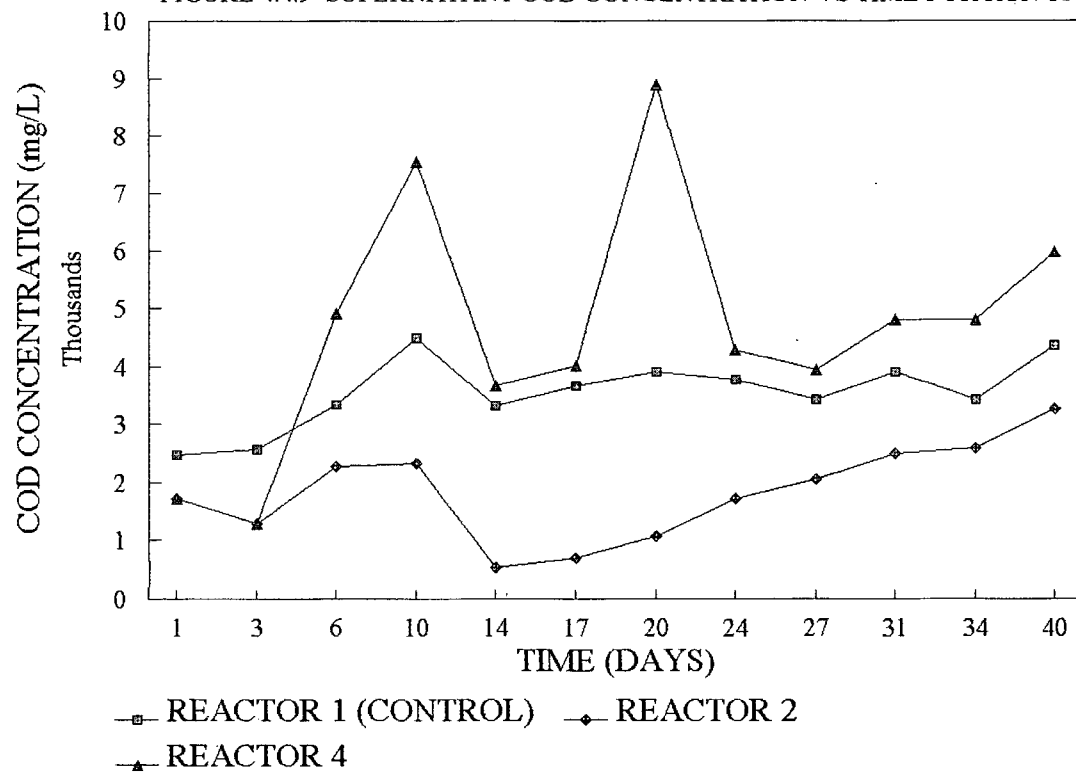


FIGURE 4.4.9 SUPERNATANT COD CONCENTRATION VS TIME FOR RUN 11



The supernatant COD in Reactor 4, Figure 4.4.9, fluctuated greatly during initial consecutive sampling periods, but generally increased over time. This was the pattern expected from experience with previous runs. When the system was "under loaded" the phenomenon did not occur; reactor 2 followed this pattern, with the supernatant COD concentration increasing little over the run.

Excess nutrients were present at all times during the experimental run, with one exception as seen in Figures 4.4.10 and 4.4.11. Reactor 4 experienced a nitrogen deficiency for one sampling period. The problem was quickly identified and corrected. An interesting item also came up in the analysis. It appears that the original sludge from this batch contained a high initial concentration of phosphorus, since the concentration in the control hovered around 10 mg/L for all the sampling periods. This was the only source of nutrient possible for the control.

For most of the run, the dissolved copper concentration was below 5 mg/L. The effect of adding phosphorus could clearly be seen early in the run. Prior to day 3, the phosphorus level in Reactor 4 was 10 mg/L, and dropping. The result was a dissolved copper concentration of between 6 and 7 mg/L. However, on day 3, phosphorus was added to the system, increasing the total concentration to above 40 mg/L. The dissolved concentration of copper fell below 2 mg/L, as seen in Figure 4.4.12. Again, the

FIGURE 4.4.10 PHOSPHORUS CONCENTRATION VS TIME FOR RUN 11

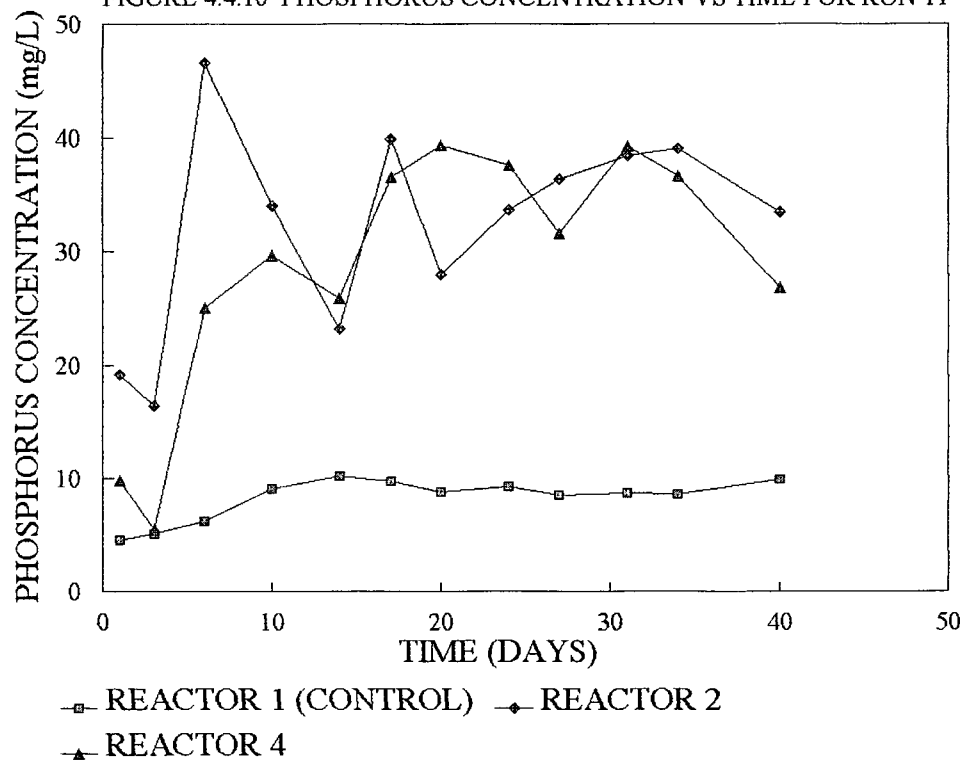
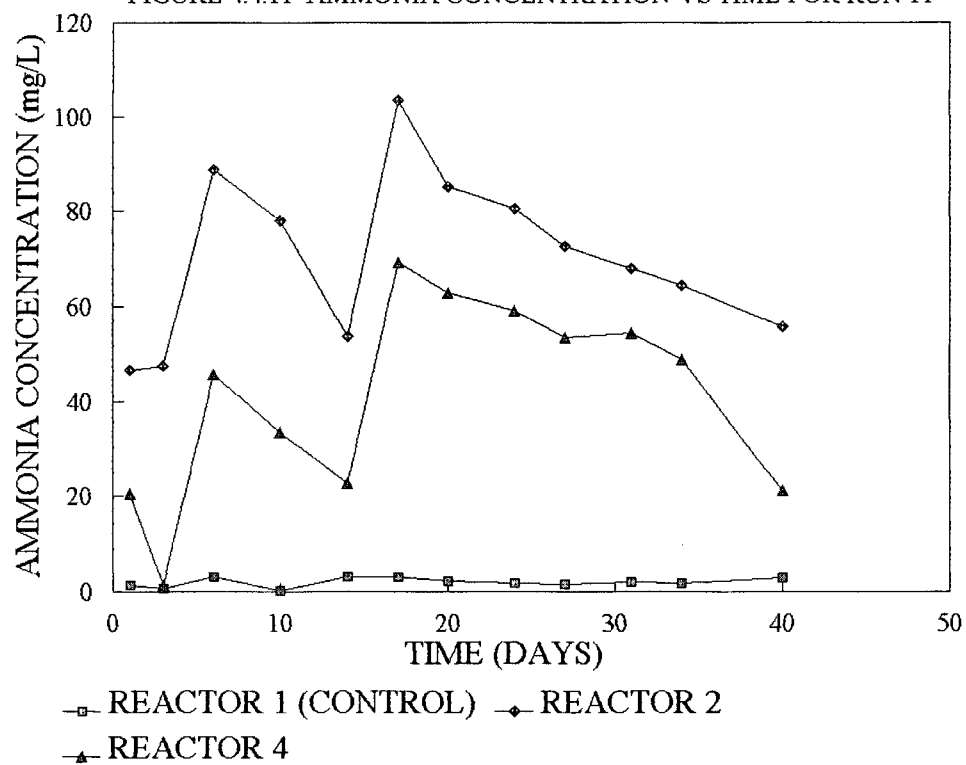


FIGURE 4.4.11 AMMONIA CONCENTRATION VS TIME FOR RUN 11



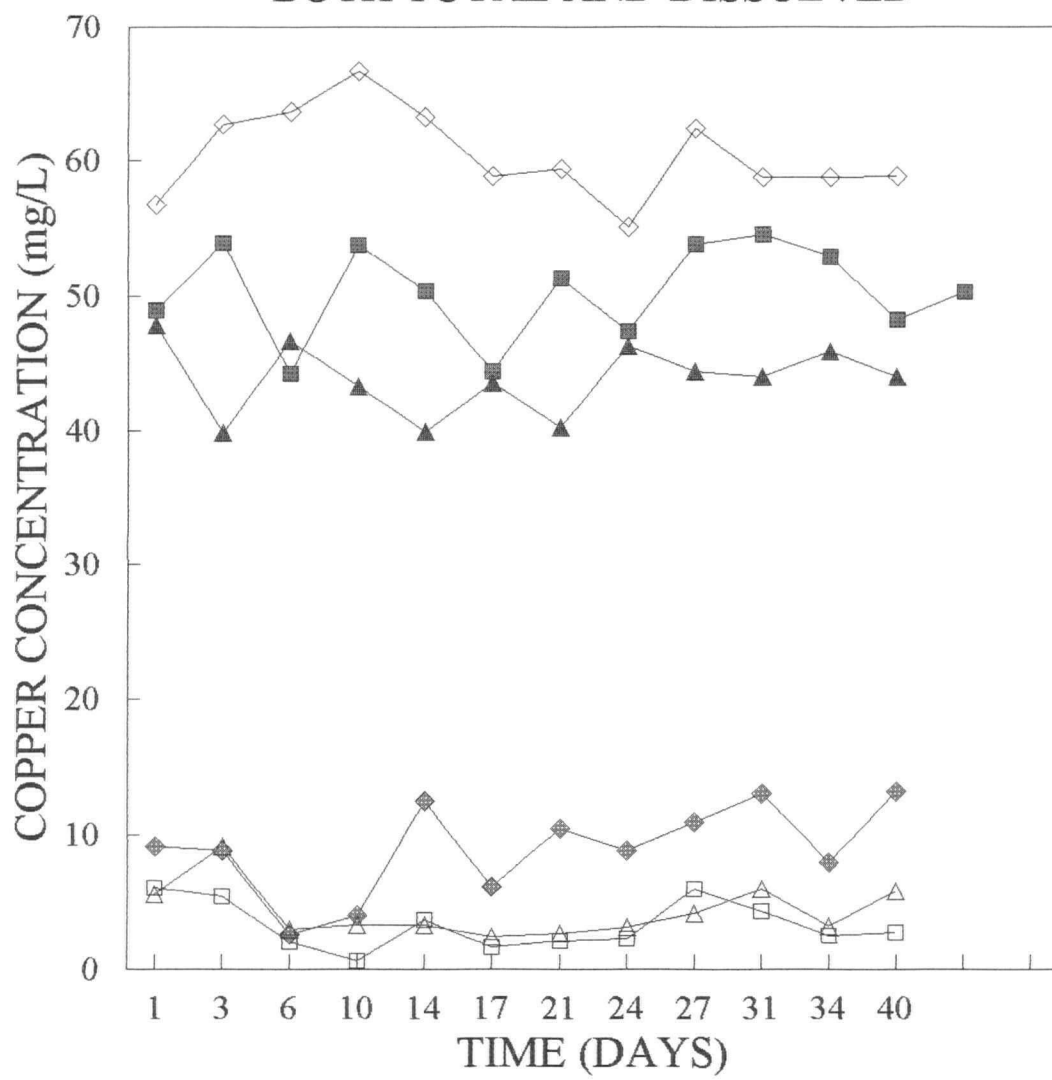
importance of monitoring the concentration of nutrients in the system was demonstrated.

The pH was a major stumbling block during the run. During the first sampling period, the pH in Reactor 4 had fallen to below 4, as can be seen in Figure 4.4.13. The low pH also caused more copper to dissolve into solution. At that point, a decision was made to add soda ash to raise the pH, to approximately 7. The raising of the pH was also partially responsible for the decrease in the copper concentration.

The abrupt pH change again seemed to "stall" the degradation process, as had been experienced in previous runs. As such, this point should have been addressed earlier during the experiment. Modifying of the pH or buffering the system should have been done prior to the start of a run. Modifying the pH during the run usually led to a "stalling" of the biotreatment system. The pH of 7 was not detrimental to the culture but the effect of the rapid change of pH, increasing more than 3 units was. The Total COD vs Time graphs (Figure 4.4.8) showed no reduction after the pH modification was made.

The pH in Reactor 2, contrary to the trend observed in Reactor 4, was initially stable. After 6 days, the pH dropped at a rapid and almost constant rate. On day 14, the pH was extremely low, at 3.60 and was only modified slightly to avoid the problems

FIGURE 4.4.12 COPPER CONCENTRATION VS TIME FOR RUN 11  
BOTH TOTAL AND DISSOLVED



■ REACTOR 1 (TOTAL)    ◆ REAC 1 (DISSOLVED)    ▲ REACTOR 2 (TOTAL)  
 □ REAC 2 (DISSOLVED)    ◇ REACTOR 4 (TOTAL)    △ REAC 4 (DISSOLVED)

FIGURE 4.4.13 PH VS TIME FOR RUN 11

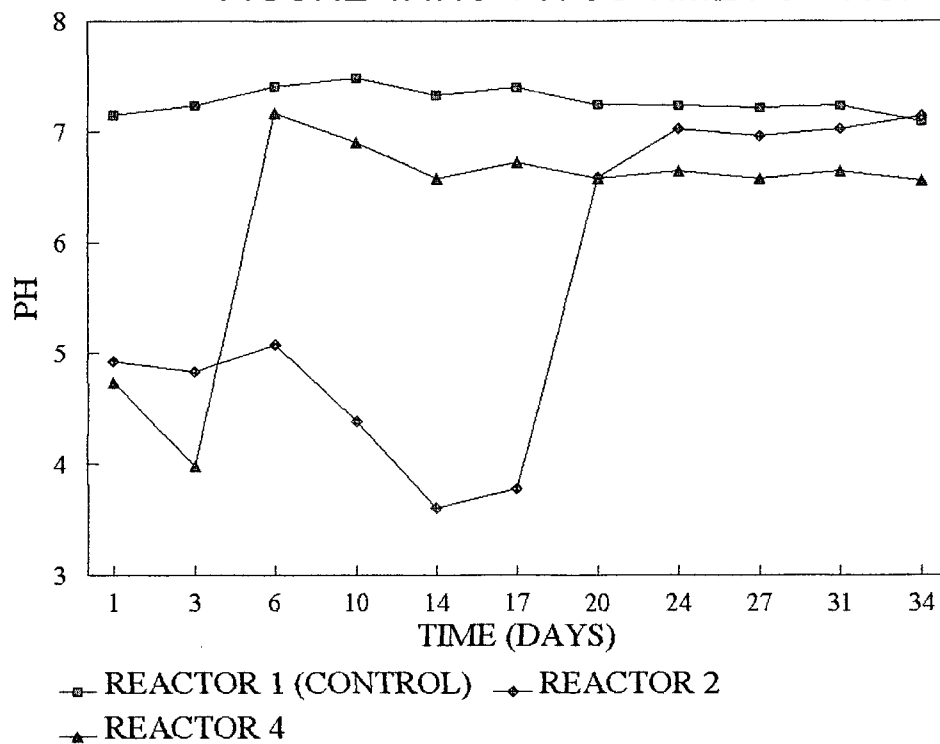
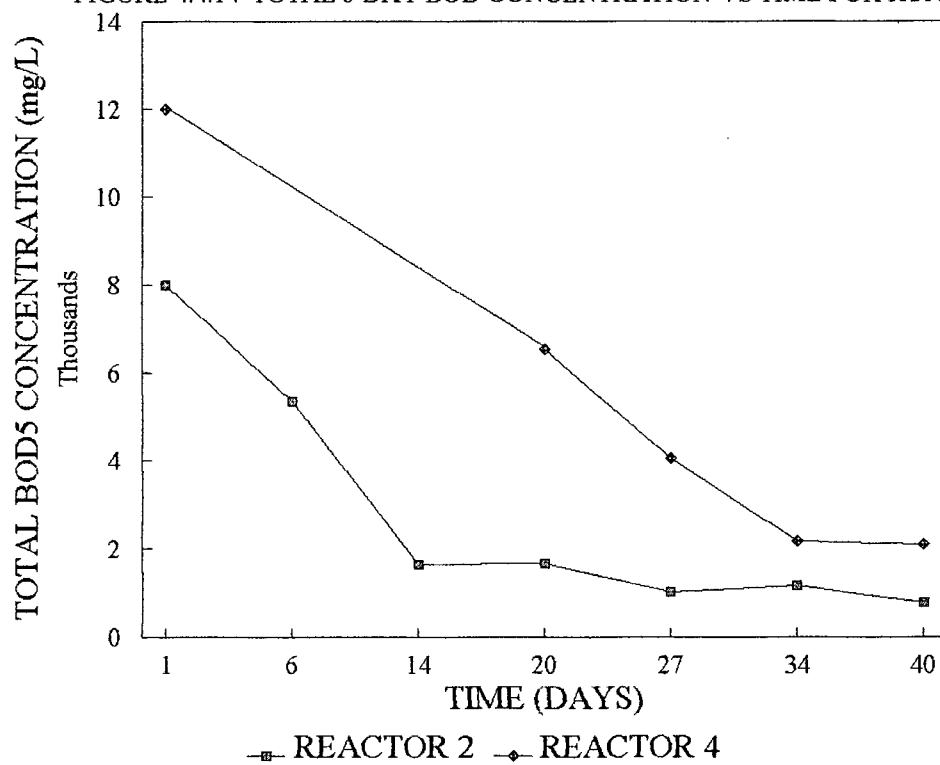


FIGURE 4.4.14 TOTAL 5 DAY BOD CONCENTRATION VS TIME FOR RUN 11



experienced by a large pH change seen in Reactor 4.

Unfortunately, the change observed was too small since the pH on day 17 was still only 3.78. Another dose of soda ash was added to the reactor; raising the pH to 6.59. Again, this was slightly higher than planned and seemed to have resulted once again in a "stalling" of the BOD<sub>5</sub> and Total COD degradation (Figures 4.4.8 and 4.4.14). The system was never able to recover from the pH modification; the high residual Total BOD<sub>5</sub> was an indication of a problem with the system, as shown in Table 4.4.11.

Table 4.4.12 shows that the control was stable in terms of the loss of target organic compounds due to volatilization. The loss in terms of the major chemical compound present, Diphenyl Ether was negligible. This further emphasizes the progress made in modifying the aeration system, thus leading to a significant

Parameter:	Reactor 1 Control	Reactor 2	Reactor 4
Initial Total COD (mg/L)	25 317	32 153	40 356
Final Total COD (mg/L)	21 023	9 428	17 762
% Degradation	17.0	70.7	56.0
Initial Total BOD <sub>5</sub> (mg/L)	NA	8 117	12 256
Final Total BOD <sub>5</sub> (mg/L)	NA	781	2 085
% Degradation	NA	90.4	83.0

**Table 4.4.11: Change in the Total COD and BOD over the course of run 11.**

reduction of loss due to volatilization. Any decrease in the concentration of the organic compounds in the test reactors must be attributed to the microbial degradation.

The run was not a success in terms of the final quality of the sludge since many of the target organic components remained after 40 days (see Table 4.4.12). The length of the experiment should have been sufficient to remediate this sludge. The run appears not to have gone to completion because of problems with the pH. The pH should have been modified prior to the start of the run; this would have avoided shocking the culture. The magnitude of the pH correction was unfavourable to the microorganisms, since the degradation rates after the pH adjustment were much lower than had previously been exhibited (Table 4.4.13). Likewise, a high concentration of phosphorus may have prevented the rise of dissolved copper concentration, thus improving biotreatment efficiency.

If proper control and monitoring conditions had been observed, it is probable that the two systems would have fared much better.

As seen from Table 4.4.13, the kinetic models for the degradation of the Total BOD<sub>5</sub> and target organics for the run were disappointing. Only some of the data fits a first order decay model. Much of the data was too variable to apply to a model with any degree of certainty; thus, in that case, an NA or not

Compound:	Parameter:	Reactor 1 Control	Reactor 2	Reactor 4
Xylene	Inn. Conc. (mg/L)	187	257	676
	Final Conc. (mg/L)	70.5	6.4	5.6
	<b>% Degradation</b>	<b>62.3</b>	<b>97.5</b>	<b>99.2</b>
Diphenyl	Inn. Conc. (mg/L)	738	949	2 334
	Final Conc. (mg/L)	685	37.3	28.2
	<b>% Degradation</b>	<b>7.24</b>	<b>96.1</b>	<b>98.8</b>
Diphenyl Ether	Inn. Conc. (mg/L)	3 494	4 425	11 016
	Final Conc. (mg/L)	3 494	301	863
	<b>% Degradation</b>	<b>0</b>	<b>93.2</b>	<b>92.2</b>
Diphenyl Methane	Inn. Conc. (mg/L)	32.7	37.4	106
	Final Conc. (mg/L)	32.7	8.1	22.0
	<b>% Degradation</b>	<b>0</b>	<b>76.2</b>	<b>79.2</b>
Benzene, 1,1' Methylene bis (4-methyl)	Inn. Conc. (mg/L)	28.8	24.3	74.7
	Final Conc. (mg/L)	12.5	8.6	25.7
	<b>% Degradation</b>	<b>56.6</b>	<b>64.8</b>	<b>65.5</b>
1,2 Dimethyl- 4-Benzyl Benzene	Inn. Conc. (mg/L)	107	64.1	341
	Final Conc. (mg/L)	61.2	0	5.5
	<b>% Degradation</b>	<b>43.0</b>	<b>100</b>	<b>98.4</b>

**Table 4.4.12: Change in the concentration of target organic over the course of run 11.**

Compound:	Parameter:	Reactor 2	Reactor 4
BOD <sub>5</sub>	Dx/Dt (mg/L day)	188.1	260.8
	K (Day <sup>-1</sup> )	0.08	NA
Xylene	Dx/Dt (mg/L day)	6.42	17.2
	K (Day <sup>-1</sup> )	0.157	NA
Diphenyl	Dx/Dt (mg/L day)	23.4	59.1
	K (Day <sup>-1</sup> )	0.104	0.201
Diphenyl Ether	Dx/Dt (mg/L day)	105.7	260.3
	K (Day <sup>-1</sup> )	0.086	0.117
Diphenyl Methane	Dx/Dt (mg/L day)	0.73	2.14
	K (Day <sup>-1</sup> )	0.048	0.096
Benzene, 1,1' Methylene bis (4- methyl)	Dx/Dt (mg/L day)	0.4	1.26
	K (Day <sup>-1</sup> )	NA	0.09
1,2 Dimethyl-4- Benzyl Benzene	Dx/Dt (mg/L day)	2.47	8.59
	K (Day <sup>-1</sup> )	0.076	0.235

**Table 4.4.13: Reaction rate constants and straight line decay values for target organics in run 11.**

applicable was cited in the table. Overall, the rate constant  $k$  was considerably higher for Reactor 4, than for Reactor 2; this was expected since the treatment process "stalled" considerably in Reactor 2 after the pH adjustment. The values presented do not come close to those experienced in run 10, the first remediation attempt using the True Batch Process.

The initial BOD/COD ratio (shown in Table 4.4.14) were in the range of those observed for previous runs. The end result,

Day	Reactor 2 BOD/COD Ratio	Reactor 4 BOD/COD Ratio
1	0.252	0.304
6	0.305	
14	0.173	
20	0.129	0.347
27	0.110	0.232
34	0.099	0.130
40	0.083	0.117

**Table 4.4.14: BOD/COD Ratios for the running reactors of run 11.**

however, was a high residual BOD/COD ratio; the result of the incomplete breakdown of the sludge.

The "stalling" in Reactor 4 was especially puzzling. It responded well to the pH modification, probably because it was done early in the run. However, the system still stalled and its demise could possibly be attributed to a combined effect of the initially high dissolved copper and the initial high sludge loading in the reactor. The kinetic rates were not very high in this particular reactor.

For much of the run the Nitrogen to Phosphorus ratio, as seen in Table 4.4.13, was not determinable, since one of the nutrients was not utilised during one sampling period to the next. The ratios are quite low, especially for Reactor 2, but this is possibly attributed to the use of phosphorus for the precipitation of the dissolved copper. The ratio further

emphasises the point where growth stopped in the reactors. Little phosphorus was used in the last 25 days of the run, which indicated that the bacteria were not very active. For Reactor 2, the BOD5:N:P ratio was 117:1.89:1, while in Reactor 4, the ratio was 266:3.07:1. In both cases, the overall ratio seemed low in terms of the utilization of nitrogen and phosphorous for the amount of BOD consumed compared to previous runs.

Time (Days)	Reactor 2 N Used (mg/L)	Reactor 2 P Used (mg/L)	N/P Ratio	Reactor 4 N Used (mg/L)	Reactor 4 P Used (mg/L)	N/P Ratio
2	0	2.7	0	19.2	4.42	4.35
3	15.7	10.4	1.51	12.6	5.35	2.35
4	10.7	12.5	0.86	12.33	0	NA
4	24.3	10.8	2.24	10.6	3.71	2.86
3	20.2	8.9	2.27	13.12	4.88	2.69
3	18.2	11.9	1.53	6.63	0	NA
4	4.73	0	NA	3.59	1.83	1.96
3	7.8	0	NA	5.77	5.89	0.98
4	4.62	0	NA	0	0	NA
3	3.48	0	NA	5.69	2.6	2.23
6	8.82	5.6	1.58	27.59	9.8	2.81
Total	118.5	62.8	1.89	117.1	38.2	3.07

**Table 4.4.13: Nutrients used by the running reactors and the nitrogen/phosphorus ratios exhibited during run 11.**

Overall, this run was not successful at demonstrating the advantages of the true batch system. It did, however, demonstrate the potential problems with the operation: a high initial dissolved metal concentration and lower pH in the system. The

operating conditions can possibly be overcome with proper monitoring and control.

Run 10 showed that the true batch process could be used to greatly improve the degradation kinetics of the sludge remediation process. The rates were three times larger than those

experienced in the most successful batch run. Thus, the true batch system appears to be a more efficient and effective means of treating the Chatterton Petrochemical sludge. However, the metal toxicity problem was not addressed in run 10. Therefore, it is possible that pretreatment may be required to achieved the same degradation rate kinetics.

## 5. Summary Of Results:

### 5.1 Range Of Treatment Parameters

Table 5.1.1 is a summary of the range of the initial and final characteristics and the kinetic degradation constants observed during treatment runs of the Chatterton Petrochemical Sludge.

Parameters:	Modified Batch Runs:	True Batch Runs:
Number of Runs/Reactors	9/27	2/5
Range Of Length of Runs (Days)	15 - 81	32 - 41
Range of Initial Total COD (mg/L)	4 058 - 113 850	13 788 - 40 356
Range of Final COD (mg/L)	1 950 - 22 928	5 443 - 17 762
Range of % Total COD Degradation	32.3 - 81.1	56.0 - 70.7
Range Of Initial Total BOD <sub>5</sub> (mg/L)	201.7 - 8322	4 584 - 12 256
Range Of Final Total BOD <sub>5</sub> (mg/L)	66.6 - 623	83.7 - 2 085
Range Of % Total BOD <sub>5</sub> Degradation	66.4 - 99.1	83.0 - 98.2
Range Of Initial Diphenyl (mg/L)	7 - 1 157	289.2 - 2 334
Range Of Final Diphenyl (mg/L)	0 - 11.2	0 - 37.3
Range Of % Diphenyl Degradation	90.6 - 100	96.1 - 100
Range Of Initial Diphenyl Ether (mg/L)	77.7 - 5 690	548 - 11 016
Range Of Final Diphenyl Ether (mg/L)	0 - 78.3	0 - 863.4
Range Of % Diphenyl Ether Degradation	48.4 - 99.3	92.2 - 100

**Table 5.1.1: Summary of the range of the initial and final parameters for all the treatment runs attempted.**

## 5.2 Profile of the Most Successful Runs

The most successful modified batch and true batch runs that were experienced during the study are shown in Table 5.2.1.

Compound:	Parameter:	Reactor 2	Reactor 3
	Run	7	10
	Setup	Modified Batch	True Batch
	Length	42	31
Total COD	Initial (mg/L)	30 169	13 788
Total COD	Final (mg/L)	5 710	5 443
Total COD	% Reduction	81.1	60.5
Total BOD <sub>5</sub>	Initial (mg/L)	8 322	4 584
Total BOD <sub>5</sub>	Final (mg/L)	74	83.7
Total BOD <sub>5</sub>	% Reduction	99.1	98.2
Diphenyl Ether	Initial (mg/L)	5 290	3 494
Diphenyl Ether	Final (mg/L)	0	0
Diphenyl Ether	% Reduction	100	100
BOD <sub>5</sub>	Reaction Rate Constant k (Days <sup>-1</sup> )	0.121	0.334
Diphenyl	Reaction Rate Constant k (Days <sup>-1</sup> )	0.54	0.565
Diphenyl Ether	Reaction Rate Constant k (Days <sup>-1</sup> )	0.332	0.31

**Table 5.2.1 Summary of the most successful sludge treatment runs in terms of Total BOD<sub>5</sub> and COD removal and Reaction Rate Constants.**

## 5.3 Comparison Of The Rates Of Reaction With a Theoretical Model

For comparison, the rates of reaction obtained during the runs can be equated to the range obtained for the degradation of Phenol as a single carbon source, under laboratory conditions, shown in Table 5.3.1 (Lewendowski 1990). It should be noted that

the degradation in that study occurred under ideal conditions; Phenol was the only compound present, no metals were present, the bacteria were acclimatized to the mixture, Phenol was present in a concentration generally under 100 ppm and at a Total COD concentration of under 250 mg/L.

Parameter:	Value:
Range Of kinetic constant k during laboratory degradation (Days -1)	3.12 - 24

**Table 5.3.1 Range of the reaction rate constant k for Phenol degradation as single carbon source under laboratory conditions (Lewendowski 1990).**

#### **5.4. Predicted Effluent Characteristics Under Ideal Treatment Conditions**

Under ideal operating conditions, experiments in this study have shown that the effluent from a modified batch reactor, initially loaded with 30 000 mg/L Total COD of sludge should have approximately the properties shown in Table 5.4.1.

Parameter:	Final Product property
Length Of Process (Days)	40 - 45
Final Total COD (mg/L)	5 000 - 6 000
Final Total BOD <sub>5</sub> (mg/L)	75 - 100
Total Copper Conc. (mg/L)	60 - 80
Final Dissolved Copper Conc. (mg/L)	2 - 5
Final Conc. Of: Xylene; Diphenyl; Diphenyl Ether; Diphenyl Methane; Benzene,1,1'Methylene bis (4-Methyl); 1,2-Dimethyl-4 Benzyl Benzene	0
Indications From GC Trace that any other compounds are present in the final product	NO

**Table 5.4.1 Probable effluent quality of sludge which has undergone the ideal treatment process as proposed by the experimental runs.**

It should be noted that, due to the variability of the organic components in the lagoon, the results may vary slightly.

Indications from the limited True Batch Process reactor work are that the same high quality effluent can be obtained in a shorter period of time, using this process. However, the question of the increased copper level in such a system was not fully investigated. Thus, it is possible that the high dissolved copper level could potentially short circuit any treatment attempt and the process might require the sludge to be pretreated.

#### 5.5 Summary of the Nitrogen:Phosphorus ratio

Run	N/P ratio
11	1.89:1 3.07:1
10	2.51:1
8	1.51:1
6	3.23:1 2.02:1
5	2.29:1
Average	2.36:1

**Table 5.5.1 Summary of the nitrogen/phosphorus ratio for experimental runs.**

The generally accepted nitrogen/phosphorus ratio for bacterial growth is 5:1 and thus, the average N/P ratio demonstrated during the experimental study is considered low. It must be noted, that phosphorus was used for the growth of the bacteria but also to precipitate dissolved copper and therefore the experimental ratio

presented is misleading. To correct for the phosphorus used for copper precipitation, Table 5.5.2 assumes a N/P ratio of 5:1 and determines the COD:N:P ratio based on this value.

Run	Actual COD:N:P Ratio	Corrected COD:N:P Ratio
11	361:1.89:1 591:3.07:1	136:5:1 362:5:1
10	118:2.51:1	59:5:1
8	50.7:1.51:1 35.8:1.51:1	15:5:1 10:5:1
6	161:3.23:1 157:2.02:1	104:5:1 63:5:1
5	186:2.29:1	85:5:1
Average	195:2.25:1	104:5:1

**Table 5.5.2 Actual and corrected COD:N:P ratio**

As can be seen in Table 5.5.2, when the phosphorus used for copper precipitation is eliminated from the ratio, the average COD:N:P ratio is very close to the literature predicted ratio of 100:5:1.

## 6. Conclusions:

1) The Chatterton Petrochemical sludge has been shown to be readily biodegradable under the proper initial loading, monitoring and operating conditions.

1.1) The phosphorus concentration in the treatment system must be kept in excess of the nutrient requirements of the culture in order to precipitate the dissolved copper present. The culture has been shown to actively degrade the sludge when the dissolved copper concentration was below 5 mg/L.

1.2) Nutrient and pH modifications should be made prior to the start of the experiment. Modifying operating conditions during the experimental run hinders the growth of the culture and ultimately slows and stalls the degradation process. pH modifications at the beginning of the run should take into account the large concentration of  $\text{CO}_2$  which will be produced during the degradation process.

1.3) The control has shown that the organics loss due to volatilization, can be minimized to less than 5% of treatment, in terms of Total COD. In a full scale process, it may be necessary to capture all exhaust gases and scrub them through a carbon filter.

1.4) The most effective technique to monitor the progress of treatment is to observe the decrease in the pH, combined with the reduction in the concentration of Diphenyl Ether. When all the Diphenyl Ether is removed from solution, the treatment has been shown to be complete.

2) The optimum initial sludge loading for a modified batch system is a Total COD concentration of approximately 30 000 mg/L. This should result in a concentration of organics and copper that the biological system can handle.

3) If the sludge undergoes ideal treatment, the final product has been shown to be free from all organic constituents. In successful runs, the removal of all organic compounds to below the detection limit of the GC was shown to be possible in 41 days. However, the sludge may still be considered a special waste due to the presence of copper. If phosphorus levels are kept high during the run, the concentration of dissolved copper will be low.

4) The Modified Batch Process (MBP) can easily be converted to a True Batch Process (TBP). The same elevated phosphorus concentration is required to avoid copper toxicity problems. However, the true batch process has been shown to reduce the time required for treatment by at least ten days, in limited testing during this study.

5) The True Batch Process has been shown to be an effective way to speed the degradation of the waste sludge. The reaction rate constant  $k$  was three times larger in this system, when compared to the best modified batch run, in terms of Total BOD<sub>5</sub> reduction. This indicates that the organisms which had been acclimated to the sludge, were able to degrade the waste without having a period of in-situ acclimatization. However, questions remain about the potential accumulation of copper in the true batch treatment system. Thus, pretreatment of the sludge to remove part of the copper may be necessary to achieve the high Total BOD<sub>5</sub> rates of removal.

## 7. Recommendations:

In order to successfully treat the Chatterton Petrochemical sludge the following Recommendations should be adhered to:

- 1) The initial sludge loading of a modified batch or true batch reactor should be 30 000 mg/L based on the Total COD.
- 2) To avoid copper toxicity problems, the phosphorus concentration in the reactor should be kept in excess of the amount required for the growth of bacteria. In experimental runs, a concentration of 100 mg/L in excess of the amount required for growth was successfully used to maintain the dissolved copper levels below 5 mg/L; however, it is possible that lower levels would produce the same results. The experimental runs indicated that, for every 120 mg/L of Total COD broken down, 3 mg/L of nitrogen and 1 mg/L of phosphorus were required.
- 3) The pH and the nutrients should be added to the reactor prior to the start of the process. Modifying the operating conditions during the run has been shown to negatively affect the process and ultimately led to the stalling of the remediation. It should be noted that, during the run, a reduction in pH will occur; thus, soda ash must be added to the system to improve it's buffering ability.
- 4) The GC and the pH should be used to monitor the progress of

the run. Diphenyl Ether is the organic compound which is the most concentrated and resistant to degradation in the sludge mixture. It has been observed that when it disappears from the sludge, the remediation process is essentially complete.

5) The time required for the batch degradation of the sludge is between 40 and 45 days. The use of a true batch system will considerably reduce the time required, but the question of copper build up in this system remains unanswered. Thus, the sludge may have to be pretreated. Further research on this point, as well as optimizing the TBP, is required.

6) The aeration of the waste must be carefully monitored to prevent the needless volatilization of the sludge. Experimental runs have shown that, under the proper operation and monitoring conditions, the volatilization can be minimized to less than 5% of the Total COD degradation.

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## 9. Appendix A

Analytical Test:	Performed in Runs:
COD	1 to 11
BOD	7 to 11
Solids	4 to 11
Nutrient Analysis	5 to 11
Metals Concentration	4 to 11
GC Data	4 to 11
pH	4 to 11

## Run 1 COD

## Reactor2 (TOTAL)

## Test samples

Sample num	abs.	Conc.	Act. Conc.	TIME
IIT1	61	755.1364	75513.64	1
IIT2	25	310.692	31069.2	2
IIT3	20	248.9636	24896.36	3
IIT4	18	224.2722	22427.22	4
IIT5	25	310.692	31069.2	5
IIT8	17	211.9265	21192.65	8
IIT11	27	442.2146	17688.58	11
IIT15	20	277.7778	6944.444	15
IIT19	16	222.2222	5555.556	19
IIT24	23	319.4444	7986.111	24
IIT30	44	611.1111	15277.78	30

## Reactor2 Supernatant

Sample num	abs.	Conc.	Act. Conc.	TIME
IIS1	18	39.08	3908	1
IIS2	3	43.5206	4352.06	2
IIS4	3	42.0672	4206.72	4
IIS5	4	51.43272	5143.272	5
IIS8	2	26.74136	2674.136	8
IIS11	4	65.78864	3289.432	11
IIS15	10	138.8889	1736.111	15
IIS19	12	166.6667	2083.333	19
IIS24	14	194.4444	2430.556	24
IIS30	16	222.2222	2777.778	30

## Reactor4 Total

Sample num	abs.	Conc.	Act. Conc.	TIME
IVT1	65	804.5191	80451.91	1
IVT2	65	804.5191	80451.91	2
IVT3	72	890.9389	89093.89	3
IVT4	60	742.7907	74279.07	4
IVT5	55	681.0623	68106.23	5
IVT8	30	372.4204	37242.04	8
IVT11	39	638.6107	25544.43	11
IV15	25	347.2222	8680.556	15

## Reactor4 Supernatant

Sample num	abs.	Conc.	Act. Conc.	TIME
IVS2	7	63.5235	6352.35	2
IVS4	4	51.43272	5143.272	4
IVS5	3	39.08704	3908.704	5
IVS8	3	39.08704	3908.704	8
IVS11	5	82.15499	4107.749	11
IVS15	12	166.6667	2083.333	15

## Run 2 COD

## Reactor 1 Total (control)

Sample:	Abs.	Conc.	Actual Conc.	Time
		mg/L	mg/L	Days
IT1	6	102.5449	2563.623	1
IT3	5	85.58744	2139.686	3
IT5	11	187.3324	2341.655	5

## Reactor 1 Supernatant (control)

Sample:	Abs.	Conc.	Actual Conc.	Time
		mg/L	mg/L	Days
IS1	12	204.2899	408.5797	1
IS3	26	441.6947	441.69	3
IS5				5

## Reactor 2 Total

Sample:	Abs.	Conc.	Actual Conc.	Time
		mg/L	mg/L	Days
IIT1	14	238.2048	5955.121	1
IIT3	13	221.2473	5531.183	3
IIT5	25	424.7372	5309.215	5

## Reactor 2 Supernatant

Sample:	Abs.	Conc.	Actual Conc.	Time
		mg/L	mg/L	Days
IIS1	60	1018.249	1018.2	1
IIS3	66	1119.994	1120	3
IIS5				

## Reactor 3 Total

Sample:	Abs.	Conc.	Actual Conc.	Time
		mg/L	mg/L	Days
IIIT1	15	255.1623	6379.058	1
IIIT3	11	187.3324	4683.309	3
IIIT5	29	492.5671	6157.089	5

## Reactor 3 Supernatant

Sample:	Abs.	Conc.	Actual Conc.	Time
		mg/L	mg/L	Days
IIIS1	72	1221.739	1221.7	1

## Reactor 4 Total

Sample:	Abs.	Conc.	Actual Conc.	Time
		mg/L	mg/L	Days
IVT1	5	85.58744	2139.686	1
IVT3	5	85.58744	2139.686	3
IVT5	9	153.4174	1917.717	5

## Reactor 4 Supernatant

Sample:	Abs.	Conc.	Actual Conc.	Time
		mg/L	mg/L	Days
IVS1	12	204.2899	2042.899	1
IVS3	11	187.3324	1873.324	3
IVT5	9	153.4174	1917.717	5

## Reactor 4 Supernatant

Sample:	Abs.	Conc.	Actual Conc.	Time
		mg/L	mg/L	Days
IVS1	12	204.2899	2042.899	1
IVS3	11	187.3324	1873.324	3

## Reactor 4 Supernatant

Sample:	Abs.	Conc.	Actual Conc.	Time
		mg/L	mg/L	Days
IVS1	12	204.2899	2042.899	1
IVS3	11	187.3324	1873.324	3

# COD Data Vs Time For Run 4

Reactor 1 Total (control)		Diluted		Time Days
Sample:	Abs. %	Conc. mg/L	Act. Conc. mg/L	
IT1	55	963.4976	96349.76	1
IT3	31	543.4986	54349.86	3
IT6	57	998.4975	99849.75	6
IT9	31	547.0814	54708.14	9
IT13	20	336.9623	33696.23	13
IT15	26	437.571	43757.1	15
IT19	33	554.9478	55494.78	19
IT22	43	692.8408	69284.08	22
IT25	20	500	50000	25
IT29	34	607.1429	60714.29	29
IT33	31	507.0082	50700.82	33
IT37	34	602.2282	60222.82	37
IT41	30	523.9534	52395.34	41
IT44	26	434.3582	43435.82	44
IT47	19	329.0611	32906.11	47
IT50	14	242.9376	24293.76	50
IT54	14	262.9147	26291.47	54
IT57	14	277.7509	27775.09	57
IT61	27	539.7851	26989.26	61
IT64	32	580.1101	23204.41	64
IT67	35	572.4286	22897.14	67
IT74	30	512.0922	20483.69	74
IT78	26	496.7235	19868.94	78
IT82	28	469.8546	18794.18	82
IT85	27	440.5472	17621.89	85

Reactor 2 Total		Diluted		Time Days
Sample:	Abs. %	Conc. mg/L	Act. Conc. mg/L	
IIT1	65	1138.497	113849.7	1
IIT3	63	1103.497	110349.7	3
IIT6	64	1120.997	112099.7	6
IIT9	57	1003.911	100391.1	9
IIT13	82	1376.585	137658.5	13
IIT15	77	1292.745	129274.5	15
IIT19	82	1376.585	137658.5	19
IIT22	60	966.2802	96628.02	22
IIT25	55	1375	137500	25
IIT29	62	1107.143	110714.3	29
IIT33	60	981.3061	98130.61	33
IIT37	33	584.5156	58451.56	37
IIT41	35	611.279	61127.9	41
IIT44	40	668.1357	66813.57	44
IIT47	40	693.6444	69364.44	47
IIT50	34	590.8484	59084.84	50
IIT54	22	412.8089	41280.89	54
IIT57	21	416.3263	41632.63	57
IIT61	43	859.4207	42971.04	61
IIT64	67	1214.168	48566.72	64
IIT67	60	981.3061	39252.24	67
IIT74	48	819.1075	32764.3	74
IIT78	34	649.5615	25982.46	78

COD Data Vs Time For Run 4 (Continued)

Reactor 3 Total		Diluted		Time Days
Sample:	Abs. %	Conc. mg/L	Act. Conc. mg/L	
IIIT1	65	1138.497	113849.7	1
IIIT3	64	1120.997	112099.7	3
IIIT6	61	1068.497	106849.7	6
IIIT9	28	494.3703	49437.03	9
IIIT13	48	806.4695	80646.95	13
IIIT15	49	823.2376	82323.76	15
IIIT19	52	873.5419	87354.19	19
IIIT23	48	773.2641	77326.41	22
IIIT25	26	650	65000	25
IIIT29	50	892.8571	89285.71	29
IIIT33	52	850.4653	85046.53	33
IIIT37	39	690.7912	69079.12	37
IIIT41	39	681.1394	68113.94	41
IIIT44	45	751.6277	75162.77	44
IIIT47	45	780.45	78045	47
IIIT50	45	782.1993	78219.93	50
IIIT54	36	675.1236	67512.36	54
IIIT57	27	535.1053	53510.53	57
IIIT61	52	1039.216	51960.79	61
IIIT64	68	1232.284	49291.36	64
IIIT67	51	834.1102	33364.41	67
IIIT74	32	546.205	21848.2	74
IIIT78	30	573.1425	22925.7	78
IIIT82	30	503.3156	20132.63	82
IIIT85	32	522.0189	20880.76	85

Reactor 4 Total		Diluted		Time Days
Sample:	Abs. %	Conc. mg/L	Act. Conc. mg/L	
IVT1	37	648.4984	64849.84	1
IVT3	36	630.9984	63099.84	3
IVT6	36	630.9984	63099.84	6
IVT9	34	599.7926	59979.26	9
IVT13	32	538.1796	53817.96	13
IVT15	32	538.1796	53817.96	15
IVT19	30	504.6434	50464.34	19
IVT22	18	290.7241	29072.41	22
IVT25	17	425	42500	25
IVT29	26	464.2857	46428.57	29
IVT33	31	507.0082	50700.82	33
IVT37	27	478.2401	47824.01	37
IVT41	30	523.9534	52395.34	41
IVT44	22	367.5647	36756.47	44
IVT47	20	346.4222	34642.22	47
IVT50	14	242.9376	24293.76	50
IVT54	12	225.4412	22544.12	54
IVT57	11	218.3614	21836.14	57
IVT61	21	419.9217	20996.09	61
IVT64	22	398.9507	15958.03	64
IVT67	21	343.4571	13738.29	67
IVT74	17	290.3589	11614.38	74
IVT78	16	305.676	12227.04	78
IVT82	16	269.0883	10763.53	82
IVT85	18	293.8981	11755.93	85

COD Data Vs Time For Run 4 (Continued)

Reactor 1 Supernatant Sample:	Abs. %	Diluted Conc. mg/L	Act. Conc. mg/L	Time Days
IS1	39	683.4983	8543.729	1
IS3	37	648.4984	8106.23	3
IS6	45	788.498	9856.225	6
IS9	20	353.8074	4422.592	9
IS13	9	152.513	3812.826	13
IS15	11	186.0493	4651.231	15
IS19	9	152.513	3812.826	19
IS22	13	210.3007	5257.518	22
IS25	21	525	6562.5	25
IS29	11	196.4286	4910.714	29
IS33	31	507.0082	6337.602	33
IS37	16	283.4015	3542.519	37
IS41	19	331.8372	4147.964	41
IS44	9	150.4855	3762.139	44
IS47	11	190.1722	4754.306	47
IS50	17	295.1242	7378.104	50
IS54	22	412.8089	10320.22	54
IS57	39	772.6632	9658.29	57
IS61	27	539.7851	6747.314	61
IS64	39	706.9217	8836.522	64
IS67	42	686.9143	8586.429	67
IS74	44	750.8818	9386.023	74
IS78	54	1031.657	12895.71	78
IS82	49	821.1956	10264.94	82
IS85	65	1059.732	10597.32	85

Reactor 2 Supernatant Sample:	Abs. %	Diluted Conc. mg/L	Act. Conc. mg/L	Time Days
IIS1	45	788.498	9856.225	1
IIS3	44	770.9981	9637.476	3
IIS6	42	735.9982	9199.977	6
IIS9	42	740.3555	9254.444	9
IIS13	20	336.9623	8424.057	13
IIS15	20	336.9623	8424.057	15
IIS19	32	538.1796	13454.49	19
IIS22	24	387.2321	9680.802	22
IIS25	40	1000	12500	25
IIS29	41	732.1429	18303.57	29
IIS33	59	964.951	12061.89	33
IIS37	35	619.9408	7749.26	37
IIS41	50	873.2557	10915.7	41
IIS44	23	384.2631	9606.576	44
IIS47	24	415.8667	10396.67	47
IIS50	14	242.9376	6073.439	50
IIS54	14	262.9147	6572.869	54
IIS57	33	653.8842	8173.553	57
IIS61	30	599.7168	7496.46	61
IIS64	38	688.8058	8610.072	64
IIS67	44	719.6245	8995.306	67
IIS74	44	750.8818	9386.023	74
IIS78	45	859.7138	10746.42	78

COD Data Vs Time For run 4 (Continued)

Reactor 3 Supernatant Sample:	Abs. %	Diluted Conc. mg/L	Act. Conc. mg/L	Time Days
IIIS1	28	490.9988	6137.485	1
IIIS3	28	490.9988	6137.485	3
IIIS6	29	508.4987	6356.234	6
IIIS9	27	476.8	5960	9
IIIS13	15	253.1217	6328.043	13
IIIS15	16	269.8898	6747.246	15
IIIS19	23	387.2666	9681.665	19
IIIS22	18	290.7241	7268.101	22
IIIS25	40	1000	12500	25
IIIS29	24	428.5714	10714.29	29
IIIS33	60	981.3061	12266.33	33
IIIS37	40	708.5038	8856.298	37
IIIS41	52	908.1859	11352.32	41
IIIS44	25	417.6598	10441.5	44
IIIS47	30	520.0333	13000.83	47
IIIS50	18	312.5197	7812.993	50
IIIS54	20	375.3353	9383.384	54
IIIS57	35	693.4772	8668.465	57
IIIS61	34	679.6257	8495.321	61
IIIS64	35	634.458	7930.725	64
IIIS67	48	785.0449	9813.061	67
IIIS74	48	819.1075	10238.84	74
IIIS78	48	917.0281	11462.85	78
IIIS82	24	402.9325	5036.656	82
IIIS85	70	1141.204	11412.04	85

Reactor 4 Supernatant Sample:	Abs. %	Diluted Conc. mg/L	Act. Conc. mg/L	Time Days
IVS1	16	280.9993	3512.491	1
IVS3	15	263.4993	3293.742	3
IVS6	19	333.4992	4168.74	6
IVS9				9
IVS13	11	186.0493	4651.231	13
IVS15	10	169.2811	4232.028	15
IVS19	11	186.0493	4651.231	19
IVS22	10	162.0467	4051.167	22
IVS25	20	500	6250	25
IVS29	19	339.2857	8482.143	29
IVS33	30	490.6531	6133.163	33
IVS37	25	442.8149	5535.186	37
IVS41	29	506.4883	6331.104	41
IVS44	12	200.5807	5014.518	44
IVS47	11	190.1722	4754.306	47
IVS50	9	155.9599	3898.996	50
IVS54	11	206.7044	5167.611	54
IVS57	22	436.1228	5451.535	57
IVS61	24	479.8534	5998.168	61
IVS64	22	398.9507	4986.884	64
IVS67	23	376.1673	4702.092	67
IVS74	23	392.6973	4908.717	74
IVS78	26	496.7235	6209.044	78
IVS82	18	302.5494	3781.867	82
IVS85	23	375.3698	3753.698	85

COD VS Time For Run 5

Reactor 2 Total

SAMPLE	ABS	CONC mg/L	Total CONC. mg/L	TIME Days
IIT1	26	497.1235	19884.94	1
IIT4	15	252.3578	10094.31	4
IIT7	9	147.2491	5889.963	7
IIT11	11	182.1475	7285.9	11
IIT14	11	185.8917	7435.668	14
IIT18	12	193.7706	7750.824	18
IIT21	11	185.6537	7426.147	21
IIT25	12	195.5321	7821.284	25
IIT27	15	258.0604	10322.42	27
IIT32	14	240.8697	9634.79	32
IIT35	14	240.526	9621.041	35
IIT42	11	188.7246	7548.983	42

Reactor 5 Total

SAMPLE	ABS	CONC mg/L	Total CONC. mg/L	TIME Days
VT1	25	478.0188	19120.75	1
VT4	26	436.3936	17455.74	4
VT7	24	391.6642	15666.57	7
VT11	28	463.3391	18533.56	11
VT14	26	438.2895	17531.58	14
VT18	25	403.2554	16130.22	18
VT21	26	438.5451	17541.8	21
VT25	30	488.8302	19553.21	25
VT27	24	412.7767	16511.07	27
VT32	25	429.9674	17198.7	32
VT35	26	446.0055	17840.22	35
VT42	26	446.0762	17843.05	42

Reactor 2 Supernatant

SAMPLE	ABS	CONC mg/L	Total CONC. mg/L	TIME Days
IIS1	6	115.0285	1437.856	1
IIS4	6	101.7831	1272.289	4
IIS7	12	196.1321	1961.321	7
IIS11	19	314.473	3144.73	11
IIS14	18	303.6773	3036.773	14
IIS18	17	274.3417	2743.417	18
IIS21	19	320.5291	3205.291	21
IIS25	24	391.0642	3910.642	25
IIS27	25	429.9674	4299.674	27
IIS32	22	377.5123	3775.123	32
IIS35	30	514.4986	5144.986	35
IIS42	24	411.7627	4117.627	42

Reactor 5 Supernatant

SAMPLE	ABS	CONC mg/L	Total CONC. mg/L	TIME Days
VS1	4	76.81901	960.2376	1
VS4	11	185.4357	2317.947	4
VS7	23	375.3698	3753.698	7
VS11	19	314.473	3144.73	11
VS14	14	236.3713	2363.713	14
VS18	24	387.1412	3871.412	18
VS21	22	371.1074	3711.074	21
VS25	24	391.0642	3910.642	25
VS27	28	481.5395	4815.395	27
VS32	28	480.2521	4802.521	32
VS35	31	531.6219	5316.219	35
VS42	35	600.4873	6004.873	42

COD vs Time For Run 6

Reactor 1 Total (Control)

SAMPLE	ABS %	CONC. mg/L	TOT. CONC mg/L	TIME Days
IT1	25	422.7121	16908.48	1
IT3	25	413.717	16548.68	3
IT6	25	421.4347	16857.39	6
IT10	24	387.1412	15485.65	10
IT13	28	472.2639	18890.56	13
IT17	26	424.2529	16970.11	17
IT19	23	395.586	15823.44	19
IT24	22	378.3953	15135.81	24
IT27	24	411.7589	16470.36	27
IT35	24	411.7627	16470.51	34
IT37	24	411.7589	16470.36	37
IT41	24	435.1826	17407.3	41
IT45	22	424.2065	16968.26	45
IT48	23	457.1492	18285.97	48
IT52	21	418.7685	16750.74	52
IT55	20	414.1104	16564.41	55

Reactor 3 Total

SAMPLE	ABS %	CONC. mg/L	TOT. CONC mg/L	TIME Days
IIIT1	22	371.9386	14877.55	1
IIIT3	21	347.5543	13902.17	3
IIIT6	15	253.1808	10127.23	6
IIIT10	16	258.2275	10329.1	10
IIIT13	15	253.0914	10123.66	13
IIIT17	14	228.7208	9148.831	17
IIIT19	17	292.4418	11697.67	19
IIIT24	14	240.8697	9634.79	24
IIIT27	15	257.6493	10305.97	27
IIIT35	14	240.1949	9607.796	35

Reactor4 Total

SAMPLE	ABS %	CONC. mg/L	TOT. CONC mg/L	TIME Days
IVT1	47	795.0507	31802.03	1
IVT3	30	496.4205	19856.82	3
IVT6	38	640.1647	25606.59	6
IVT10	28	451.5981	18063.92	10
IVT13	28	472.2639	18890.56	13
IVT17	28	456.8415	18273.66	17
IVT19	33	567.493	22699.72	19
IVT24	33	567.493	22699.72	24
IVT27	32	548.7452	21949.81	27
IVT35	33	566.1737	22646.95	34
IVT37	35	600.1151	24004.6	37
IVT41	34	616.342	24653.68	41
IVT45	34	655.4827	26219.31	45
IVT48	35	695.2444	27809.78	48
IVT52	27	538.3595	21534.38	52
IVT55	26	538.2235	21528.94	55

COD Vs Time For Run 6 (continued)

Reactor 1 Supernatant (control)

SAMPLE	ABS %	CONC. mg/L	TOT. CONC mg/L	TIME Days
IS1	11	185.7693	1857.693	1
IS3	17	281.3916	2813.916	3
IS6	17	286.8316	2868.316	6
IS10	14	225.999	2259.99	10
IS13	20	337.3885	3373.885	13
IS17	24	391.6642	3916.642	17
IS19	23	395.586	3955.86	19
IS24	16	274.7726	2747.726	24
IS27	24	411.7589	4117.589	27
IS35	30	514.7034	5147.034	34
IS37	19	326.1425	3261.425	37
IS41	20	362.7188	3627.188	41
IS45	16	308.5683	3085.683	45
IS48	12	238.8952	2388.952	48
IS52	14	279.2457	2792.457	52
IS55	12	248.6262	2486.262	55

Reactor 3 Supernatant

SAMPLE	ABS %	CONC. mg/L	TOT. CONC mg/L	TIME Days
IIIS1	17	287.3162	2873.162	1
IIIS3	19	314.473	3144.73	3
IIIS6	19	320.4823	3204.823	6
IIIS10	23	371.027	3710.27	10
IIIS13	30	505.9828	5059.828	13
IIIS17	27	440.5472	4405.472	17
IIIS19	33	567.493	5674.93	19
IIIS24	31	531.6219	5316.219	24
IIIS27	24	411.7589	4117.589	27
IIIS35	31	531.8601	5318.601	35

Reactor4 Supernatant

SAMPLE	ABS %	CONC. mg/L	TOT. CONC mg/L	TIME Days
IVS1	18	304.2407	3042.407	1
IVS3	20	331.0136	3310.136	3
IVS6	16	270.0062	2700.062	6
IVS10	18	290.4559	2904.559	10
IVS13	27	455.4045	4554.045	13
IVS17	22	359.0755	3590.755	17
IVS19	21	361.2046	3612.046	19
IVS24	27	463.1288	4631.288	24
IVS27	30	514.4986	5144.986	27
IVS35	35	600.4873	6004.873	34
IVS37	37	634.3616	6343.616	37
IVS41	40	725.0377	7250.377	41
IVS45	40	771.1209	7711.209	45
IVS48	44	873.8159	8738.159	48
IVS52	46	917.0643	9170.643	52
IVS55	43	889.8773	8898.773	55
IVS48	44	873.8159	8738.159	48
IVS52	46	917.0643	9170.643	52
IVS55	43	889.8773	8898.773	55

# COD vs Time Data for Run 7

SAMPLE	ABS.	CONC.	TOT. CONCTIME	
IIT1		44 754.2247	30168.99	1
IIT5		25 453.2986	18131.94	5
IIT9		12 231.4763	9259.05	9
IIT12		8 159.5302	6381.206	12
IIT16		9 179.5865	7183.46	16
IIT19		20 414.1104	8282.207	19
IIT23		16 331.3683	6627.366	23
IIT26		13 296.422	5928.441	26
IIT30		18 325.0095	6500.189	30
IIT33		15 346.5084	6930.167	33
IIT37		21 361.2046	4816.062	37
IIT40		25 428.2822	5710.429	40

SAMPLE	ABS.	CONC.	TOT. CONCTIME	
IIIT1		43 737.1014	29484.05	1
IIIT5		40 725.0377	29001.51	5
IIIT9		27 520.5716	20822.86	9
IIIT12		21 417.4667	16698.67	12
IIIT16		16 319.1093	12764.37	16
IIIT19		30 620.9655	12419.31	19
IIIT23		23 476.1669	9523.338	23
IIIT26		23 524.2851	10485.7	26
IIIT30		28 504.6814	10093.63	30
IIIT33		18 415.77	8315.4	33
IIIT37		37 636.2558	8483.41	37
IIIT40		42 719.3781	9591.708	40

COD Data vs Time For Run 7 (Continued)

SAMPLE	ABS.	CONC.	TOT. CONC.TIME	
VT1		42 719.9781	28799.12	1
VT5		44 797.5014	31900.06	5
VT9		40 771.1209	30844.83	9
VT12		38 754.7683	30190.73	12
VT16		36 717.746	28709.84	16
VT19		33 683.0221	27320.88	19
VT23		34 703.7076	28148.3	23
VT26		28 638.2167	25528.67	26
VT30		35 630.4517	25218.07	30
VT33		29 669.7295	26789.18	33
VT37		37 636.2558	25450.23	37
VT40		37 633.7616	25350.47	40

SAMPLE	ABS.	CONC.	TOT. CONC.TIME	
IIS1		8 137.7863	1377.863	1
IIS5		8 145.3275	1453.275	5
IIS9		8 154.3842	1543.842	9
IIS12		7 139.6889	1396.889	12
IIS16		12 239.382	2393.82	16
IIS19		13 269.3117	2693.117	19
IIS23		12 248.6262	2486.262	23
IIS26		7 159.7042	1597.042	26
IIS30		12 217.2063	2172.063	30
IIS33		9 207.985	2079.85	33
IIS37		14 240.8697	1204.349	37
IIS40		35 599.5151	2997.575	40

SAMPLE	ABS.	CONC.	TOT. CONC.TIME	
IIIS1		7 120.663	1206.63	1
IIIS5		20 362.7188	3627.188	5
IIIS9		17 327.8414	3278.414	9
IIIS12		15 298.419	2984.19	12
IIIS16		40 797.4733	7974.733	16
IIIS19		21 434.7959	4347.959	19
IIIS23		18 372.7393	3727.393	23
IIIS26		10 228.0631	2280.631	26
IIIS30		11 199.2391	1992.391	30
IIIS33		9 207.985	2079.85	33
IIIS37		38 653.4465	3267.232	37
IIIS40		34 582.3918	2911.959	40

SAMPLE	ABS.	CONC.	TOT. CONC.TIME	
VS1		6 103.5397	1035.397	1
VS5		7 127.2116	1272.116	5
VS9		7 135.1112	1351.112	9
VS12		9 179.3714	1793.714	12
VS16		12 239.382	2393.82	16
VS19		13 269.3117	2693.117	19
VS23		8 165.8841	1658.841	23
VS26		8 182.4905	1824.905	26
VS30		22 396.8782	3968.782	30
VS33		18 415.77	4157.7	33
VS37		53 911.3069	4556.535	37
VS40		41 702.2548	3511.274	40

# COD vs Time Data For Run 8

## Reactor 1 Total (Control)

SAMPLE	ABS. %	CONC. mg/L	TOT. CONC mg/L	TIME Days
IT1	27	558.909	11178.18	1
IT3	26	538.2235	10764.47	3
IT6	30	683.7893	13675.79	6
IT10	28	504.6814	10093.63	10
IT13	22	508.1189	10162.38	13
IT17	40	687.8279	9171.038	17
IT20	40	685.1315	9135.087	20
IT24	58	982.3343	9823.343	24
IT27	60	1049.997	10499.97	27
IT31	63	1096.319	10963.19	31
IT34	61	1043.321	10433.21	34
IT38	60	1069.052	10690.52	38
IT41	58	1007.144	10071.44	41
IT45	55	972.2296	9722.296	45
IT48	62	1098.381	10983.81	48

## Reactor 4 Total

SAMPLE	ABS. %	CONC. mg/L	TOT. CONC mg/L	TIME Days
IVT1	30	620.9655	12419.31	1
IVT3	24	496.8524	9937.049	3
IVT6	21	478.7125	9574.25	6
IVT10	22	396.8782	7937.564	10
IVT13	15	346.5084	6930.167	13
IVT17	31	533.1116	7108.155	17
IVT20	28	479.6521	6395.361	20
IVT24	45	761.8869	7618.869	24
IVT27	42	734.9982	7349.982	27
IVT31	42	731.0127	7310.127	31
IVT34	43	735.1014	7351.014	34
IVT38	44	783.918	7839.18	38
IVT41	48	833.5333	8335.333	41
IVT45	48	848.4913	8484.913	45
IVT48	46	814.9794	8149.794	48

COD vs Time Data For Run 8 (Continued)

Reactor 1 Supernatant (Control)

SAMPLE	ABS. %	CONC. mg/L	TOT. CONC mg/L	TIME Days
IS1	6	124.5131	1245.131	1
IS3	7	145.1986	1451.986	3
IS6	5	114.1315	1141.315	6
IS10	4	73.46877	734.6877	10
IS13	3	69.46167	694.6167	13
IS17	15	258.0604	1290.302	17
IS20	20	342.6658	1713.329	20
IS24	19	320.9923	1604.961	24
IS27	24	419.999	2099.995	27
IS31	18	313.5197	1567.599	31
IS34	22	375.5123	1877.562	34
IS38	20	356.2173	1781.086	38
IS41	24	416.8667	2084.333	41
IS45	23	406.5687	2032.844	45
IS48	27	478.4401	2392.2	48

Reactor 4 Supernatant

SAMPLE	ABS. %	CONC. mg/L	TOT. CONC mg/L	TIME Days
IVS1	4	83.14207	831.4207	1
IVS3	7	145.1986	1451.986	3
IVS6	5	114.1315	1141.315	6
IVS10	9	163.3047	1633.047	10
IVS13	9	207.985	2079.85	13
IVS17	30	515.9209	2579.604	17
IVS20	36	616.6384	3083.192	20
IVS24	33	558.3971	2791.985	24
IVS27	28	489.9988	2449.994	27
IVS31	26	452.684	2263.42	31
IVS34	39	666.6082	3333.041	34
IVS38	35	623.5303	3117.651	38
IVS41	33	573.1167	2865.583	41
IVS45	26	459.5994	2297.997	45
IVS48	12	212.7511	1063.756	48

# COD Data Vs Time For Run 9

## Reactor 2 Total

SAMPLE	ABS. %	Sample CONC. TOT.CONC.		TIME Days
		mg/L	mg/L	
IIT1	25	422.7372	4227.372	1
IIT3	19	320.9923	3209.923	3
IIT6	17	297.4993	2974.993	6
IIT10	10	174.3554	1743.554	10
IIT13	13	222.4027	2224.027	13
IIT17	11	195.8295	1958.295	17
IIT20	13	225.8944	2258.944	20
IIT24	10	176.769	1767.69	24
IIT27	11	195.0385	1950.385	27

## Reactor 3 Total

SAMPLE	ABS. %	Sample CONC. TOT.CONC.		TIME Days
		mg/L	mg/L	
IIIT1	24	405.7797	4057.797	1
IIIT3	22	371.8647	3718.647	3
IIIT6	19	332.4992	3324.992	6
IIIT10	14	243.9376	2439.376	10
IIIT13	16	273.7726	2737.726	13
IIIT17	13	231.4712	2314.712	17
IIIT20	15	260.6167	2606.167	20

## Reactor 5 Total (Control)

SAMPLE	ABS. %	Sample CONC. TOT.CONC.		TIME Days
		mg/L	mg/L	
VT1	26	439.6947	17587.79	1
VT3	26	439.6947	17587.79	3
VT6	27	472.4988	18899.95	6
VT10	28	487.4751	19499	10
VT13	30	513.4986	20539.95	13
VT17	32	570.0677	22802.71	17
VT20	29	503.6722	20146.89	20
VT24	26	459.5994	18383.98	24
VT27	32	567.0031	22680.12	27

COD Data Vs Time For Run 9 (Continued)  
Reactor 2 Supernatant

SAMPLE	ABS. %	Sample CONC. TOT.CONC.		TIME Days
		mg/L	mg/L	
IIS1	12	202.2899	1011.449	1
IIS3	10	168.3749	841.8744	3
IIS6	6	104.9997	524.9987	6
IIS10	6	104.7732	523.8662	10
IIS13	9	153.9096	769.5479	13
IIS17	11	195.8295	979.1476	17
IIS20	15	260.6167	1303.083	20
IIS24	12	212.1228	1060.614	24
IIS27	4	71.05038	355.2519	27

Reactor 3 Supernatant

SAMPLE	ABS. %	Sample CONC. TOT.CONC.		TIME Days
		mg/L	mg/L	
IIIS1	23	388.8222	1944.111	1
IIIS3	20	337.9498	1689.749	3
IIIS6	20	349.9991	1749.996	6
IIIS10	16	278.7286	1393.643	10
IIIS13	21	359.389	1796.945	13
IIIS17	11	195.8295	979.1476	17
IIIS20	12	208.5333	1042.667	20

Reactor 5 Supernatant (Control)

SAMPLE	ABS. %	Sample CONC. TOT.CONC.		TIME Days
		mg/L	mg/L	
VS1	44	744.9295	3724.647	1
VS3	44	744.9295	3724.647	3
VS6	46	804.998	4024.99	6
VS10	44	765.8038	3829.019	10
VS13	44	753.2247	3766.123	13
VS17	45	801.7389	4008.695	17
VS20	45	781.45	3907.25	20
VS24	43	760.1068	3800.534	24
VS27	53	938.9676	4694.838	27

# COD Data Vs Time For Run 10

## Reactor 3 Total

SAMPLE	ABS. %	Sample CONC. TOT. CONC		TIME Days
		mg/L	mg/L	
IIIT1	39	689.3992	13787.98	1
IIIT3	32	565.6609	11313.22	3
IIIT6	33	584.7156	5847.156	6
IIIT10	25	427.8482	8556.964	10
IIIT13	15	262.5039	6562.598	13
IIIT17	23	412.8454	8256.908	17
IIIT21	21	365.7127	7314.254	21
IIIT24	20	348.3168	6966.337	24
IIIT27	19	337.6202	6752.405	27
IIIT31	17	291.1288	5822.575	31
IIIT34	19	325.3086	6506.172	34
IIIT38	17	302.1234	6042.467	38
IIIT41	17	291.8959	5837.918	41
IIIT48	15	272.1391	5442.783	47

## Reactor 3 Supernatant

SAMPLE	ABS. %	Sample CONC. TOT. CONC		TIME Days
		mg/L	mg/L	
IIIS1		365.47	1827.35	1
IIIS3	23	406.5687	2032.844	3
IIIS6	14	248.1763	1240.882	6
IIIS10	13	222.7691	1113.845	10
IIIS13	18	315.0047	3150.047	13
IIIS17	18	323.0095	1615.047	17
IIIS21	10	174.3584	1743.584	21
IIIS24	9	156.9626	1569.626	24
IIIS27	18	319.8718	3198.718	27
IIIS31	10	171.4993	1714.993	31
IIIS34	10	171.4993	1714.993	34
IIIS38	10	177.8843	1778.843	38
IIIS41	12	206.2795	2062.795	41
IIIS47	6	109.0957	1090.957	47

COD DATA VS TIME FOR RUN 11  
SBR OF RUN 8 (REACTOR4) AND RUN 9 (REACTOR2)

Reactor 1 Total (Control)

SAMPLE	ABS. %	CONC. mg/L	TOT. CONC mg/L	TIME Days
IT1	37	632.9273	25317.09	1
IT3	36	615.8374	24633.5	3
IT6	51	892.4978	22312.44	6
IT10	62	1113.566	22271.32	10
IT14	62	1078.942	21578.84	14
IT17	60	1044.151	20883.01	17
IT20	60	1065.306	21306.12	20
IT24	61	1043.086	20861.71	24
IT27	59	1008.906	20178.11	27
IT31	57	1012.061	20241.21	31
IT34	58	993.9507	19879.01	34
IT40	58	1051.125	21022.49	40

Reactor 2 Total

SAMPLE	ABS. %	CONC. mg/L	TOT. CONC mg/L	TIME Days
IIT1	47	803.8266	32153.06	1
IIT3	34	581.6575	23266.3	3
IIT6	40	699.9983	17499.96	6
IIT10	33	592.5173	11850.35	10
IIT14	27	470.0877	9401.755	14
IIT17	24	417.9002	8358.004	17
IIT20	36	639.3436	12786.87	20
IIT24	40	684.1971	13683.94	24
IIT27	27	462.028	9240.561	27
IIT31	27	479.6077	9592.154	31
IIT34	34	582.9918	11659.84	34
IIT40	26	471.4145	9428.29	40

Reactor 4 Total

SAMPLE	ABS. %	CONC. mg/L	TOT. CONC mg/L	TIME Days
IVT1	59	1008.906	40356.23	1
IVT3	48	820.9165	32836.66	3
IVT6	53	927.4977	23187.44	6
IVT10	57	1023.73	20474.6	10
IVT14	54	939.7755	18795.51	14
IVT17	52	904.9838	18099.68	17
IVT20	53	941.067	18821.34	20
IVT24	53	906.3661	18127.32	24
IVT27	51	872.1863	17443.73	27
IVT31	48	852.3248	17046.5	31
IVT34	49	839.8411	16796.82	34
IVT40	49	888.0812	17761.62	40

COD Data Vs Time For run 11 (Continued)

Reactor 1 Supernatant (Control)

SAMPLE	ABS. %	CONC. mg/L	TOT. CONC mg/L	TIME Days
IS1	29	496.2079	2481.039	1
IS3	30	513.2978	2566.489	3
IS6	19	332.4992	3324.992	6
IS10	25	448.7798	4487.798	10
IS14	19	330.921	3309.21	14
IS17	21	365.7127	3657.127	17
IS20	22	390.8655	3908.655	20
IS24	22	376.5784	3765.784	24
IS27	20	342.3985	3423.985	27
IS31	22	390.8655	3908.655	31
IS34	20	343.2658	3432.658	34
IS40	24	435.1826	4351.826	40

Reactor 2 Supernatant

SAMPLE	ABS. %	CONC. mg/L	TOT. CONC mg/L	TIME Days
IIS1	20	342.3985	1711.993	1
IIS3	15	256.9489	1284.745	3
IIS6	13	227.4994	2274.994	6
IIS10	13	233.1735	2331.735	10
IIS14	3	52.58753	525.8753	14
IIS17	4	69.98337	699.8337	17
IIS20	6	106.8906	1068.906	20
IIS24	10	171.4993	1714.993	24
IIS27	12	205.6791	2056.791	27
IIS31	14	248.8781	2488.781	31
IIS34	15	257.6493	2576.493	34
IIS40	18	326.487	3264.87	40

Reactor 4 Supernatant

SAMPLE	ABS. %	CONC. mg/L	TOT. CONC mg/L	TIME Days
IVS1	20	342.3985	1711.993	1
IVS3	15	256.9489	1284.745	3
IVS6	28	489.9988	4899.988	6
IVS10	42	754.2221	7542.221	10
IVS14	21	365.7127	3657.127	14
IVS17	23	400.5044	4005.044	17
IVS20	50	887.8217	8878.217	20
IVS24	25	427.8482	4278.482	24
IVS27	23	393.6683	3936.683	27
IVS31	27	479.6077	4796.077	31
IVS34	28	480.2521	4802.521	34
IVS40	33	598.2261	5982.261	40

BIOLOGICAL OXYGEN DEMAND RUN7  
For Reactor 2

SAMPLE	Disolved Oxygen in Blank Originally	Disolved Oxygen in Blank After 5days	Disolved Oxygen in Sample Initially	Disolved Oxygen in Sample After 5days	Amount Of Sample In BOD Bottle	Amount Sample is Diluted Prior to being put in bottle	5 Day BOD Of Sample Bottle	5 Day BOD Of Sample Waste In Reactors
	DObi mg/L	DObf mg/L	DOsi mg/L	DOsf mg/L	AMT. SAMP ml	DIL.	SAM. BOD mg/L	TOT. BOD mg/L
IIT1	9.2	9	9.2	5.53	5	40	208.2	8328
IIT1	9.2	9	9.2	2.07	10	40	207.9	8316
IIT5	9.01	9.5	9.01	0.83	20	40	130.05	5202
IIT5	9.01	9.5	9.01	4.99	10	40	135.3	5412
IIS5	9.01	9.5	9.01	5.27	45	10	28.2	282
IIT9	8.78	8.47	8.17	5.22	20	40	39.6	1584
IIT9	8.78	8.47	8.34	6.75	10	40	38.4	1536
IIT19	8.94	8.78	8.94	7.85	20	40	13.95	558
IIT19	8.94	8.78	8.94	6.81	40	40	14.775	591
IIT23	8.94	8.78	8.94	8.1	20	40	10.2	408
IIT23	8.94	8.78	8.94	7.07	40	40	12.825	513
IIT30	9.53	9.42	9.12	7.17	50	20	11.04	220.8
IIT30	9.53	9.42	9.28	3.65	80	20	20.7	414
IIS30	9.53	9.42	9.33	7.12	50	10	12.6	126
IIT40	8.45	8.56	8.29	7.6	50	13.33333	4.8	64
IIT40	8.45	8.56	8.06	6.08	100	13.33333	6.27	83.6
IIT40	8.45	8.56	8.45	6.1	10	1	73.8	73.8
IIS40	8.45	8.56	8.3	7.72	45	5	4.6	23

For Reactor 3

SAMPLE	DObi mg/L	DObf mg/L	DOsi mg/L	DOsf mg/L	AMT. SAMP ml	DIL.	SAM. BOD mg/L	TOT. BOD mg/L
IIIT1	9.2	9	9.2	6.44	5	40	153.6	6144
IIIt1	9.2	9	9.2	3.86	10	40	154.2	6168
IIIT5	9.01	9.5	9.01	0.05	20	40	141.75	5670
IIIT5	9.01	9.5	9.01	4.94	10	40	136.8	5472
IIIS5	9.01	9.5	9.01	1.3	45	10	54.66667	546.6667
IIIT9	8.78	8.47	8.17	3.02	20	40	72.6	2904
IIIT9	8.78	8.47	8.34	5.5	10	40	75.9	3036
IIIT19	8.94	8.78	8.94	7.66	20	40	16.8	672
IIIT19	8.94	8.78	8.94	6.09	40	40	20.175	807
IIIT23	8.94	8.78	8.94	8.18	20	40	9	360
IIIT23	8.94	8.78	8.94	6.96	40	40	13.65	546
IIIT30	9.53	9.42	9.21	6.91	50	20	13.14	262.8
IIIT30	9.53	9.42	9.29	5.19	80	20	14.9625	299.25
IIIS30	9.53	9.42	9.37	5.98	50	10	19.68	196.8
IIIT40	8.45	8.56	8.3	6.13	50	13.33	13.68	182.3544
IIIT40	8.45	8.56	8.05	3.18	100	13.33	14.94	199.1502
IIIS40	8.45	8.56	8.3	6.28	45	5	14.2	71

# BIOLOGICAL OXYGEN DEMAND RUN8

	Disolved O2 In Blank Initially	Disolved O2 In Blank After 5days	Disolved O2 In Sample Initially	Disolved O2 In Sample After 5days	Amount Of Sample In BOD Bottle	Dilution Prior To BOD Bottle	BOD5 Of Sample Bottle	Total BOD5 Of Waste
SAMPLE	DObi mg/L	DObf mg/L	DOsi mg/L	DOsf mg/L	AMT. SAMP ml	DIL.	SAM. BOD mg/L	TOT. BOD mg/L
IVT1	9	8.9	9	2	25	40	82.8	3312
IVT1	9	8.9	9	0.65	30	40	82.5	3300
IVT10	9.53	9.42	9.28	0	50	20	55.02	1100.4
IVT10	9.53	9.42	9.37	0	80	20	33.6375	672.75
IVS10	9.53	9.42	9.31	2.59	50	10	38.28	382.8
IVT20	8.45	8.56	8.45	5.73	25	13.33	38.88	518.2704
IVT20	8.45	8.56	8.45	2.93	40	13.33	45.3	603.849
IVS20	8.45	8.56	8.3	1.74	45	5	48.2	241
IVT24	8.92	8.55	8.9	2.27	30	10	67	670
IVT24	8.92	8.55	8.64	0	60	10	44.85	448.5
IVS24	8.92	8.55	8.9	3.08	50	5	35.34	176.7
IVT31	8.87	8.45	8.78	2.12	30	10	68.5	685
IVT31	8.87	8.45	8.71	0	50	10	53.82	538.2
IVT31	8.87	8.45	8.63	0	80	10	33.6375	336.375
IVS31	8.87	8.45	8.65	1.35	50	4.166667	45.72	190.5
IVT41	8.88	8.64	8.49	7.14	1	1	549	549
IVT41	8.88	8.64	8.48	5.34	2	1	544.5	544.5
IVT41	8.88	8.64	8.45	0.9	4	1	605.25	605.25
IVT41	8.88	8.64	8.45	0	5	1	538.2	538.2
IVS41	8.88	8.64	8.47	5.06	5	1	234.6	234.6
IVT46	9.15	9.21	9.19	6.85	1	1	636	636
IVT46	9.15	9.21	9.2	2.88	3	1	609	609
IVT46	9.15	9.21	9.14	4.26	5	1	282.6	282.6

BIOLOGICAL OXYGEN DEMAND RUN9  
For Reactor 2

	Dissolved O2 In Blank	Dissolved O2 In Blank	Dissolved O2 In Sample	Dissolved O2 In Sample	Amount Of Sample In BOD5 Bottle	Amount Of Dillution Prior To Test	BOD5 Of Sample Bottle	BOD5 Of Waste
SAMPLE	DObi mg/L	DObf mg/L	DOsi mg/L	DOsf mg/L	AMT. SAMP ml	DIL.	SAM. BOD mg/L	TOT. BOD mg/L
IIT1	9.2	9.1	9.2	3.8	50	20	31.8	636
IIT1	9.2	9.1	9.2	1.4	75	20	30.8	616
IIT3	8.92	8.54	8.9	2.26	40	10	46.95	469.5
IIT3	8.92	8.54	8.75	0	100	10	26.91	269.1
IIS3	8.92	8.54	8.9	3.47	50	5	33	165
IIT10	8.87	8.45	8.8	0	10	1	269.1	269.1
IIT10	8.87	8.45	8.71	0	20	1	134.55	134.55
IIS10	8.87	8.45	8.82	7.65	3	1	132	132
IIT20	8.88	8.64	8.44	4.13	5	1	290.4	290.4
IIT20	8.88	8.64	8.35	0	10	1	269.1	269.1
IIS20	8.88	8.64	8.48	6.78	5	1	131.4	131.4
IIT24	9.15	9.21	9.1	5.57	5	1	204	204
IIT24	9.15	9.21	9.05	1.69	10	1	218.4	218.4
IIS24	9.15	9.21	9.04	2.93	10	1	181.2	181.2

For Reactor 3

SAMPLE	DObi mg/L	DObf mg/L	DOsi mg/L	DOsf mg/L	AMT. SAMP ml	DIL.	SAM. BOD mg/L	TOT. BOD mg/L
IIIT1	9.2	9.1	9.2	5.7	50	10	20.4	204
IIIT1	9.2	9.1	9.2	2.3	100	10	20.01	200.1
IIIT3	8.9	8.54	8.9	7.66	25	10	10.56	105.6
IIIT3	8.9	8.54	8.9	6.56	50	10	14.46	144.6
IIIT3	8.9	8.54	8.9	4.24	100	10	14.19	141.9
IIS3	8.9	8.54	8.9	6.32	50	5	15.9	79.5
IIIT10	8.87	8.45	8.81	6.35	10	1	78.6	78.6
IIIT10	8.87	8.45	8.81	4.72	15	1	85	85
IIS10	8.87	8.45	8.74	6.41	50	4.166667	15.36	64
IIIT20	8.88	8.64	8.46	6.75	10	1	66.6	66.6
IIS20	8.88	8.64	8.52	8.2	5	1	46.2	46.2

Run 10 BOD Data Vs time For Reactor 3

SAMPLE	Dissolved O2 In Blank	Dissolved O2 In Blank	Dissolved Oxygen In Sample	Dissolved Oxygen In Sample	Amount Of Sample In BOD Bottle	Dilution Prior To Entry Into BOD Bottle	BOD5 Of Sample Bottle	BOD5 Of Waste
	Initially DObi mg/L	After 5days DObf mg/L	Initially DOsi mg/L	After 5days DOsf mg/L	AMT. SAMP ml	DIL.	SAM. BOD mg/L	TOT. BOD mg/L
IIIT1	9.15	9.21	9.19	0	1	1	2763	2763
IIIT1	9.15	9.21	9.2	1.57	0.5	1	4584	4584
IIIT5	9.15	9.21	9.19	6.52	1	1	807	807
IIIT5	9.15	9.21	9.2	8.04	0.5	1	702	702
IIIS5	9.15	9.21	9.13	2.93	5	1	376.8	376.8
IIIT13	9.12	8.91	9.12	7.75	1	1	348	348
IIIT13	9.12	8.91	9.12	8.03	0.8	1	330	330
IIIS13	9.12	8.91	9.12	5.8	5	1	186.6	186.6
IIIT21	9.07	8.73	9.07	5.84	2	1	433.5	433.5
IIIT21	9.07	8.73	9.07	3.93	3	1	480	480
IIIT27	9.07	8.73	9.07	8.02	2	1	106.5	106.5
IIIT27	9.07	8.73	9.07	7.23	3	1	150	150
IIIT34	9.07	8.06	9.07	6.87	3	1	119	119
IIIT34	9.07	8.06	9.07	5.58	5	1	148.8	148.8
IIIS34	9.07	8.06	9.07	7.21	5	1	51	51
IIIT41	9.3	8.38	9.3	7.47	4	1	68.25	68.25
IIIT41	9.3	8.38	9.3	6.68	6	1	85	85
IIIS41	9.3	8.38	9.3	7.83	5	1	33	33
IIIT47	9.94	8.92	9.94	7.46	5	1	87.6	87.6
IIIT47	9.94	8.92	9.94	6.26	10	1	79.8	79.8
IIIS47	9.94	8.92	9.94	8.44	5	1	28.8	28.8

# BOD Data For Run 11

## For Reactor 2

SAMPLE	Dissolved O2 In Blank		Dissolved O2 In Sample		Amount Of Diluted Sample In BOD Bottle		Dilution Of Waste Prior To In BOD Bottle		BOD 5 Of Sample Bottle		Total BOD5 Of Waste	
	Initially	After 5Days	Initially	After 5Days	AMT. SAMP	DIL.	SAM.	BOD	TOT.	BOD	TOT.	BOD
	DObi mg/L	DObf mg/L	DOsi mg/L	DOsf mg/L	ml			mg/L	mg/L			mg/L
IIT1	9.12	8.91	9.12	3.62	10	50		158.7				7935
IIT1	9.12	8.91	9.12	6.22	5	50		161.4				8070
IIT6	9.12	8.91	9.12	0	0.5	1		5346				5346
IIT6	9.12	8.91	9.12	0	1	1		2673				2673
IIS6	9.12	8.91	9.12	1.19	5	1		463.2				463.2
IIT14	9.07	8.73	9.07	4.83	1	1		1170				1170
IIT14	9.07	8.73	9.07	3.17	0.8	1		2085				2085
IIT20	9.07	8.73	9.07	2.06	1	1		2001				2001
IIT20	9.07	8.73	9.07	0	2	1		1309.5				1309.5
IIT27	9.07	8.06	9.07	4.69	1	1		1011				1011
IIT27	9.07	8.06	9.07	1.29	2	1		1015.5				1015.5
IIS27	9.07	8.06	9.07	2.77	5	1		317.4				317.4
IIT34	9.3	8.38	9.3	3.48	1	1		1470				1470
IIT34	9.3	8.38	9.3	0	3	1		838				838
IIS34	9.3	8.38	9.3	3.7	5	1		280.8				280.8
IIT40	9.94	8.92	9.94	6.28	1	1		792				792
IIT40	9.94	8.92	9.94	3.79	2	1		769.5				769.5
IIS40	9.94	8.92	9.94	4.14	5	1		286.8				286.8

## For Reactor 4

SAMPLE	Dissolved O2 In Blank		Dissolved O2 In Sample		Amount Of Diluted Sample In BOD Bottle		Dilution Of Waste Prior To In BOD Bottle		BOD 5 Of Sample Bottle		Total BOD5 Of Waste	
	Initially	After 5Days	Initially	After 5Days	AMT. SAMP	DIL.	SAM.	BOD	TOT.	BOD	TOT.	BOD
	DObi mg/L	DObf mg/L	DOsi mg/L	DOsf mg/L	ml			mg/L	mg/L			mg/L
IVT1	9.12	8.91	9.12	0.93	10	50		239.4				11970
IVT1	9.12	8.91	9.12	4.9	5	50		240.6				12030
IVT6	9.12	8.91	9.12	0	0.5	1		5346				5346
IVT6	9.12	8.91	9.12	0	1	1		2673				2673
IVS6	9.12	8.91	9.12	0	5	1		534.6				534.6
IVT14	9.07	8.73	9.07	0	1	1		2619				2619
IVT14	9.07	8.73	9.07	0	0.5	1		5238				5238
IVT20	9.07	8.73	9.07	0	1	1		2619				2619
IVT20	9.07	8.73	9.07	0	0.8	1		3273.75				3273.75
IVT27	9.07	8.06	9.07	0.55	0.5	1		4506				4506
IVT27	9.07	8.06	9.07	0	1	1		2418				2418
IVT27	9.07	8.06	9.07	0	2	1		1209				1209
IVT27	9.07	8.06	9.07	1.53	0.3	1		6530				6530
IVS27	9.07	8.06	9.07	0	5	1		483.6				483.6
IVT34	9.3	8.38	9.3	4.75	0.5	1		2178				2178
IVT34	9.3	8.38	9.3	0	1	1		2514				2514
IVS34	9.3	8.38	9.3	0.83	4	1		566.25				566.25
IVT40	9.94	8.92	9.94	4.14	0.5	1		2868				2868
IVT40	9.94	8.92	9.94	1.97	1	1		2085				2085
IVS40	9.94	8.92	9.94	0.1	5	1		529.2				529.2

## Run 4 PH VS TIME

TIME	R#1	R#2	R#3	R#4
Days				
1	5.98	8.67	8.63	6.2
6	6.26	8.67	8.53	6.19
9	5.86	9.14	8.72	6.58
13	5.38	9	8.33	6.29
15	6.19	9.03	8.46	6.29
19	6.12	8.54	8.48	6.53
22	6.09	8.53	8.46	
25	6.03	8.95	8.5	6.4
29	6.07	8.54	8.53	6.88
33	6.49	8.39	8.77	6.61
37	6.4	8.58	8.8	6.87
41	6.53	8.9	8.74	6.83
44	6.42	8.69	8.55	6.77
47	6.83	8.78	8.687	7.05
50	6.64	8.75	8.44	6.75
54	7.06	8.51	8.39	6.73
57	6.86	8.96	8.84	6.75
61	6.71	8.81	8.66	6.41
64	6.8	8.33	8.62	6.61
74	7.6	8.49	8.36	6.85
78	7.45	8.73	8.4	7.06
82	7.84		8.66	6.95
85			8.66	6.59

# PH vs Time Data For Specific Runs

## FOR RUN 5

TIME	pH	pH
Days	R#2	R#5
1	7.59	7.06
4	7.59	6.77
7	7.29	6.91
11	7.47	6.93
14	6.65	6.95
18	6.67	6.74
21	6.6	7.4
25	6.99	8.34
27	6.75	7.8
32	6.65	8.28
35	6.56	8.22
42	7.25	7.91

## FOR RUN 6

Days	pH	pH	pH
TIME	R#1	R#3	R#4
1	8.52	7.39	5.83
3	7	7.58	6.64
6	7.43	6.75	5.09
10	7.36	6.92	5.1
13	7.01	6.91	5.34
17	7.14	6.69	5.06
19	7.69	7.89	5.13
24	7.71	9.1	4.66
27	7.6	9.2	4.88
34	7.49	9.14	4.83
37	7.46		7.1
41	8.12		8.85
45	7.55		8.61
48	7.4		8.4
52	6.82		7.43
55	7.76		8.27

FOR RUN 7

Days TIME	pH R#2	pH R#3	pH R#5
1	6.05	6.35	6.22
5	6.37	6.67	6.22
9	5.56	6.43	6.28
12	5.15	5.87	6.68
16	5.64	5.39	5.94
19	6.43	5.86	6.42
23	5.99	5.58	6.2
26	6.34	5.52	6.36
30	6.27	4.92	6.57
33	6.46	5.28	6.7
37	6.35	4.91	7.06
40	6.29	4.86	6.74

FOR RUN 8

Days TIME	pH R#1	pH R#4
1	6.35	6.54
3	6.51	6.53
6	6.51	6.36
10	7.72	6.36
13	6.94	6.07
17	6.85	5.44
20	6.77	5.45
27	7.18	5.88
31	7.12	5.73
34	7.03	5.43
38	7.18	5.35
41	7.23	4.77
45	7.07	4.56
48	7.43	4.11

PH vs Time (Continued)  
FOR RUN 9

TIME	pH	pH	pH
Days	R#2	R#3	R#5
6	5.89	8.54	7.57
10	5.56	8.35	7.55
13	5.97	8.21	7.4
17	6.21	8.18	7.75
20	6.11	8	7.45
24	6.15		7.66
27	6.11		7.25

FOR RUN 10

TIME	pH	pH
Days	R#3	R#1
1	7.17	7.15
3	6.58	7.24
6	5.12	7.41
10	3.68	7.48
13	5.84	7.33
17	5.45	7.4
21	5.14	7.25
24	5.6	7.24
27	5.59	7.22
31	5.84	7.24
34	5.23	7.09
38	5.84	
41	5.44	

FOR RUN 11

TIME	pH	pH	pH
Days	R#1	R#2	R#4
1	7.15	4.93	4.74
3	7.24	4.83	3.98
6	7.41	5.08	7.17
10	7.48	4.38	6.9
14	7.33	3.6	6.58
17	7.4	3.78	6.72
20	7.25	6.59	6.58
24	7.24	7.03	6.65
27	7.22	6.96	6.58
31	7.24	7.03	6.65
34	7.09	7.14	6.56

## SOLIDS FOR RUN5

## DAY4

REACTOR	DISH W.	T. WEI.	110C.	550C.	TS	%TS	VS	%VS	VS/TS (%)
	g	g	g	g	g	%	g	%	%
2	44.2582	64.2342	44.3436	44.2902	0.0854	0.427513	0.0534	0.267321	62.52927
5	40.4559	64.0804	40.6355	40.5862	0.1796	0.760228	0.0493	0.208682	27.44989

## DAY11

REACTOR	DISH W.	T. WEI.	110C.	550C.	TS	%TS	VS	%VS	VS/TS (%)
	g	g	g	g	g	%	g	%	%
2	47.1613	65.078	47.3006	47.2184	0.1393	0.777487	0.0822	0.45879	59.00933
5	45.2187	61.694	45.421	45.3392	0.2023	1.227899	0.0818	0.496501	40.435

## DAY14

REACTOR	DISH W.	T. WEI.	110C.	550C.	TS	%TS	VS	%VS	VS/TS (%)
	g	g	g	g	g	%	g	%	%
2	40.4674	66.4677	40.6643	40.5398	0.1969	0.757299	0.1245	0.478841	63.23007
5	47.5523	70.2158	47.737	47.671	0.1847	0.814967	0.066	0.291217	35.73362

## DAY 18

REACTOR	DISH W.	T. WEI.	110C.	550C.	TS	%TS	VS	%VS	VS/TS (%)
	g	g	g	g	g	%	g	%	%
2	45.1855	61.594	45.3053	45.2278	0.1198	0.730109	0.0775	0.472316	64.69115
5	46.4047	69.9725	46.8701	46.7622	0.4654	1.974728	0.1079	0.457828	23.18436

## DAY 21

REACTOR	DISH W.	T. WEI.	110C.	550C.	TS	%TS	VS	%VS	VS/TS (%)
	g	g	g	g	g	%	g	%	%
2	47.5393	77.2117	47.744	47.6048	0.2047	0.689867	0.1392	0.469123	68.00195
5	47.4367	70.3587	47.7982	47.7123	0.3615	1.577088	0.0859	0.374749	23.7621

## DAY 25

REACTOR	DISH W.	T. WEI.	110C.	550C.	TS	%TS	VS	%VS	VS/TS (%)
	g	g	g	g	g	%	g	%	%
2	40.4531	64.932	40.6415	40.5177	0.1884	0.769642	0.1238	0.505742	65.71125
5	40.6986	60.7767	41.2397	41.1615	0.5411	2.694976	0.0782	0.389479	14.45204

## DAY 27

REACTOR	DISH W.	T. WEI.	110C.	550C.	TS	%TS	VS	%VS	VS/TS (%)
	g	g	g	g	g	%	g	%	%
2	45.0516	64.7798	45.2207	45.1041	0.1691	0.857149	0.1166	0.591032	68.95328
5	48.5593	68.3395	48.9979	48.9129	0.4386	2.217369	0.085	0.429723	19.37984

## DAY 32

REACTOR	DISH W.	T. WEI.	110C.	550C.	TS	%TS	VS	%VS	VS/TS (%)
	g	g	g	g	g	%	g	%	%
2	40.7054	67.0655	40.8947	40.7546	0.1893	0.718131	0.1401	0.531485	74.00951
5	46.4049	72.4985	46.9976	46.9185	0.5927	2.271438	0.0791	0.303139	13.34571

## DAY 35

REACTOR	DISH W.	T. WEI.	110C.	550C.	TS	%TS	VS	%VS	VS/TS (%)
	g	g	g	g	g	%	g	%	%
2	43.8413	66.2173	43.9912	43.8806	0.1499	0.669914	0.1106	0.49428	73.78252
5	46.4328	64.1652	46.9025	46.8149	0.4697	2.648824	0.0876	0.494011	18.6502

## DAY 42

REACTOR	DISH W.	T. WEI.	110C.	550C.	TS	%TS	VS	%VS	VS/TS (%)
	g	g	g	g	g	%	g	%	%
2	43.6826	68.5466	43.8303	43.7092	0.1477	0.594032	0.1211	0.48705	81.99052
5	47.4441	60.3028	47.9418	47.8117	0.4977	3.870531	0.1301	1.011766	26.14025

## SOLIDS FOR RUN6

DAY3									
REACTOR	DISH W. g	T. WEI. g	110C. g	550C. g	TS g	%TS %	VS g	%VS %	VS/TS (%) %
1	39.9723	59.1532	40.1998	40.1335	0.2275	1.186076	0.0663	0.345656	29.14286
3	45.1845	64.4878	45.3051	45.2346	0.1206	0.624764	0.0705	0.365223	58.45771
4	40.7032	59.834	40.9316	40.7946	0.2284	1.193886	0.137	0.716123	59.98249
DAY6									
REACTOR	DISH W. g	T. WEI. g	110C. g	550C. g	TS g	%TS %	VS g	%VS %	VS/TS (%) %
1	44.2792	59.6708	44.4393	44.4024	0.1601	1.040178	0.0369	0.239741	23.04809
3	46.4104	70.4471	46.5484	46.4566	0.138	0.574122	0.0918	0.381916	66.52174
4	47.4092	67.1023	47.5761	47.4634	0.1669	0.847505	0.1127	0.572282	67.52546
DAY10									
REACTOR	DISH W. g	T. WEI. g	110C. g	550C. g	TS g	%TS %	VS g	%VS %	VS/TS (%) %
1	44.2633	66.7764	44.5331	44.4748	0.2698	1.198413	0.0583	0.25896	21.6086
3	40.4724	61.6139	40.587	40.5019	0.1146	0.542062	0.0851	0.402526	74.25829
4	40.7036	64.0783	40.9608	40.7914	0.2572	1.100335	0.1694	0.724715	65.86314
DAY13									
REACTOR	DISH W. g	T. WEI. g	110C. g	550C. g	TS g	%TS %	VS g	%VS %	VS/TS (%) %
1	47.4002	71.6632	47.7436	47.6463	0.3434	1.415324	0.0973	0.401022	28.3343
3	48.5569	69.3717	48.705	48.6026	0.1481	0.711513	0.1024	0.491958	69.14247
4	45.0493	69.7387	45.319	45.1382	0.2697	1.092372	0.1808	0.732298	67.03745
DAY17									
REACTOR	DISH W. g	T. WEI. g	110C. g	550C. g	TS g	%TS %	VS g	%VS %	VS/TS (%) %
1	47.5332	73.7459	47.8725	47.7904	0.3393	1.294411	0.0821	0.313207	24.19688
3	46.3974	71.3312	46.5857	46.4645	0.1883	0.7552	0.1212	0.486087	64.36537
4	44.2595	74.4626	44.6783	44.4059	0.4188	1.386613	0.2724	0.901894	65.04298
DAY19									
REACTOR	DISH W. g	T. WEI. g	110C. g	550C. g	TS g	%TS %	VS g	%VS %	VS/TS (%) %
1	39.971	59.3688	40.2929	40.2232	0.3219	1.659467	0.0697	0.359319	21.65269
3	45.1863	72.727	45.5101	45.3332	0.3238	1.175714	0.1769	0.642322	54.63249
4	47.4003	67.4907	47.7572	47.5207	0.3569	1.77647	0.2365	1.177179	66.26506
DAY24									
REACTOR	DISH W. g	T. WEI. g	110C. g	550C. g	TS g	%TS %	VS g	%VS %	VS/TS (%) %
1	47.5372	70.5593	47.8631	47.8031	0.3259	1.415596	0.06	0.260619	18.41056
3	40.4618	62.272	40.6816	40.5701	0.2198	1.007785	0.1115	0.511229	50.72793
4	44.2658	65.2575	44.6177	44.3865	0.3519	1.676377	0.2312	1.101388	65.70048

## Solids Data For Run 6 Continued

## DAY27

REACTOR	DISH W.	T. WEI.	110C.	550C.	TS	%TS	VS	%VS	VS/TS (%)
	g	g	g	g	g	%	g	%	%
1	43.2525	58.136	43.4584	43.4221	0.2059	1.383411	0.0363	0.243894	17.62992
3	46.8709	64.0729	47.0192	46.9336	0.1483	0.862109	0.0856	0.497617	57.72084
4	44.8775	61.3418	45.1601	44.9646	0.2826	1.716441	0.1955	1.187418	69.17905

## DAY34

REACTOR	DISH W.	T. WEI.	110C.	550C.	TS	%TS	VS	%VS	VS/TS (%)
	g	g	g	g	g	%	g	%	%
1	41.1113	52.8941	41.2975	41.2353	0.1862	1.58027	0.0622	0.527888	33.40494
3	46.9378	61.2159	47.0774	46.9906	0.1396	0.977721	0.0868	0.607924	62.17765
4	40.6921	56.682	41.0388	40.8095	0.3467	2.168244	0.2293	1.43403	66.13787

## DAY37

REACTOR	DISH W.	T. WEI.	110C.	550C.	TS	%TS	VS	%VS	VS/TS (%)
	g	g	g	g	g	%	g	%	%
1	44.2652	74.0288	44.7074	44.624	0.4422	1.485707	0.0834	0.280208	18.86024
4	47.5373	80.2747	48.1356	47.7723	0.5983	1.827573	0.3633	1.10974	60.72205

## DAY41

REACTOR	DISH W.	T. WEI.	110C.	550C.	TS	%TS	VS	%VS	VS/TS (%)
	g	g	g	g	g	%	g	%	%
1	44.8774	69.2246	45.2648	45.2016	0.3874	1.591148	0.0632	0.259578	16.31389
4	40.7045	63.5064	41.0546	40.8547	0.3501	1.535398	0.1999	0.876681	57.09797

## DAY45

REACTOR	DISH W.	T. WEI.	110C.	550C.	TS	%TS	VS	%VS	VS/TS (%)
	g	g	g	g	g	%	g	%	%
1	46.4222	65.8878	46.7005	46.6525	0.2783	1.429702	0.048	0.246589	17.24757
4	40.4586	60.2604	40.8602	40.6197	0.4016	2.028098	0.2405	1.214536	59.88546

## DAY48

REACTOR	DISH W.	T. WEI.	110C.	550C.	TS	%TS	VS	%VS	VS/TS (%)
	g	g	g	g	g	%	g	%	%
1	48.1027	67.2778	48.3738	48.3101	0.2711	1.413813	0.0637	0.332202	23.49686
4	43.8347	65.2372	44.2958	44.0054	0.4611	2.154421	0.2904	1.356851	62.97983

## DAY52

REACTOR	DISH W.	T. WEI.	110C.	550C.	TS	%TS	VS	%VS	VS/TS (%)
	g	g	g	g	g	%	g	%	%
1	41.1031	59.7805	41.3701	41.3184	0.267	1.429535	0.0517	0.276805	19.3633
4	40.4579	57.6381	40.723	40.5593	0.2651	1.543055	0.1637	0.952841	61.75028

## DAY55

REACTOR	DISH W.	T. WEI.	110C.	550C.	TS	%TS	VS	%VS	VS/TS (%)
	g	g	g	g	g	%	g	%	%
1	46.934	64.7345	47.1877	47.144	0.2537	1.425241	0.0437	0.245499	17.22507
4	43.253	63.0143	43.5322	43.3688	0.2792	1.412863	0.1634	0.826869	58.52436

## SOLIDS DATA FOR RUN7

	Dish Weight	Total Weight Dish+Sample	Weight Of Sample After Drying at 110C	Weight Of Sample After Drying at 550C	Total Solids Of Sample	% Total Solids Of Sample	Volatile Solids In Sample	% Volatile Solids In Sample	Ratio Volatile To Total Solids
DAY1									
REACTOR	DISH W.	T. WEI.	110C.	550C.	TS	%TS	VS	%VS	VS/TS (%)
	g	g	g	g	g	%	g	%	%
2	46.8694	79.3042	47.194	47.002	0.3246	1.000777	0.192	0.591957	59.14972
3	43.2505	65.157	43.50058	43.3557	0.25008	1.141579	0.14488	0.661356	57.93346
5	39.9691	64.2337	40.1053	40.0309	0.1362	0.561312	0.0744	0.30662	54.62555
DAY5									
REACTOR	DISH W.	T. WEI.	110C.	550C.	TS	%TS	VS	%VS	VS/TS (%)
	g	g	g	g	g	%	g	%	%
2	40.6847	65.3388	40.8365	40.7378	0.1518	0.615719	0.0987	0.400339	65.01976
3	45.0548	70.1234	45.2997	45.1495	0.2449	0.976919	0.1502	0.599156	61.33116
5	43.6843	70.4452	43.8043	43.7387	0.12	0.448415	0.0656	0.245134	54.66667
DAY9									
REACTOR	DISH W.	T. WEI.	110C.	550C.	TS	%TS	VS	%VS	VS/TS (%)
	g	g	g	g	g	%	g	%	%
2	46.4036	64.1387	46.5237	46.448	0.1201	0.677188	0.0757	0.426837	63.03081
3	41.1073	60.6154	41.3231	41.1868	0.2158	1.106207	0.1363	0.698684	63.16033
5	46.9352	66.3704	47.0978	47.0065	0.1626	0.836626	0.0913	0.469766	56.15006
DAY12									
REACTOR	DISH W.	T. WEI.	110C.	550C.	TS	%TS	VS	%VS	VS/TS (%)
	g	g	g	g	g	%	g	%	%
2	47.4001	65.8603	47.5106	47.435	0.1105	0.598585	0.0756	0.40953	68.41629
3	48.5595	67.3763	48.7852	48.6336	0.2257	1.19946	0.1516	0.805663	67.16881
5	45.1856	67.1259	45.5076	45.3222	0.322	1.467619	0.1854	0.84502	57.57764
DAY16									
REACTOR	DISH W.	T. WEI.	110C.	550C.	TS	%TS	VS	%VS	VS/TS (%)
	g	g	g	g	g	%	g	%	%
2	46.4003	66.3305	46.549	46.4555	0.1487	0.746104	0.0935	0.469137	62.87828
3	47.4003	64.6242	47.5772	47.4641	0.1769	1.027061	0.1131	0.656646	63.93443
5	43.8351	63.8134	44.0889	43.9721	0.2538	1.270378	0.1168	0.584634	46.02049
DAY19									
REACTOR	DISH W.	T. WEI.	110C.	550C.	TS	%TS	VS	%VS	VS/TS (%)
	g	g	g	g	g	%	g	%	%
2	45.1848	69.0958	45.3716	45.2591	0.1868	0.78123	0.1125	0.470495	60.22484
3	39.9695	61.981	40.1814	40.0472	0.2119	0.962679	0.1342	0.609681	63.33176
5	45.0573	65.147	45.3259	45.2025	0.2686	1.337004	0.1234	0.614245	45.94192
DAY23									
REACTOR	DISH W.	T. WEI.	110C.	550C.	TS	%TS	VS	%VS	VS/TS (%)
	g	g	g	g	g	%	g	%	%
2	43.6824	61.2965	43.7974	43.7254	0.115	0.652886	0.072	0.408763	62.6087
3	40.709	59.786	40.8676	40.7697	0.1586	0.831368	0.0979	0.513183	61.72762
5	40.6876	58.9077	40.8589	40.7802	0.1713	0.94017	0.0787	0.431941	45.94279

## Run 7 Solids (Continued):

## DAY26

REACTOR	DISH W. g	T. WEI. g	110C. g	550C. g	TS g	%TS %	VS g	%VS %	VS/TS (%)
2	40.4632	55.202	40.5604	40.5014	0.0972	0.659484	0.059	0.400304	60.69959
3	47.4039	65.4227	47.5769	47.4556	0.173	0.960108	0.1213	0.673186	70.11561
5	43.837	57.094	44.029	43.9277	0.192	1.448291	0.1013	0.764125	52.76042

## DAY30

REACTOR	DISH W. g	T. WEI. g	110C. g	550C. g	TS g	%TS %	VS g	%VS %	VS/TS (%)
2	43.2549	58.1111	43.3515	43.2938	0.0968	0.650234	0.0577	0.38839	59.73085
3	46.9357	67.0196	47.0846	46.9878	0.1489	0.74139	0.0968	0.481978	65.01007
5	40.7039	61.2025	40.9915	40.8817	0.2876	1.403023	0.1098	0.535646	38.17803

## DAY33

REACTOR	DISH W. g	T. WEI. g	110C. g	550C. g	TS g	%TS %	VS g	%VS %	VS/TS (%)
2	46.4043	66.026	46.5212	46.4483	0.1169	0.595769	0.0729	0.371527	62.36099
3	43.6892	64.0575	43.8279	43.7353	0.1387	0.68096	0.0926	0.454628	66.7628
5	45.1923	64.7658	45.4101	45.3008	0.2178	1.112729	0.1093	0.558408	50.18365

## DAY37

REACTOR	DISH W. g	T. WEI. g	110C. g	550C. g	TS g	%TS %	VS g	%VS %	VS/TS (%)
2	43.6885	62.258	43.7803	43.7154	0.0918	0.494359	0.0649	0.349498	70.69717
3	45.1864	64.8301	45.3382	45.2361	0.1518	0.772767	0.1021	0.51976	67.25955
5	40.7059	60.6906	40.9163	40.8526	0.2104	1.052805	0.0637	0.318744	30.27567

## DAY40

REACTOR	DISH W. g	T. WEI. g	110C. g	550C. g	TS g	%TS %	VS g	%VS %	VS/TS (%)
2	43.836	66.4546	43.9348	43.869	0.0988	0.436809	0.0658	0.290911	66.59919
3	46.4081	62.1139	46.5187	46.4334	0.1106	0.704198	0.0853	0.543111	77.12477
5	46.9376	66.2667	47.0967	47.0521	0.1591	0.823111	0.0446	0.23074	28.03268

## SOLIDS DATA FOR RUN8

		Total Weight Of Sample+dish	Sample Weight After Drying At 110C	Sample Weight After Drying At 550C	Total Solids In Sample	% Total Solids In Sample	Volatile Solids In Sample	% Volatile Solids In Sample	Ratio Of Volatile To Total Solids
DAY1	Dish Weight								
REACTOR	DISH W. g	T. WEI. g	110C. g	550C. g	TS g	%TS %	VS g	%VS %	VS/TS (%) %
1	46.8662	68.0069	46.9657	46.9213	0.0995	0.470656	0.0444	0.210021	44.62312
4	44.2694	52.94	44.3247	44.294	0.0553	0.637787	0.0307	0.35407	55.51537
DAY3									
REACTOR	DISH W. g	T. WEI. g	110C. g	550C. g	TS g	%TS %	VS g	%VS %	VS/TS (%) %
1	47.5412	64.2477	47.5805	47.5644	0.0393	0.235238	0.0161	0.09637	40.96692
4	44.8795	61.1273	44.9447	44.9036	0.0652	0.401285	0.0411	0.252957	63.03681
DAY6									
REACTOR	DISH W. g	T. WEI. g	110C. g	550C. g	TS g	%TS %	VS g	%VS %	VS/TS (%) %
1	46.4033	57.7806	46.4894	46.4393	0.0861	0.75677	0.0501	0.440351	58.18815
4	41.1078	59.1414	41.214	41.1393	0.1062	0.588901	0.0747	0.414227	70.33898
DAY10									
REACTOR	DISH W. g	T. WEI. g	110C. g	550C. g	TS g	%TS %	VS g	%VS %	VS/TS (%) %
1	44.8784	58.185	44.9253	44.9118	0.0469	0.352457	0.0135	0.101453	28.78465
4	46.8676	63.3498	46.9396	46.893	0.072	0.436835	0.0466	0.282729	64.72222
DAY13									
REACTOR	DISH W. g	T. WEI. g	110C. g	550C. g	TS g	%TS %	VS g	%VS %	VS/TS (%) %
1	44.2665	64.3785	44.4069	44.3467	0.1404	0.698091	0.0602	0.299324	42.87749
4	43.8366	64.0742	43.9356	43.8664	0.099	0.489188	0.0692	0.341938	69.89899
DAY17									
REACTOR	DISH W. g	T. WEI. g	110C. g	550C. g	TS g	%TS %	VS g	%VS %	VS/TS (%) %
1	46.8663	67.8255	46.9812	46.9314	0.1149	0.548208	0.0498	0.237604	43.34204
4	44.877	67.3762	44.9814	44.9026	0.1044	0.464016	0.0788	0.350235	75.47893
DAY20									
REACTOR	DISH W. g	T. WEI. g	110C. g	550C. g	TS g	%TS %	VS g	%VS %	VS/TS (%) %
1	43.2577	60.3421	43.324	43.2917	0.0663	0.388073	0.0323	0.189061	48.71795
4	44.2662	54.9943	44.3134	44.2726	0.0472	0.439966	0.0408	0.38031	86.44068

## SOLIDS DATA FOR RUN 9

SOLIDS DATA FOR RUN 9			Weight After Drying At	Weight After Drying At	Total Solids Of Sample	% Total Solids Of Sample	Volatile Solids Of Sample	% Volatile Solids Of Sample	Ratio Volatile To Total Solids
DAY1 REACTOR	Dish Weight DISH W.	Weight Sample+dish T. WEI.	110C. 110C.	550C. 550C.	TS g	%TS %	VS g	%VS %	VS/TS (%) %
2	48.1064	68.3504	48.1969	48.1449	0.0905	0.447046	0.052	0.256866	57.45856
3	48.5753	58.1601	48.6065	48.5875	0.0312	0.325515	0.019	0.198231	60.89744
5									
DAY3									
DAY3 REACTOR	DISH W. g	T. WEI. g	110C. g	550C. g	TS g	%TS %	VS g	%VS %	VS/TS (%) %
2	40.4659	60.4957	40.4984	40.4767	0.0325	0.162258	0.0217	0.108339	66.76923
3	40.6895	62.4966	40.7873	40.745	0.0978	0.448478	0.0423	0.193974	43.25153
5	46.4272	65.4672	46.9702	46.8499	0.543	2.851891	0.1203	0.631828	22.1547
DAY6									
DAY6 REACTOR	DISH W. g	T. WEI. g	110C. g	550C. g	TS g	%TS %	VS g	%VS %	VS/TS (%) %
2	46.8681	68.8505	46.9189	46.8866	0.0508	0.231094	0.0323	0.146936	63.58268
3	44.2673	64.3266	44.3585	44.3196	0.0912	0.454652	0.0389	0.193925	42.65351
5	40.7024	60.3131	41.092	41.066	0.3896	1.986671	0.026	0.132581	6.673511
DAY10									
DAY10 REACTOR	DISH W. g	T. WEI. g	110C. g	550C. g	TS g	%TS %	VS g	%VS %	VS/TS (%) %
2	43.2541	66.9559	43.2893	43.2668	0.0352	0.148512	0.0225	0.094929	63.92045
3	44.8777	66.9075	44.9697	44.9323	0.092	0.417616	0.0374	0.16977	40.65217
5	43.696	62.2049	43.9617	43.9133	0.2657	1.435526	0.0484	0.261496	18.21603
DAY13									
DAY13 REACTOR	DISH W. g	T. WEI. g	110C. g	550C. g	TS g	%TS %	VS g	%VS %	VS/TS (%) %
2	47.5424	63.8477	47.5725	47.5522	0.0301	0.184603	0.0203	0.124499	67.44186
3	40.6869	60.1743	40.7677	40.7333	0.0808	0.414627	0.0344	0.176524	42.57426
5	48.565	68.4526	48.8453	48.7895	0.2803	1.409421	0.0558	0.280577	19.90724
DAY17									
DAY17 REACTOR	DISH W. g	T. WEI. g	110C. g	550C. g	TS g	%TS %	VS g	%VS %	VS/TS (%) %
2	44.881	64.6897	44.9145	44.8915	0.0335	0.169118	0.023	0.116111	68.65672
3	41.1135	57.358	41.1733	41.1455	0.0598	0.368125	0.0278	0.171135	46.48829
5	45.0594	62.206	45.306	45.2308	0.2466	1.438186	0.0752	0.438571	30.49473
DAY20									
DAY20 REACTOR	DISH W. g	T. WEI. g	110C. g	550C. g	TS g	%TS %	VS g	%VS %	VS/TS (%) %
2	46.4251	63.1832	46.4536	46.4329	0.0285	0.170067	0.0207	0.123522	72.63158
3	44.2694	60.417	44.3339	44.3055	0.0645	0.39944	0.0284	0.175878	44.03101
5	43.8428	58.8989	44.0546	43.9722	0.2118	1.406739	0.0824	0.547286	38.90463
DAY24									
DAY24 REACTOR	DISH W. g	T. WEI. g	110C. g	550C. g	TS g	%TS %	VS g	%VS %	VS/TS (%) %
2	46.8705	64.9563	46.8959	46.8767	0.0254	0.140442	0.0192	0.106161	75.59055
5	46.4123	59.6933	46.6024	46.5701	0.1901	1.431368	0.0323	0.243205	16.99106

SOLIDS DATA FOR RUN10

		Total Weight Of	Weight After	Weight After	Total Solids	%Total	Volatile	%Volatile	Ratio
	Dish	Weight Of	Drying At	Drying At	In Sample	Solids	Solids	Solids	Volatile To
DAY1	Weight	Dish+Sample	110C	550C.		In Sample	In Sample	In Sample	Total Solids
REACTOR	DISH W.	T. WEI.	110C.	550C.	TS	%TS	VS	%VS	VS/TS (%)
	g	g	g	g	g	%	g	%	%
3	40.4647	54.7167	40.5427	40.5009	0.078	0.547292	0.0418	0.293292	53.58974
DAY3									
REACTOR	DISH W.	T. WEI.	110C.	550C.	TS	%TS	VS	%VS	VS/TS (%)
	g	g	g	g	g	%	g	%	%
3	40.7056	56.1338	40.7766	40.7353	0.071	0.460196	0.0413	0.267692	58.16901
DAY6									
REACTOR	DISH W.	T. WEI.	110C.	550C.	TS	%TS	VS	%VS	VS/TS (%)
	g	g	g	g	g	%	g	%	%
3	46.8701	65.8366	46.9558	46.9058	0.0857	0.451849	0.05	0.263623	58.34306
DAY10									
REACTOR	DISH W.	T. WEI.	110C.	550C.	TS	%TS	VS	%VS	VS/TS (%)
	g	g	g	g	g	%	g	%	%
3	48.1035	65.9582	48.2035	48.1413	0.1	0.560077	0.0622	0.348368	62.2
DAY13									
REACTOR	DISH W.	T. WEI.	110C.	550C.	TS	%TS	VS	%VS	VS/TS (%)
	g	g	g	g	g	%	g	%	%
3	40.7015	55.4219	40.7886	40.7377	0.0871	0.591696	0.0509	0.345779	58.43858
DAY17									
REACTOR	DISH W.	T. WEI.	110C.	550C.	TS	%TS	VS	%VS	VS/TS (%)
	g	g	g	g	g	%	g	%	%
3	46.8696	64.258	46.973	46.9096	0.1034	0.594649	0.0634	0.364611	61.31528

## Run 10 Solids Continued:

Run 15 Series Continued.

DAY21										
REACTOR	DISH W.	T. WEI.	110C.	550C.	TS	%TS	VS	%VS	VS/TS (%)	
	g	g	g	g	g	%	g	%	%	
3	40.4634	56.1501	40.5441	40.4902	0.0807	0.514449	0.0539	0.343603	66.79058	
DAY24										
REACTOR	DISH W.	T. WEI.	110C.	550C.	TS	%TS	VS	%VS	VS/TS (%)	
	g	g	g	g	g	%	g	%	%	
3	48.5627	61.0188	48.6304	48.5831	0.0677	0.543509	0.0473	0.379734	69.86706	
DAY27										
REACTOR	DISH W.	T. WEI.	110C.	550C.	TS	%TS	VS	%VS	VS/TS (%)	
	g	g	g	g	g	%	g	%	%	
3	40.6985	55.5358	40.7855	40.7325	0.087	0.58636	0.053	0.357208	60.91954	
DAY31										
REACTOR	DISH W.	T. WEI.	110C.	550C.	TS	%TS	VS	%VS	VS/TS (%)	
	g	g	g	g	g	%	g	%	%	
3	48.1007	61.8015	48.1771	48.1308	0.0764	0.557632	0.0463	0.337936	60.60209	
DAY34										
REACTOR	DISH W.	T. WEI.	110C.	550C.	TS	%TS	VS	%VS	VS/TS (%)	
	g	g	g	g	g	%	g	%	%	
3	41.1062	56.355	41.1956	41.1396	0.0894	0.586276	0.056	0.367242	62.63982	
DAY38										
REACTOR	DISH W.	T. WEI.	110C.	550C.	TS	%TS	VS	%VS	VS/TS (%)	
	g	g	g	g	g	%	g	%	%	
3	43.8393	57.471	43.9094	43.865	0.0701	0.514243	0.0444	0.325711	63.33809	

## SOLIDS DATA FOR RUN11

		Total Weight Dish Sample+Dist	Weight After Drying At 110C.	Weight After Drying At 550C.	Total Solids Of Sample TS	% Total Solids Of Sample %TS	Volatile Solids Of Sample VS	% Volatile Solids Of Sample %VS	Ratio Volatile To Total Solids VS/TS (%)
DAY1 REACTOR	DISH W. g	T. WEI. g	110C. g	550C. g	g	%	g	%	%
1	43.2529	59.1823	43.4696	43.4021	0.2167	1.360378	0.0675	0.423745	31.14905
2	40.4622	58.1971	40.6191	40.5263	0.1569	0.884696	0.0928	0.523262	59.14595
4	44.2672	61.0468	44.5811	44.3939	0.3139	1.870724	0.1872	1.11564	59.63683
DAY3 REACTOR	DISH W. g	T. WEI. g	110C. g	550C. g	TS g	%TS %	VS g	%VS %	VS/TS (%) %
1	46.427	62.5158	46.6723	46.5862	0.2453	1.524663	0.0861	0.535155	35.09988
2	40.7066	52.9501	40.767	40.7269	0.0604	0.493323	0.0401	0.327521	66.39073
4	45.1906	57.1923	45.3417	45.2433	0.1511	1.258988	0.0984	0.819884	65.12244
DAY6 REACTOR	DISH W. g	T. WEI. g	110C. g	550C. g	TS g	%TS %	VS g	%VS %	VS/TS (%) %
1	43.2523	58.9021	43.469	43.3954	0.2167	1.384682	0.0736	0.470294	33.96401
2	44.2685	63.7238	44.4097	44.3265	0.1412	0.725766	0.0832	0.427647	58.92351
4	46.9351	63.2141	47.1477	47.018	0.2126	1.305977	0.1297	0.796732	61.00659
DAY10 REACTOR	DISH W. g	T. WEI. g	110C. g	550C. g	TS g	%TS %	VS g	%VS %	VS/TS (%) %
1	48.1043	62.7148	48.319	48.2449	0.2147	1.469491	0.0741	0.50717	34.51327
2	46.4243	63.155	46.5158	46.4559	0.0915	0.546899	0.0599	0.358024	65.46448
4	45.1888	62.5811	45.4548	45.2895	0.266	1.529412	0.1653	0.950421	62.14286
DAY14 REACTOR	DISH W. g	T. WEI. g	110C. g	550C. g	TS g	%TS %	VS g	%VS %	VS/TS (%) %
1	41.1062	56.0307	41.3055	41.2605	0.1993	1.335388	0.045	0.301518	22.57903
2	43.8426	56.6458	43.9051	43.8583	0.0625	0.488159	0.0468	0.365534	74.88
4	40.687	55.7762	40.8511	40.7387	0.1641	1.087533	0.1124	0.744904	68.49482
DAY17 REACTOR	DISH W. g	T. WEI. g	110C. g	550C. g	TS g	%TS %	VS g	%VS %	VS/TS (%) %
1	45.057	59.9019	45.295	45.2283	0.238	1.603244	0.0667	0.449313	28.02521
2	47.5403	60.343	47.6231	47.5681	0.0828	0.646739	0.055	0.429597	66.42512
4	44.8803	60.0669	45.0354	44.9323	0.1551	1.021295	0.1031	0.678888	66.47324
DAY20 REACTOR	DISH W. g	T. WEI. g	110C. g	550C. g	TS g	%TS %	VS g	%VS %	VS/TS (%) %
1	46.864	59.3992	47.1149	47.0333	0.2509	2.001564	0.0816	0.650967	32.52292
2	46.4187	59.4553	46.5359	46.4658	0.1172	0.899007	0.0701	0.537717	59.81229
4	45.1852	59.7332	45.3824	45.2536	0.1972	1.355513	0.1288	0.885345	65.3144

## Solids Run 11 (Continued)

## DAY24

REACTOR	DISH W. g	T. WEI. g	110C. g	550C. g	TS g	%TS %	VS g	%VS %	VS/TS (%) %
1	44.2661	58.7794	44.5107	44.4428	0.2446	1.685351	0.0679	0.467847	27.75961
2	43.2499	57.2888	43.3858	43.3012	0.1359	0.968025	0.0846	0.602611	62.25166
4	46.9354	59.058	47.0553	46.9784	0.1199	0.989062	0.0769	0.634352	64.13678

## DAY27

REACTOR	DISH W. g	T. WEI. g	110C. g	550C. g	TS g	%TS %	VS g	%VS %	VS/TS (%) %
1	48.562	62.2466	48.8542	48.7491	0.2922	2.135247	0.1051	0.768017	35.96851
2	47.5394	63.2145	47.6339	47.5686	0.0945	0.602867	0.0653	0.416584	69.10053
4	45.0581	58.0788	45.2163	45.1143	0.1582	1.214988	0.102	0.783368	64.47535

## DAY31

REACTOR	DISH W. g	T. WEI. g	110C. g	550C. g	TS g	%TS %	VS g	%VS %	VS/TS (%) %
1	40.6862	55.1312	40.9556	40.8692	0.2694	1.865005	0.0864	0.598131	32.07127
2	40.4629	52.1807	40.5371	40.4873	0.0742	0.633225	0.0498	0.424994	67.1159
4	44.8793	67.6041	45.132	44.9679	0.2527	1.112001	0.1641	0.722119	64.93866

METAL CONCENTRATION FOR BOTH TOTAL AND DISSOLVED COPPER  
FOR RUN 6

REACTOR1	SAMPLE	TOTAL	SAMPLE	DISOLVED
SAMPLE	CONC.(T)	TOT. CONC	D. CONC.	TOT. DIS.
Days	mg/L	mg/L	mg/L	mg/L
19	0.8	32		
24	0.8	32	0.1	4
27	0.7	28	0.3	12
34	0.8	32	0.2	8
37	1	40	0.2	8
41	1.1	44	0.2	8
45	0.7	28	0.56	5.6
48	0.8	32	0.17	6.8
52	0.8	32	0.67	6.7
55	0.8	32	0.23	9.2

REACTOR2	SAMPLE	CONC.(T)	TOT. CONC	D. CONC.	TOT. DIS.
	Days	mg/L	mg/L	mg/L	mg/L
IIT26		0.95	38		
IIT32		0.95	38	0.1	4
IIT35		0.7	28	0.1	4
IIT42		0.8	32	0.1	4

REACTOR3	SAMPLE	CONC.(T)	TOT. CONC	D. CONC.	TOT. DIS.
	Days	mg/L	mg/L	mg/L	mg/L
IIIT19		1	40	0.1	4
IIIT24		0.7	28	0.1	4
IIIT27		1	40	0.1	4
IIIT34		0.7	28	0.2	8

REACTOR4	SAMPLE	CONC.(T)	TOT. CONC	D. CONC.	TOT. DIS.
	Days	mg/L	mg/L	mg/L	mg/L
IVT19		2.1	84	0.2	8
IVT24		2.1	84	0.2	8
IVT27		2	80	0.2	8
IVT34		2.2	88	0.2	8
IVT37		2.2	88	0.3	12
IVT41		2.2	88	0.4	16
IVT45		1.9	76	0.438	4.38
IVT48		2.2	88	0.2	8
IVT52		1.9	76	0.53	5.3
IVT55		1.8	72	0.23	9.2

METAL CONCENTRATION FOR BOTH TOTAL AND DISOLVED COPPER  
FOR RUN 7

REACTOR2

SAMPLE DAYS	CONC.(T) mg/L	TOT. CONC mg/L	D. CONC. mg/L	TOT. DIS. mg/L
1	2	80	0	0
5	2	80	0.1	4
9	1.8	72	0.32	3.2
12	1.9	76	0.14	5.6
16	1.8	72	0.2	2
19	1.7	68	0.2	2
22	1.8	72	0.12	2.4
26	1.8	72	0.16	3.2
30	1.7	68	0.295	5.9
33	1.75	70	0.202	4.04
37	1.7	68	0.203	2.706667
40	1.7	68	0.219	2.92

SAMPLE DAYS	CONC.(T) mg/L	TOT. CONC mg/L	D. CONC. mg/L	TOT. DIS. mg/L
IIIT1	2.1	84	0	0
IIIT5	2	80	0.1	4
IIIT9	1.9	76	0.51	5.1
IIIT12	2	80	0.17	6.8
IIIT16	1.9	76	0.63	6.3
IIIT19	2	80	0.27	5.4
IIIT22	1.9	76	0.2	4
IIIT26	1.9	76	0.26	5.2
IIIT30	1.8	72	0.239	4.78
IIIT33	1.85	74	0.186	3.72
IIIT37	2	80	0.26	3.466667
IIIT40	2	80	0.222	2.96

REACTOR 5 (Control)

SAMPLE DAYS	CONC.(T) mg/L	TOT. CONC mg/L	D. CONC. mg/L	TOT. DIS. mg/L
VT1	1.2	48	0	0
VT5	1.2	48	0.1	4
VT9	1.3	52	0.38	3.8
VT12	1.4	56	0.15	6
VT16	1.4	56	0.49	4.9
VT19	1.4	56	0.16	6.4
VT22	1.3	52	0.16	6.4
VT26	1.5	60	0.15	6
VT30	1.4	56	0.28	5.6
VT33	1.5	60	0.23	4.6
VT37	1.55	62	0.232	3.093333
VT40	1.5	60	0.247	3.293333

BOTH DISSOLVED AND TOTAL COPPER CONCENTRATION  
FOR RUN 8

For Reactor 1 (Control)

Time Days	TOTAL SAMPLE		TOTAL DISSOLVED	
	CONC.	TOT. CONC	SAMPLE CONC.	DISSOLVED TOT. CONC
1	2.4	48	0.2	2
3	2.5	50	0.123	2.46
6	2.5	50	0.124	2.48
10	2.52	50.4	0.268	5.36
13	2.51	50.2	0.227	4.54
17	2.47	49.4	0.207	2.76
20	2.42	48.4	0.326	4.346667
24	2.51	50.2	0.18	1.8
27	2.53	50.6	0.285	2.85
31	5.1	51	0.39	3.9
34	5.2	52	0.209	2.09
38	5.1	51	0.347	3.47
41	4.785	47.85	0.462	4.62
45	4.716	47.16	0.461	4.61
48	5.1	51	0.449	4.49

Reactor 4

Time Days	TOTAL SAMPLE		TOTAL DISSOLVED	
	CONC.	TOT. CONC	SAMPLE CONC.	DISSOLVED TOT. CONC
1	2.1	42	0.11	1.1
3	1.9	38	0.145	2.9
6	2.1	42	0.106	2.12
10	1.9	38	0.143	2.86
13	1.9	38	0.115	2.3
17	2.1	42	0.201	2.68
20	2.07	41.4	0.143	1.907
24	2	40	0.129	1.29
27	2.1	42	0.1	1
31	4.05	40.5	0.655	6.55
34	4.11	41.1	0.328	3.28
38	4.051	40.51	0.409	4.09
41	3.952	39.52	0.288	2.88
45	3.896	38.96	0.318	3.18
48	3.961	39.61	0.343	3.43

# Copper Concentrations Both Dissolved And Total For Run 9

## For Reactor 2

Time DAY	Dil. Sample		Dil. Sample	
	Total CONC.	Reactor 2 TOT. CONC	DISOLVED CONC.	Reactor 2 TOT. CONC
	mg/L	mg/L	mg/L	mg/L
1	0	0	0.07	0.7
3	0.709	7.09	0.115	1.15
6	0.617	6.17	0.105	1.05
10	0.916	9.16	0.126	1.26
13	0.97	9.7	0.142	1.42
17	0.854	8.54	0.212	2.12
20	0.73	7.3	0.269	2.69
24	0.822	8.22	0.194	1.94
27	0.732	7.32	0.156	1.56

## For Reactor 3

Time DAY	Dil. Sample		Dil. Sample	
	Total CONC.	Reactor 2 TOT. CONC	DISOLVED CONC.	Reactor 2 TOT. CONC
	mg/L	mg/L	mg/L	mg/L
1	0.976	9.76	0.086	0.86
3	0.883	8.83	0.222	2.22
6	1.134	11.34	0.147	1.47
10	1.079	10.79	0.393	3.93
13	1.274	12.74	0.439	4.39
17	1.163	11.63	0.199	1.99
20	1.032	10.32	0.55	5.5

## For Reactor 5 (Control)

Time DAY	Dil. Sample		Dil. Sample	
	Total CONC.	Reactor 2 TOT. CONC	DISOLVED CONC.	Reactor 2 TOT. CONC
	mg/L	mg/L	mg/L	mg/L
1	0.958	38.32	0.243	9.72
3	0.958	38.32	0.243	9.72
6	0.947	37.88	0.519	20.76
10	1.087	43.48	0.516	20.64
13	1.196	47.84	0.448	17.92
17	1.056	42.24	0.509	20.36
20	1.145	45.8	0.481	19.24
24	0.946	37.84	0.492	19.68
27	1.254	50.16	0.437	17.48

BOTH TOTAL AND DISSOLVED COPPER CONCENTRATION FOR RUN 10

REACTOR3 DAY	DILUTED SAMPLE TOTAL		DILUTED SAMPLE DISSOLVED	
	CONC.	TOT. CONC	CONC.	TOT. CONC.
	mg/L	mg/L	mg/L	mg/L
1	1.125	22.5	0.179	3.58
3	0.869	17.38	0.211	4.22
6	1.929	19.29	0.422	4.22
10	0.955	19.1	0.289	5.78
13	0.755	18.875	0.125	3.125
17	0.946	18.92	0.15	3
21	0.989	19.78	0.155	3.1
24	1.093	21.86	0.084	1.68
27	1.052	21.04	0.157	3.14
31	1.115	22.3	0.121	2.42
34	0.928	18.56	0.194	3.88
38	0.974	19.48	0.508	10.16
41	0.922	18.44	0.228	4.56
47	0.866	17.32	0.189	3.78

# TOTAL AND DISSOLVED COPPER CONCENTRATION FOR RUN 11

## For Reactor 1 (Control)

Time	Diluted Sample	Reactor1	Diluted Sample	Reactor1
DAYS	TOTAL CONC.	TOT. CONC	DISOLVED CONC.	Dissolved Conc.
	mg/L	mg/L	mg/L	mg/L
1	1.223	48.92	0.228	9.12
3	1.348	53.92	0.219	8.76
6	1.771	44.275	0.102	2.55
10	2.685	53.7	0.202	4.04
14	2.52	50.4	0.626	12.52
17	2.218	44.36	0.305	6.1
21	2.566	51.32	0.524	10.48
24	2.368	47.36	0.44	8.8
27	2.693	53.86	0.546	10.92
31	2.725	54.5	0.65	13
34	2.643	52.86	0.397	7.94
40	2.413	48.26	0.661	13.22

## For Reactor 2

Time	Diluted Sample	Reactor2	Diluted Sample	Reactor2
DAYS	TOTAL CONC.	TOT. CONC	DISOLVED CONC.	Dissolved Conc.
	mg/L	mg/L	mg/L	mg/L
1	1.197	47.88	0.151	6.04
3	0.997	39.88	0.136	5.44
6	1.866	46.65	0.081	2.025
10	2.164	43.28	0.033	0.66
14	1.996	39.92	0.184	3.68
17	2.175	43.5	0.081	1.62
21	2.013	40.26	0.105	2.1
24	2.313	46.26	0.112	2.24
27	2.221	44.42	0.296	5.92
31	2.202	44.04	0.214	4.28
34	2.295	45.9	0.124	2.48
40	2.2	44	0.135	2.7

## For Reactor 4

Time	Diluted Sample	Reactor4	Diluted Sample	Reactor4
DAYS	TOTAL CONC.	TOT. CONC	DISOLVED CONC.	Dissolved Conc.
	mg/L	mg/L	mg/L	mg/L
1	2.839	56.78	0.139	5.56
3	1.567	62.68	0.227	9.08
6	2.545	63.625	0.119	2.975
10	3.331	66.62	0.163	3.26
14	3.164	63.28	0.165	3.3
17	2.942	58.84	0.122	2.44
21	2.969	59.38	0.133	2.66
24	2.755	55.1	0.158	3.16
27	3.119	62.38	0.208	4.16
31	2.939	58.78	0.299	5.98
34	2.941	58.82	0.16	3.2
40	2.942	58.84	0.292	5.84

# NUTIENT ANALYSIS FOR RUN 5

## Phosphorous Concentration Vs Time

	Reactor2	Reactor2	Reactor5	Reactor5
TIME	ORTHO-P	TOTAL	ORTHO-P	TOTAL
Days	Diluted	mg/L	Diluted	mg/L
4	0.526	5.26	0.391	3.91
11	6.176	61.76	0.382	3.82
18	3.53	35.3	0.502	5.02
25	8.5	85	0.651	6.51
32	7.3932	73.932	0.435	4.35
42	8.989	89.89	0.554	5.54

## Ammonia Concentration Vs Time

	Reactor2	Reactor2	Reactor5	Reactor5
TIME	NH4+	TOTAL	NH4+	TOTAL
Days	Diluted	mg/L	Diluted	mg/L
4	0.109	1.09	0.429	4.29
11	5.569	55.69	0.179	1.79
18	0.078	0.78	0.369	3.69
25	5.583	55.83	0.077	0.77
32	2.877	28.77	0.631	6.31
42	8.643	86.43	0.608	6.08

## Nutrient Analysis For Run 6

### Phosphorous Concentration Vs Time

	Reactor1	Reactor1	Reactor3	Reactor3	Reactor4	Reactor4
TIME	ORTHO-P	TOTAL	ORTHO-P	TOTAL	ORTHO-P	TOTAL
Days	Diluted	mg/L	Diluted	mg/L	Diluted	mg/L
3	0.723	7.23	6.464	64.64	5.052	50.52
10	0.732	7.32	3.98	39.8	1.11	11.1
17	0.774	7.74	9.015	90.15	5.45	54.5
24	0.62	6.2	8.113	81.13	1.808	18.08
34	0.41	4.1	10.517	105.17	1.543	15.43
37	0.431	4.31			0.781	7.81
48	0.7	7			2.736	27.36
55	0.996	9.96			3.784	37.84

### Ammonia Concentration Vs Time

	Reactor1	Reactor1	Reactor3	Reactor3	Reactor4	Reactor4
Time	NH4+	TOTAL	NH4+	TOTAL	NH4+	TOTAL
Days	Diluted	mg/L	Diluted	mg/L	Diluted	mg/L
3	0.529	5.29	6.287	62.87	5.461	54.61
10	0.166	1.66	0.133	1.33	0.154	1.54
17	0.216	2.16	5.014	50.14	4.407	44.07
24	0.313	3.13	1.162	11.62	0.284	2.84
34	1.39	13.9	2.402	24.02	5.957	59.57
37	0.219	2.19			2.954	29.54
55	0.848	8.48			5.786	57.86

## NUTRIENT ANALYSIS FOR RUN 7

### Phosphorous Concentration vs Time For Run 7

Time	Reactor2	Reactor2	Reactor3	Reactor3	Reactor5	Reactor5
DAYS	Sample	Tot. Conc.	Sample	Tot. Conc.	Sample	Tot. Conc.
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	0.27	2.7	0.533	5.33	0.178	1.78
12	12.593	125.93	17.735	177.35	0.525	5.25
19	23.257	232.57	19.839	198.39	0.742	7.42
23	22.829	228.29	19.697	196.97	0.437	4.37
26	21.231	212.31	17.67	176.7	0.557	5.57
30	22.107	221.07	17.811	178.11	1.374	13.74
33	21.379	213.79	16.571	165.71	1.401	14.01
37	8.825	220.625	7.192	179.8	1.231	6.155
40	13.432	223.8667	9.637	160.6167	1.767	8.835

### Ammonia Concentration Vs Time For Run 7

Time	Reactor2	Reactor2	Reactor3	Reactor3	Reactor5	Reactor5
DAYS	Sample	Tot. Conc.	Sample	Tot. Conc.	Sample	Tot. Conc.
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	0.85	8.5	0.548	5.48	0.193	1.93
12	73.675	736.75	51.435	514.35	0.21	2.1
19	61.149	611.49	43.166	431.66	0.092	0.92
23	55.334	553.34	39.08	390.8	0.11	1.1
26	63.351	633.51	42.773	427.73	0.194	1.94
30	62.569	625.69	42.799	427.99	0.831	8.31
33	61.964	619.64	41.241	412.41	0.395	3.95
37	31.796	794.9	18.385	459.625	0.367	1.835
40	44.304	738.4	26.674	444.5667	0.185	0.925

# NUTRIENT ANALYSIS FOR RUN 8

## Phosphorous Concentration vs Time

	REACTOR1		REACTOR4	
	Sample	Total	Sample	Total
Time	Conc.	Conc.	Conc.	Conc.
DAY	mg/L	mg/L	mg/L	mg/L
3	0.152	1.52	0.528	5.28
6	0.431	4.31	4.988	49.88
10	0.358	3.58	4.149	41.49
13	0.621	3.105	3.59	35.9
17	0.552	2.76	7.114	35.57
20	0.743	3.715	4.923	30.76875
24	0.767	3.835	5.904	29.52
27	0.833	4.165	4.674	23.37
31	0.761	3.805	8.878	44.39
34	0.914	4.57	12.345	61.725
38	0.821	4.105	10.948	54.74
41	0.944	4.72	10.958	54.79
45	0.667	3.335	8.799	43.995
48	0.948	4.74	6.258	31.29

## Ammonia Concentration Vs Time

	REACTOR1		REACTOR4	
	Sample	Total	Sample	Total
Time	Conc.	Conc.	Conc.	Conc.
DAY	mg/L	mg/L	mg/L	mg/L
3	0.142	1.42	0.418	4.18
6	0.089	0.89	3.058	30.58
10	0.226	2.26	2.245	22.45
13	0.287	1.435	1.103	11.03
17	0.125	0.625	0.416	2.08
20	0.078	0.39	0.563	3.51875
24	0.175	0.875	0.173	1.08125
27	0.275	1.375	0.142	0.8875
31	0.1	0.5	8.992	56.2
34	0.162	0.81	14.558	90.9875
38	0.054	0.27	14.908	93.175
41	0.089	0.445	11.832	73.95
45	0.139	0.695	10.179	63.61875
48	0.269	1.345	3.997	24.98125

# NUTRIENT ANALYSIS FOR RUN9

## Phosphorous Concentration Vs Time

SAMPLE	Dil. Sample REACTOR2		Dil. Sample REACTOR3		Dil. Sample REACTOR5	
	CONC.	TOT. CONC	CONC.	TOT. CONC	CONC.	TOT. CONC
Days	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
3	3.892	19.46	14.951	74.755	1.713	8.565
6	4.438	22.19	14.587	72.935	2.204	11.02
10	5.453	27.265	14.556	72.78	2.162	10.81
13	8.59	42.95	15.884	79.42	1.561	7.805
17	9.132	45.66	13.086	65.43	1.837	9.185

## Ammonia Concentration Vs Time

SAMPLE	Dil. Sample REACTOR2		Dil. Sample REACTOR3		Dil. Sample REACTOR5	
	CONC.	TOT. CONC	CONC.	TOT. CONC	CONC.	TOT. CONC
Days	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
3	14.947	74.735	47.975	239.875	0.37	1.85
6	14.27	71.35	45.023	225.115	1.15	5.75
10	13.612	68.06	38.091	190.455	0.585	2.925
13	18.752	93.76	38.193	190.965	2.685	13.425
20	26.789	133.945	34.011	170.055	1.188	5.94

# NUTRIENT ANALYSIS FOR RUN10

## Phosphorous Concentration Vs Time

Time Days	Diluted Sample REACTOR3	
	CONC. mg/L	TOT. CONC mg/L
1	8.82	44.1
3	7.871	39.355
6	6.091	30.455
10	4.587	22.935
13	4.741	47.41
17	4.49	44.9
21	3.834	38.34
24	6.399	63.99
27	5.816	58.16
31	5.866	58.66
34	5.042	50.42
38	4.962	49.62
41	5.099	50.99
47	3.548	35.48

## Ammonia Concentration Vs Time

Time Days	Diluted Sample REACTOR3	
	CONC. mg/L	TOT. CONC mg/L
1	18.009	90.045
3	15.09	75.45
6	7.948	39.74
10	1.777	8.885
13	3.352	33.52
17	1.889	18.89
21	1.17	11.7
24	6.067	60.67
27	5.376	53.76
31	5.914	59.14
34	4.643	46.43
38	4.643	46.43
41	4.477	44.77
47	2.522	25.22

# NUTRIENT ANALYSIS FOR RUN11

## Phosphorous Concentration Vs Time

Time Days	R#1 Diluted		R#2 Diluted		R#4 Diluted	
	Sample REACTOR1		Sample REACTOR2		Sample REACTOR4	
	CONC. TOT. CONC	CONC. TOT. CONC	CONC. TOT. CONC	CONC. TOT. CONC	CONC. TOT. CONC	CONC. TOT. CONC
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	0.896	4.48	3.834	19.17	1.968	9.84
3	1.01	5.05	3.29	16.45	1.085	5.425
6	0.615	6.15	4.659	46.59	2.508	25.08
10	0.906	9.06	3.408	34.08	2.968	29.68
14	1.022	10.22	2.325	23.25	2.597	25.97
17	0.972	9.72	3.985	39.85	3.659	36.59
20	0.88	8.8	2.796	27.96	3.936	39.36
24	0.925	9.25	3.363	33.63	3.753	37.53
27	0.852	8.52	3.639	36.39	3.164	31.64
31	0.87	8.7	3.844	38.44	3.922	39.22
34	0.863	8.63	3.907	39.07	3.667	36.67
40	0.991	9.91	3.348	33.48	2.687	26.87

## Ammonia Concentration Vs Time

Time Days	R#1 Diluted		R#2 Diluted		R#4 Diluted	
	Sample REACTOR1		Sample REACTOR2		Sample REACTOR4	
	CONC. TOT. CONC	CONC. TOT. CONC	CONC. TOT. CONC	CONC. TOT. CONC	CONC. TOT. CONC	CONC. TOT. CONC
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	0.258	1.29	9.298	46.49	4.105	20.525
3	0.144	0.72	9.505	47.525	0.264	1.32
6	0.3	3	8.876	88.76	4.565	45.65
10	0.022	0.22	7.806	78.06	3.332	33.32
14	0.316	3.16	5.376	53.76	2.272	22.72
17	0.32	3.2	10.337	103.37	6.94	69.4
20	0.215	2.15	8.516	85.16	6.277	62.77
24	0.173	1.73	8.043	80.43	5.918	59.18
27	0.143	1.43	7.263	72.63	5.341	53.41
31	0.192	1.92	6.801	68.01	5.447	54.47
34	0.186	1.86	6.453	64.53	4.878	48.78
40	0.289	2.89	5.571	55.71	2.122	21.22

GC Area Data For Run 6

Compound :Xylene

Day	Area	R#1	R#3	R#4
1	26085	32760	9350	
6	10288	9928	14845	
13	8539	0	850	
34	8971	0	0	
37	8466		0	
48	0		0	

Compound :Diphenyl

Day	Area	R#1	R#3	R#4
1	612795	1028183	1080678	
6	543082	255835	499029	
13		35371	501822	
34	264414	25468	337915	
37	229000		80360	
48	249027		50733	

Compound :Diphenyl Ether

Day	Area	R#1	R#3	R#4
1	3072504	6064720	1080678	
6	2852054	2447160	6856301	
13	3470630	371987	2195869	
34	1709155	211206	2511867	
37	1490319		639461	
48	2125884		163770	

## GC Data Continued Run 6

Compound :Diphenyl Methane

Area			
Day	R#1	R#3	R#4
1	43458	100874	99031
6	45567	71759	186183
13	125105	27193	80656
34	29651	11839	137093
37	26593		103314
48	38532		157618

Compound :Benzene, 1,1' Methylene bis (4-methyl)

Area			
Day	R#1	R#3	R#4
1	40441	71386	74258
6	45669	53996	138725
13	135817	27393	60774
34	30264	15089	51288
37	28149		40832
48	37283		57366

Compound :1,2-Dimethyl-4-Benzyl Benzene

Area			
Day	R#1	R#3	R#4
1	57929	133146	83000
6	61021	17629	42278
13	164066	0	18232
34	27798	0	32212
37	23568		10015
48	13308		11437

## GC Data For Run 7

## Compound Xylene

Day	Area	REACTOR2	REACTOR3	REACTOR5
1	601124	606692	507598	
12	0	0	88705	
33	21620	26238	174597	
42	27785	25874	169060	

## Compound Diphenyl

Day	Area	REACTOR2	REACTOR3	REACTOR5
1	2857254	3104883	2813771	
12	7366	13985	1528158	
33	12519	0	1978840	
42	0	11102	2334758	

## Compound Diphenyl Ether

Day	Area	REACTOR2	REACTOR3	REACTOR5
1	13063536	14050811	12522000	
12	338863	3672268	7389715	
33	82952	25897	9236297	
42	0	66325	10851424	

## Compound Diphenyl Methane

Day	Area	REACTOR2	REACTOR3	REACTOR5
1	141741	166077	158577	
12	24745	75611	101010	
33	13564	14774	131798	
42	0	12753	154933	

## Compound Benzene, 1,1' Methylene bis (4-methyl)

Day	Area	REACTOR2	REACTOR3	REACTOR5
1	46849	53602	50678	
12	16987	23453	49703	
33	10717	14314	119230	
42	0	10139	284277	

## Compound 1,2-Dimethyl-4-Benzyl Benzene

Day	Area	REACTOR2	REACTOR3	REACTOR5
1	341776	412960	344486	
12	0	0	22516	
33	0	0	131109	
42	0	0	179021	

## GC Target Organics Concentration For Run 7

## Xylene

ppm	ppm	ppm
REACTOR2	REACTOR3	REACTOR5
243.43	245.6848	205.5559
0	0	35.9218
8.755192	10.62529	70.70445
10.41398	9.697724	63.36466

## Diphenyl

ppm	ppm	ppm
REACTOR2	REACTOR3	REACTOR5
1157.068	1257.347	1139.459
2.98292	5.663337	618.8398
5.069669	0	801.3471
0	4.161093	875.0807

## Compound Diphenyl Ether

ppm	ppm	ppm
REACTOR2	REACTOR3	REACTOR5
5290.183	5689.988	5070.884
137.2253	1487.114	2992.524
33.59207	10.4872	3740.312
0	24.85899	4067.176

## Compound Diphenyl Methane

ppm	ppm	ppm
REACTOR2	REACTOR3	REACTOR5
57.39915	67.25421	64.21702
10.02069	30.61928	40.90481
5.49285	5.982849	53.37265
0	4.779898	58.06978

## Compound Benzene, 1,1' Methylene bis (4-meth

ppm	ppm	ppm
REACTOR2	REACTOR3	REACTOR5
18.97188	21.70656	20.52246
6.879021	9.49748	20.12763
4.339935	5.796569	48.28314
0	3.800155	106.5487

## Compound 1,2-Dimethyl-4-Benzyl Benzene

ppm	ppm	ppm
REACTOR2	REACTOR3	REACTOR5
138.4049	167.2314	139.5024
0	0	9.118034
0	0	53.09364
0	0	67.0981

## GC Data Vs Time For Run 10

FOR RUN10

Compound :	Xylene
	Area
Day	R#3
1	177852
6	5125
13	0
24	0
27	143290
34	0
41	0

## GC Conscentration Of target Organics Vs Time

RUN 10

Compound :	Xylene
	ppm
Day	R#3
1	78.2861
6	2.2559
13	0
24	0
27	45.73525
34	0
41	0

Compound :	Diphenyl
	Area
Day	R#3
1	657054
6	38916
13	12177
24	0
27	0
34	0
41	0

Compound :	Diphenyl
	ppm
Day	R#3
1	289.2191
6	17.12987
13	5.275719
24	0
27	0
34	0
41	0

Compound :Diphenyl Ether

	Area
Day	R#3
1	3518673
6	724409
13	94426
24	60904
27	61670
34	0
41	0

Compound :Diphenyl Ether

	ppm
Day	R#3
1	1548.834
6	318.8671
13	40.91032
24	20.54485
27	19.68381
34	0
41	0

## Run 10 GC Data and Concentration (Continued)

Compound :Diphenyl Methane

Day	Area R#3
1	25868
6	13840
13	18430
24	12081
27	10765
34	0
41	0

Compound :Diphenyl Methane

Day	ppm R#3
1	11.38646
6	6.09203
13	7.984848
24	4.075305
27	3.435969
34	0
41	0

Compound :Benzene, 1,1' Methylene bis (4-methBenzene, 1,1' Methylene bis (4-meth

Day	Area R#3
1	17522
6	9823
13	14696
24	0
27	0
34	0
41	0

Day	ppm R#3
1	7.712756
6	4.323845
13	6.367082
24	0
27	0
34	0
41	0

Compound :1,2-Dimethyl-4-Benzyl

Day	Area Benzene R#3
1	58588
6	0
13	0
24	0
27	0
34	0
41	0

1,2-Dimethyl-4-Benzyl Benzene

Day	ppm R#3
1	25.78901
6	0
13	0
24	0
27	0
34	0
41	0

## GC Data Vs Time For Run 11

## GC Concentration Data Vs Time For Run 11

Compound : Xylene

Day	Area R#1	R#2	R#4
1	431888	592953	1560198
6	163959	191510	46806
17	106078	73426	48735
20	188469	164312	188577
27	265748	14068	32394
34	81400	20093	21560
40	190545	17172	15212

Compound :Xylene

Day	ppm R#1	ppm R#2	ppm R#4
1	187.1167	256.8985	675.9601
6	71.03569	82.97223	20.27883
17	35.78348	24.76892	16.43986
20	60.15547	52.44504	60.18994
27	82.76147	4.381174	10.08841
34	27.56929	6.805279	7.302136
40	70.50944	6.354342	5.629062

Compound : Diphenyl

Day	Area R#1	R#2	R#4
1	1704291	2191289	5386252
6	1501050	1218249	1911125
17	834286	361301	277663
20	1355637	537875	418201
27	2649999	204253	503320
34	1938067	221450	323951
40	1850763	100798	76277

Compound :Diphenyl

Day	ppm R#1	ppm R#2	ppm R#4
1	738.3887	949.382	2333.608
6	650.334	527.8097	828.0001
17	281.4312	121.8783	93.66455
20	432.6917	171.6787	133.4812
27	825.2849	63.61018	156.7481
34	656.4021	75.00269	109.7187
40	684.858	37.29938	28.22561

Compound :Diphenyl Ether

Day	Area R#1	R#2	R#4
1	8064313	10212919	25425872
6	8657503	7457528	10564312
17	4933501	2425089	5012795
20	8701526	3395222	7302680
27	16668164	1518022	5556599
34	9316714	1624876	4214936
40	11314676	813713	2333167

Compound :Diphenyl Ether

Day	ppm R#1	ppm R#2	ppm R#4
1	3493.886	4424.775	11015.83
6	3750.887	3230.994	4577.017
17	1664.227	818.0595	1690.975
20	2777.35	1083.686	2330.867
27	5190.939	472.7551	1730.483
34	3155.469	550.3277	1427.553
40	4186.893	301.1071	863.3672

## GC Data Vs Time For Run 11(Continued)

Compound :Diphenyl Methane

Day	Area R#1	R#2	R#4
1	75396	86379	243841
6	79984	67049	119671
17	42265	32666	66937
20	93343	49745	127071
27	164105	25158	92091
34	152282	46376	66477
40	128865	24097	59515

## GC Concentration Data Vs Time For Run 11

Compound :Diphenyl Methane

Day	ppm R#1	ppm R#2	ppm R#4
1	32.66552	37.42394	105.6448
6	34.65329	29.04916	51.84779
17	14.25733	11.01928	22.57998
20	29.79318	15.87759	40.55847
27	51.10695	7.834915	28.67975
34	51.57625	15.70704	22.51503
40	47.68532	8.916875	22.02298

Compound :Benzene, 1,1' Methylene bis (4-methyl)

Day	Area R#1	R#2	R#4
1	66403	56182	172439
6	83694	46047	87201
17	47938	28428	52840
20	85382	37776	85468
27	60357	5588	27876
34	49524	35407	23677
40	33745	23140	69579

Benzene, 1,1' Methylene bis (4-methyl)

Day	ppm R#1	ppm R#2	ppm R#4
1	28.76928	24.34101	74.70967
6	36.26065	19.94999	37.78007
17	16.17101	9.589667	17.82461
20	27.2522	12.05733	27.27964
27	18.79688	1.740262	8.681377
34	16.77324	11.99196	8.019141
40	12.48703	8.562746	25.74708

Compound :1,2-Dimethyl-4-Benzyl Benzene

Day	Area R#1	R#2	R#4
1	247929	147980	786422
6	161707	78824	251996
17	103352	56446	23702
20	128067	54804	24505
27	240563	0	23055
34	163454	0	18381
40	165412	0	14917

Compound :1,2-Dimethyl-4-Benzyl BCompound :

Day	ppm R#1	ppm R#2	ppm R#4
1	107.4159	64.11274	340.7195
6	70.06	34.15071	109.178
17	34.86391	19.04103	7.995437
20	40.87638	17.49232	7.821497
27	74.91814	0	7.179981
34	55.36008	0	6.225443
40	61.2092	0	5.5199

## FOR RUN8 GC Data

Compound :Xylene

Day	Area		R#1T	R#4S	R#4T
	R#1S				
1	35824		314482	45529	370582
3	9068		5292	0	5292
6	10851		195738	0	6834
10	11056		23935	0	6089
13	53742		223943	35474	20465
17	10995		56290	0	0
20	8949		16118	0	0
24	40844		78419	26775	29149
27	18069		128196	0	18069
31	12273		150198	0	0
34			165226		0
41			18196		0
48	12154		134954	0	0

Compound :Diphenyl

Day	Area		R#1T	R#4S	R#4T
	R#1S				
1	16969		1144097	18847	1286241
3	11541		245177	24574	577366
6	14762		1838567	0	135926
10	19096		248291	0	28939
13	25634		1257860	0	10643
17	16549		426219	0	0
20	10904		215658	0	0
24	31649		769005	0	6549
27	39137		1018529	0	90139
31	29445		1468000	0	13500
34			1623063		12946
41			230163		
48	49711		1577825	0	8283

Compound :Diphenyl Ether

Day	Area		R#1T	R#4S	R#4T
	R#1S				
1	91234		5633244	114824	6302583
3	72804		1505417	147511	3032592
6	125904		9714849	220602	3669137
10	241631		1646734	134987	1863057
13	145695		6426396	176599	1964704
17	185769		2664412	360330	1404930
20	140448		1505772	221520	739967
24	193509		4227287	110943	579730
27	221976		5323431	156731	1252524
31	254021		8035526	137000	374074
34			8876656		191506
41			1489324		90432
48	294467		8507148	0	92105

GC Data Continued (Run8):

□ Diphenyl Methane					
Area					
Day	R#1S	R#1T	R#4S	R#4T	
1		0	54354	0	65255
3		0	13424	0	34911
6		0	100662	0	45208
10		0	15174	0	23543
13		0	67423	0	31822
17		0	29600	10096	42460
20		0	17152	9449	27285
24		0	31818	0	22740
27		0	59505	0	31214
31		0	82665	12000	21668
34			92728		24589
41			15120		25322
48	0		96002	0	22303

Compound : Benzene, 1,1' Methylene bis (4-methyl)

Area					
Day	R#1S	R#1T	R#4S	R#4T	
1		0	36548	0	42620
3		0	9142	0	23742
6		0	71481	0	30339
10		0	13714	0	20052
13		0	53372	0	24273
17		0	24994	9888	32534
20		0	12227	0	25998
24		0	77260	0	0
27		0	58339	0	29371
31		0	87836	11550	21668
34			104029		23610
41			23721		24891
48	0		122900	0	18491

Compound : 1,2-Dimethyl-4-Benzyl Benzene

Area					
Day	R#1S	R#1T	R#4S	R#4T	
1		0	137170	0	200277
3		0	32892	0	58894
6		0	207560	0	16536
10		0	27025	0	17951
13		0	144229	0	3517
17		0	25098	0	12904
20		0	9509	0	0
24		0	109323	0	0
27		0	103160	0	0
31		0	103160	0	0
34			145360		0
41			21810		0
48	0		120382	0	0

## GC Concentration vs Time For Run 8

Compound :Xylene

PPM

R#1S	R#1T	R#4S	R#4T
14.50721	127.352	18.43733	150.0701
3.672159	2.143038	0	2.143038
4.394199	79.26567	0	2.767483
4.477215	9.692669	0	2.465789
21.76325	90.68751	14.36548	8.287465
3.951754	20.2314	0	0
3.216394	5.793031	0	0
15.30857	29.39189	10.03542	10.92521
6.772365	48.0486	0	6.772365
4.661195	57.0441	0	0
0	62.75162	0	0
0	6.906354	0	0
5.349894	59.40345	0	0

Compound :Diphenyl

PPM

R#1S	R#1T	R#4S	R#4T
6.871732	463.3112	7.632243	520.8736
4.67362	99.28638	9.951437	233.809
5.97799	744.5424	0	55.04432
7.733078	100.5474	0	11.71908
10.38069	509.3804	0	4.309968
5.947938	153.189	0	0
3.919047	77.51045	0	0
11.86223	288.2275	0	2.454603
14.66877	381.7505	0	33.78461
11.183	557.5356	0	5.127201
0	616.4274	0	4.916796
0	87.35916	0	0
21.88157	694.52	0	3.645974

Compound :Diphenyl Ether

PPM

R#1S	R#1T	R#4S	R#4T
36.94594	2281.227	46.4989	2552.281
29.48256	609.6306	59.73576	1228.072
50.98583	3934.106	89.33454	1485.846
97.8504	666.8581	54.66406	754.4598
59.00035	2602.42	71.51517	795.6226
66.76793	957.6263	129.5076	504.9511
50.47894	541.1951	79.61733	265.9543
72.52828	1584.411	41.58207	217.2861
83.19788	1995.252	58.74368	469.4532
96.47532	3051.834	52.0316	142.0706
0	3371.289	0	72.73258
0	565.278	0	34.32378
129.6172	3744.639	0	40.54237

## GC Concentration Continued(Run8)

## Diphenyl Methane

PPM

R#1S	R#1T	R#4S	R#4T
0	22.01109	0	26.42553
0	5.436156	0	14.13749
0	40.76388	0	18.30734
0	6.144832	0	9.533926
0	27.30348	0	12.88657
0	10.63865	3.628641	15.26071
0	6.164664	3.3961	9.806604
0	11.92557	0	8.523082
0	22.30282	0	11.69919
0	31.39556	4.557512	8.229348
0	35.21742	0	9.338722
0	5.738848	0	9.611052
0	42.25773	0	9.817236

## Compound Benzene, 1,1' Methylene bis (4-methyl)

PPM

R#1S	R#1T	R#4S	R#4T
0	14.8004	0	17.25931
0	3.702126	0	9.614512
0	28.9468	0	12.28602
0	5.553594	0	8.120217
0	21.61342	0	9.829545
0	8.983187	3.553883	11.69317
0	4.394552	0	9.344038
0	28.95749	0	0
0	21.86579	0	11.00842
0	33.35947	4.386605	8.229348
0	39.50945	0	8.966905
0	9.003387	0	9.447464
0	54.09758	0	8.139286

## Compound :1,2-Dimethyl-4-Benzyl Benzene

PPM

R#1S	R#1T	R#4S	R#4T
0	55.54809	0	81.10377
0	13.31988	0	23.8496
0	84.05308	0	6.696385
0	10.94399	0	7.269401
0	58.40668	0	1.424237
0	9.020566	0	4.637875
0	3.417665	0	0
0	39.29219	0	0
0	38.66496	0	0
0	38.66496	0	0
0	55.20666	0	0
0	8.27806	0	0
0	52.98921	0	0

GC Data For Run 9  
Compound :Xylene

Day	Area			Xylene		
	REACTOR2	REACTOR3	REACTOR5	ppm	ppm	ppm
1	266633	45515	169060	107.9752	18.43166	68.4622
6	40518	0	169060	16.40809	0	68.4622
13	0	0	99381	0	0	37.74418
20	0	0	47903	0	0	18.18175
27	0		97741	0	0	43.0232

GC Data On Concentration Of Target Organic  
Compounds For Run 9

Compound :Diphenyl				Diphenyl		
Day	Area			ppm	ppm	ppm
	REACTOR2	REACTOR3	REACTOR5	REACTOR2	REACTOR3	REACTOR5
1	1144032	17217	2334758	463.2849	6.972162	945.4789
6	73963	0	2334758	29.95191	0	945.4789
13	22498	0	1741993	8.544576	0	661.5962
20	0	0	823501	0	0	312.5626
27	25418		1659993	11.18838	0	730.6884

Compound :Diphenyl Ether				Compound :Diphenyl Ether		
Day	Area			ppm	ppm	ppm
	REACTOR2	REACTOR3	REACTOR5	REACTOR2	REACTOR3	REACTOR5
1	5531308	191791	10851424	2239.947	77.6673	4394.371
6	631377	74552	10851424	255.6812	30.19043	4394.371
13	192669	0	7945759	73.17427	0	3017.741
20	88368	0	3870408	33.54038	0	1469.027
27	177821		7494024	78.27246	0	3298.686

Compound :Diphenyl Methane				Compound :Diphenyl Methane		
Day	Area			ppm	ppm	ppm
	REACTOR2	REACTOR3	REACTOR5	REACTOR2	REACTOR3	REACTOR5
1	42197	0	154933	17.08801	0	62.74135
6	8931	0	154933	3.61668	0	62.74135
13	4624	0	117002	1.756161	0	44.4365
20	0	0	56655	0	0	21.5036
27	0		107379	0	0	47.26561

Compound :Benzene, 1,1' Methylene bis (4-meth				Compound :Benzene, 1,1' Methylene bis (4-meth		
Day	Area			ppm	ppm	ppm
	REACTOR2	REACTOR3	REACTOR5	REACTOR2	REACTOR3	REACTOR5
1	26564	0	284277	10.7573	0	115.1202
6	0	0	284277	0	0	115.1202
13	0	0	354193	0	0	134.5199
20	0	0	162823	0	0	61.80003
27	0		442849	0	0	194.9313

Compound :1,2-Dimethyl-4-Benzyl Benzene				Compound :1,2-Dimethyl-4-Benzyl Benzene		
Day	Area			ppm	ppm	ppm
	REACTOR2	REACTOR3	REACTOR5	REACTOR2	REACTOR3	REACTOR5
1	122482	0	179022	49.60006	0	72.49639
6	0	0	179022	0	0	72.49639
13	0	0	117363	0	0	44.57361
20	0	0	69284	0	0	26.29698
27	0		114359	0	0	50.33804

GC Data On Concentration Of Target Organic  
Compounds For Run 9

Xylene

ppm	ppm	ppm
REACTOR2	REACTOR3	REACTOR5
107.9752	18.43166	68.4622
16.40809	0	68.4622
0	0	37.74418
0	0	18.18175
0	0	43.0232

Diphenyl

ppm	ppm	ppm
REACTOR2	REACTOR3	REACTOR5
463.2849	6.972162	945.4789
29.95191	0	945.4789
8.544576	0	661.5962
0	0	312.5626
11.18838	0	730.6884

Compound :Diphenyl Ether

ppm	ppm	ppm
REACTOR2	REACTOR3	REACTOR5
2239.947	77.6673	4394.371
255.6812	30.19043	4394.371
73.17427	0	3017.741
33.54038	0	1469.027
78.27246	0	3298.686

Compound :Diphenyl Methane

ppm	ppm	ppm
REACTOR2	REACTOR3	REACTOR5
17.08801	0	62.74135
3.61668	0	62.74135
1.756161	0	44.4365
0	0	21.5036
0	0	47.26561

Compound :Benzene, 1,1' Methylene bis (4-meth

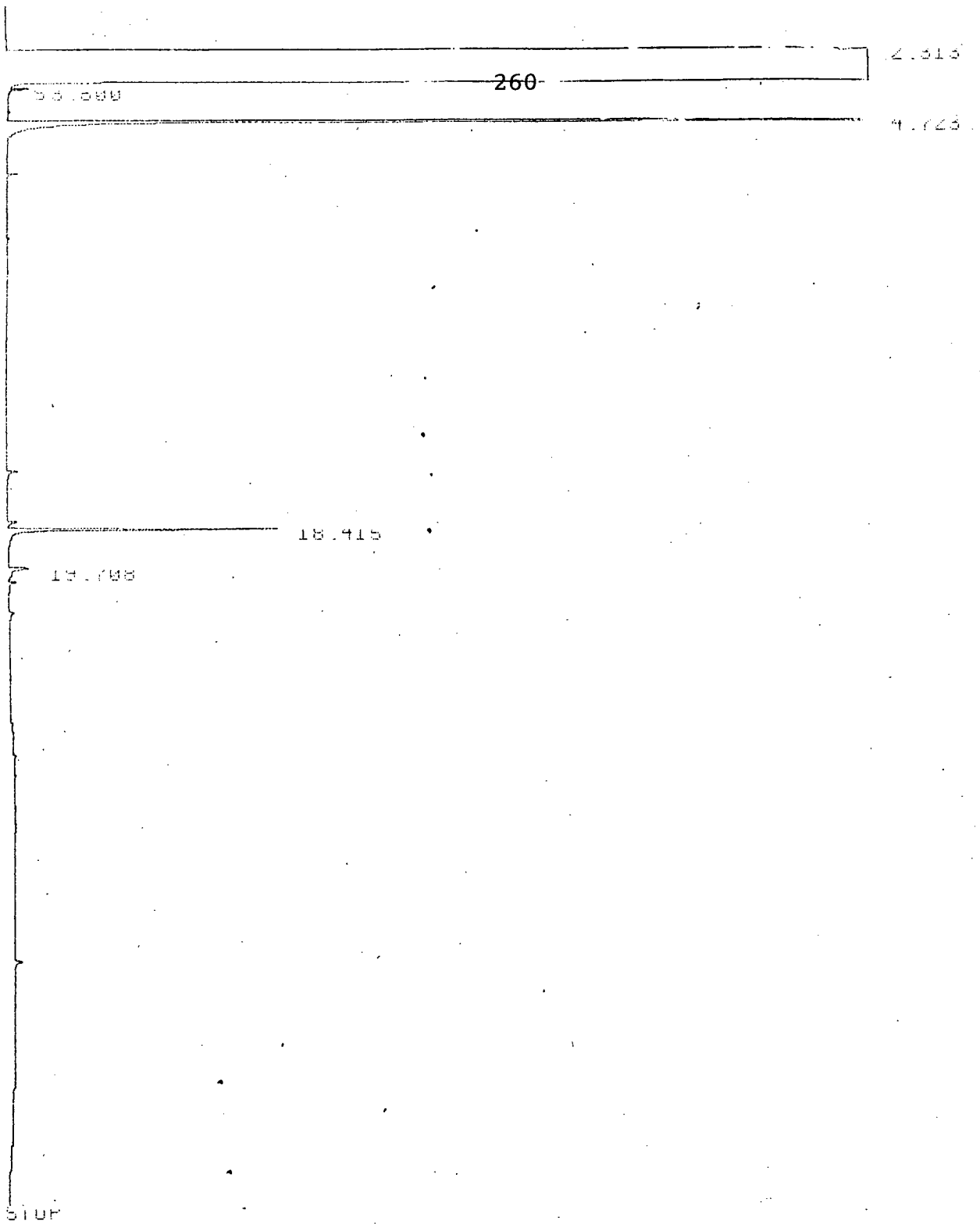
ppm	ppm	ppm
REACTOR2	REACTOR3	REACTOR5
10.7573	0	115.1202
0	0	115.1202
0	0	134.5199
0	0	61.80003
0	0	194.9313

Compound :1,2-Dimethyl-4-Benzyl Benzene

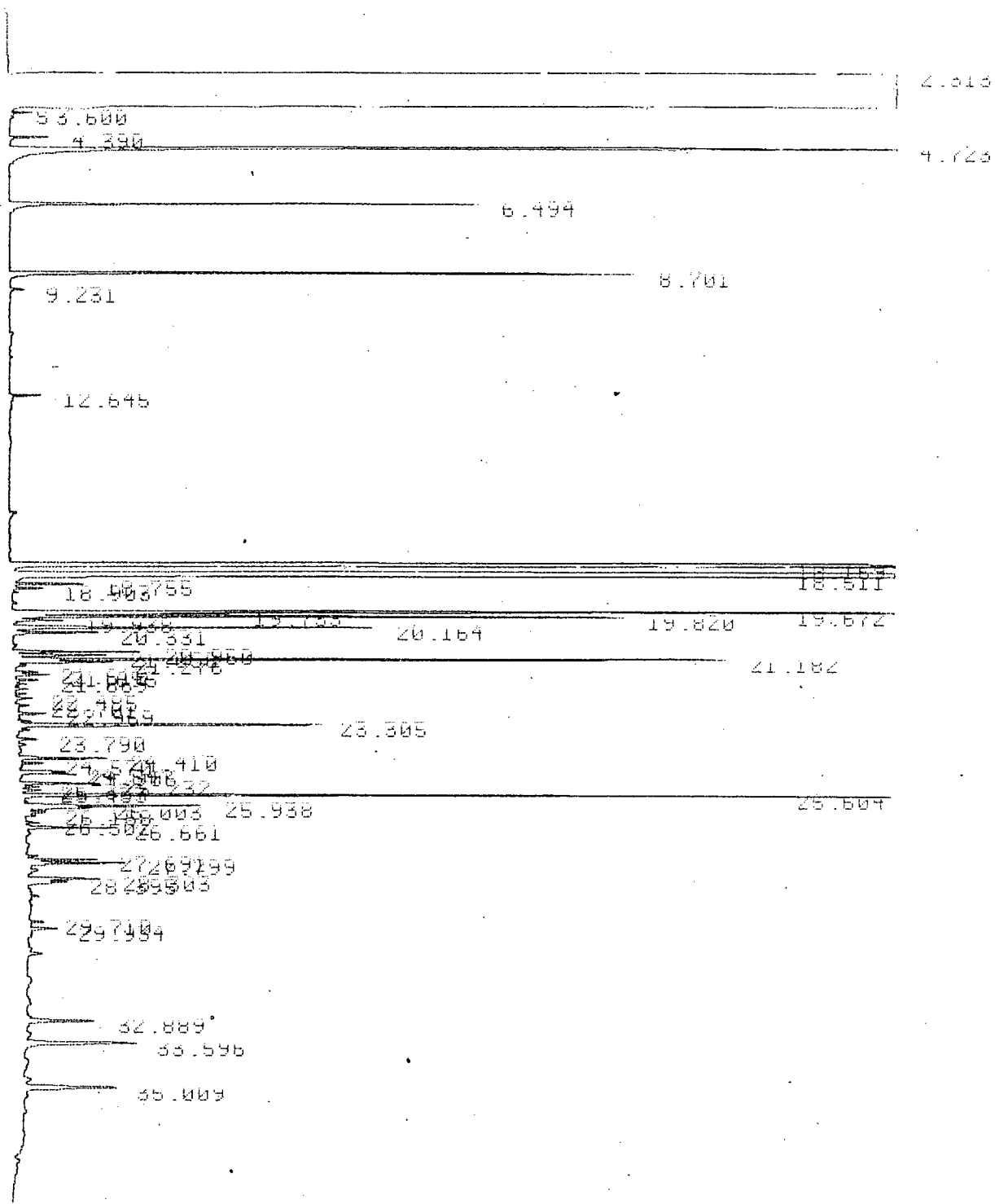
ppm	ppm	ppm
REACTOR2	REACTOR3	REACTOR5
49.60006	0	72.49639
0	0	72.49639
0	0	44.57361
0	0	26.29698
0	0	50.33804

## Appendix B

The initial and final Gas Chromatograph traces for run 5.



Initial GC trace for run 5



The Final GC trace for run 5 (Day 41).