

FEASIBILITY STUDY OF SLUDGE LYSIS AND RECYCLE IN THE ACTIVATED SLUDGE PROCESS

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ABSTRACT

Activated sludge is one of the most widely used biological processes in municipal wastewater treatment plants. This treatment was borrowed by the pulp and paper industry; approximately 33% of all wastewater treatment within the industry utilizes activated sludge. Sludge disposal is the main disadvantage of the process as it can involve up to 60% of the total operating costs.

The purpose of this research was to investigate the feasibility of an activated sludge process with complete lysis and recycle of sludge. The proposed process would produce zero biological solids, thus eliminating the expensive solids disposal associated with secondary biological treatment. A synthetic total Kraft Mill effluent was treated with the process to assess the application within the pulp and paper industry. The Kady Mill, which utilized high shear and heat, was used to mechanically lyse the sludge recycled back to the treatment reactor. The performance of this process was compared to a conventional system, in two bench-scale bio-oxidation units.

Several conclusions can be made from this research. First, the efficiency of cell destruction obtained with the Kady Mill and IKA disperser are quite comparable with those obtained by proven, but energy intensive devices. Second, it is feasible to operate a bench scale activated sludge process in a sludge lysis and recycle extended aeration mode. The proposed system demonstrated a COD removal efficiency of 80%, compared to 87% removal for the conventional process. The modified system operated free of bulking. Finally, the proposed process offers an economically attractive solution for the problem of waste sludge disposal. However, more research on full scale systems would be required to confirm this statement.

KEY WORDS

Activated sludge, sludge disposal, biological solids, sludge destruction,

bacteria cell destruction, lyse, bio-oxidation, dispersion, waste sludge.

INTRODUCTION

The protection of the environment has been a top priority issue in the United States for more than 30 years. In the early 1950's the Federal Government developed an ambitious program to encourage the construction of wastewater treatment plants. Up to date, the number of such facilities is greater than 15,000 [1]. Most of these use the activated sludge process. The bacteria in the activated sludge process transform the organic compounds present in the wastewater into carbon dioxide, water and new cells. The organic material can be indirectly determined as Biochemical Oxygen Demand (BOD). Forty to sixty-five percent of the BOD is transformed into new cells in the activated sludge process [2]. The cells generated must be separated from the system and disposed of, if a proper performance of the whole process is desired. This waste stream is known as waste activated sludge.

According to the United States Environmental Protection Agency (USEPA), about 0.1 kilograms of dry waste activated sludge are generated per citizen per day; this number is equivalent to 9.6 million dry metric tons per year. Frequently, the waste activated sludge is mixed with primary treatment sludge in order to improve its dewaterability. A dry solids content of the combined sludge of 20% as well as handling and disposal costs of 35-40 dollars per wet metric ton can be considered as averages [3]. The disposal costs just for waste activated sludge from municipal wastewater treatment plants are almost two billion dollars per year.

From the above it can be seen that disposal of waste activated sludge involves heavy expenses. Some wastewater treatment plants use an anaerobic digestion stage of the waste activated sludge in order to reduce the amount of solids wasted. The solids reduction efficiency of that stage is about 50%, so the final disposal problem is minimized but not eliminated. As a result, other means must be sought to deal with the problem.

In the late 1960's Anthony and Elizabeth Gaudy [4] examined the extended aeration concept, a variation of the activated sludge process. Extended aeration involves a total recycle of the waste activated sludge to the reactor(s). A bench-scale, extended aeration system operated over 1,000 days performed well. However, the microbial population showed prolonged growth and death periods. To avoid this problem, the waste activated sludge was digested in either acidic or alkaline conditions at elevated pressures and temperatures [5]. Again, bench-scale plants performed well, but the high costs involved in the physical-chemical

digestion made the process economically prohibitive. Ultrasonic treatment was also attempted [6,7,8] with good results but it proved to be energy intensive. Simple, high-shear producing devices seem promising to achieve waste activated sludge destruction. This approach has not been evaluated.

In these days, when public concern is imposing strict legislation in matters of solid waste management and disposal, it seems desirable to reassess how technically and economically feasible it would be to operate the activated sludge process in extended aeration mode with an intermediate, mechanical waste activated sludge cell destruction stage.

This work addresses the problem above by use of simple devices for waste activated sludge destruction. The performance of two bench-scale activated sludge process systems was compared. One unit operated in modified extended aeration and the other in conventional mode. The latter one served as a control unit.

PROBLEM STATEMENT

The activated sludge process transforms a substantial part of the organic components present in wastewater into excess sludge. That excess sludge must be disposed of in a proper manner. Therefore, the activated sludge process transfers a water pollution control problem into a solid waste disposal problem.

Public awareness on the matters of solid waste handling and disposal provides the driving force for new and innovative ways to dispose of the waste activated sludge. The best way to deal with the waste activated sludge is not to produce it. Therefore it is necessary to reassess the extended aeration concept under new perspectives. An intermediate cell destruction stage must be included if a more stable system operation is desired. Simple, mechanical high-shear producing devices have not yet been evaluated to accomplish this. The performance of an activated sludge process working in modified extended aeration has to be evaluated against a conventional process.

OBJECTIVES

- (1) Selection of a suitable cell destruction device.

Simple, high-shear producing devices were evaluated for their ability to destroy cells in waste activated sludge. The Cowles disperser, Kady mill, IKA disperser and Ball mill were selected. The efficiency of each device was compared with that obtained by already proven procedures such as chemical and ultrasonic treatments.

- (2) Comparison between modified extended aeration and conventional activated sludge processes.

Two bench-scale, activated sludge plants were compared for a two month period. One unit was operated in conventional mode with wasting conditions typical of a municipal wastewater treatment plant and served as a control. The second unit was operated in modified extended aeration mode with the selected technique of cell destruction of the waste sludge, which was recycled as feed to the reactor.

Figure 1 shows a schematic diagram of the proposed process.

EXPERIMENTAL PROCEDURE

The experimental approach was divided into three stages. A description of stages one and two is given below. Stage three is the economic analysis.

Stage I

The purpose of this phase was to evaluate and select a suitable technique for cell disintegration of the waste activated sludge. The following techniques were investigated:

- 1) Chemical digestion under acidic and alkaline conditions.
- 2) Ultrasonic treatment.
- 3) Boiling
- 4) High-shear producing devices:
 - Cowles Disperser.
 - Kady Mill.
 - IKA Disperser.
 - Ball milling.

Biological sludge from the City of Hamilton, Ohio, Wastewater Treatment Plant was used as the source of waste activated sludge for experimentation. A sample of sludge from the reactor was collected, gravity thickened, characterized, refrigerated when necessary and subjected to each one of the treatments at preset conditions.

For ball mill and chemical digestion treatments, one single run was performed. A minimum of two replicate runs for each set of conditions of the individual remaining treatments were performed.

The general experimental procedure for this phase was as follows:

- 1) Sample collection and physical-chemical characterization.

- 2) Sample treatment with selected technique of cell disintegration.
- 3) Physical-chemical characterization of the treated sample obtained.
- 4) Centrifugation of the treated sample in order to separate solids from the liquid phase.
- 5) Physical-chemical analysis of supernatant from the step above.
- 6) Evaluation of cell disintegration efficiency of the treatment.

The following physical-chemical tests were used for sample analysis before and after treatment:

- 1) Total and Soluble Chemical Oxygen Demand (COD).
- 2) Mixed Liquor Suspended Solids (MLSS).
- 3) pH
- 4) Sludge Volume Index (SVI).

The first two analyses were performed in order to evaluate the global efficiency of the cell destruction treatment. The extent of cell destruction of the sludge for each treatment was calculated from the increment in COD soluble, as compared with the COD available in the original sample. A correction for the stripping of volatile compounds in the original sample was included. The last two analyses were carried out to evaluate the characteristics of the final product. All the analytical tests were performed according to Standard Methods [9]. For details on how the treatments were performed, see reference [10].

Lab Bench Scale Biotreatment Units

Feed

In order to make appropriate comparisons between the treatment and control units, a constant organic loading was established. A synthetic, constant COD feed that simulated a typical weak kraft mill effluent was prepared. The composition of the synthetic wastewater is shown in Table I.

The COD of the feed is about 260 mg/L. The organic components used are highly biodegradable. To minimize biological degradation, the recipe was prepared daily. A concentrated solution of the chemicals was prepared and divided in two equal parts.

Operating Conditions

Figure 2 shows a schematic diagram of the bench scale bio-oxidation units. Both units were operated under equal hydraulic residence times of 7.5 hours. The usable

volume of each reactor was 9.9 liters. Twenty four liters per day (16.7 mL/min) of influent were fed to meet that condition. Wastage from both units was performed by withdrawing every 24 hours one liter of total mixed reactor contents.

For the start-up of both units, waste sludge from the City of Oxford, Ohio, Wastewater Treatment Plant was used as the source of microorganisms. This seed was chosen because of its low ash content.

After transferring to the bio-oxidation units, the systems were fed continually with no solids wastage until an adequate MLSS level (about 1.5 grams per liter) was reached.

After start-up, the control unit was operated under the specified sludge wasting conditions. By contrast, in the treatment unit the waste activated sludge was treated in the Kady mill for 25 or 30 minutes, depending on the amount of waste activated sludge treated. The resultant product after mechanical treatment was mixed with the synthetic wastewater, stirred continuously and pumped to the reactor.

Effluents from both units were collected in buckets. Two composite samples of effluent, each one representing 12 hours of operation of each unit were collected, the first being refrigerated. To minimize accidental biomass losses from this stream, the MLSS collected in the bucket were separated and recycled back to reactors. The non-intentional MLSS losses from the effluents were determined.

RESULTS AND DISCUSSION

Phase I

The results obtained during Phase I are shown below.

Chemical digestion

The raw sludge for both acidic (pH 2) and alkaline (pH 11.5) digestions had the following characteristics:

Total COD	=	9.007	g/L
Soluble COD	=	0.104	g/L
Available COD	=	8.903	g/L
Susp. Solids	=	10.04	g/L
Settleable Solids	=	950	mL/L
SVI	=	.95	mL/g
pH	=	8.0	

After treatment under alkaline conditions, the resultant sludge showed the following characteristics:

Total COD	=	8.230	g/L
Stripped COD	=	0.777	g/L
Soluble COD	=	5.394	g/L
Susp. Solids	=	5.4	g/L
Settleable Solids	=	250	mL/L
SVI	=	46	mL/g

The percent conversion to COD soluble for alkaline treatment was 65.1%. For calculation details, see reference 10.

After treatment under acidic conditions, the resultant sludge showed the following characteristics:

Total COD	=	7.962	g/L
Stripped COD	=	1.045	g/L
Soluble COD	=	4.452	g/L
Suspended Solids	=	4.60	g/L
Settleable Solids	=	150	mL/L
SVI	=	33	mL/g

The conversion to COD soluble for this treatment was 56.6%. Note that despite the lower conversion to COD soluble under acidic conditions, the final suspended solids concentration was also lower as compared with alkaline digestion. Likewise, the ratio Total COD/MLSS in the raw sludge is quite low (0.89), as compared to normal ratios of 1.40 to 1.60. These facts led to the suspicion that the raw sludge sample had a high ash content. This could be logical since the City of Hamilton wastewater treatment plant receives effluents from two non-integrated, specialty paper mills. The effluents from those mills contain calcium carbonate and clay fillers not retained in the paper web during the papermaking process.

The calcium carbonate will be dissolved in an acidic environment. Therefore, the final suspended solids concentration after acidic digestion will be lower than expected. In average, the ash content of the sludge sample was 40%, based on dry sludge.

Arbitrarily, if we average the efficiencies of alkaline and acidic digestions, we can use 60.8% as the ultimate conversion to COD soluble. The efficiencies of conversion of COD soluble for the remaining treatments were related to this value.

Table 2 summarizes the results in a very brief form. For details, see reference [10]. It is apparent from the table that both the IKA disperser and the uncooled Kady mill are very effective at solubilization of the waste activated sludge. Both high temperature and mechanical shear need to be present to obtain the destruction.

Ultrasonic destruction is also effective, but would be considerably more expensive than the simple mechanical treatments. The Kady mill was chosen as the preferred alternative because one was available at Miami University at no cost. Let us now turn to the effects total solids recycle has on biological treatment.

Phase II

The upper and lower control limits of all graphs in the results and discussion

section are defined by two standard deviations above the mean.

MLSS

The results obtained from MLSS determinations are shown in Figures 3 and 4. From these figures, it can be seen that the average MLSS concentration was slightly higher in the treatment unit during the experimental phase. The average MLSS concentration during this phase was 1154 and 1086 in the treatment and control respectively. The slightly higher values in the treatment unit are to be expected because of the higher COD in the influent due to the recycle of the disintegrated sludge. A higher influent strength causes the system to generate more biomass.

As can be seen from the graphs, all MLSS values for both the treatment and control units were between the upper and lower limits indicating no significant losses or gains of solids during this phase.

Around the 37th day of operation, the control began experiencing solids build-up on the glass cone of the unit. This build-up was due to increased levels of CaCO_3 . The unit was washed on day 38 with diluted HCl and it is likely that not all the HCl was cleaned from the glass resulting in the decrease in MLSS concentration.

COD feed

The results of the influent COD determinations are shown in Figure 5.

The initial COD level to both units was kept the same except for the increase to the treatment feed by the readdition of the recycled sludge. The average total and soluble COD to the treatment unit and COD soluble to the control unit were 334, 304 and 257 mg/L respectively. Therefore the global average percent of conversion to COD soluble in the Kady Mill for this phase was $(304-257)*100/(334-257) = 61\%$ [10]. For the most part, the COD trends and MLSS trends are similar. A comparison of the graphs indicates that an increase in influent COD caused an increase in MLSS concentration. This will be more evident in Phase III results.

SVI

Figures 6 and 7 show the SVI data collected in phase II. The average values for the SVI during this time were 105 and 117 for the treatment and control units respectively.

In general both the treatment and control units had SVI values that correspond to that of a healthy operating system. It is important to have SVI values below 300ml/g to avoid bulking in the system. As seen from the graphs, the values in both

units were never above 300mL/g. The units usually settled down to good SVI values during the 40 minute settling period, however, the treatment unit usually reached its final volume much more quickly than the control unit. A possible explanation for this phenomenon is that the recycle of the disintegrated waste activated sludge develops a better settling sludge due to the added cell material mass.

Day 1-8 of phase II, for the treatment unit, show SVI values much higher than the subsequent days in phase II. Most likely, this was due to the adjustment of the treatment unit to the new experimental conditions. When compared to the control unit, the treatment unit appears slightly out of control; however, after the eight day transition phase the system recovered and did not experience any further high SVI values.

The SVI values follow the values of the MLSS concentration. In general at higher MLSS concentrations, the SVI values were lower (better settling), indicating that the SVI may be directly related to the MLSS concentration. The results of the treatment unit SVI values were important because they demonstrated that the system could be operated free of bulking. The treatment unit had extremely good SVI values for the majority of phase II and were uniform in nature, more so than the control unit values. This uniformity of SVI values is of great significance in this research.

Soluble COD in effluent

Figures 8 and 9 graphically show the results of the COD concentration in mg/L for both the treatment and control units respectively.

The average COD concentration in the treatment unit was 61 mg/L and in the control was 33mg/L. It was expected that a slightly higher COD would be found in the treatment unit because of the larger influent concentration and that small fraction of COD not solubilized during treatment with the Kady Mill.

In general the treatment unit showed good removal; however, during the first ten days there was a larger variation likely due to the transition state of the system. The unit experienced a sharp increase in removal on day 37; however, this peak cannot be explained by a decrease in MLSS or an increase in SVI. This day saw a slight excess of colloidal material in the effluent bucket. Although, the excess colloidal material was returned to the reactor, perhaps higher values inadvertently contributed to the higher COD measurement on day 37.

The control unit also operated well within the control limits. The results were usually smooth except for some variation

during the first few days of phase II.

Percent removal

Figure 10 depicts graphically the percent removal results for both the treatment and control units.

When the COD in the effluents was high, then the removal efficiency was low and likewise when the COD in the effluents was low the removal efficiency was high. The average removal efficiencies were 80 and 87 for the treatment and control respectively. The control operated 7% more efficiently; however the treatment unit was fed a higher strength influent. Possibly increasing the hydraulic residence time in the treatment unit would improve the efficiency.

The sludge lysis and recycle would increase the effluent BOD from a treatment process, thus the new treatment would only be applicable in mills that operate at less than their EPA permit BOD discharge level.

Suspended Solids in the Effluent

In general both sets of values were low. The averages were 15 and 16mg/L for the treatment and control units respectively during phase II. These values did not have a deleterious effect on the system. In cases of high suspended solids in the effluent, the COD will increase and the system would fail due to substantial losses of biomass.

MCRT

Theoretically the MCRT was to be kept at 7.5 days, however, the amounts of non intentional biomass lost in the effluent caused the MCRT average to be 6.0 days in the control unit during phase II.

The MCRT in the treatment unit must be considered separately from the control unit. Theoretically the MCRT would approach infinity because of complete solids recycle. However, this is not the case because of inadvertent solids losses to the effluent buckets and the 100ml removed every day for MLSS concentration determinations. The average MCRT in the treatment unit was 24.8 days. The MCRT increased on days when lower amounts of suspended solids were lost in the effluent and subsequently decreased when greater amounts of solids were lost in the effluent.

ECONOMICS

Phase III

Even though this research was not designed to investigate the economic feasibility of the modified extended aeration process, a rough economic analysis can be performed.

In order to perform this analysis, it will be assumed that two full-scale

wastewater treatment plants (which will be identified as "treatment" and "control" plants), will be operated under the same conditions outlined for both treatment and control units. The average data found for COD soluble in feed and effluent, COD soluble removal efficiency and MLSS in reactors of both units will be used. Likewise, the target MCRT in the control unit will be used. The hydraulic retention time will be 7.5 hours for each plant. For details of the calculations, consult Dietrich-Velazquez [10]. Cost for control sludge disposal = \$608.45/day; cost for treatment condition = \$407.43/day.

Potential savings obtained in the "treatment" plant = 608.45 - 407.43 \$/day
 = 201.02 \$/day
 = 73,373 \$/year

The installation cost of the Kady mill Model 800B is approximately \$70,000.

From this rough analysis, it can be observed that the proposed process seems to be economically attractive over the conventional activated sludge process. It is worthy to remember that, because of the lack of landfills and the high costs of alternative waste activated sludge disposal techniques, the costs of such operations will show sharp increases in the near future.

CONCLUSIONS

Several things can be concluded from this study:

1. The bacteria in the waste activated sludge can be destroyed by use of simple, high-shear producing devices.
2. Neither high shear or boiling point temperatures alone are enough to provide an acceptable degree of cell destruction. The Kady mill is an example of a simple mechanical device which combines the two factors above. The IKA disperser may also be an acceptable alternative to accomplish the above task.
3. It is feasible to operate an activated sludge plant in a sludge lysis and recycle extended aeration mode.
4. The process may be an alternative wastewater treatment system applicable in the pulp and paper industry. The system would be most applicable to mills operating well within EPA permit discharge limits.
5. The proposed system operates with an average COD removal efficiency of 80% as compared to 87% removal for the conventional system, both with an influent COD strength of 260mg/L.
6. The sludge lysis and recycle process

can be operated free of bulking problems.

7. The sludge lysis and recycle extended aeration seems to offer an attractive economical solution to waste activated sludge disposal problems. However, more extensive research, on a full scale system, is required to better substantiate this statement.

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TABLE I: COMPOSITION OF THE SYNTHETIC WASTEWATER

<u>Component</u>	<u>Amount</u>
Weak Black Liquor	36.3 ml
Soluble Starch	2.65 g
KH ₂ PO ₄	0.3 g
K ₂ HPO ₄	0.8 g
Na ₂ PO ₄	1.1 g
Urea	2.5 g
NH ₄ Cl	0.1 g
Ca Cl ₂	2.66 g
M _s SO ₄	2.96 g
Distilled Water	36.0 l

TABLE 2. RELATIVE AVERAGE PERCENT OF CONVERSION TO SOLUBLE COD

Chemical Digestion	100			
Ball Milling	38			
		<u>20 min</u>	<u>40 min</u>	<u>60 min</u>
Cowles Disperser:	3000 rpm	1.1	1.1	0.9
	4000 rpm	1.1	1.4	1.9
	5000 rpm	1.0	1.3	2.6
Boiling		34.8	37.0	40.3
Cooled Kady		7.8	8.7	9.5
Uncooled Kady	To = 30°C	52.3	63.6	71.5
	To = 40°C	54.8	65.8	76.0
IKA Disperser		35.4	63.6	71.5
Ultrasound	To = 30°C	54.4	75.1	86.1
	To = 40°C	60.3	76.0	87.7

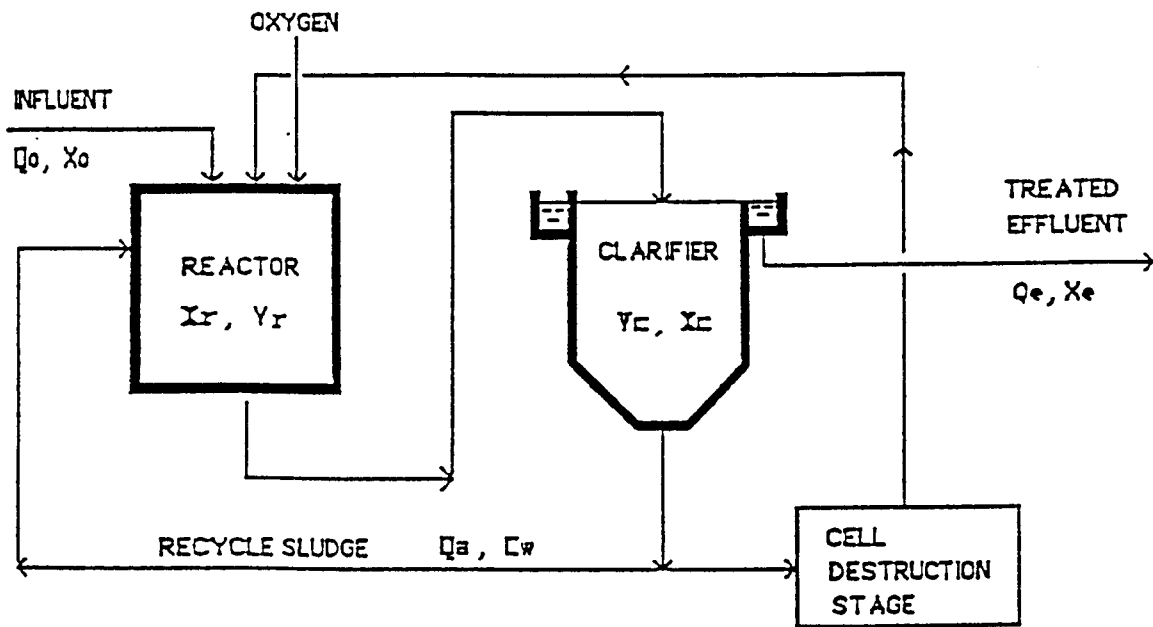


FIGURE 1. PROPOSED PROCESS

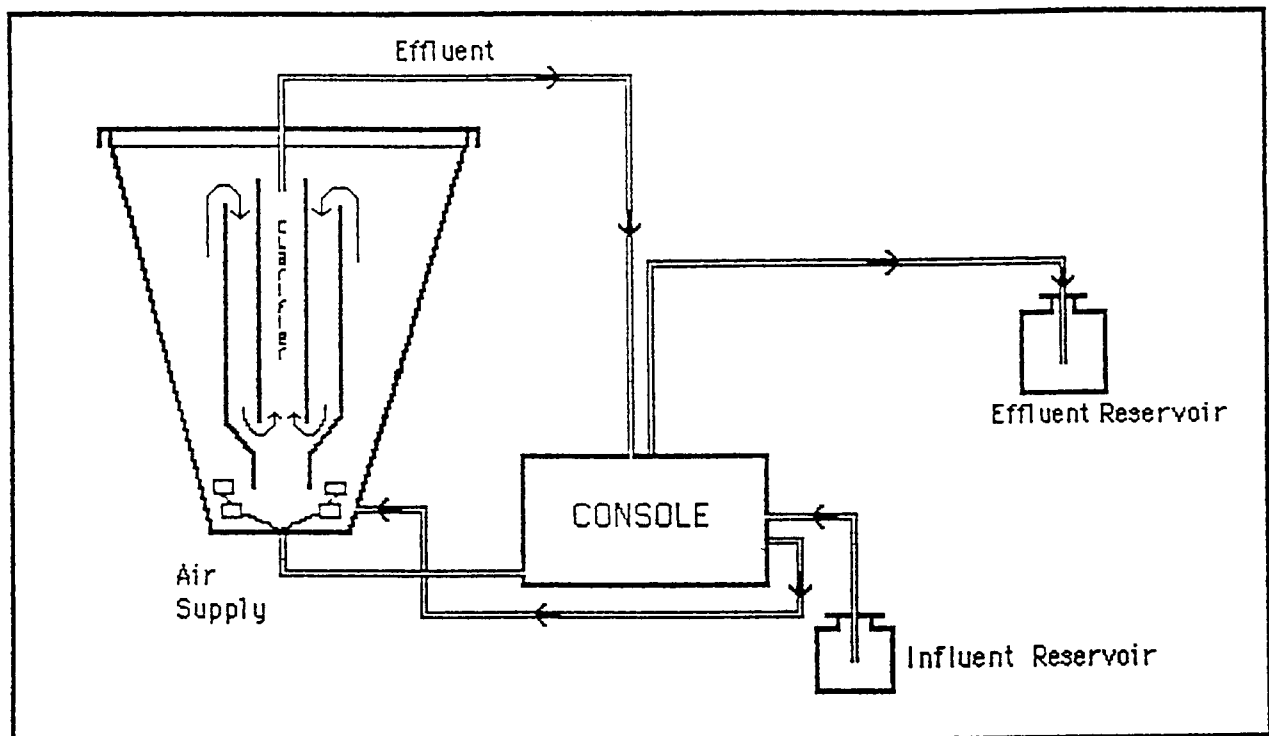


FIGURE 2: Schematic diagram of Horizon Bio-Oxidation Units

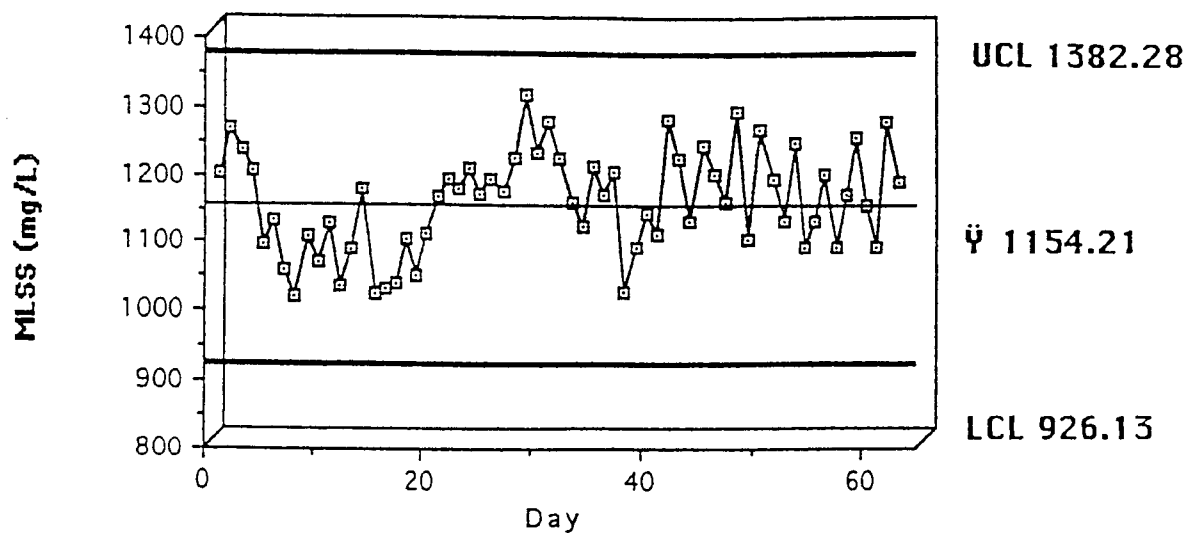


FIGURE 3: Phase II Treatment MLSS

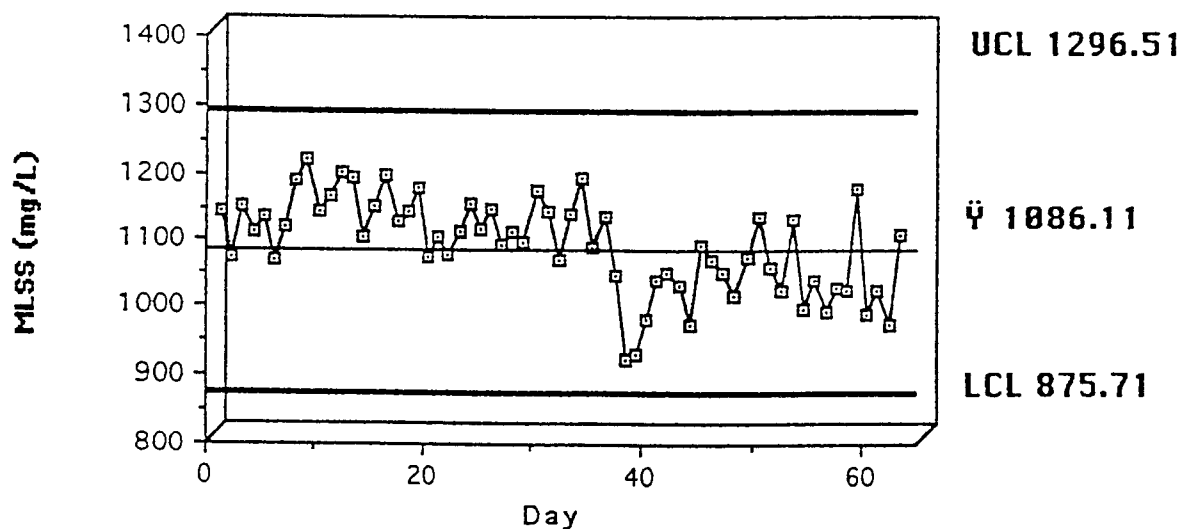


Figure 4: Phase II Control Unit MLSS

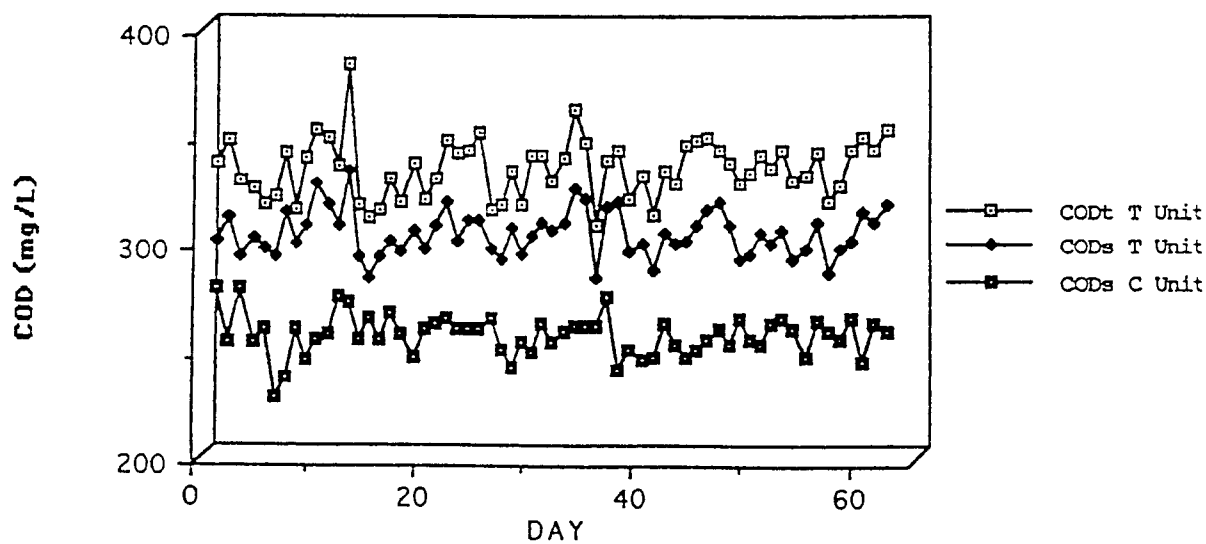


Figure 5: Phase II Influent COD (mg/L)

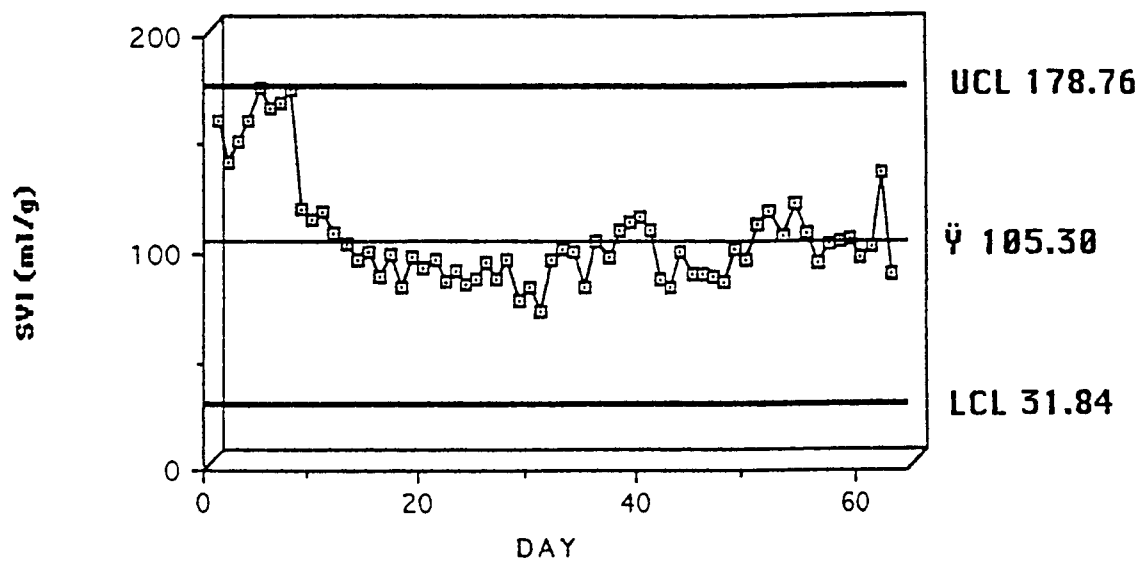


Figure 6: Phase II Treatment SVI

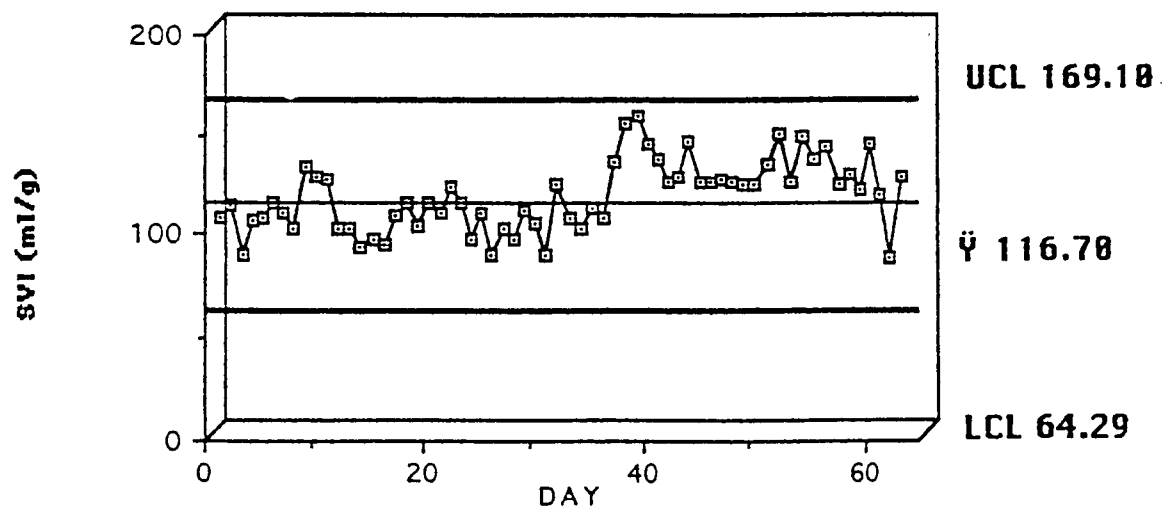


Figure 7: Phase II Control SVI

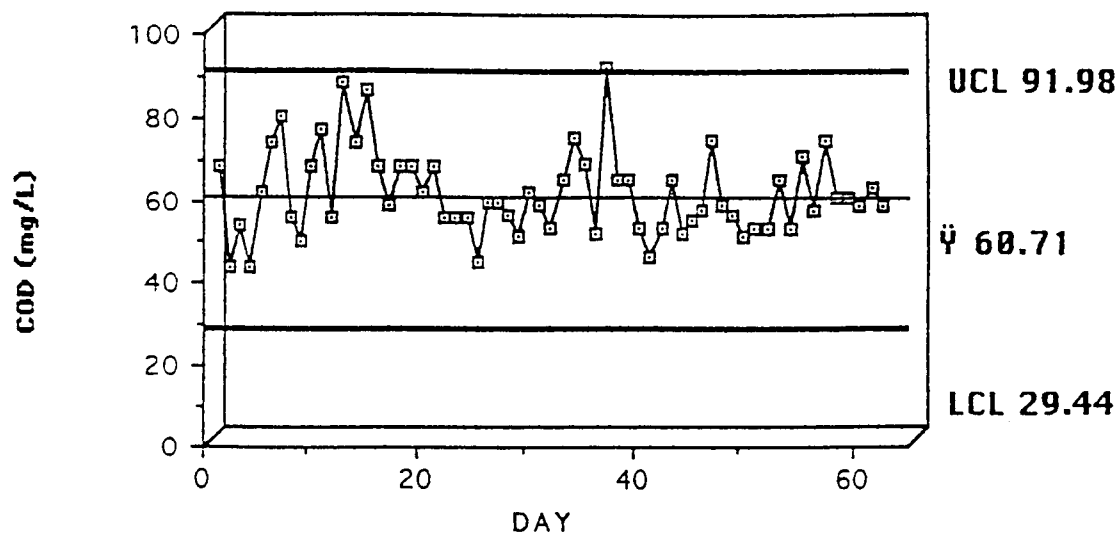


Figure 8: Phase II Treatment Effluent COD

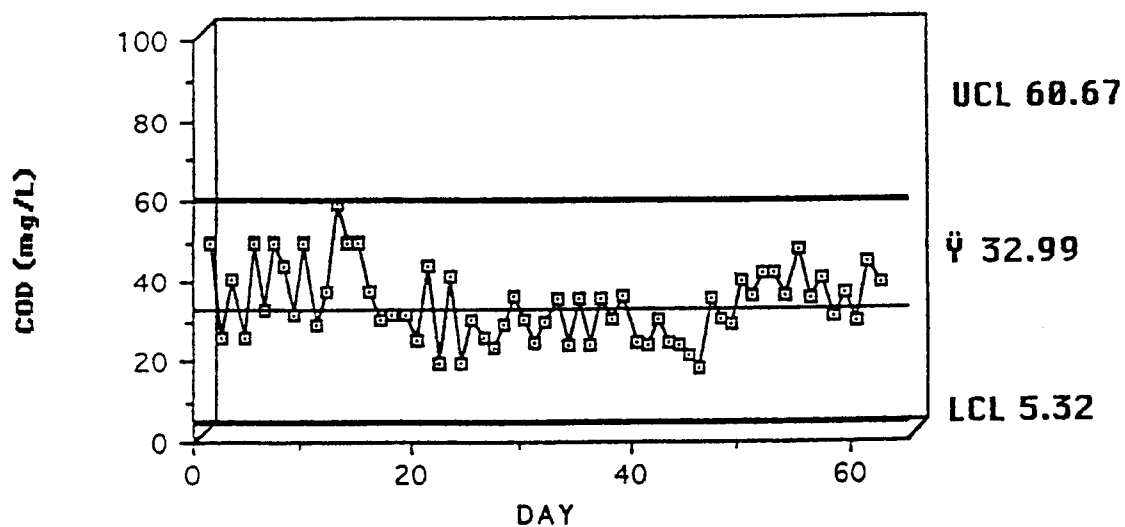


Figure 9: Phase II Control Effluent COD

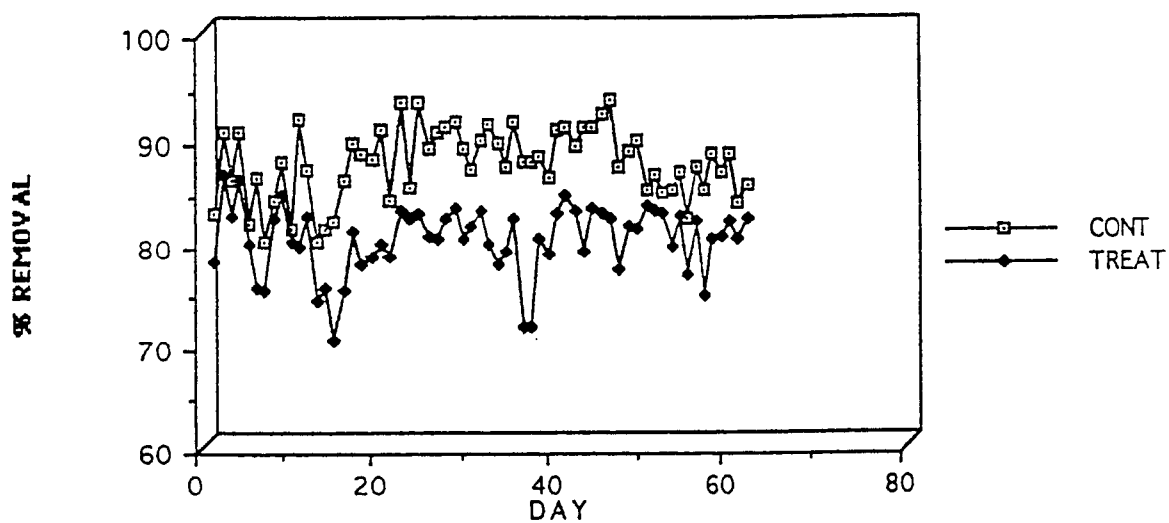


Figure 10: Phase II Percent Removal Treatment and Control

