STUDIES ON TOTAL OXIDATION WITH EXTERNAL SLUDGE RECYCLE

By

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Dedicated to my Beloved Parents

STUDIES ON TOTAL OXIDATION WITH EXTERNAL

SLUDGE RECYCLE

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LIST OF SYMBOLS

D - Dilution Rate. Ratio of the rate of flow, F, and the volume of liquor in the aeration tank, V. It is equal to the reciprocal of the mean hydraulic residence time, $\bar{t}$, in a completely mixed reactor, hr^{-1}

K_d - Maintenance energy coefficient, day^{-1}

K_s - A biological "constant" used in the hyperbolic expression relating specific growth rate to substrate concentration. It is known as the saturation constant. It is numerically equal to the substrate concentration at which specific growth rate is equal to half the maximum specific growth rate for the system, mg/l

S - Substrate concentration, measured as COD, mg/l

S_i - Concentration of substrate in the inflowing feed in continuous flow operation, measured as COD, mg/l

S_o - Initial substrate concentration used in batch growth studies measured as COD, mg/l

S_e - Concentration of substrate in the effluent filtrate measured as COD, mg/l

$\bar{t}$ - Mean hydraulic detention time, hrs

$\bar{V}$ - Volume of liquor in aerator #1, liters

X - Biological solids concentration, mg/l

X_e - Biological solids concentration in the clarifier effluent, mg/l

X_R - Biological solids concentration in the recycle flow to the reactor, mg/l

X_W - Excess biological solids (sludge wasted), mg/day

Y_o - Observed mean cell yield obtained during growth at specific growth rate (continuous system with cell recycle)

Y_t - True cell yield

μ_n - Net specific growth rate in continuous system with cell feedback, hr^{-1}

μ_m - Maximum specific growth rate for a system in exponential growth, hr^{-1}

CHAPTER I

INTRODUCTION

The rapidly increasing use of extended aeration processes as a secondary treatment of wastewater in rural and small communities, in many commercial establishments and some industrial installations, attests its ever increasing popularity all over the world.

This increasing use of the extended aeration process has intensified concern of regulatory agencies about the quality of the effluent produced by these plants.

The extended aeration sewage treatment is one of the various modifications of the activated sludge process and is claimed to be simple in operation, low in cost, and stable to environmental changes. The basic plant is designed to provide a longer detention time than a standard activated sludge plant, in the order of 24-36 hours in the aeration tank. The biological solids are continually returned to the aeration chamber without wasting any sludge on the theory that the net increase in biological solids will be counterbalanced by the decrease in biological solids due to endogenous respiration resulting in a state of equilibrium in regard to biomass concentration in the system.

Although it has been reported by many researchers that it is impossible to operate an extended aeration process without sludge accumulation, the investigation herein reported indicated that during a 2½ year period, at least twice for periods of five months and four months, the system reached a steady state condition without sludge accumulation. Throughout this investigation, sludge wasting was not practiced at any time. The "hydrolytic-assist" method was applied whenever it was felt necessary.

The objectives of the study were:

1) study of operational performance of a total oxidation process using Gaudy's method for controlling biomass concentration, i.e., the "hydrolytic assist;"

2) to determine frequency of the "hydrolytic-assist" to solve the sludge handling and disposal problem.

CHAPTER II

LITERATURE REVIEW

Theoretically, extended aeration in sewage treatment involves total oxidation of the substrate by an activated sludge and the eventual conversion of the substrate to oxidized nitrogen compounds and carbon dioxide without any increase or decrease in the total weight of the activated sludge.

Porges and his co-workers (1) introduced this concept in 1952 as a consequence of their research on the biological treatment of dairy wastes. They found that skim milk at a concentration of 1000 mg/l was completely removed from the solution in six hours; 60 percent was assimilated into cell tissue, and 40 percent was oxidized completely to CO_2 and H_2O. Casein and lactose were converted into cell tissue in a similar manner, but at a slightly lower rate. They concluded that by employing a longer detention time in the order of 24-36 hours and adopting a proper food-to-microorganism ratio, and by continually returning all of the biomass to the aeration chamber without wasting any sludge, the net increase in biological solids due to assimilation of exogenous substrate would be counterbalanced by the decrease in biological solids due to endogenous respiration, resulting in a state of equilibrium in the system. This concept was supported by the work of Thayer (2), who developed a waste disposal plan applicable to small dairies.

Kuntz (3) supported the total oxidation concept but recommended the suspended solids concentration not exceed 3000 mg/l. In a later study by both Kuntz and Fourney (4) using a continuous flow reactor, they concluded that total bio-oxidation does occur and an equilibrium of solids is established as an inherent condition. The equilibrium value of biological solids concentration was twelve times the substrate concentration in the feed.

In 1957, Symons and McKinney (5) presented an article at the 30th Annual Meeting of the Federation of Sewage and Industrial Wastes Association which repudiated earlier findings on extended aeration. In a 35-day test period on five batch units using extended aeration, they studied the effects of various methods of nitrogen supplementation on the biochemistry of nitrogen in the synthesis of activated sludge; they found that an increase in volatile solids occurred throughout the 35-day test period. This buildup was attributed to external waste products in the form of polysaccharide material which was resistant to further biological degradation. On these findings they concluded that batch-fed or conventional activated sludge systems could not operate without a gradual solids buildup unless some solids were wasted. They were supported in their conclusions by Fourney and Kuntz (6) who, after more research with skim milk, agreed that total endogenous oxidation was not possible within reasonable times and sizes of treatment systems. They found that they could not operate the system at equilibrium without wasting sludge at the rate of 0.122 lbs/day.

In 1958, Tapleshay (7) performed his investigation on the extended aeration process and concluded that it would be quite possible to maintain the solids concentration at relatively fixed levels without the necessity of wasting any sludge if a 24-hour aeration period and a four-hour detention period in the settling tank were maintained, and a BOD loading of 30 lbs/day/1000 cu ft aeration capacity was not exceeded. The process accomplished a BOD reduction between 80 to 90 percent; effluent BOD was as low as 20 mg/l, and volatile solids in the system were reported as about 50 percent.

Up until now, all experimental units had been run for only a short period of time. In 1959, Busch and Myrick (8) reported on a study they had done involving both batch and continuous flow total oxidation systems utilizing a soluble substrate and no intentional wasting of solids. After one year of operation, they found that total oxidation was not possible without sludge wasting. They noted that in neither environment was equilibrium reached between food and population even after as long as 103 days of operation at BOD loadings of 0.05 lbs/day/lb of VSS. Biological solids in the continuous system showed cyclic fluctuations in concentration and settling characteristics as well. They concluded that a condition of biological solids "equilibrium" would be impossible, and that the total oxidation process is neither theoretically sound nor practically attainable, since buildup of biological solids is inevitable unless the amount of carryover of biomass in the effluent is counterbalanced by the amount accumulating in the system.

Washington and Symons (9) in their investigation concluded that the continuing accumulation of biological inert solids consisting mainly of non-biodegradable extracellular polysaccharides would cause the system to undergo a biochemical failure. Ludzack (10) performed a total oxidation study and concluded that as the percentage of solids wastage per week was decreased gradually from 20 percent to zero percent, i.e., no sludge wastage, the content of volatile solids decreased gradually from 75 percent to 50 percent.

In a batch study by McWhorter and Heukelekian (11) on the endogenous phase of metabolism, they observed the typical rise in cell mass as the substrate glucose was consumed until a maximum was reached which coincided with the exhaustion of the substrate. Upon further aeration, however, they observed a sharp decrease in cell mass with the rates of decrease reaching a minimum in 10-12 days. After 25 days, an inactive cell mass remained which amounted to 12 percent of the initial substrate fed. This was in agreement with the earlier study by Washington and Symons (9) who had reported a VSS accumulation in the amount of 10 percent to 15 percent of the ultimate BOD removed.

In 1962, McCarty and Broderson (12) in their report suggested that solids accumulation would be an important design criteria for designing any extended aeration process, because there must be an accumulation of sludge, and this excess solids would be discharged in the effluent if no facilities for its disposal were provided.

Washington, Hetling and Rao (13) made a long-term study and did not find the system to reach any steady state condition, but observed periodic fluctuations in biological solids concentration.

In 1964, Simson (14) from his investigation on total oxidation process, suggested that in order to use the total oxidation process, the sludge-wasting should be practiced at about 8500 mg/l solids concentration providing a six-hour detention time in the settling tank with a surface overflow rate of 150 gpd/ft^2 at maximum design flow rate.

In 1965, the suggestions made by Sawyer (15) on the use of the total oxidation process were as follows: an aeration period of 24 hours, a BOD loading of approximately 15 lbs/day/1000 cu ft of aeration chamber capacity and 5000 to 8000 mg/l biological solids concentration at a temperature of 15.5°C or above.

By this time it was pretty well agreed upon that total oxidation of the substrate was not possible. It was agreed that there would always be an inactive solids accumulation of between 10 to 15 percent of the substrate fed and for the activated solids to maintain an equilibrium, solids had to be wasted at the same rate as it was accumulating. This buildup of sludge was attributed to waste products consisting mostly of polysaccharide material which was resistant to further biological degradation.

The Oklahoma State University bioenvironmental engineering laboratory under the guidance of Dr. A. F. Gaudy, Jr. started a long-term study on the total oxidation process in the mid-1960s.

In 1967, Gaudy (16) noted that although it had been agreed upon that a gradual accumulation of solids would eventually lead to a functional failure of total oxidation plants, it had not been determined how long this would take.

In a three-year study on the operational stability of the extended aeration process, Gaudy et al. looked at this problem using both batch and continuous flow units. During the study, all solids were returned to the aeration chamber by passing the effluent through a centrifuge.

The first part of their study (17) dealt with shock loading during batch and continuous flow operations. They observed that for both types of operations, the process could handle slug organic loadings up to five times the initial loadings although the sludge during periods of continuous flow operation responded more successfully than under periods of batch operation. It was also observed that the continuous flow operation yielded much better COD removal under both steady and shock loading conditions.

The second part of their study (18) dealt with the observation of a continuous flow unit to see how long it would take the biologically inert fraction as reported by earlier investigators to build up large enough to cause biological failure of the system. After nearly two years of operation, the unit was still operating as biologically efficiently as it had when the tests were first initiated; it was still providing approximately 90 percent COD removal efficiency for a feed of approximately 530 mg/l and an aeration chamber detention time of 16 hours. The solids concentration never reached an equilibrium as Porges and his co-workers (1) first suggested, but increased and decreased in cycles of roughly 280 days. During periods of decreasing solids concentration, the COD removal efficiency of the system was never affected to a great extent. From these observations, Gaudy and his co-workers concluded that although there are engineering problems, an extended aeration activated sludge system without sludge wasting could be operated without continual solids accumulation of a prolonged endogenous metabolism of biological solids in the extended aeration system is provided.

From the foregoing review, it seems to be surprising that although the theory of total oxidation was proven to be valid, the majority of investigators concluded that there was no possibility to attain a steady state condition in biological solids concentration due to continual buildup of inert materials in the system. It is interesting to note that any experimental verification regarding inertness of biological materials was not done by any of the researchers which had gone before.

Obayashi and Gaudy (20) were the first to conduct a study on the biodegradability of heteropolysaccharides produced by the different microorganisms, and concluded that the extracellular polysaccharides they studied were completely biodegradable and could not be classified as biologically inert materials which cause the system to undergo a biochemical failure as reported by Washington, Symons, McKinney, and other investigators.

On a short-term basis, sludge buildup is obvious and inevitable, and steady state condition of solids concentration is impossible to attain, so it was deemed necessary to investigate operational stability of an extended aeration activated sludge process with positive engineering control of retention of biological solids in the system. Yang (19) was the first investigator who, under Gaudy's guidance, employed engineering control of a total oxidation process through chemical "hydrolytic-assist." The chemical hydrolytic-assist is a procedure of withdrawing some of the sludge from the settling tank underflow periodically and acidifying and hydrolyzing it chemically at a particular temperature, pressure, and pH condition, neutralizing it and then recycling the liquified cells to the aeration chamber. This procedure offered an effective way to combine ideal features of chemical and biological treatment for concurrent treatment of the wastewater and essentially total aerobic digestion of sludge developed in the process. The results from the study indicated that such a system could be operated successfully with substrate removal efficiency remaining high. Further studies (21) (22) also indicated that the hydrolytic-assist would not militate against the production of a highly nitrified effluent or the efficiency could not be impaired for a waste containing a large portion of inorganic solids.

While the debate was going on as to whether total oxidation was theoretically possible, reports were coming in from the field as early as 1960 (23) that systems designed using the total oxidation concept were working quite well. Some of the first plants which used the principle were manufactured, predesigned package plants installed for use on low volume wastes, such as those for motels, trailer parks, country clubs, etc. They were characterized by their lack of primary sedimentation tanks and by a 20-hour aeration period with a final settling of four hours.

In Florida, there were two basic types being installed. One type used the extended aeration process and consisted of an aeration tank and a sedimentation tank. The other type used the contact stabilization process and consisted of a mixing chamber, a sedimentation tank, and a sludge reaeration tank. Data collected on the different types showed a BOD removal of over 90 percent in most cases.

By 1963, the number of extended aeration plants had increased to almost 3000 (24) and were being used to treat wastewaters from domestic, industrial, and military activities. A report in 1968 on a plant in Harahan, Louisiana (25), which was designed for an average dry weather flow of 1.6 mgd for a population of 15,000 showed an average BOD removal of 87 percent and suspended solids removal of 97 percent over a two-month period. The concept of extended aeration was not being used just in the United States. An extended aeration plant using orbal circuits (similar to an oxidation ditch) was developed in South Africa for capacities up to 2,250 cu m/day (26). The aeration chamber is divided into numbers of endless concentric channels interconnected by ports so positioned at the channel bottom level that the outlet from any one channel is upstream of the corresponding inlet to eliminate direct short circuiting between the channels. Instead of using the diffused air system, perforated disks were used that not only aerated the waste but helped in mixing and moving the waste forward. Performance studies on this type of plant showed a BOD removal of 97.9 percent, a COD removal of 78.1 percent, and a total nitrogen removal of 65.6 percent.

Not only has the extended aeration process been proven capable of handling domestic sewage, but it has also been proven capable of handling industrial waste as well. An example was Atlantic Richfield's decision to build a deep tank extended aeration plant instead of more conventional aeration plant for its East Chicago, Indiana Refinery. This decision was made because of the extended aeration process pilot plant's ability to produce good effluent quality during shock BOD loadings and high pH variations which are inherent in the daily operations of the refinery. A two-month study done on the plant after construction showed a BOD removal of 94 percent and a removal of 84 percent for the oily water being treated. The study was done during a period of high organic loadings caused by non-normal refinery operations and high hydraulic loadings caused by spring rains. Also during this period, the system was upset by the discharge of oil into the refinery waste collection system which resulted in an average influent oil concentration of 50 mg/l. This high concentration of oil resulted in a noticeable increase in floating sludge in both the aeration and the clarification tanks which resulted in an increased effluent BOD. The effluent BOD was 21 mg/l and suspended solids were 82 mg/l, but the increased loadings did not shut down the system (27).

CHAPTER III

MATERIALS AND METHODS

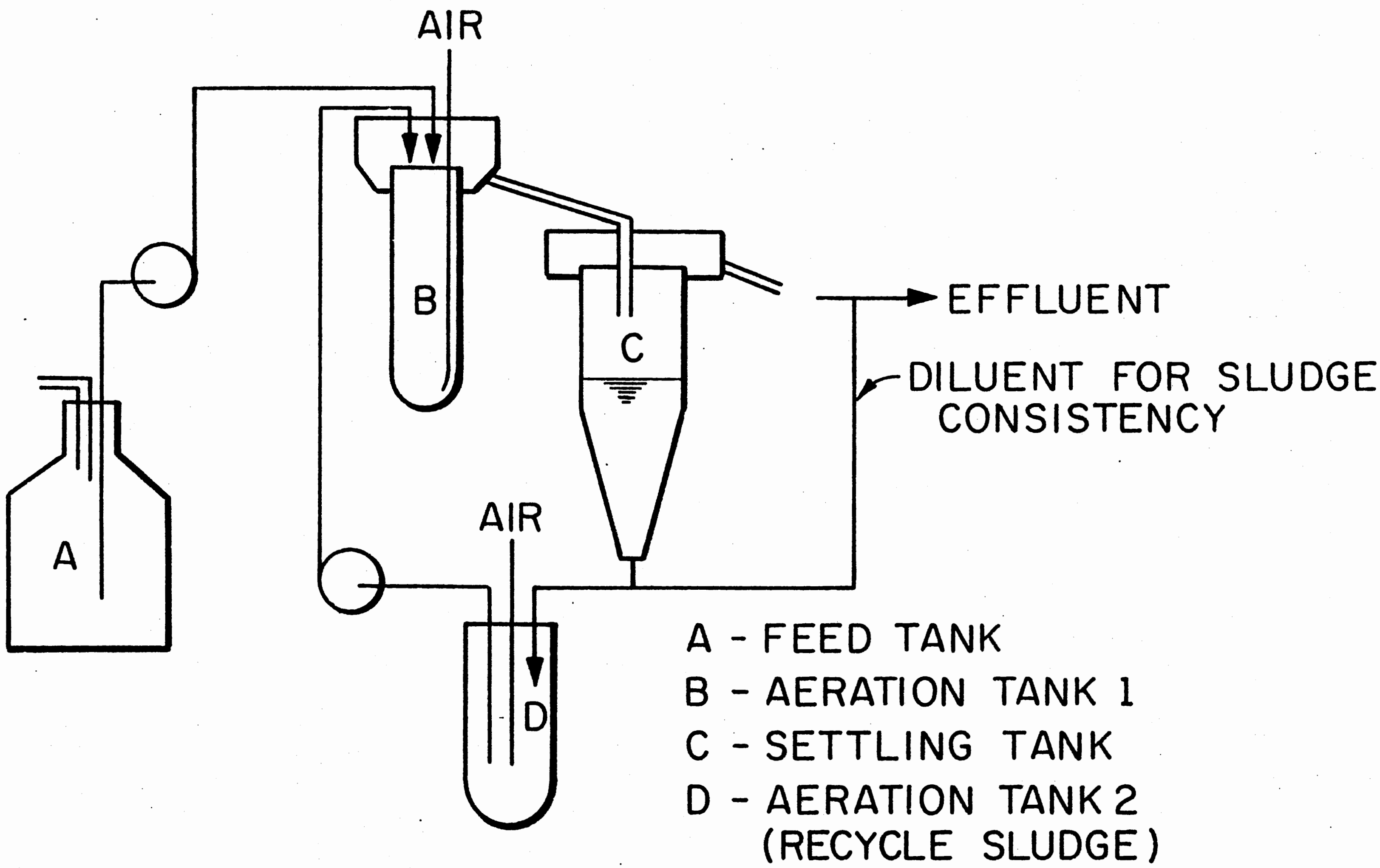
The bench-scale extended aeration pilot plant employed in these studies is shown in Figure 1. The unit was taken over by the author from P. S. Reddy on June 9, 1976. The existing unit was run for about 190 days. Many samples of cell materials were being taken and this was amounting to a significant wastage of sludge, so it was decided that the existing unit should be replaced by a larger unit as early as possible. Operation of the new unit was started after February 15, 1977.

Laboratory Apparatus

Continuous Flow Apparatus (small unit)

A drawing of the small-scale pilot plant is shown in Figure 1. The volume of aeration tank #1 was two liters, and the volume of the settling tank was five liters. For sludge recycling, a sludge consistency tank (aeration tank #2) with a capacity of two liters was used. A continuous feed rate of two liters per day was maintained to the reactor via a pump. The feed rate was monitored and adjusted daily. The daily rate could be monitored, since a 10-liter bottle made of clear glass and marked in one-liter graduations was used as feed reservoir. If the pumping rate was slightly off, a graduated cylinder and a timer were used to adjust the pumping. Flow from the reactor to the

Figure 1. Activated Sludge Pilot Plant of Smaller Size for Operation With External Sludge Recycle


AIR
B
C
EFFLUENT
DILUENT FOR SLUDGE
CONSISTENCY
A
AIR
D
A - FEED TANK
B - AERATION TANK 1
C - SETTLING TANK
D - AERATION TANK 2
(RECYCLE SLUDGE)

settling tank was accomplished via gravity flow. The sludge was recycled at a rate of 500 ml/day. Air was supplied to the reactor through porous carborundum diffusers. The airflow was monitored via airflow meters and maintained at 4000 cc/min/l. A glass cotton filter was placed between air diffusers and the air outlet to prevent any oil in the air lines from entering the experimental reactor. The pH of the system was monitored daily with a pH meter, and was maintained at approximately 7.0 by means of a phosphate buffer system. The temperature was monitored daily with a laboratory thermometer.

Continuous Flow Apparatus (larger unit)

A diagram of the new system is shown in Figure 2. The description and operations of the larger continuous flow unit were similar to those of the smaller unit with the following exceptions:

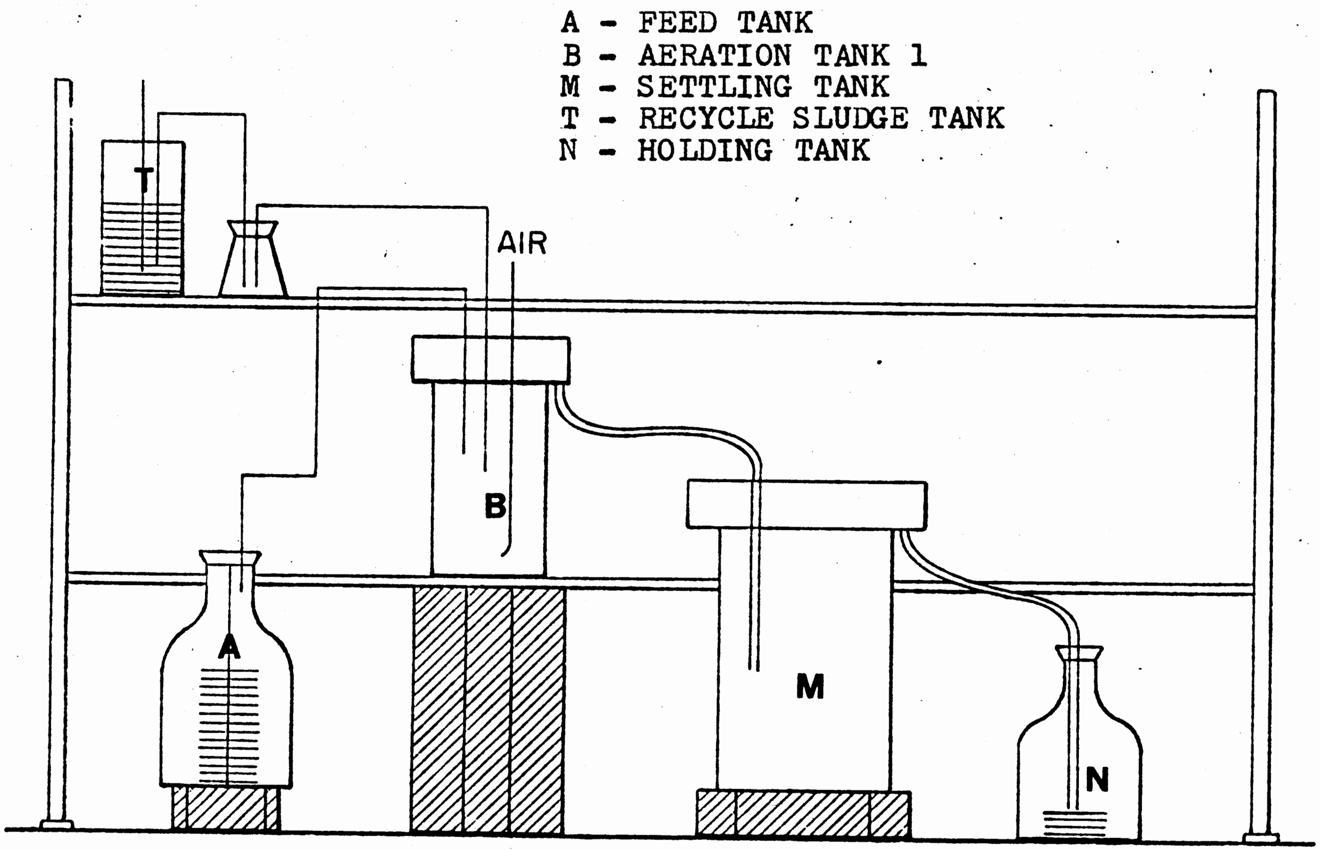
1) volume of aeration tank #1 was 12 liters
2) volume of settling tank was 18 liters
3) volume of sludge consistency tank #2 was 4 liters

The reactor and settling tank were made up of PVC materials.

Growth Study

The inocula for these studies were taken from the extended aeration pilot plant. The cells were grown in 250-ml Erlenmeyer flasks with glucose concentrations ranging from 100-1000 mg/l as the limiting nutrient. Composition of the feed is shown in Table I. Initial cell concentration was the same in all flasks; an initial optical density of approximately 0.0605 (percent transmission = 87) was used. The total volume of the reaction fluid per flask in these experiments was 40 ml. The flasks

Figure 2. Activated Sludge Pilot Plant of Large Size for Operation With External Sludge Recycle


A - FEED TANK
B - AERATION TANK 1
M - SETTLING TANK
T - RECYCLE SLUDGE TANK
N - HOLDING TANK
T
AIR
B
A
M
N

were placed on an oscillating shaker, which was adjusted to 100 oscillations/min. The growth curve was obtained by measuring the optical density at regular intervals. The final suspended solids and substrate concentration were measured, which allowed determination of the cell yield, Y_t. The μ_m and K_s were calculated using the data obtained from the growth study.

TABLE I

COMPOSITION OF FEED PER 500 mg/l GLUCOSE AS SUBSTRATE

Glucose	500 mg/l
$(NH_4)_2SO_4$	250 mg/l
$MgSO_4 \cdot 7H_2O$	50 mg/l
$FeCl_3 \cdot 6H_2O$	0.25 mg/l
$CaCl_2$	3.75 mg/l
$MnSO_4 \cdot H_2O$	4 mg/l
Phosphate buffer, 1.0m pH 7.0	5 ml/l
$(KH_2PO_4 + K_2HPO_4)$	30 ml/l
Tap water	50 ml/l

Chemical Hydrolytic-Assist

When subjecting portions of the sludge to hydrolytic-assist, this portion was withdrawn and hydrolyzed as follows: it was acidified to pH 1.0 with concentrated H_2SO_4, autoclaved for five hours at 15 psi, 120^oC, and then neutralized to pH 7 with 10 N KOH. Then it was divided into several equal portions and frozen for later feeding at a rate of one portion per day along with the synthetic waste.

Feed Solution

Stock solutions were made up in concentrated form and stored in a deep freezer. The chemical composition of the feed for the continuous flow reactor is shown in Table I. Feed was prepared by adding a measured quantity of each stock solution to the feed reservoirs and then adding the distilled water and tap water in order to obtain the desired feed concentration.

Experimental and Analytical Procedures

Two feed reservoirs were used, and feed was made up each 48 hours. While one feed bottle was being used, the other was washed and cleaned with chromic acid, rinsed with tap water, and made ready for use. There were never signs of contamination; thus, nature and concentration of the feed remained constant. Periodically (once or twice daily), the clear effluent contained in the holding tank was discarded and any solids in the bottom of the holding tank which had been carried over from the settling tank were collected carefully and returned to the settling tank. Thus throughout the study, no biological solids were either inadvertantly or intentionally lost from the system; the only solids lost from the system were those taken for samples to assess operational behavior and those registered as X_e.

At a regular interval of 24 hours, the sludges were carefully collected (in a measuring cylinder) from the settling tank and the required amount of solids were measured and placed in the recycling tank to be recycled at a constant rate as per the detention time. Whenever there was an excess of sludge (over the required amount), the excess was centrifuged and the packed solids were returned to the sludge recycling tank. Thus, all sludge was returned to the aeration tank. The recycling rate and feed rate were checked frequently.

The recycling sludge tank was aerated vigorously to keep the sludge aerobic and properly mixed.

During the study period, the sampling and analysis schedule shown in Table II was established.

TABLE II

SAMPLING AND ANALYSIS SCHEDULE

Analysis	Frequency	Methods
Feed		
COD	daily	COD*
NH_3-N	once/twice month	Ammonia Nitrogen**
Effluent		
Filtrate		
COD	daily	Standard Methods*
NH_3-N	once/twice month	Ecker & Lockhart**
NO_3^--N	once/twice month	Brucine*
Total		
COD	daily	Standard Methods*
SS	daily	Membrane Filter Tech*
MLSS	daily	Membrane Filter Tech*
pH	daily	pH Meter (digital)
VSS on X_R	once month	Standard Methods*
Oxygen Uptake	once month	DO Meter
Microscopic Analysis	once week	Wet Mount

*Standard Methods for the Examination of Water and Wastewater, 14th ed. (28)

**Ecker and Lockhart (29)

CHAPTER IV

RESULTS AND DISCUSSION

Results of this investigation will be presented in two parts. The first part deals with the operational performances of the continuous flow plant of the extended aeration process using a pilot plant of smaller size (see Figure 1), and the second part deals with the pilot plant of larger size (see Figure 2).

Operational Performance of the Small-sized Extended Aeration Pilot Plant

The small unit was operated for a total of 250 days. Figures 3, 4, 5, and 6 show the daily operation performance of the system. In the earlier stage of operation, from the starting day to day 52 (June 9, 1976, to August 1, 1976), the system did not reach steady state at all. Microscopic examinations showed a large amount of filaments were present without any protozoa in the system. The system was run with α = 0.25 and detention time $\bar{t}$ = 24 hours. The X_R values varied from 10,000 to 14,000 mg/l, and biomass concentration, X, ranged from 2,000 to 3,000 mg/l. The values for S_e ranged between 4 to 60 mg/l, and suspended solids in the settling tank overflow, X_e, ranged from 5 to 60 mg/l. Because of the wide variation observed in the system which was not expected and was so inconsistent with other data, it was finally decided not to include these data in this report.

Figure 3. Operational Performance of Extended Aeration Pilot Plant of Smaller Size Showing Influent and Effluent Characteristics for Days 53 to 121

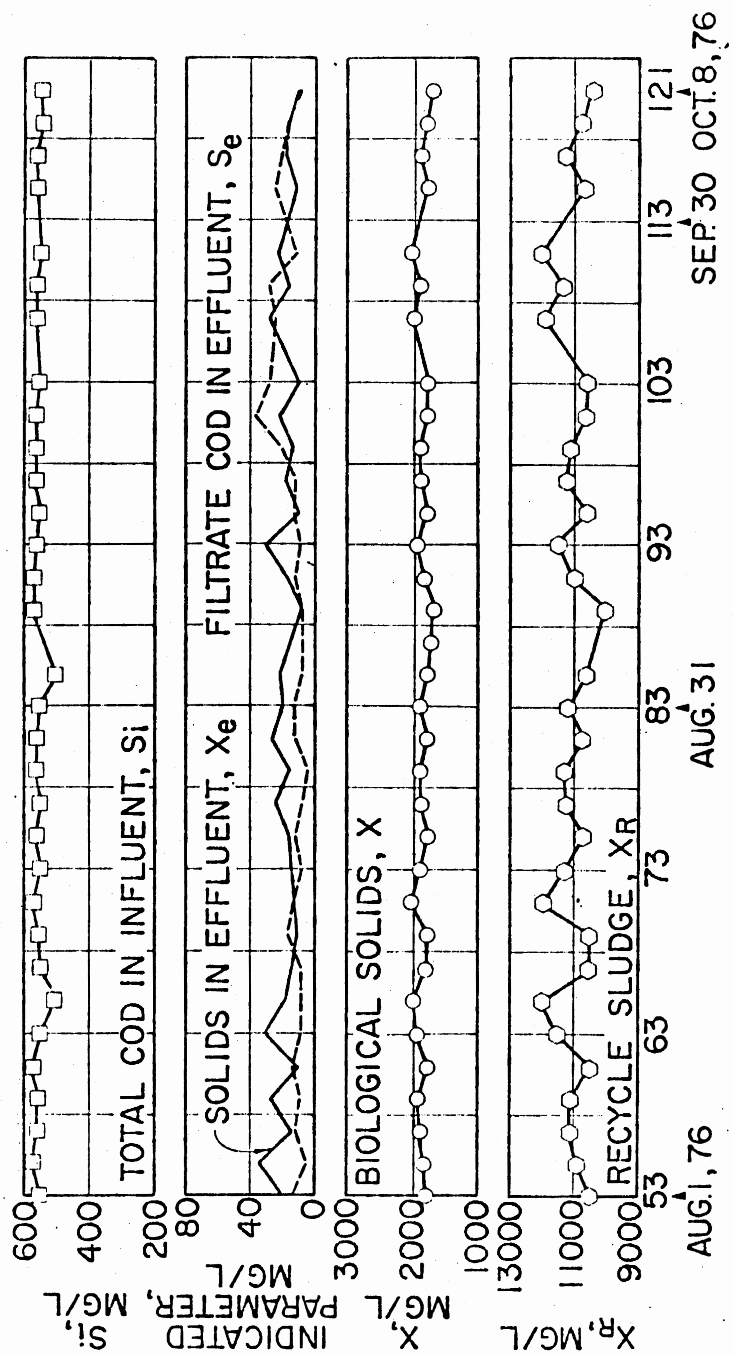

TOTAL COD IN INFLUENT, Si
SOLIDS IN EFFLUENT, Xe
FILTRATE COD IN EFFLUENT, Se
BIOLOGICAL SOLIDS, X
RECYCLE SLUDGE, XR
Si, MG/L
INDICATED PARAMETER, MG/L
X, MG/L
XR, MG/L
600
400
200
80
40
0
3000
2000
1000
13000
11000
9000
53
63
73
83
93
103
113
121
AUG. 1, 76
AUG. 31
SEP. 30
OCT. 8, 76

Figure 4. Operational Performance of Extended Aeration Pilot Plant of Smaller Size Showing Influent and Effluent Characteristics for Days 121 to 183

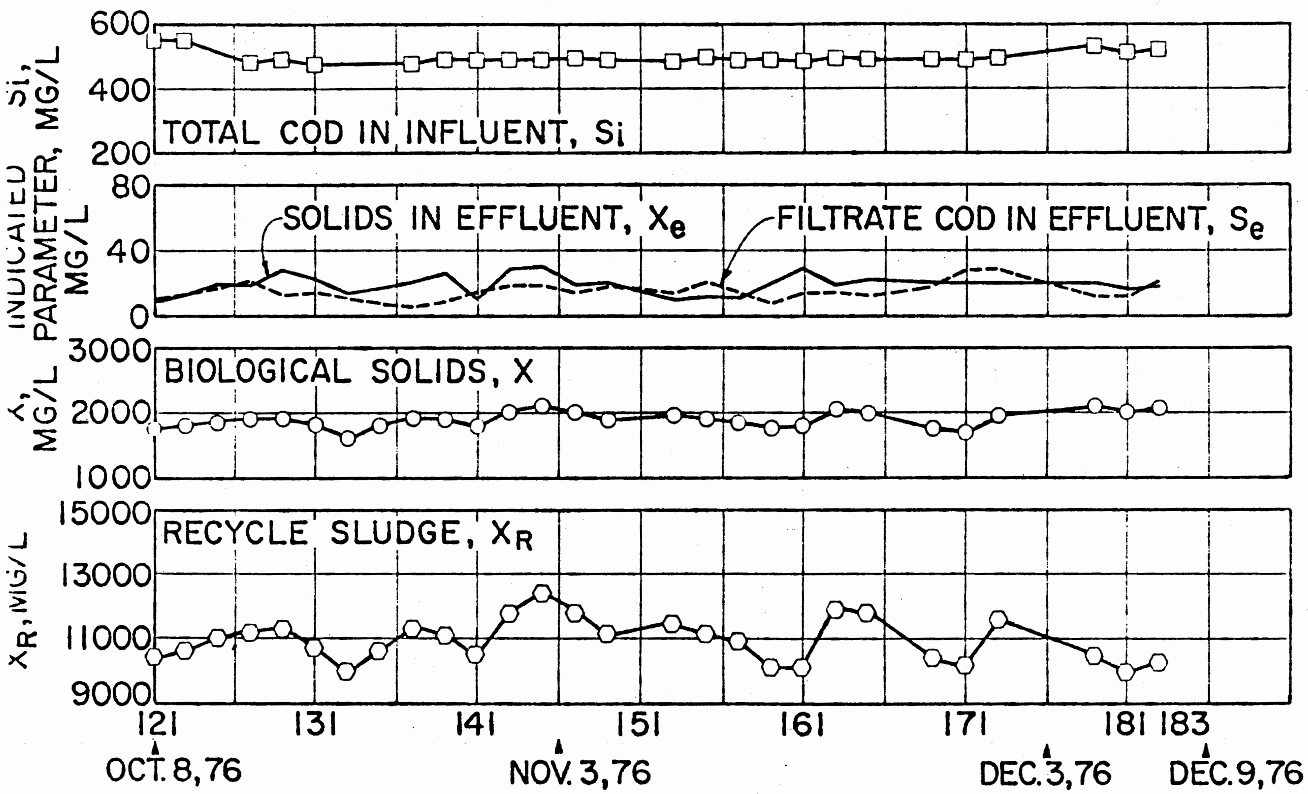

TOTAL COD IN INFLUENT, Si
Si, MG/L
600
400
200
INDICATED PARAMETER, MG/L
SOLIDS IN EFFLUENT, Xe
FILTRATE COD IN EFFLUENT, Se
MG/L
80
40
0
BIOLOGICAL SOLIDS, X
X, MG/L
3000
2000
1000
RECYCLE SLUDGE, XR
XR, MG/L
15000
13000
11000
9000
121
131
141
151
161
171
181 183
OCT. 8,76
NOV. 3,76
DEC. 3,76
DEC. 9,76

Figure 5. Operational Performance of Extended Aeration Pilot Plant of Smaller Size Showing Influent and Effluent Characteristics for Days 183 to 250

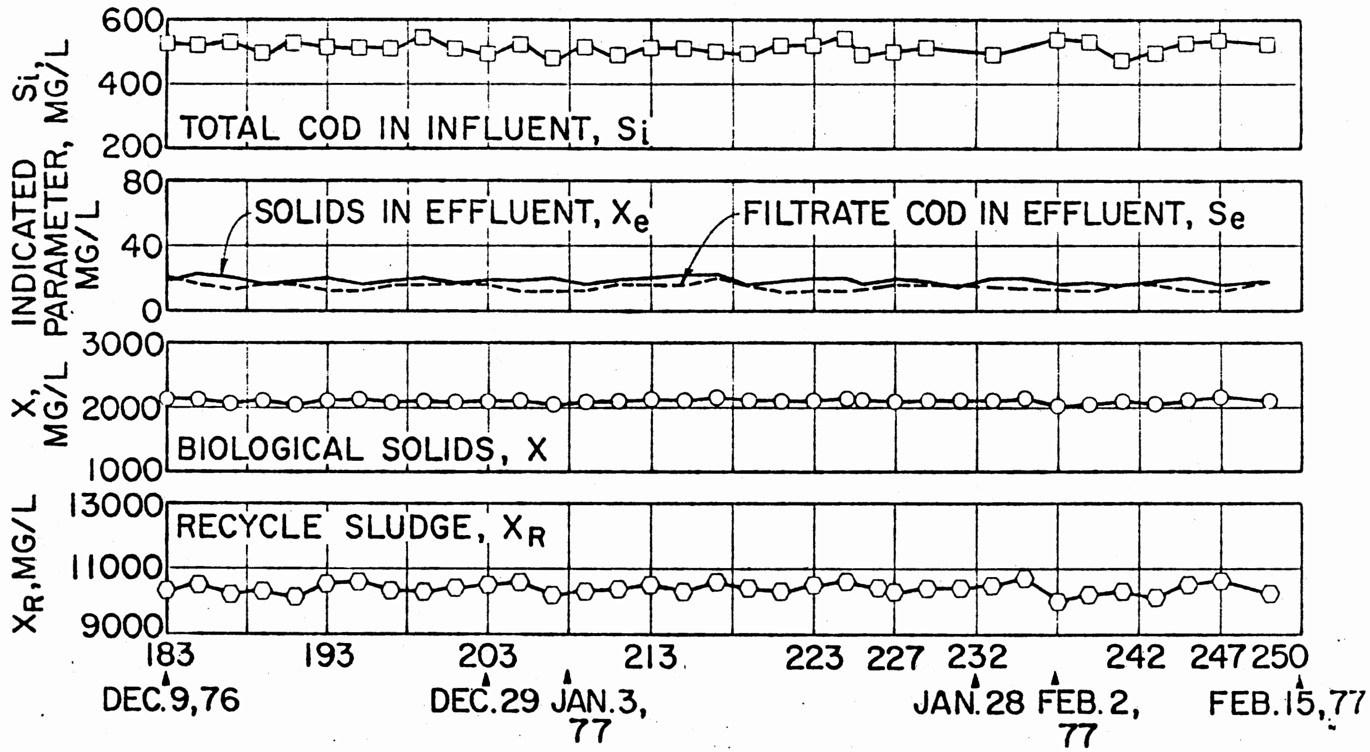
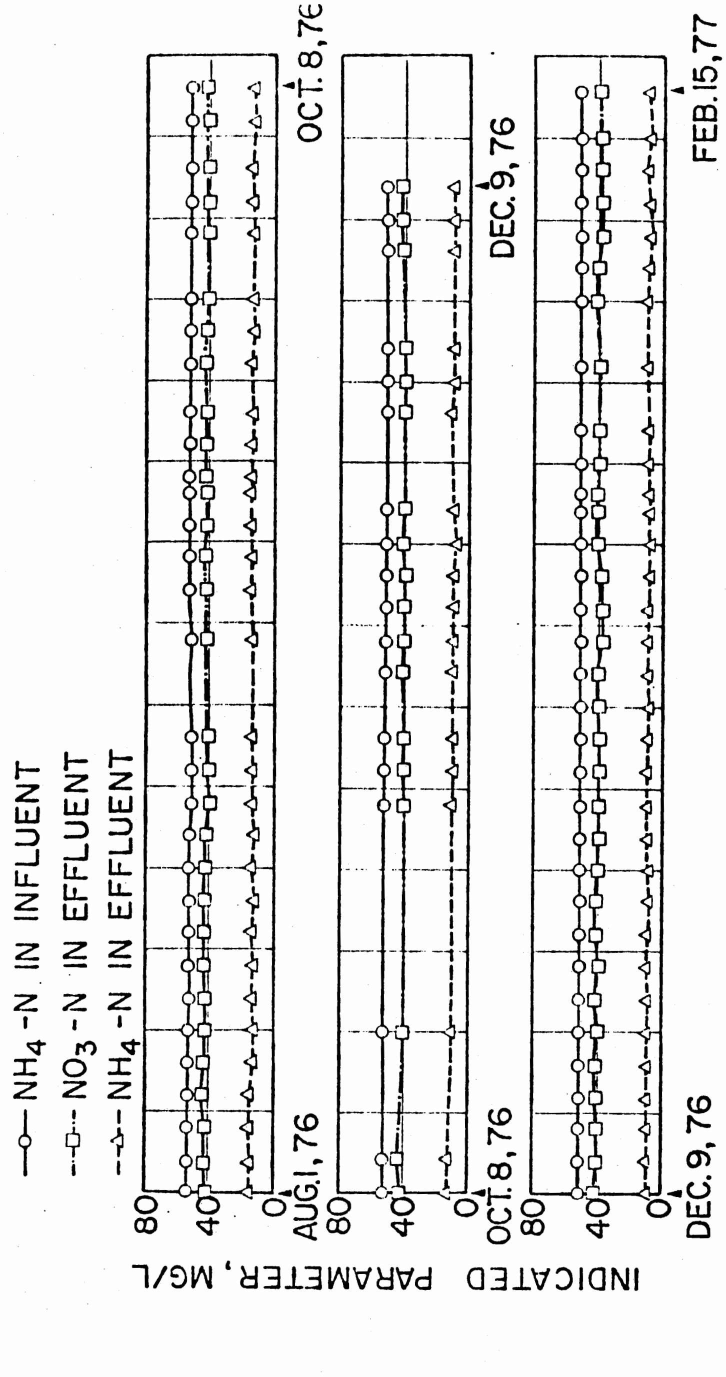

TOTAL COD IN INFLUENT, Si
SOLIDS IN EFFLUENT, Xe
FILTRATE COD IN EFFLUENT, Se
BIOLOGICAL SOLIDS, X
RECYCLE SLUDGE, XR
INDICATED PARAMETER, MG/L
Si, MG/L
MG/L
X, MG/L
XR, MG/L
600
400
200
80
40
0
3000
2000
1000
13000
11000
9000
183
193
203
213
223
227
232
242
247
250
DEC. 9, 76
DEC. 29
JAN. 3, 77
JAN. 28
FEB. 2, 77
FEB. 15, 77

Figure 6. Operational Performance of Extended Aeration Pilot Plant of Smaller Size Showing Nitrogen Concentration in Influent and Effluent During our Investigation



NH$_4$-N IN INFLUENT
NO$_3$-N IN EFFLUENT
NH$_4$-N IN EFFLUENT
INDICATED PARAMETER, MG/L
80
40
0
AUG.1, 76
OCT. 8, 76
DEC. 9, 76
FEB.15, 77

In the second stage, from day 53 to day 143 (August 1, 1976, to October 31, 1976), the unit was run with $\alpha = 0.20$, and the other controlling parameters remained the same as before. During this period, the system appeared to be more or less at steady state. Since a lack of protozoa and the predominance of filaments were observed in the system from the beginning, it was decided to add protozoa from an external source regularly (twice a month) until the shutdown of the small unit (on day 250, i.e., February 15, 1977). Frequent microscopic examination showed that there were less filaments than before, and a few protozoa were present in the system during this period.

From the beginning, the size of the sample needed to assess performance was a problem. Sludge wastage due to sampling was approximately 0.6 percent of the total amount of solids contained in the system, and about 0.4 percent was due to solids lost as X_e. It was finally decided to cut down the sample size in order to operate in closer accord with the concepts of a total cell retention, and to replace the existing unit with a larger unit as early as possible, thus minimizing the percentage of cell loss due to sampling.

In the third stage, from day 144 to day 176 (November 1 to December 3, 1977), the system was run exactly in the same way as it was in the second stage, except the sample size was cut down. The system was found to be at steady state.

In the fourth stage, from day 177 to day 250 (December 4 to February 15, 1977), α was changed to 0.25, and the system was operated in the same way as it was running in the third stage. The system remained at steady state during this period.

A comparison of the results of the different stages of operation for the small-size unit are shown in Table III. It is seen that a considerable amount of nitrification took place during each stage. The table also indicates that after reducing the sample size, Y_o, the observed yield and the corresponding K_d, the maintenance coefficient yielded values of about 6 percent and 0.11 percent, respectively.

Operational Performance of the Large Scale Extended Aeration Pilot Plant

The large unit was put into operation on February 16, 1977. It was felt necessary to run tests on complete mixing by the "dilute-in" and/or "dilute-out" method. The results of such a study are shown in Figure 7, and it is clearly seen that the unit was completely mixed. Growth studies were run to determine if there was a relation between μ and substrate concentration at various times throughout this experimentation. In all cases, a plot of μ vs. S_o could be fit ideally to a rectangular hyperbola (Monod Equation). The results of the eight growth studies made are shown in Figure 8. The growth "constants" μ_m and K_s were obtained from a double reciprocal plot, $1/S_o$ vs. $1/\mu$. The values for μ were obtained from a semi-logarithmic plot, optical density vs. time. The graphs of this relationship shown in Figure 8 are plots of μ at various values of S_o using the determined values of K_s and μ_m in the Monod equation $\left(\mu = \frac{\mu_m S}{K_s + S}\right)$. It can be seen that the plotted curves do fit the plotted data points for μ at various S_o values thus indicating that the Monod equation provides a rather good fit of the data.

Most researchers in this field who have investigated the extended aeration process have concluded that an extended aeration process could not be maintained in a steady state with respect to biological solids.

TABLE III

SUMMARY RESULTS OF DIFFERENT STAGES OF OPERATIONS

STAGE NO. 2 — August 1, 1976 - October 31, 1976; $a = 0.25$ - $\bar{t} = 24$ hours

	X_R mg/l	X mg/l	X_e mg/l	X_w mg	S_i mg/l	S_e mg/l	$(NH_3\text{-}N)_e$ mg/l	$(NO_3\text{-}N)_e$ mg/l	% Nitrif. Rate
Mean (μ)	11020	1868	18	139	555	11.0	12.6	42.3	
Range									
Max.	12000	2200	36	170	570	36	14.23	45.9	
Min.	9000	1600	8	80	480	4	9.5	39.0	79
SD (σ)	547	92	5.4	37.6	11.6	2.75	1.26	1.37	
CV ($\frac{\sigma}{\mu}$) %	4.9	4.9	30	27	2.1	25	10	3.2	
μ_n^*			0.0203						
μ_n^{**}			0.0368						
Y_o^*			0.0696						
Y_o^{**}			0.126						

STAGE NO. 3 — November 1, 1976 - December 2, 1976; $a = 0.20$ - $\bar{t} = 24$ hours

	X_R mg/l	X mg/l	X_e mg/l	X_w mg	S_i mg/l	S_e mg/l	$(NH_3\text{-}N)_e$ mg/l	$(NO_3\text{-}N)_e$ mg/l	% Nitrif. Rate
Mean (μ)	11282	1914	20	61	500	7.0	10.2	40.9	
Range									
Max.	12400	2100	30	80	530	28	11.5	41.9	
Min.	10000	1700	10	40	480	3	9.6	40.1	77
SD (σ)	785	131	5.4	15.2	12.5	1.75	.40	0.575	
CV ($\frac{\sigma}{\mu}$) %	6.9	6.8	27	25	2.5	25	3.9	1.4	
μ_n^*			0.0214						
μ_n^{**}			0.0156						
Y_o^*			0.0825						
Y_o^{**}			0.0591						

STAGE NO. 4 — December 4, 1976 - February 15, 1977; $a = 0.25$ - $\bar{t} = 24$ hours

	X_R mg/l	X mg/l	X_e mg/l	X_w mg	S_i mg/l	S_e mg/l	$(NH_3\text{-}N)_e$ mg/l	$(NO_3\text{-}N)_e$ mg/l	% Nitrif. Rate
Mean (μ)	10020	2028	19	62.0	512	15.0	10.24	41.4	
Range									
Max.	10700	2150	22	65	550	20	10.7	42.6	
Min.	10000	2000	12	58	470	12	9.5	39.1	78
SD (σ)	490	91	4.8	14.9	12.3	3.45	0.293	1.00	
CV ($\frac{\sigma}{\mu}$) %	4.8	4.4	25	24	2.4	23	2.9	2.4	
μ_n^*			0.0147						
μ_n^{**}			0.015						
Y_o^*			0.060						
Y_o^{**}			0.061						

$\mu_n^* = D\left(1 + a - a\frac{X_R}{X}\right)$ $\qquad$ $Y_o^* = \frac{\mu_n X}{D(S_i - S_e)}$

$\mu_n^{**} = \frac{X_w}{VX}$ $\qquad$ $Y_o^{**} = X_w / F(S_i - S_e)$

Figure 7. Results of Tests on Complete Mixing by "Dilute-in" Method for Larger Pilot Plants Aeration Tank

. . . . theoretical

* * * * experimental

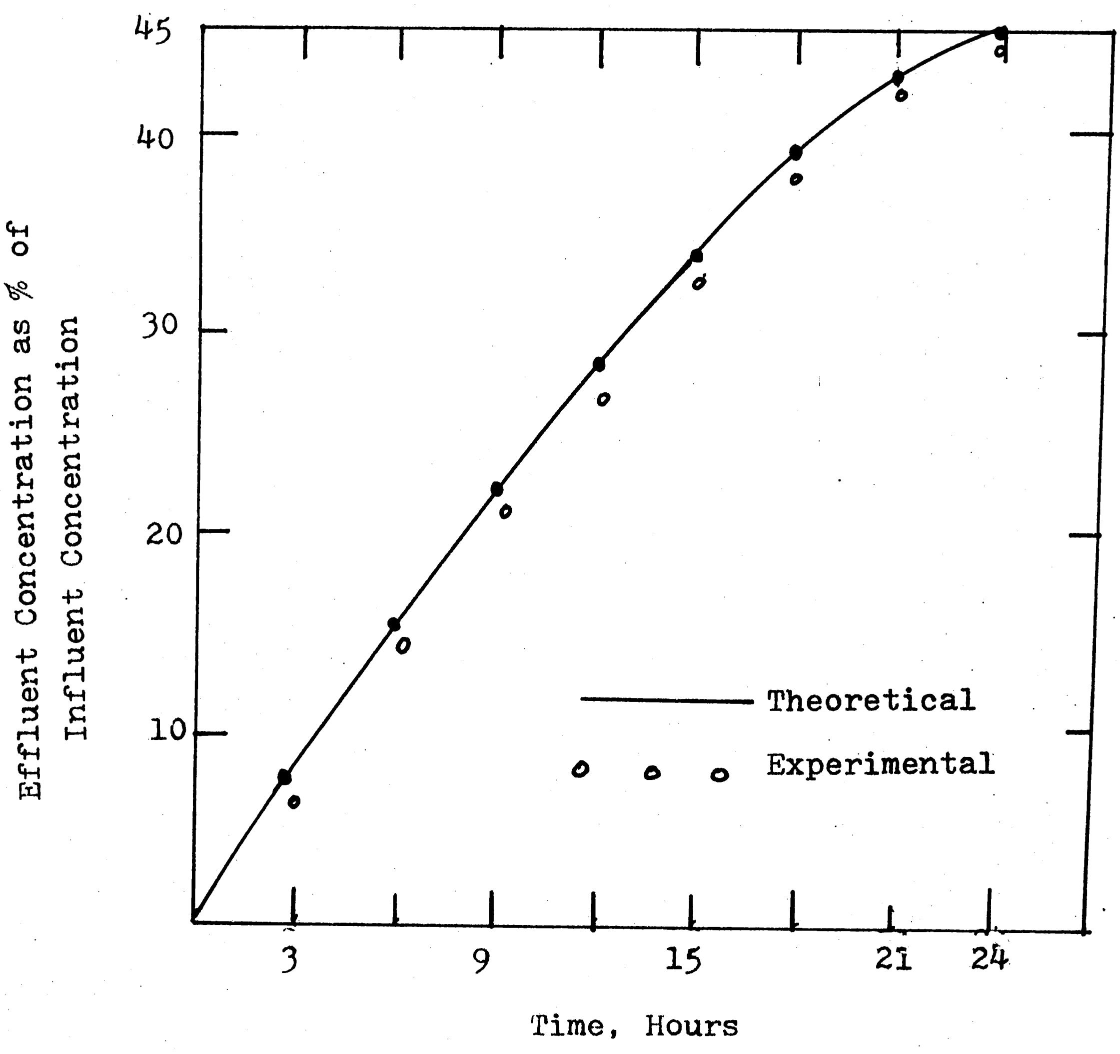
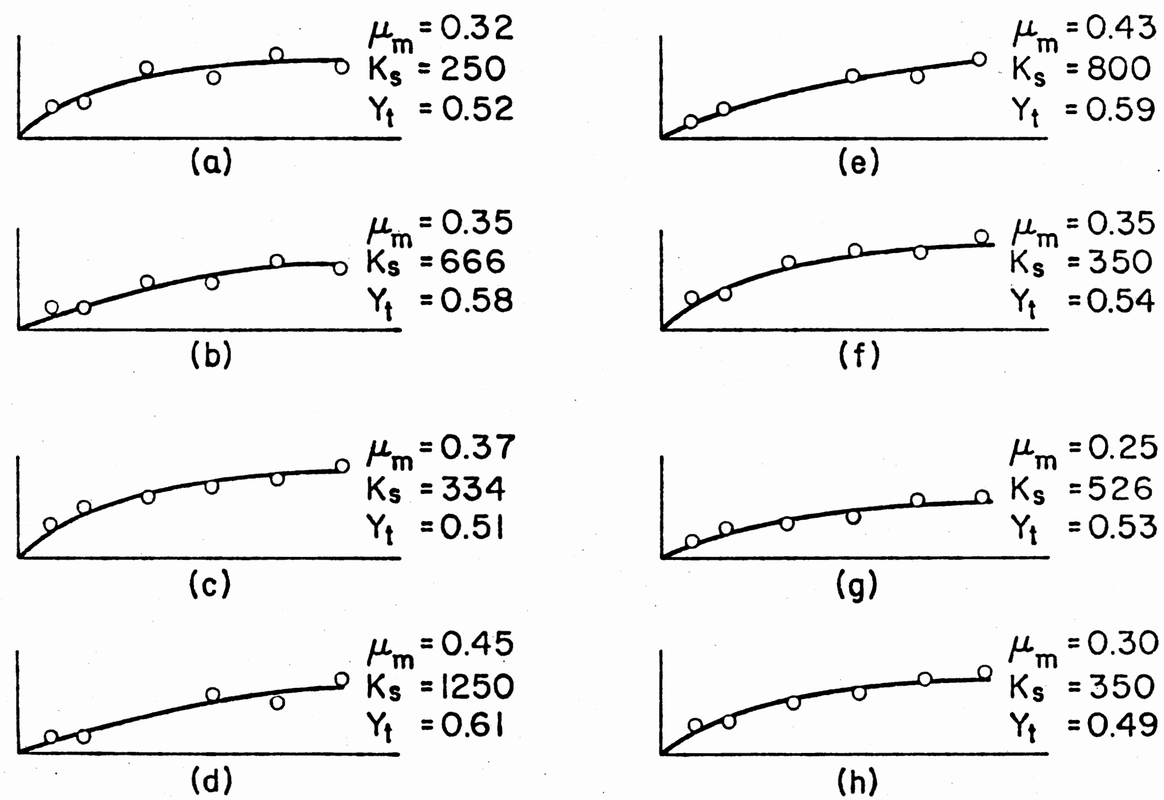

45
40
30
20
10
Effluent Concentration as % of Influent Concentration
3
9
15
21
24
Time, Hours
Theoretical
Experimental

Figure 8. Graphical Representation of Monod Equation Showing Relationship Between μ and S at Determined μ_m and K_s During Operation of the Larger Unit

0 o o o --------- experimental data



μm = 0.32
Ks = 250
Yt = 0.52
(a)
μm = 0.35
Ks = 666
Yt = 0.58
(b)
μm = 0.37
Ks = 334
Yt = 0.51
(c)
μm = 0.45
Ks = 1250
Yt = 0.61
(d)
μm = 0.43
Ks = 800
Yt = 0.59
(e)
μm = 0.35
Ks = 350
Yt = 0.54
(f)
μm = 0.25
Ks = 526
Yt = 0.53
(g)
μm = 0.30
Ks = 350
Yt = 0.49
(h)

However, they did not operate the system with the control of recycle solids concentration. In the Oklahoma State University laboratories, Gaudy and co-workers had accomplished research which indicated that the concept of total oxidation was sound. Furthermore, using the general activated sludge model they had developed, it was possible to calculate an activated sludge process employing a constant X_R (if the biological constants remained constant) could be operated with no excess sludge production (total oxidation). From the beginning of this investigation, the primary aim was to test this premise, i.e., could close control of X_R aid or enhance the system to attain a steady state with respect to X and S_e if all other parameters were held constant? It was thought that the system could possibly produce just enough sludge to provide for the recycle concentration without any wasting. The best concentration of X_R and $\bar{t}$ and α to investigate the situation were not known.

The biological solids concentration was allowed to build up for about a month. Sampling was started on March 20, 1977. It was decided to set $\alpha = 0.25$ and $D = 1/24\ hr^{-1}$ since these are reasonable values from field experience. Observations were made to determine if X_e (and thus X) could eventually attain a steady state. The operational performance of this pilot plant is shown in Figures 9 through 16.

From day 44 to day 86 (May 3 to June 15, 1977) (see Figures 9 and 10) the system appeared to be at steady state with the following parameters: X_R = 10,400 mg/l; X = 2020 mg/l; X_e = 36 mg/l; S_i = 528 mg/l; S_e = 20 mg/l, and VSS = 0.54. D.O. was observed to be at the level of 8.0 mg/l. The degree of nitrification of the effluent was found to be approximately 43 percent. Oxygen uptake was measured both on X_R and X,

Figure 9. Operational Performances of Extended Aeration Pilot Plant of Larger Size Showing Influent and Effluent Charactistics for Days 0 to 70

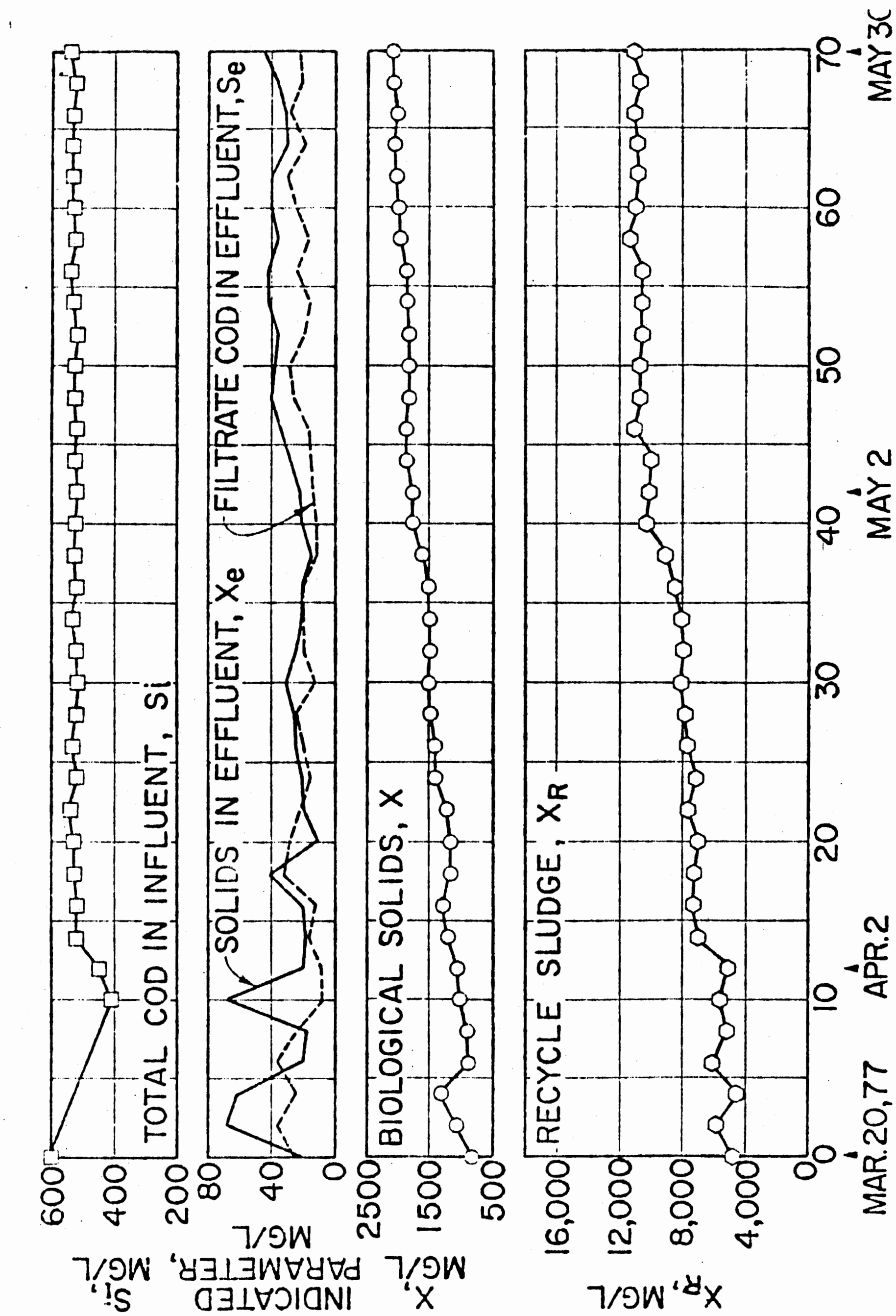

TOTAL COD IN INFLUENT, Si
SOLIDS IN EFFLUENT, Xe
FILTRATE COD IN EFFLUENT, Se
BIOLOGICAL SOLIDS, X
RECYCLE SLUDGE, XR
Si, MG/L
INDICATED PARAMETER, MG/L
X, MG/L
XR, MG/L
600
400
200
80
40
0
2500
1500
500
16,000
12,000
8,000
4,000
0
0
10
20
30
40
50
60
70
MAR. 20,77
APR. 2
MAY 2
MAY 30

Figure 10. Operational Performance of Extended Aeration Pilot Plant of Larger Size Showing Influent and Effluent Characteristics for Days 70 to 140

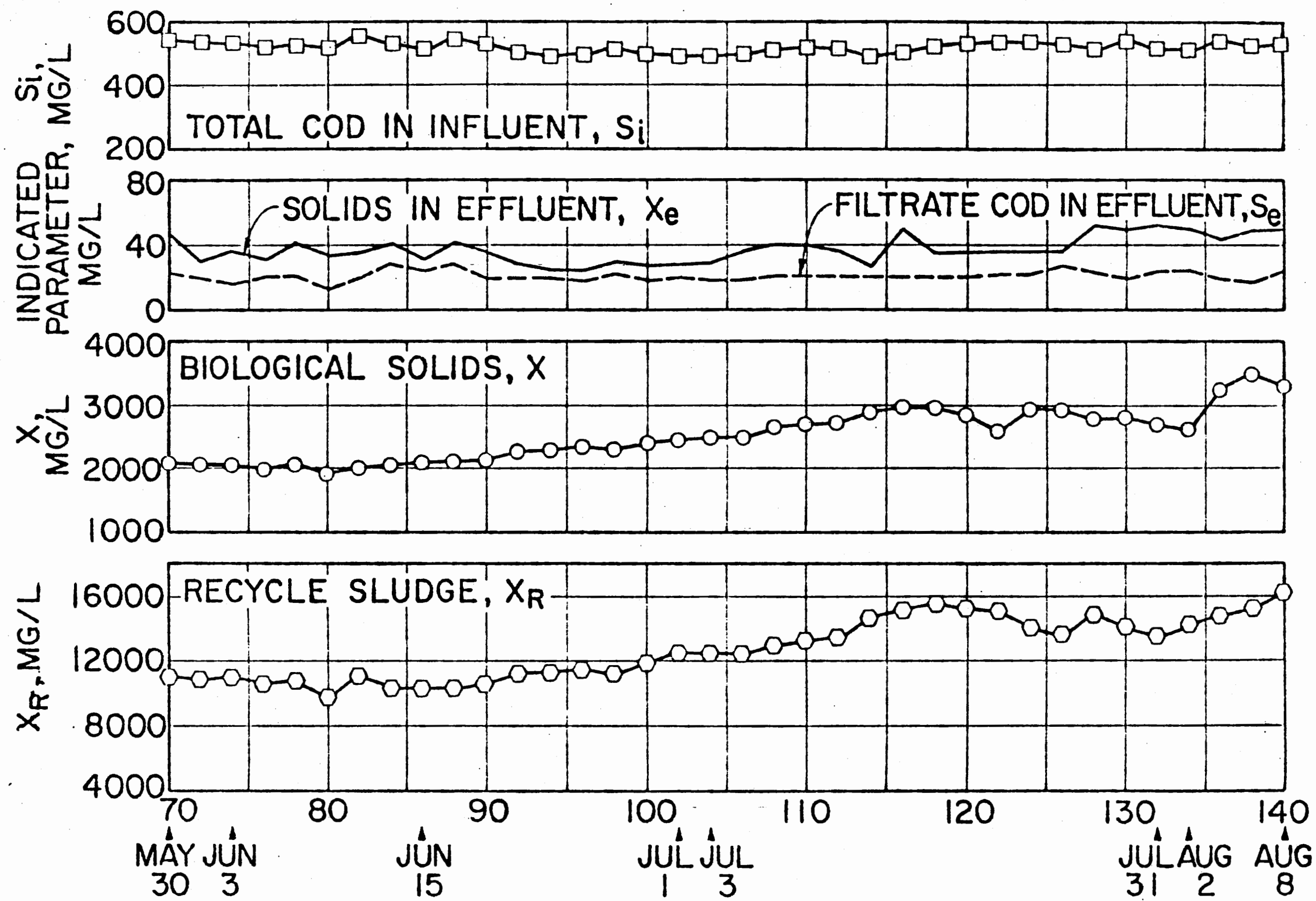
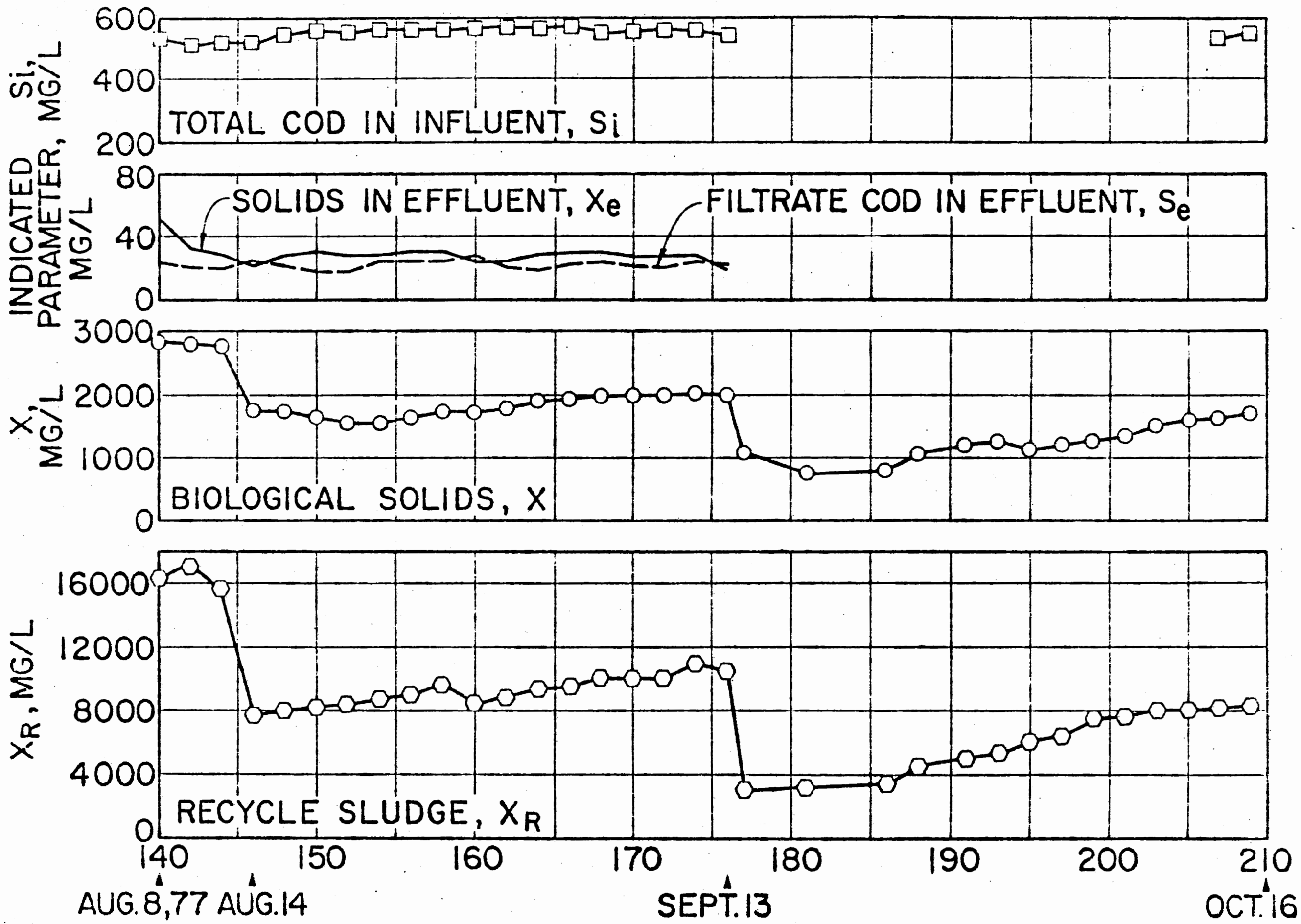

TOTAL COD IN INFLUENT, Si
Si, MG/L
600
400
200
INDICATED PARAMETER, MG/L
SOLIDS IN EFFLUENT, Xe
FILTRATE COD IN EFFLUENT, Se
MG/L
80
40
0
BIOLOGICAL SOLIDS, X
X, MG/L
4000
3000
2000
1000
RECYCLE SLUDGE, XR
XR, MG/L
16000
12000
8000
4000
70
80
90
100
110
120
130
140
MAY 30
JUN 3
JUN 15
JUL 1
JUL 3
JUL 31
AUG 2
AUG 8

Figure 11. Operational Performance of Extended Aeration Pilot Plant of Larger Size Showing Influent and Effluent Characteristics for Days 140 to 210



TOTAL COD IN INFLUENT, Si
Si, INDICATED PARAMETER, MG/L
SOLIDS IN EFFLUENT, Xe
FILTRATE COD IN EFFLUENT, Se
MG/L
X, MG/L
BIOLOGICAL SOLIDS, X
XR, MG/L
RECYCLE SLUDGE, XR
AUG. 8,77
AUG. 14
SEPT. 13
OCT. 16

Figure 12. Operational Performance of Extended Aeration Pilot Plant of Larger Size Showing Influent and Effluent Characteristics for Days 210 to 280

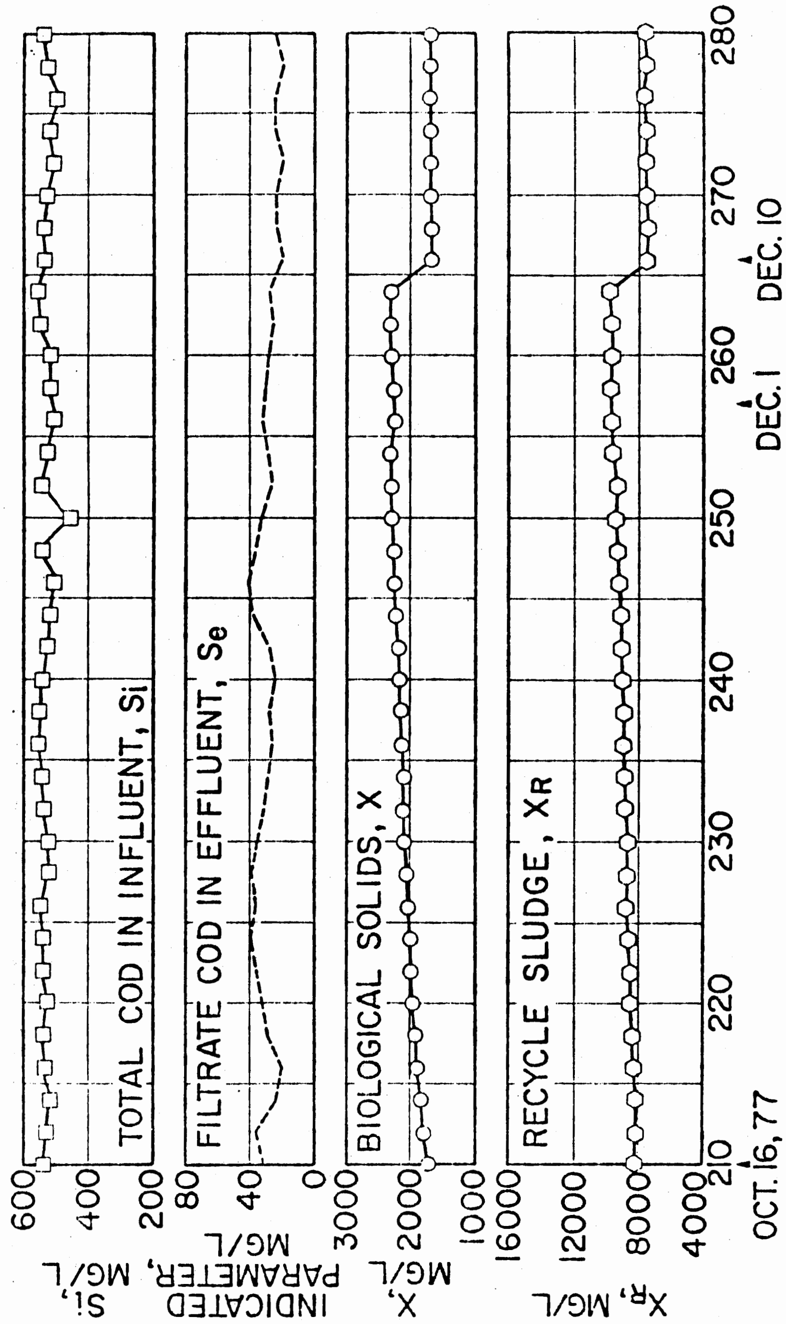

TOTAL COD IN INFLUENT, Si
FILTRATE COD IN EFFLUENT, Se
BIOLOGICAL SOLIDS, X
RECYCLE SLUDGE, XR
Si, MG/L
INDICATED PARAMETER, MG/L
X, MG/L
XR, MG/L
600
400
200
80
40
0
3000
2000
1000
16000
12000
8000
4000
210
220
230
240
250
260
270
280
OCT. 16, 77
DEC. 1
DEC. 10

Figure 13. Operational Performance of Extended Aeration Pilot Plant of Larger Size Showing Influent and Effluent Characteristics for Days 280 to 350

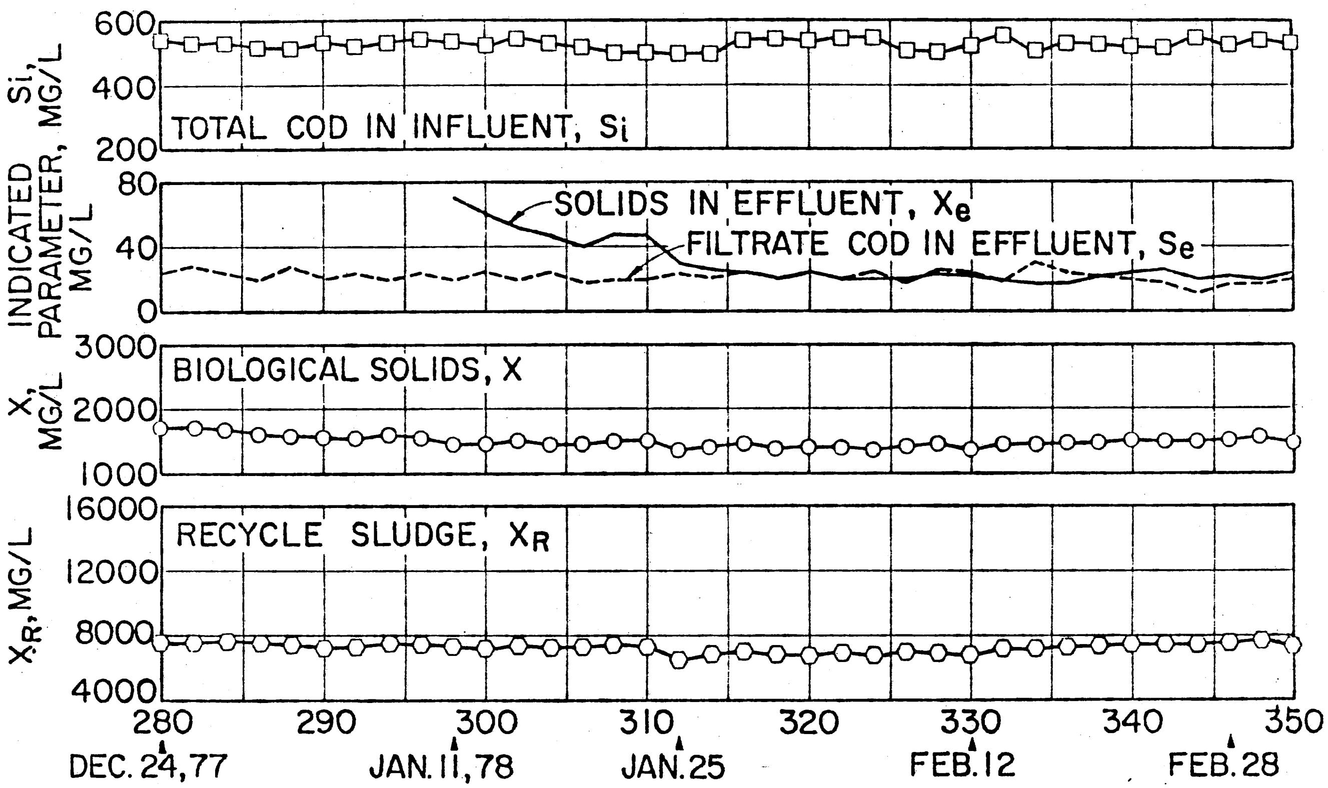

TOTAL COD IN INFLUENT, Si
Si, MG/L
INDICATED PARAMETER, MG/L
SOLIDS IN EFFLUENT, Xe
FILTRATE COD IN EFFLUENT, Se
BIOLOGICAL SOLIDS, X
X, MG/L
RECYCLE SLUDGE, XR
XR, MG/L
DEC. 24, 77
JAN. 11, 78
JAN. 25
FEB. 12
FEB. 28

Figure 14. Operational Performance of Extended Aeration Pilot Plant of Larger Size Showing Influent and Effluent Characteristics for Days 350 to 420

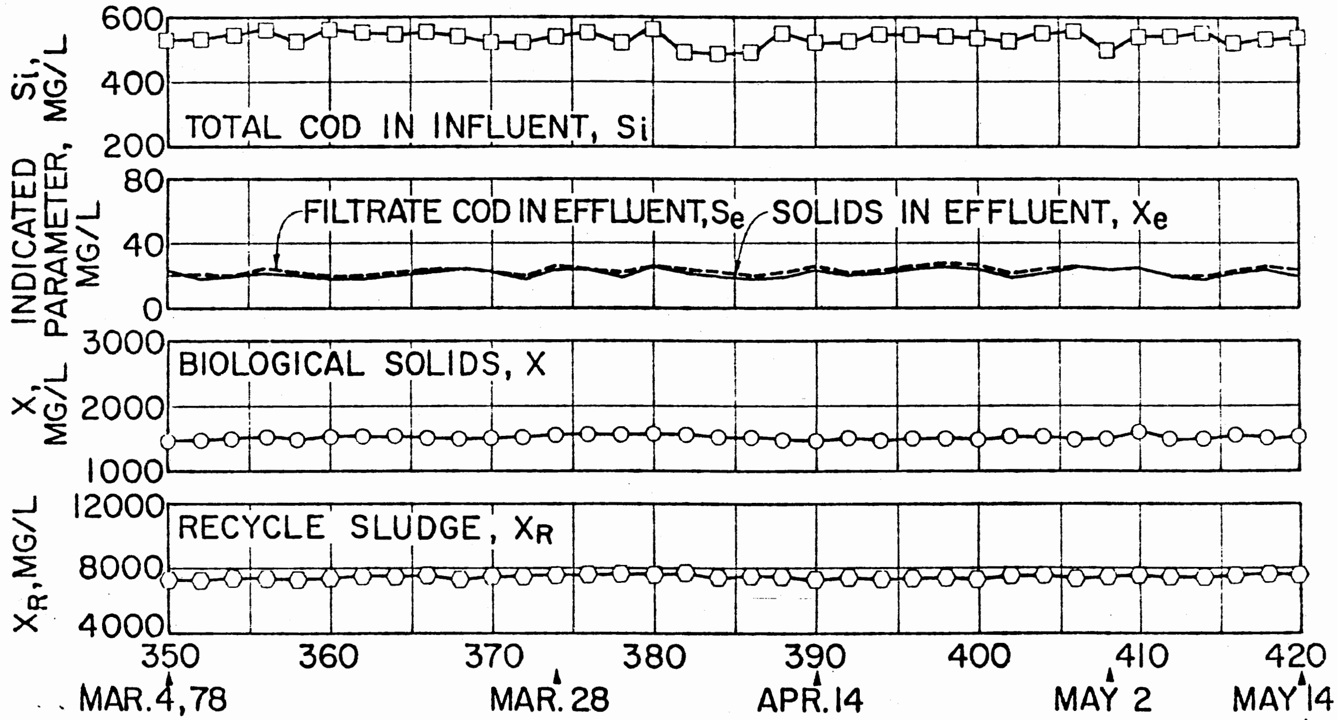

TOTAL COD IN INFLUENT, Si
FILTRATE COD IN EFFLUENT, Se
SOLIDS IN EFFLUENT, Xe
BIOLOGICAL SOLIDS, X
RECYCLE SLUDGE, XR
Si, MG/L
INDICATED PARAMETER, MG/L
X, MG/L
XR, MG/L
600
400
200
80
40
0
3000
2000
1000
12000
8000
4000
350
360
370
380
390
400
410
420
MAR. 4, 78
MAR. 28
APR. 14
MAY 2
MAY 14

Figure 15. Operational Performance of Extended Aeration Pilot Plant of Larger Size Showing Influent and Effluent Characteristics for Days 420 to 490

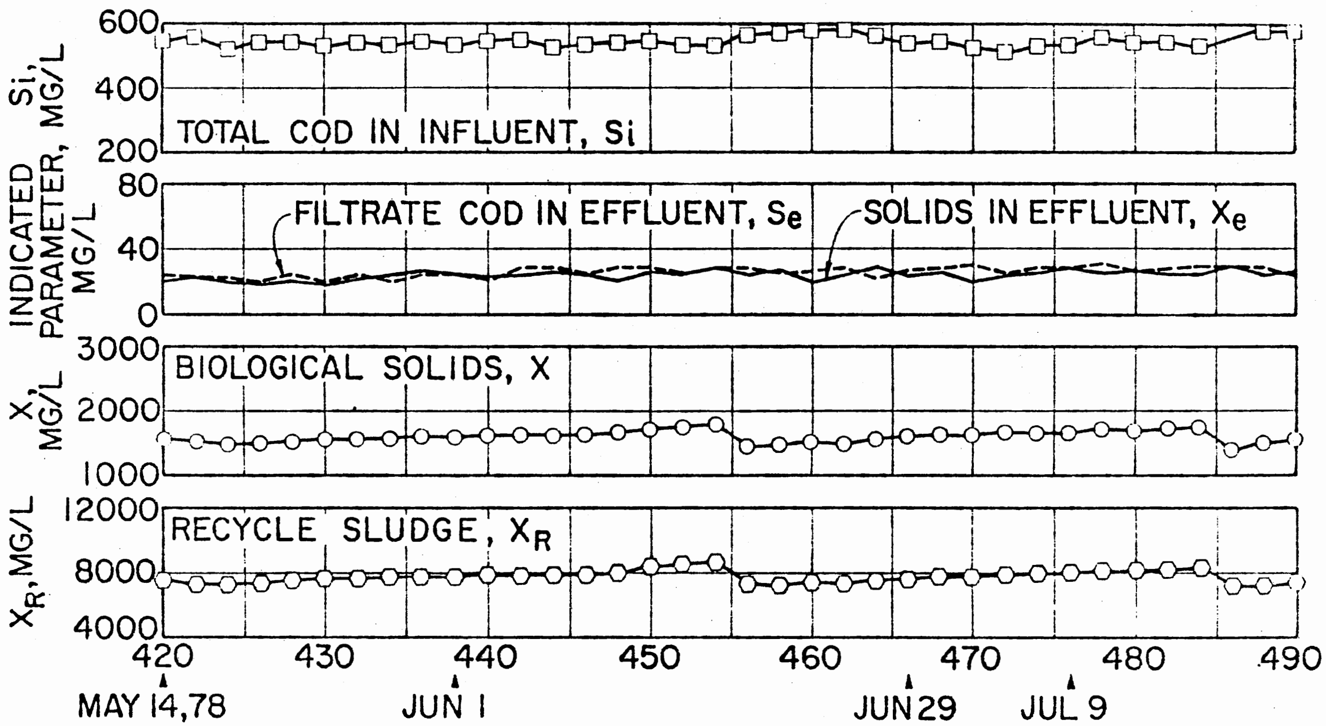
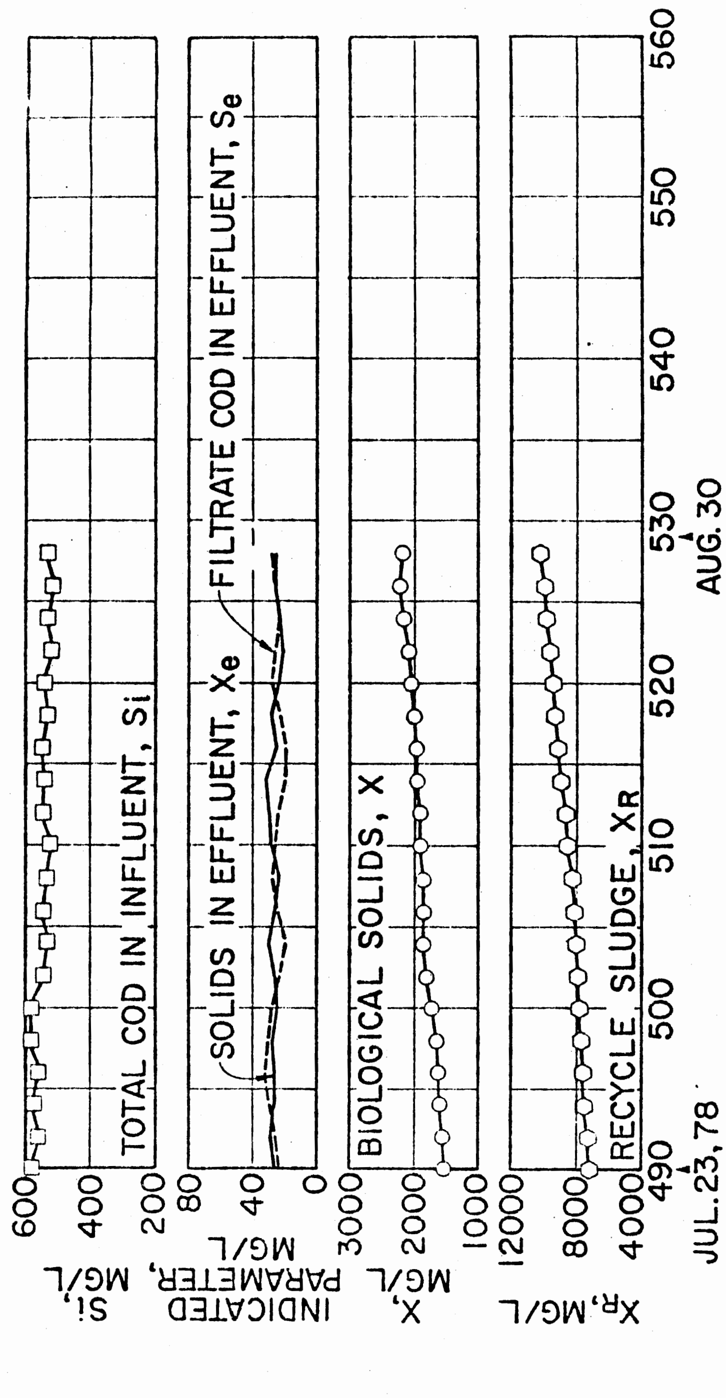

TOTAL COD IN INFLUENT, Si
FILTRATE COD IN EFFLUENT, Se
SOLIDS IN EFFLUENT, Xe
BIOLOGICAL SOLIDS, X
RECYCLE SLUDGE, XR
Si, MG/L
INDICATED PARAMETER, MG/L
X, MG/L
XR, MG/L
600
400
200
80
40
0
3000
2000
1000
12000
8000
4000
420
430
440
450
460
470
480
490
MAY 14,78
JUN 1
JUN 29
JUL 9

Figure 16. Operational Performance of Extended Aeration Pilot Plant of Larger Size Showing Influent and Effluent Characteristics for Days 490 to 530



TOTAL COD IN INFLUENT, Si
SOLIDS IN EFFLUENT, Xe
FILTRATE COD IN EFFLUENT, Se
BIOLOGICAL SOLIDS, X
RECYCLE SLUDGE, XR
Si, MG/L
INDICATED PARAMETER, MG/L
X, MG/L
XR, MG/L
600
400
200
80
40
0
3000
2000
1000
12000
8000
4000
490
500
510
520
530
540
550
560
JUL.23,78
AUG.30

and the values were found to be 4.4 and 5.6 mg of O_2 per gm of solids per hour, respectively. A growth study was run on day 75 (June 3, 1977); the values of biological constants were as follows: K_s = 334 mg/l, μ_m = 0.37 and Yt = 0.51 (Figure 8(c). Microscopic observation revealed that many filaments were present at the end of this period. Gradually, occurrences of sludge bulking began to increase, and settling tests indicated sludge settling to be poor.

From day 87 to day 144 (June 16 to August 12, 1977) (see Figures 10 and 11), the system experienced a considerable amount of sludge bulking and X_R climbed to 17,000 mg/l. Correspondingly, values of X rose to 3000 mg/l. Although the values of X_e fluctuated considerably during this period, the S_e values remained at about 22 mg/l. Microscopic examination showed the system to be composed mainly of filamentous microorganisms and it was essentially devoid of any protozoa. A growth study was run during this period (on day 136, i.e., August 3, 1977) (see Figure 8d) The biological constants obtained were as follows: K_s = 1250 mg/l; μ_m = 0.45, and Y_t = 0.61. D.O. was found to be at the level of 9.0 mg/l. The values of oxygen uptake for X_R and X were found to be 2.7 and 4.4 mg of O_2 per gm of solids per hour, respectively. Nitrification increased to 60 percent on the basis of NH_3-N fed to the system. Because of the high values of X_R and X, it was finally decided to apply hydrolytic-assist to lower the X_R to around 8000 mg/l in order to control the growth of filaments or in any event, to solubilize a fraction of the filamentous cells. The volume of sludge to be hydrolyzed was calculated using the following mass balance equation:

$$V_a = C_f V/C_r - V$$

where

V_a = volume of sludge at concentration C_f to be hydrolyzed, in liters

V = volume of sludge recycled daily, in liters

C_f = concentration of X_R in existing state

C_r = concentration of X_R desired

Although the substrate removal performance of the system was excellent, the high X_R values posed a problem in getting a fixed amount of sludge to be recycled. It was necessary to centrifuge six to eight liters of sludge daily to get three liters of sludge to be recycled. The high value of X_R caused another problem. The sludge blanket formed in the settling chamber was very thick, and the sludge had a tendency to raise at times.

This problem was alleviated by taking the sludge out of the bottom of the settling tank frequently and putting it into a holding tank, aerating the entire contents for about 15 to 20 minutes and then letting the solids settle for about three to four hours before centrifugation.

After application of the hydrolytic-assist, it was observed that X_R was going to increase again. After a month, X_R reached a level of 10,000 mg/l and biomass, X, rose to 2000 mg/l. A growth study (on day 168, September 5, 1977) (see Figure 8e) provided the following values of the biological constants: K_s = 800 mg/l; μ_m = 0.43, and Y_t = 0.59. Microscopic examination indicated that there were no protozoa in the system, and the system remained permanently filamentous. Because of lack of protozoa in the system, it was felt that a part of the old sludge should be discarded and new sludge from another continuous flow plant should be added to the system.

From day 177 to day 205 (September 13 to October 11, 1977) (see Figure 11), the unit was broken in and biomass accumulated in the system. Shortly thereafter, settling tests indicated the presence of a very poor sludge settling. This time a holding tank was used to get the sludge from the bottom of the settling tank at the end of 24 hours, and the sludge was allowed to settle for about three to four hours; then settled sludge was centrifuged and measured to obtain the sludge for the dosing (aeration tank #2) tank. X_e was measured on the settled supernatant in the holding tank. The values of X_e were in the range of 150-200 mg/l. This supernatant was then centrifuged, and all of the solids--without wasting any--were returned to the recycling tank. The values of X_e during this period (through January 11, 1978) are not plotted because they would fall off the scale (see Figures 10-12); also, they are meaningless since the solids were returned in the holding tank, centrifuged and returned to the system. However, on January 11, 1978, it was decided that the supernatant liquid containing 150-200 mg/l solids should be treated as effluent, and without centrifuging it should be wasted until the effluent quality, X_e, was obtained at an agreeable level of about 40 mg/l. This occurred on day 312, January 25, 1978.

During the period between day 206 and day 264 (Figures 11 and 12), X_R and the corresponding X values again increased gradually, and on day 264, X_R came to the level of 10,000 mg/l. Microscopic examination showed the lack of protozoa in the system, and the predominance of filaments, but it was a matter of fact that S_e was at the low level of 30 mg/l and nitrification was as high as 75 percent. It was decided that hydrolytic-assist should be applied to lower the X_R to 8000 mg/l, and that the detention time should be increased to 36 hours. Accordingly, sludge was removed and hydrolyzed on day 264 and the mean hydraulic detention time, $\bar{t}$, was changed to 36 hours on day 268. It was felt that the increased $\bar{t}$ might provide enough extra holding time to prevent the biomass concentration from increasing. Also, this lowered the mass feeding rate which could enhance a leveling off of the increasing biomass concentration.

After application of a small hydrolytic-assist and initiating detention time at 36 hours, the system appeared to operate at a relatively steady state with the following parameters obtained during this period (from day 312 to day 436): X_R = 7453 mg/l, X = 1514 mg/l, X_e = 22 mg/l, S_e = 22 mg/l, S_i = 537 mg/l. Growth studies were run during this period and the biological constants obtained were as follows: On day 320 (February 2, 1978) (see Figure 8f): K_s = 350 mg/l, μ_m = 0.35 per hour, Y_t = 0.54.

On day 350 (March 4, 1978) (see Figure 8g): K_s = 526 mg/l, μ_m = 0.25 per hour, Y_t = 0.53.

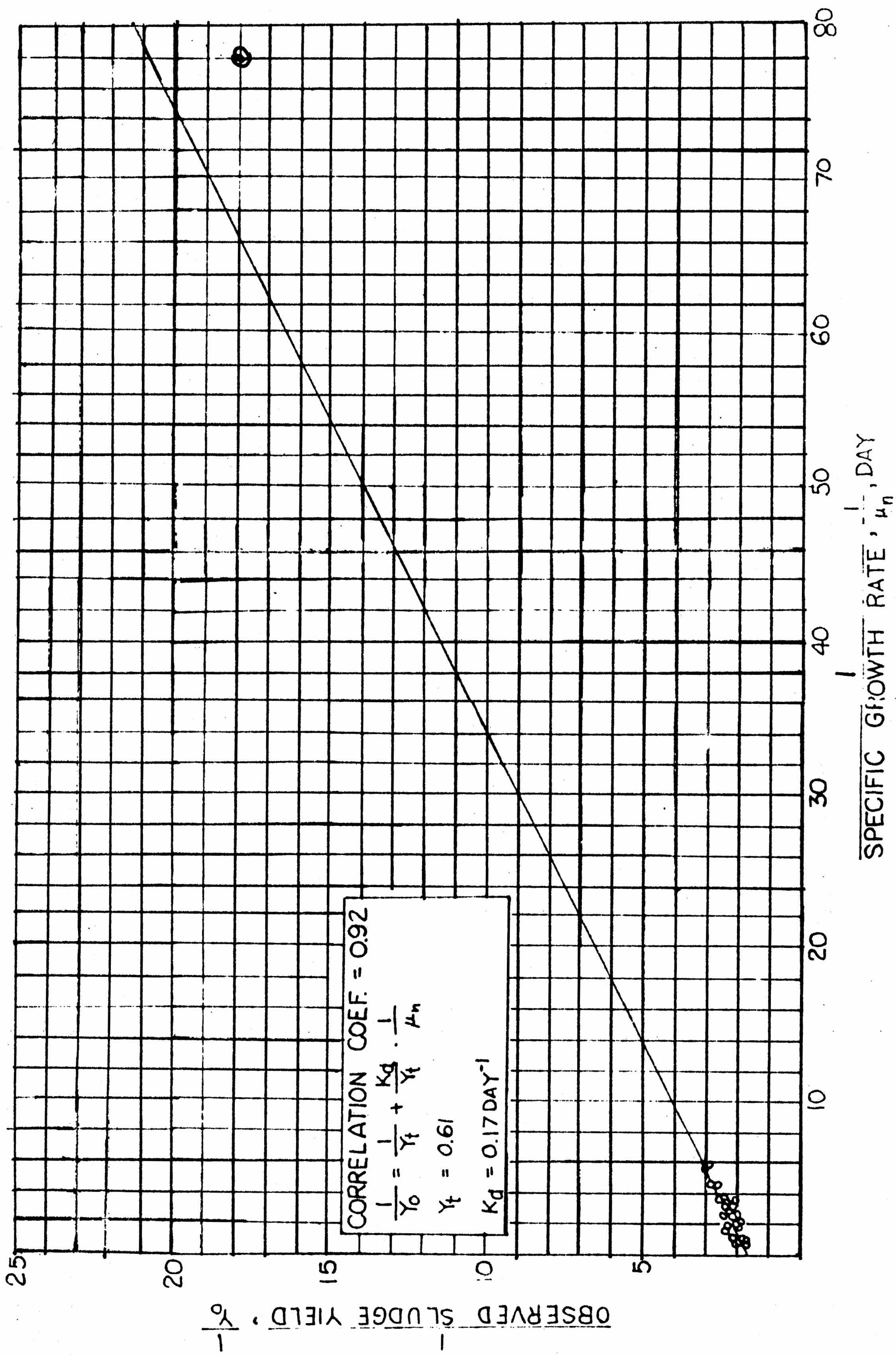
On day 412 (May 6, 1978) (see Figure 8h): K_s = 350 mg/l, μ_m = 0.30 per hour, Y_t = 0.49.

The observed yield, Y_o, obtained from the data and by calculation using formula $\mu_n = D(1 + \alpha - \alpha \frac{X_R}{X})$ gave very similar values (about 0.05 and 0.06, respectively). The corresponding maintenance coefficient, K_d, obtained from the maintenance plot (see Figure 17) and from calculation using formula $\frac{1}{Y_o} = \frac{1}{Y_t} + K_d/\mu_n Y_t$ (see Figure 15) yielded very similar results (0.116 and 0.12, respectively).

After day 265, the solids level again increased gradually. The X_R was allowed to be increased to 8500 mg/l, and on day 454 it was again hydrolyzed to keep it at approximately 7500 mg/l. After that, the

Figure 17. Plot of Maintenance Energy Equations to Determine and/or Verify True Cell Yield, Y_t, and Maintenance Coefficient, K_d

Values at lower left are replotted from the data of Saleh (17). The point plotted in the upper right-hand portion was obtained for the data of this current study between days 312 and 436.


CORRELATION COEF. = 0.92
$\frac{1}{Y_o} = \frac{1}{Y_t} + \frac{K_d}{Y_t} \cdot \frac{1}{\mu_n}$
$Y_t = 0.61$
$K_d = 0.17\ DAY^{-1}$
SPECIFIC GROWTH RATE, $\frac{1}{\mu_n}$, DAY
$\frac{1}{\text{OBSERVED SLUDGE YIELD}}$, $\frac{1}{Y_o}$
10
20
30
40
50
60
70
80
5
10
15
20
25

system was allowed to run as usual for a month. During this period, X_R rose slightly, and this time (day 484, July 18, 1978), a portion was hydrolyzed. Calcium hydroxide was used to neutralize the hydrolysate. Volatile suspended solids, VSS, were measured before and after hydrolysis with calcium hydroxide. The difference in VSS (51 percent vs. 50 percent) was not significant. In the following days, X_R was allowed to increase until (on day 530, August 30, 1978) it reached 10,000 mg/l and the present investigation ended.

In Tables III, IV, V, VI, and VII, various parameters obtained during this investigation are summarized.

TABLE IV

NITROGEN CONCENTRATION IN INFLUENT AND IN EFFLUENT

Day		Influent NH_4-N (mg/l)	Effluent NH_4-N (mg/l)	Effluent NO_3-N (mg/l)
	1977			
0-36	March 20 to April 25	51.0	33.5	17.1
48	May 7	51.9	19.5	32.0
73	June 1	54.4	20.0	32.0
86	June 14	51.8	20.8	30.6
98	June 26	52.2	20.6	31.2
106	July 4	51.5	20.1	30.8
224	Oct. 30	51.6	10.8	40.2
257	Dec. 1	52.2	10.1	41.8
280	Dec. 24	52.4	20.1	30.2
	1978			
306	Jan. 19	53.7	20.9	31.8
346	Feb. 28	50.4	10.6	38.9
374	March 28	54.0	10.9	42.4
390	April 14	52.0	11.1	40.6
408	May 2	51.5	10.7	39.6
418	May 12	53.6	10.2	42.7
434	May 28	50.6	10.0	38.7
466	June 29	51.6	10.9	40.1
494	July 27	53.6	11.2	41.0
520	Aug. 22	51.7	9.9	40.3

TABLE V

KINETIC CONSTANTS OBTAINED FROM BATCH GROWTH STUDIES

Day	Date	K_s	μ_m	Y_t
	1977			
-	March 5	250	0.32	0.52
-	March 18	666	0.35	0.58
75	June 3	334	0.37	0.51
136	Aug. 3	1250	0.45	0.61
168	Sept. 5	800	0.43	0.59
	1978			
320	Feb. 2	350	0.35	0.54
350	March 4	526	0.25	0.53
412	May 6	350	0.30	0.49

Note: There was a lag period of approximately 12-18 hours in all growth studies.

TABLE VI

VOLATILE SUSPENDED SOLIDS

Day	Date	Percent VSS on X	Percent VSS on X_R
	1977		
83	June 11	44.6	-
89	June 17	41.0	-
104	July 2	-	54.0
109	July 7	41.4	-
	1978		
362	March 16	51.2	-
448	June 11	-	51.0
478	June 11	-	51.0
492	July 25	-	50.5 ($Ca(OH)_2$)

TABLE VII

ENDOGENOUS OXYGEN UPTAKE OF SLUDGES
(mg O_2/gm sludge/hr)

Day	Date	X	X_R
	1977		
33	April 22	-	3.3
34	April 23	-	3.5
84	June 12	3.0	2.2
106	July 4	3.16	1.98
128	July 26	2.73	2.06
	1978		
316	Jan. 29	2.79	2.00
346	Feb. 28	2.30	1.49
366	March 20	2.13	1.47
392	April 16	3.48	2.50
466	June 29	3.50	2.60
492	July 25	3.72	2.7

TABLE VIII

SUMMARY RESULTS OF OPERATIONAL PERFORMANCE AT STEADY STATE CONDITION (February 2 - May 6, 1978)

Parameters	Average Values
X_R, mg/l	7453
X, mg/l	1514
X_e, mg/l	22
S_i, mg/l	537
S_e, mg/l	22
μ_m, hr^{-1}	0.30
Y_t	0.52
μ_n day^{-1}	0.128
Y_o	0.56

CHAPTER V

CONCLUSIONS

Performances of extended aeration plants as cited above demonstrate the ability of these types of systems to treat waste with varying organic loading and oxygen demands. Although these plants do waste sludge, the quantity is much less than with conventional aeration plants with less detention time. As land values increase and the population expands, even this small amount of sludge may be eliminated by such engineering aids as the hydrolytic-assist recommended by Gaudy.

Results of the current investigation on the extended aeration process support the following conclusions:

1) Over a long period of time it does not appear to be possible to operate an extended aeration process without periods of sludge accumulation. However, the current study has shown that it is quite possible for some period of time (over four months, in one instance) to attain a steady state condition with respect to sludge concentration producing about 94 percent total oxidation, i.e., a net cell yield of about six percent based on COD of the substrate.

2) As an approximate guideline, the frequency of application of the hydrolytic-assist may be once a month in order to provide routine solids level control.

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