

THESIS



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ABSTRACT

OPERATIONAL FEASIBILITY STUDY OF A SUBMERGED BIOLOGICAL FILTER

By

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The problem investigated in this research is the operational feasibility of a submerged biological filter in treating primary effluent from the East Lansing, Michigan Wastewater Treatment Plant and ultimately to show that the filter can be used to effectively treat waste water.

Research was done for nine months and involved performing all basic tests on the incoming flow and final effluent from the filter to help determine the effectiveness of the filter.

It was concluded from the study that the submerged filter does indeed yield a well-treated effluent from a system which is both simple and easy to maintain. Also shown in the study was the effect of solids build-up in the media compartment and the need to effectively arrange the media to eliminate this build-up. Finally, it was demonstrated that to effectively maintain a dissolved oxygen concentration greater than 1.0 mg/l throughout the media, a recirculation pump was needed. In this way, a flow of oxygen-laden water is always passing through the compartment thus maintaining the desired oxygen concentration.

OPERATIONAL FEASIBILITY STUDY
OF A SUBMERGED BIOLOGICAL FILTER

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Dedicated to
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TABLE OF CONTENTS

INTRODUCTION	1
EXPERIMENTAL APPARATUS AND PROCEDURE	2
A. Material	2
B. Apparatus	2
C. Operation	8
D. Instrumentation	11
ANALYTICAL PROCEDURES	12
LITERATURE REVIEW	16
EXPERIMENTAL DATA	18
EXPERIMENTAL RESULTS	52
1. Random Media, No Recirculation	53
2. Random Media, With Recirculation	57
3. Layered Media Arrangement, With Recirculation	61
CONCLUSIONS	76

LIST OF FIGURES

FIGURE 1	Top View of Filter	3
FIGURE 2	Side View of Filter	4
FIGURE 3	Aeration Compartment	5
FIGURE 4	Final Compartment	6
FIGURE 5	(Mode #1) Random Filter Arrangement	41
FIGURE 6	(Mode #2) Layered Filter Media	42
FIGURE 7	Flow Diagram	43
FIGURE 8-A	Average BOD Values of Influent and Effluent for Random Arrangement of Filter Media, No Recirculation	54
FIGURE 9-A	Average Suspended Solids Values of Influent and Effluent for Random Arrangement of Filter Media and No Recirculation	56
FIGURE 10-A	Average BOD Values for Random Arrangement of Filter Media with a Recycle Flow	58
FIGURE 10-B	Average Suspended Solids Values for Random Arrangement of Filter Media with a Recycle Flow	59
FIGURE 10-C	Average Turbidity Values for Random Arrangement of Filter Media with a Recycle Flow	60
FIGURE 11-A	Average BOD and ODI Values for Vertical Arrangement of Filter Media with a Recycle Flow	62

FIGURE 11-B	Average Suspended Solids and Turbidity Values for Vertical Arrangement of Filter Media With a Recycle Flow	63
FIGURE 12-A	Average Ammonia-Nitrogen Values for Mode #1 and Mode #2 Under Recirculation	64

LIST OF TABLES

TABLE 1	Data of Retention Time, 48 Hrs. Mode #1	19
TABLE 2	Data of Retention Time, 25 Hrs. Mode #1	21
TABLE 3	Data of Retention Time, 48 Hrs. Mode #1	22
TABLE 4	Data of Retention Time, 30 Hrs. Mode #1	23-24
TABLE 5	Data of Retention Time, 32 Hrs. Mode #1	26
TABLE 5-1	Data of Retention Time, 22 Hrs. Mode #2	27
TABLE 6	Data of Retention Time, 22 Hrs. Mode #2	30-31
TABLE 7	Data of Retention Time, 16 Hrs. Mode #2	33
TABLE 8	Data of Retention Time, 22 Hrs. Mode #2	34-36
TABLE 9	Data of Retention Time, 17 Hrs. Mode #2	37-39
TABLE 10	Data of Retention Time, 48 Hrs. Mode #3	45-48
TABLE 11	Data of Retention Time, 24 Hrs. Mode #3	49-50
TABLE 12 & 13	Average Data for Mode #1	69
TABLE 14	Average Data for Mode #2	70-71

TABLE 15	Average Data for Mode #3	72-74
TABLE 16	Overall Performance Data for All Three Modes of Operation	75
TABLE 17	Overall Air Requirements for All Three Modes of Operation	66

INTRODUCTION

The main objective of this research has been to determine the operating efficiency of a submerged biological filter utilizing primary effluent from the East Lansing, Michigan Waste Water Treatment Plant as its incoming flow. Various retention times were employed during the operation period to determine the performance of the filter with increasing hydraulic and organic loadings. The study also revealed the effects of media arrangement on the efficiency of the filter and the importance of having a recycle flow to help maintain the dissolved oxygen concentration within the unit.

EXPERIMENTAL APPARATUS AND PROCEDURE

A. MATERIAL

The material used for the incoming flow to the filter was primary effluent taken from a sample line located in the boiler room of the East Lansing, Michigan Waste Water Treatment Plant. This plant employs the "biosorption" modification of the activated sludge process for treatment of settled sewage. Chemical treatment by ferric chloride and a polymer is used for phosphate removal in the primary settling tanks. This makes for an excellent primary effluent which is low in BOD₅ and in Suspended Solids. However, due to two factors the strength of the primary effluent can vary markedly. These two factors are: the student population at the university which differs greatly between fall and summer terms, and the fact that the collection system is a combined one, thus during periods of rain the waste strength is greatly reduced.

B. APPARATUS

An overall view of the submerged filter unit is shown in Figure 1. The tank proper measures forty-eight inches long by thirty inches wide by thirty-six inches deep and is fabricated of one half inch Lucite plastic. The three compartments within the tank measure: first compartment- twelve inches long by thirty inches wide by thirty-two inches deep

FIGURE 1 TOP VIEW OF FILTER

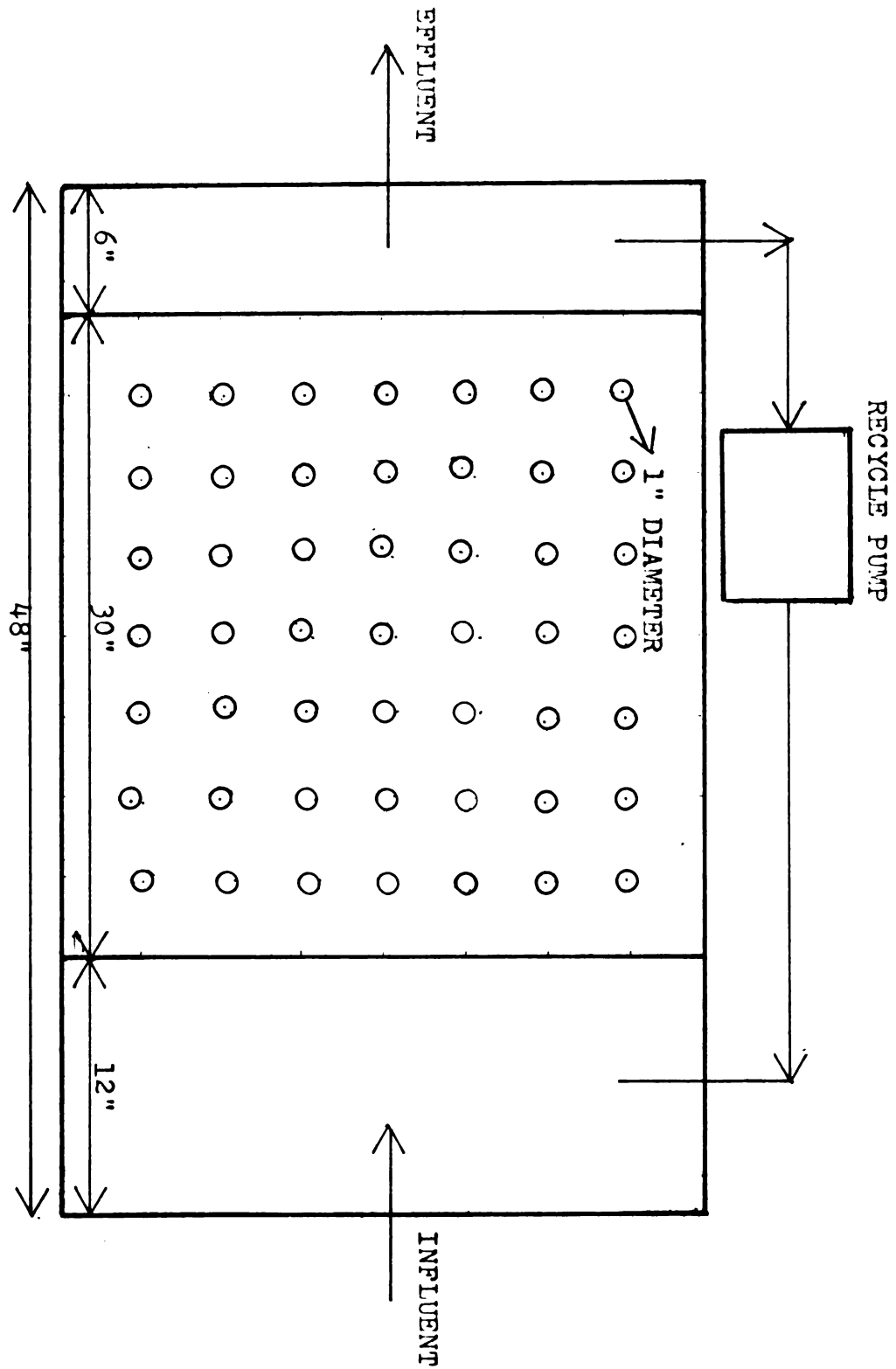


FIGURE 2 SIDE VIEW OF FILTER

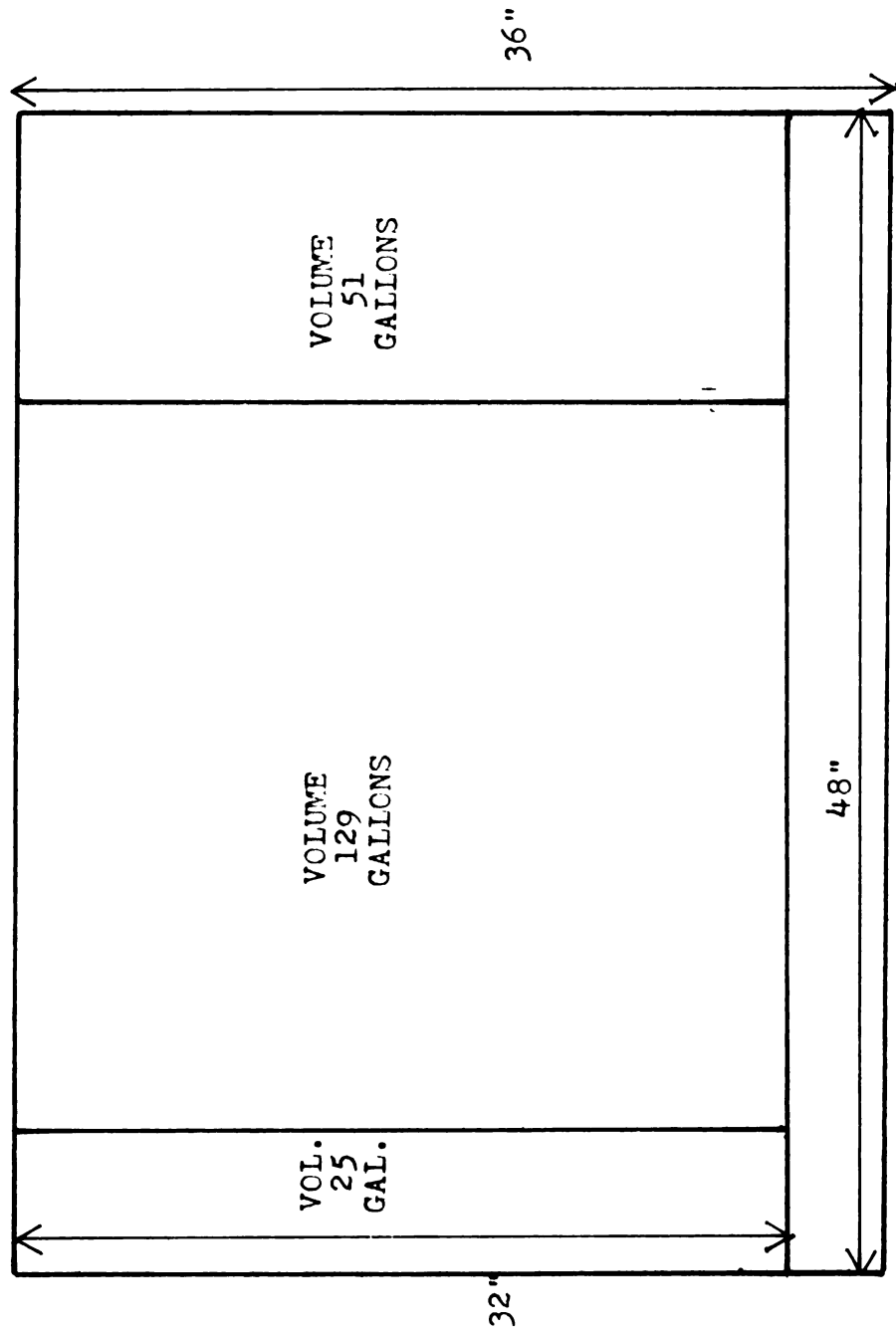


FIGURE 3 FRONT VIEW AERATION COMPARTMENT

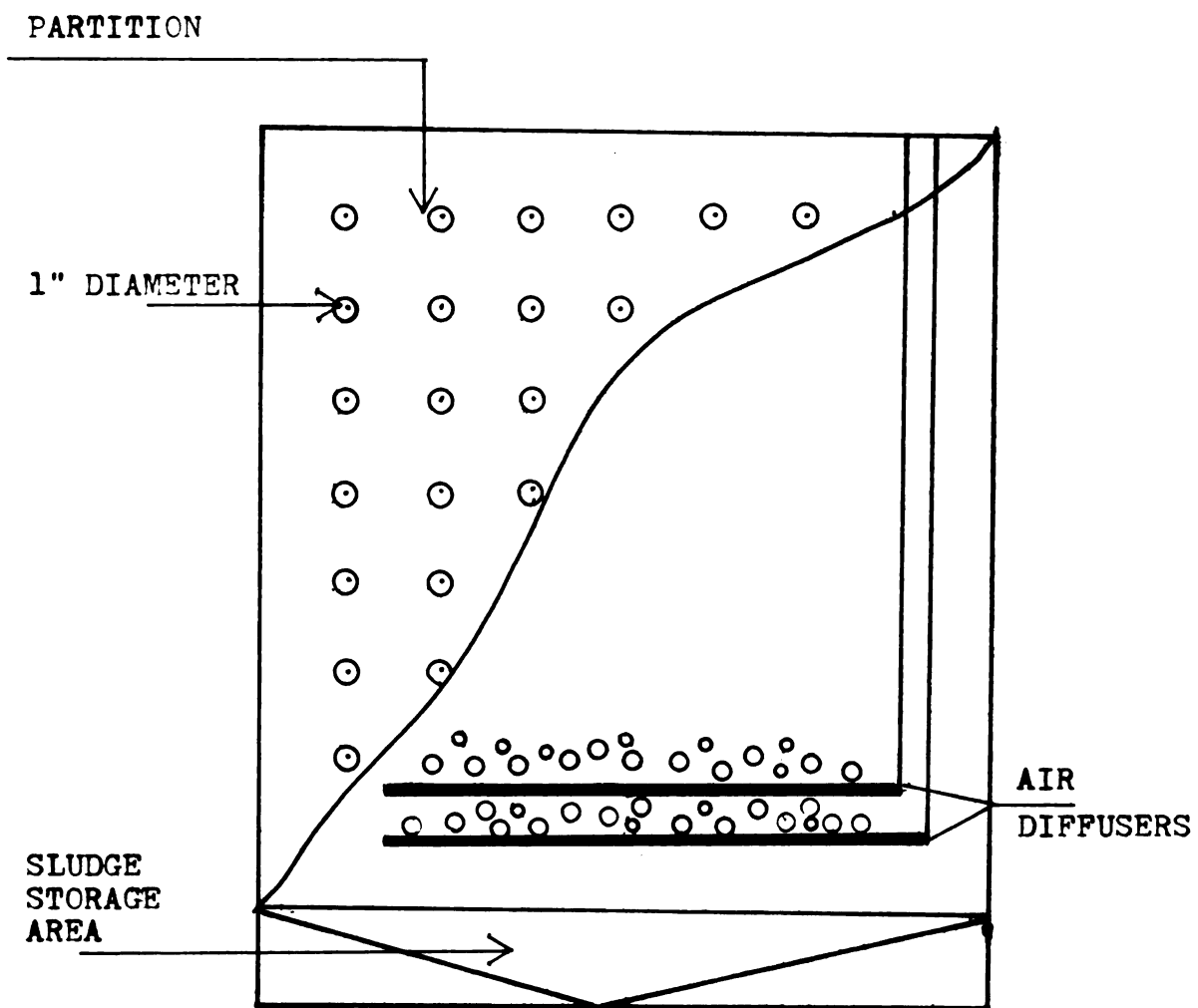
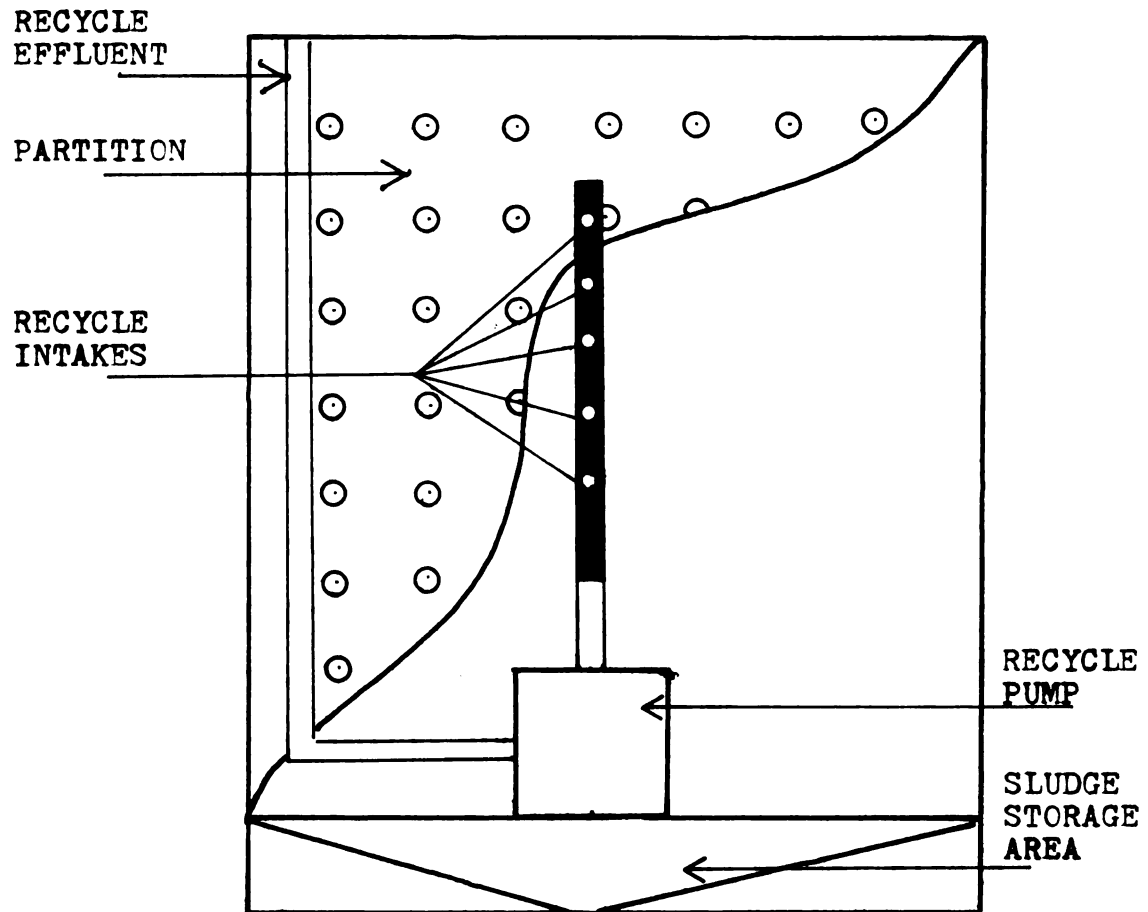


FIGURE 4 BACK VIEW FINAL COMPARTMENT



with a volume of 50 gallons, second compartment- thirty inches long by thirty inches wide by thirty-two inches deep with a volume of 125 gallons, third compartment- six inches long by thirty inches wide by thirty-two inches deep with a volume of 25 gallons. The bottom of the tank serves as a sludge storage area which is triangular in shape and measuring forty-eight inches long by thirty inches at its base with two equal sides of fifteen and one half inches producing a volume of 12.4 gallons. The partitions between the compartments measure thirty-two inches long by thirty inches wide and are made of quarter inch Lucite plastic. The perforations in both partitions are one inch diameter circles drilled every four inches on center with a four inch border on top, giving a total of forty-nine holes for each partition. The bottom plate covering the sludge storage area measures forty-eight inches long by thirty inches wide and is made of three-eighths inch Lucite plastic. Its perforations are one inch diameter circles drilled every four inches on center with a thirteen inch border on top and a seven inch border on the bottom; this means that only the bottom of the center compartment has holes for the collection of sludge.

The filter media was collected from the various cafeterias on campus and consisted of polyurethane plastic cottage cheese containers. The containers were then cut into rings two inches high with a wall thickness of one-thirty-second inch. Many of the plastic rings were circular in shape but there were also many flat pieces. Initially, all the plastic rings

(Dry Weight- 100 lbs.) were randomly distributed in the media compartment; these included both circular and flat pieces. However, this eventually proved to be inefficient due to sludge build-up within the media itself. This sludge build-up reduced the effective surface area of the filter considerably. On rearranging the rings only those that were circular in shape were used and they were oriented so that the walls were vertical. This allowed more efficient downward flow of the waste sludge into the storage area. However, it also reduced the total surface area of the media from about 150 sq. ft. to about 40 sq. ft.

C. OPERATION

A flow of primary effluent was continuously allowed to flow by gravity from the treatment plant's sample line into a stilling well through a five-eighth inch garden hose. From the stilling well, the primary effluent was continuously fed into the aeration compartment of the submerged filter by a variable speed peristaltic pump using one half inch tygon tubing. This arrangement caused delays in the units' operation because the garden hose and the tygon tubing were continually clogging. Daily backflushing was therefore necessary to keep the lines open.

Eventually a direct connection from the plant's sample line to a Cole-Parmer Masterflex pump, utilizing head no. 7017, relieved this problem completely.

The primary effluent was pumped at a controlled rate, corresponding to the desired retention time, into the first or aeration compartment of the tank. There it was aerated and mixed. Aeration was initially accomplished through two homemade diffusers, consisting of five-eighth inch rigid plastic tubing, twenty-four inches long with one quarter inch holes drilled every two inches on center and wrapped with nylon string. This created very good mixing but the bubble size was so large that there was an inefficient transfer of oxygen into the water and an unreasonable amount of air had to be used to maintain a desired dissolved oxygen concentration in the compartment.

After two and one half months of operation a much more efficient air diffuser made from porous plastic was used. (Marineland, Bubble Wand) It produced very small bubbles so that less than half the amount of air was needed to maintain the same dissolved oxygen concentration as before.

The compressed air used for the aeration was taken from the plant's high pressure air supply. Due to considerable water, rust and oil in the plant air, it was first passed through a Sioux Tools Corporation, model no. 1646 air filter. Following filtration, the air passed through a Conoflow Corporation pressure regulator which was set to reduce the pressure from 120 to 10 psi. The air then flowed through a Gelman Air Meter before it was diffused into the aeration chamber contents. The air flow was set at 15 lpm per diffuser

with the homemade diffusers and at 7.5 to 10 lpm with the porous plastic diffusers. The tubing used throughout the aeration system was three-eighth inch tygon tubing.

At times it became necessary to aerate the final compartment due to low dissolved oxygen concentrations. A separate diffuser using an air flow of 5 l/min was always sufficient to maintain a dissolved oxygen concentration of 1 MG/L in this compartment.

Following aeration, the oxygen-laden water passed through the baffling partition into the filter media compartment. The filter media provided a large surface area for the growth of biological slime which rapidly metabolized the soluble organics and adsorbed the colloidal organics from the waste water as it flowed over the microbial film. The oxygen needed to oxidize the waste is taken from the surrounding water and is replenished by the continuing flow of oxygen-laden water past the media.

Once through the filter media compartment, the flow enters the final compartment where any remaining solids are allowed to settle out and a major part of the flow is recycled back at the rate of 10 L/MIN into the aeration compartment by means of a Little Giant Submersible Pump, model 4-SMD using one half inch tygon tubing. After repeatedly passing through the unit, the effluent is finally discharged into the plant's drainage system through a five-eighth inch garden hose. At first the submerged filter was used without recycling. However the data showed soon that the oxygen uptake rate in the media

compartment was too great to maintain aerobic conditions throughout the unit. Aerating the final compartment will raise the dissolved oxygen concentration but it will also keep suspended solids in suspension resulting in poor solids removal. When recycling from the final compartment is used, there is no need to provide any additional air supply to the final compartment.

D. INSTRUMENTATION

Oxygen Meter and Sensor

Dissolved oxygen and oxygen uptake rates were measured with the YSI model 54 oxygen meter (Yellow Springs Instrument Company).

Turbidimeter

Turbidity measurements on the incoming flow and on the effluent from the filter unit were made using the Hach Chemical Company Turbidimeter, model 2100A. Measurements for turbidity were all done on grab samples for the filter effluent and on composite samples from the East Lansing plant for the incoming flow.

Recorders

The output of the YSI meter measuring dissolved oxygen concentrations was either recorded manually or on a Leeds & Northrup, Speedomax Recorder. The chart speed was set at 5 CM/MIN for all measurements.

The output of the YSI meter measuring oxygen uptake rates, R_R , was recorded by a Bausch and Lomb, model V.O.M. 5 Recorder. The chart speed of this recorder was set at .2 IN/MIN during all the R_R experiments.

Colorimeter

In performing the oxygen demand index test, ODI it is necessary to measure colorimetrically the amount of dichromate reduced to its green trivalent state by the organic material in the sample. This was done on a Bausch and Lomb, Spectronic 20 Colorimeter, utilizing the one inch test tube holder.

ANALYTICAL PROCEDURES

The following data were obtained for the primary effluent from the plant and for the final effluent from the filter.

1. Biochemical Oxygen Demand (BOD_5 , mg/l)
2. Chemical Oxygen Demand (COD, mg/l)
3. Oxygen Demand Index (ODI, mg/l)
4. Suspended Solids (mg/l)
5. Ammonia Nitrogen (mg/l)
6. Phosphate (as P, mg/l)
7. Turbidity (J.T.U.)
8. R_R and K_R (mg/l/hr and mg/g SS/hr)
9. Dissolved Oxygen Concentrations (D.O., mg/l)

1. BIOCHEMICAL OXYGEN DEMAND

The standard five day BOD_5 test as described in Standard Methods was used throughout the study. Seeded dilution water as described in Standard Methods was used to determine the BOD_5 . Samples from the Aeration Compartment and Final Compartment of the filter were always grab samples. Primary Effluent samples were taken from the treatment plant's composite sample for the day. Data for incoming suspended solids and BOD_5 were taken from the East Lansing plant lab records.

2. CHEMICAL OXYGEN DEMAND

The standard COD test as described in Standard Methods was used for all COD determinations.

3. OXYGEN DEMAND INDEX

This test is a modification of the chemical oxygen demand test. The dichromate is reduced from the yellow hexavalent to the green trivalent state by organic material in the sample. The amount of green color produced is measured colorimetrically. The procedure was taken from an article by Arnold F. Westerhold in THE DIGESTER, entitled "Measurement of Waste".¹

4. SUSPENDED SOLIDS

Aeration Compartment suspended solids were determined by filtration through a Reeve Angel glass fiber filter, no. 943AH. The volume filtered was 200 ml for all determinations.

Final Compartment suspended solids were determined by filtration through a 0.45 micron Sartorius membrane filter. The volume filtered ranged from 500 ml to 2000 ml depending on expected suspended solids value.

5. DISSOLVED OXYGEN

Measurement of the dissolved oxygen concentration was accomplished by placing the probe directly into the desired compartment and either recording the value manually or by the

¹A. F. Westerhold, 1965, THE DIGESTER, Vol. 22, No. 1, Springfield, Ill. Feb. 1965.

Speedomax Recorder. Care must be taken in the Final Compartment to maintain sufficient flow past the membrane of the probe to obtain accurate readings from the meter.

6. TURBIDITY

Samples from the unit were placed in the meter and the turbidity values recorded manually.

7. AMMONIA NITROGEN TEST

The phenate method as described in Standard Methods was used to determine ammonia nitrogen concentrations.

8. TOTAL PHOSPHATE TEST

The Stannous Chloride method as described in Standard Methods was used to determine phosphate levels in the final effluent of the filter. These samples were all grab samples. Primary Effluent phosphate concentrations were taken from plant records. (They too use the Stannous Chloride test)

9. R_R DETERMINATIONS

R_R determinations were made on grab samples from the Aeration Compartment and from the Final Compartment of the filter unit.

Prior to beginning the determinations it is necessary to calibrate the oxygen meter with the recorder. This is accomplished by allowing the oxygen probe to reach equilibrium with the air and then correct for pressure and temperature to determine the saturation value for the dissolved oxygen concentration. After calibrating the instruments, place the

oxygen probe in a sample of return sludge which has a low dissolved oxygen concentration close to zero so that when the oxygen probe is placed in the sample the dissolved oxygen reading will first rise to the initial dissolved oxygen concentration and then will begin to fall as the oxygen (dissolved) is used up.

The sample from the aeration chamber or from the final chamber is filled into a 250 ml Erlenmeyer wide mouth flask. The oxygen probe and a magnetic stirrer are also placed in the flask and the recorder is turned on. The recorder will then record the dissolved oxygen concentration versus time. R_R was then calculated from the slopes of the recorder curves.

10. K_R DETERMINATION

To find K_R , a suspended solids determination must be made. For a sample from the Final Compartment ~~of the filter~~ filter through a Sartorius membrane filter 1000 ml of sample, for a sample from the Aeration Compartment filter 200 ml through a Reeve Angel glass fiber filter. Dry the filter at 103 C for one hour. Weigh and record weight in Grams/ Liter. K_R is now calculated by dividing the suspended solids concentration into the oxygen uptake rate. K_R is then expressed in terms of MG O_2 /HR/Gram SS.

LITERATURE REVIEW

The first reference goes back to 1937, when there was a process developed called the Hayes Process. It would be more descriptive to call it a solids-contact process because the treatment was accomplished by having the wastewater pass by asbestos plates on which grew a biological slime. The slime would then utilize the dissolved oxygen in the water to oxidize the waste present in the water. This is basically the same process which occurs in the submerged filter. However, the mechanisms involved in operating the two systems are different. The main differences are that in the submerged filter the aeration is separated from the contact media and that flow from the final compartment is recycled to the aeration chamber. Westville, New Jersey has a small sewage treatment plant, capacity 100,000 GPD, which employs the Hayes process. After the raw waste is settled, it is pumped into an aeration tank where it is aerated for two hours. From here it is pumped into a settling basin where it remains for an additional three hours. In both the aeration tank and the settling tank, the waste is treated by exposure of the sewage to biochemical activity of active slime growing on asbestos plates which are placed in the tanks. Finally, the treated effluent is aerated for a second time before being discharged from the plant. It should be mentioned that the average BOD removal from this plant is 90-95%.

Although the treatment is excellent, the basic design of the process is faulty. Aeration and exposure to the floc should be carried out separately to avoid any unnecessary build-up of waste sludge due to too much turbulence among the asbestos plates. Also, utilizing the plates in the settling basin only creates a demand for oxygen where none can be supplied, thus creating the need to aerate twice to raise the final effluent dissolved oxygen concentration. The second reference is a very recent study conducted at Arizona State University under the direction of Prof. J. W. Klock. Prof. Klock's submerged filter is similar to the one described here. However there are several differences in the operation of the process: In the device described by Professor Klock aeration and recycling are performed at the same time, through the use of an air-lift. This necessarily means that if the amount of aeration is changed, this also changes the recycle flow. This reduces the flexibility in operating the filter.

Secondly, no provision is made within the filter for the removal of waste solids. They will simply pass through the filter and be discharged in the final effluent. According to Prof. Klock no sludge build-up will occur because of auto-oxidation of the sludge. Personal experience has however shown that, no matter how small the amount, there will be a solids build-up during the operation of the filter.

Finally, the article implies that more than one submerged filter is needed to obtain complete treatment of the waste.

In data supplied by Prof. Klock,¹ all his studies were being conducted with a series of filters. It appears however, that there is no real gain in using these devices in series. This will be discussed later.

Substrate concentration in the incoming and outgoing flow was measured by the ODI test (see Analytical Procedures). The data obtained by this method showed a very good correlation ~~with~~ ~~units~~ the 5-day BOD data as demonstrated in Table 10 and 11.

EXPERIMENTAL DATA

Operation of the submerged filter was begun on May 25, 1972 at a retention time of 50 hours. The filter media was arranged randomly in the media compartment, there was no recycling of final effluent and aeration was performed only in the first compartment at a rate of 15 liters per minute (1/min).

For eight days (5/25/72--6/1/72) primary effluent was pumped at 250 ml/min (50 hours retention) into the unit. During this time it was difficult to keep the dissolved oxygen concentration in the final compartment above 1.0 mg/l at a rate of air supply of 10 to 15 l/min. (Refer to Table 1)

BOD removal during this time was limited but this was due to the fact that very little microbial slime was growing on the filter media as yet and so the unit was acting as a sedimentation tank and removing mostly suspended solids.

¹Personal correspondence

TABLE 1

Date	Aeration Compartment D.O. mg/l	Final Compartment D.O. mg/l	BOD Influent mg/l	BOD Effluent mg/l	Suspended Solids Influent mg/l	Turbidity Effluent J.T.U.	Air Flow IPM	Temp. Aeration Compartment C
5/25/72	6.9	Trace	82.0	67.0	44.0	14.0	15	20.5
5/26/72	7.8	2.6	87.0	69.0	48.0	14.0	15	20.5
5/27/72	5.3	2.0	53.0	40.0	34.0	7.0	10	21.5
5/28/72	-	-	-	-	-	-	-	-
5/29/72	5.0	1.0	67.0	51.0	44.0	7.0	10	21.5
5/30/72	5.1	1.0	100.0	87.0	60.0	7.0	10	21.5
5/31/72	3.8	1.0	134.0	120.0	74.0	7.0	15	20.0
6/01/72	4.4	Trace	98.0	87.0	68.0	6.5	15	20.0

OPERATING PARAMETERS

Retention Time - 48 hours
Flow Rate - 250 ml/min
Aeration - Diffusers in Aeration
Compartment Only

For the following three weeks the unit was operated at 25 hours retention (500 ml/min). The problem of low dissolved oxygen in the final compartment remained. As shown in Table 2 the performance of the unit did not improve during this period.

Microbial slime was beginning to grow more profusely on the filter media. However towards the end of the media compartment, the growth of the slime was sharply retarded because of a lack of dissolved oxygen.

During the period 6/28/72--7/11/72, the filter was operated at 47 hours retention (265 ml/min) (see Table 3). The air supply was increased to 25 l/min and the final compartment dissolved oxygen concentration increased slightly. Towards the end of this period good treatment was obtained with BOD₅ values of 38 mg/l and suspended solids of 1.5 mg/l for the effluent. The only problem encountered was that the peristaltic feed pump would become clogged if it was not backwashed at least once a day.

Next the unit was operated at 28 hours retention time from 7/12/72--7/31/72. The data are shown in Table 4. Treatment during this period was excellent with BOD values for the effluent ranging from 1.5 to 7.8 mg/l and suspended solids from 0.5 to 3 mg/l.

The dissolved oxygen concentration in the final compartment still hovered around the 1.0 mg/l level, but it did not affect the performance of the filter. Treatment continued to improve throughout the operating period with better than 90% removal of both BOD₅ and Suspended Solids.

TABLE 2

Date	Aeration Compartment D.O. mg/l	Final Compartment D.O. mg/l	BOD Influent mg/l	BOD Effluent mg/l	Suspended Solids Influent mg/l	Turbidity Effluent J.T.U.	Air Flow LPM	Temp. Aeration Compartment C
6/01/72	4.2	Trace	87.0	78.0	71.0	6.5	15	20.5
6/02/72	4.4	0.9	98.0	90.0	55.0	6.0	15	20.0
6/03/72	-	-	-	-	-	-	-	-
6/04/72	-	-	-	-	-	-	-	-
6/05/72	5.5	5.2*	84.0	75.0	47.0	6.0	15	20.0
6/06/72	1.5**	0.2	95.0	88.0	57.0	5.5	15	20.0
6/07/72	4.0	Trace	93.0	-	43.0	5.5	15	20.0
6/08/72	4.0	Trace	110.0	96.0	49.0	5.5	15	21.0
6/09/72	4.8	Trace	84.0	72.0	57.0	5.5	15	21.0
6/26/72	2.9	0.6	93.0	80.0	60.0	5.7	20	23.0
6/27/72	4.0	Trace	98.0	87.0	55.0	-	20	23.0

* Not representative due to clogged feed line

** Air diffuser clogged; replaced

OPERATING PARAMETERS

Retention Time - 540 ml/min
 Flow Rate - 25 hours
 Aeration - Diffusers in Aeration
 Compartment Only (Replaced one diffuser)

TABLE 3

Operating Parameters	Date	Aeration Tank D.O. mg/l	Final Tank D.O. mg/l	BOD Influent mg/l	BOD Effluent mg/l	Susp. Solids Influent mg/l	Susp. Solids Effluent mg/l	Air Flow LPM	Temp. Aeration Tank C
Retention Time	6/28/72	5.7	Trace	104.0	92.0	51.0	20.0	20	22.5
48 hours	6/29/72	6.1	0.9	97.0	86.0	42.0	20.0	25	22.5
Flow Rate 265 ml/min	6/30/72	6.2	0.8	95.0	84.0	47.0	19.0	25	22.5
	7/01/72	6.2	0.9	94.0	80.0	49.0	19.0	25	22.5
Aeration Only in First Tank	7/02/72	6.3	0.9	76.0	62.0	52.0	26.0	25	22.5
	7/03/72	6.4	3.7*	84.0	70.0	38.0	17.0	25	22.5
	7/04/72	5.8	1.5*	90.0	79.0	-	15.1	25	22.7
	7/05/72	6.0	1.2*	-	-	-	-	-	-
	7/06/72	6.2	1.0	99.0	80.0	84.0	10.9	25	22.0
	7/07/72	5.7	0.8	84.0	75.0	48.0	9.8	25	23.0
	7/08/72	5.4	0.7	72.0	60.0	34.0	8.5	25	22.0
	7/09/72	-	-	-	-	-	-	-	-
	7/10/72	5.7	0.9	99.0	-	42.0	4.0	25	22.8
	7/11/72	6.0	0.9	113.0	38.0	70.0	1.5	25	22.8

* Not representative due to clogged feed lines

TABLE 4 RETENTION TIME - 30 HOURS

Date	Aeration Tank D.O. mg/l	Final Tank D.O. mg/l	BOD Influent mg/l	BOD Effluent mg/l	Susp. Solids Influent mg/l	Susp. Solids Effluent mg/l	Air Flow LPM	Temp. Aeration Tank C	Turbidity Effluent J.T.U.
7/12/72	6.0	1.1	68.0	16.5	88.0	7.0	25	22.0	2.0
7/13/72	6.4	1.0	68.0	4.0	52.0	9.0	25	22.0	1.5
7/14/72	7.1*	1.5*	80.0	3.7	48.0	1.0	25	22.5	1.5
7/15/72	6.5	1.0	40.0	4.0	62.0	1.0	25	22.4	1.9
7/16/72	6.2	1.0	55.0	2.5	30.0	4.0	25	22.6	2.0
7/17/72	6.6	0.9	62.0	2.0	14.0	1.0	25	22.9	2.5
7/18/72	6.2	1.1	-	-	-	-	25	23.0	2.5
7/19/72	6.0	0.9	38.0	1.5	36.0	0.6	25	22.5	2.5
7/20/72	5.8	0.8	42.0	2.0	32.0	0.7	25	22.7	2.0
7/21/72	5.5	0.8	76.0	6.0	24.0	0.5	25	23.0	2.8
7/22/72*	-	-	-	-	-	-	-	-	-
7/23/72	5.8	0.9	-	-	20.0	0.8	25	23.5	2.4
7/24/72	5.6	1.1	52.0	4.5	32.0	1.0	25	23.5	2.0
7/25/72	5.8	1.1	-	-	38.0	1.0	25	23.0	2.5

* No data taken because flow into unit was stopped due to clogged feed line

TABLE 4 (cont'd)

Date	Aeration Tank D.O. mg/l	Final Tank D.O. mg/l	BOD Influent mg/l	BOD Effluent mg/l	Susp. Solids Influent mg/l	Susp. Solids Effluent mg/l	Air Flow LPM	Temp. Aeration Tank C	Turbidity Effluent J.T.U.
7/26/72	6.2	1.1	62.0	7.8	62.0	1.0	25	23.0	2.0
7/27/72	6.4	1.2	49.0	3.0	36.0	0.8	25	23.0	2.5
7/28/72	6.8	1.1	54.0	5.0	22.0	1.0	25	23.0	2.5
7/29/72	6.2	1.0	63.0	4.0	18.0	0.8	25	23.5	2.0
7/30/72	6.4	0.9	71.0	5.2	8.0	1.1	25	23.5	2.2
7/31/72	5.8	0.9	79.0	7.0	23.0	2.3	25	23.4	2.0

OPERATING PARAMETERS

Retention Time - 30 hours
 Flow Rate - 445 ml/min
 Aeration - Diffusers in Aeration Compartment Only
 (cleaned of scum on alternate days)

Due to an accident, the tank was completely drained of its contents at the end of this period and so it became necessary to begin over again.

On August 1, 1972, the unit was started at 50 hour retention time. Within two days, the effluent appeared much clearer and so the retention time was lowered to 32 hours on August 5th. The air supply was increased to 30 l/min. For eight days, 8/7/72--8/14/72, the treatment became progressively better until it was as good as had previously occurred before the tank was drained. (Refer to Table 5-0)

At the end of the eight days, the retention time was lowered to 21 hours (600 ml/min). Treatment remained excellent with over 90 percent removal of both BOD₅ and suspended solids as shown in Table 5-1. The final compartment dissolved oxygen concentration still remained at 1.0 mg/l but the brown floc growing on the filter media became black in places, indicating anaerobic conditions. Also, the floc began to build-up in flat areas of the media.

During the summer term break between 9/3/72--9/11/72, the filter was operated at 16 hours retention time producing a good clear effluent, but no data were recorded. On September eleventh, the retention time was lowered to 9.6 hours (feed rate 1300 ml/min), but this rate proved to be too high. The liquid in the aeration compartment became turbid even though the dissolved oxygen concentration was still 6.5 mg/l. The final compartment was very turbid and there was no evidence

TABLE 5

Date	Aeration Tank D.O. mg/l	Final Tank D.O. mg/l	BOD Influent mg/l	BOD Effluent mg/l	Susp. Solids Influent mg/l	Susp. Solids Effluent mg/l	Air Flow LPM	Temp. Aeration Tank C	Turbidity Effluent J.T.U.
8/02/72*	6.7	1.1	60.0	45.0	55.0	22.0	25	-	3.4
8/03/72*	6.1	1.0	58.0	37.0	62.0	10.0	25	-	3.3
8/04/72*	5.3	1.3	86.0	25.0	56.0	14.0	25	22.6	2.9
8/05/72	3.8	0.3	68.0	23.0	48.0	15.0	30	22.8	3.5
8/06/72	-	-	-	-	-	-	30	-	3.7
8/07/72	4.5	1.3	60.0	15.0	56.0	8.0	30	22.5	3.9
8/08/72	6.8	1.1	44.0	13.5	48.0	6.0	30	22.5	2.5
8/09/72	6.4	1.0	58.0	9.5	34.0	2.1	30	22.5	2.0
8/10/72	6.3	0.9	62.0	12.0	26.0	2.5	30	22.5	2.0
8/11/72	6.5	0.9	60.0	8.7	28.0	1.5	30	22.5	1.8
8/12/72	-	-	-	-	-	-	30	-	-
8/13/72	6.7	1.1	72.0	5.0	28.0	1.8	30	22.7	1.5
8/14/72	6.2	1.0	87.0	5.7	62.0	1.9	30	22.8	1.3

* Indicates operation of unit at 48 HRS retention

OPERATING PARAMETERS

Retention Time - 32 hours

Flow Rate - 400 ml/min

Aeration - First Compartment

TABLE 5-1

Date	Aeration Tank D.O. mg/l	Final Tank D.O. mg/l	BOD Influent mg/l	BOD Effluent mg/l	Susp. Solids Influent mg/l	Susp. Solids Effluent mg/l	Air Flow LPM	Temp. Aeration Tank C	Turbidity Effluent J.T.U.
8/15/72	6.3	0.9	79.0	7.0	84.0	1.1	30	-	1.5
8/16/72	6.0	1.0	87.0	6.5	28.0	1.3	30	22.0	1.0
8/17/72	6.4	0.9	92.0	9.0	42.0	1.0	30	22.4	1.0
8/18/72	5.7	1.2	56.0	4.3	57.0	1.7	30	22.7	1.5
8/19/72	6.5	1.2	63.0	4.0	70.0	1.5	30	22.3	1.0
8/20/72	6.4	1.0	74.0	7.0	47.0	1.0	30	22.0	1.5
8/21/72	5.9	0.8	81.0	6.5	51.0	1.0	30	22.6	1.5
8/22/72	5.6	0.9	83.0	4.3	62.0	2.1	30	22.3	1.7
8/23/72	6.3	1.1	70.0	6.2	71.0	1.8	30	22.0	1.4
8/24/72	6.2	1.0	56.0	4.5	42.0	1.5	30	22.7	1.0

OPERATING PARAMETERS

Retention Time - 22 hours
Flow Rate - 600 ml/min
Aeration - First Compartment Only
Diffuser replaced 8/25/72

of any dissolved oxygen present. Obviously, 9.6 hours retention time was too short to obtain the BOD₅ removal which is needed for full treatment.

In order to get the filter back in operation the feed rate was reduced to 800 ml/min (15.6 hours retention) and then to 600 ml/min (21 hours retention) when 800 ml/min proved too much for the filter to handle. At this time new plastic porous diffusers were installed in the aeration compartment. These produced very fine bubbles which aided both aeration and mixing. Less than half the amount of air was needed to maintain the same dissolved oxygen concentration as with the old homemade diffusers. The new air supply rate was only 15 LPM at 5 PSI, compared to 30 LPM at 10 PSI before.

Finally, all feed into the filter was stopped and both the aeration compartment and the final compartment were aerated because the floc was turning anaerobic. After one day's aeration the floc had started turning brown again, indicating the return of aerobic conditions. However anaerobic conditions returned to the final compartment and the media compartment as soon as feeding was started. Because of the heavy growth of floc which had accumulated in the media compartment, it was utilizing the dissolved oxygen present in the water faster than it could be supplied. A solution to the problem was found by recycling the water from the final compartment back into the aeration chamber.

A submersible pump was installed to pump water from the final compartment back into the aeration compartment (Figure 7). In this way an internal flow existed within the tank carrying oxygen-laden water to all parts of the filter at a rate much greater than before. Initially, a recycle flow of 60 l/min. was used which resulted in an exchange rate of 8 min within the media compartment. However, this was soon reduced to 30 l/min (exchange rate = 16 min) with the same excellent results.

On September 28, 1972, operation was begun at a feed rate of 600 ml/min (21 hours retention), utilizing the recycle pump and aerating only in the first compartment. After only one day's operation, the final effluent looked like tap water, was free of almost all turbidity and maintained a dissolved oxygen concentration of over 5.0 mg/l.

For the following ten days as shown in Table 6, treatment was excellent. The recycling system had solved the problem of maintaining dissolved oxygen concentration in the final compartment. It was first thought that the recycle flow might cause suspended solids to be moved through the media compartment and to be discharged from the filter. However, this was not the case at all, even with an exchange rate of only 8 minutes. Suspended solids removal within the filter was as good as with no recycle flow for the same retention time.

Since the dissolved oxygen concentration remained well above 1.0 mg/l in the final compartment, it appeared that the filter should be able to handle a lower retention time and still

TABLE 6

Date	Aeration Tank D.O. mg/l	Final Tank D.O. mg/l	Turb. P.E. JTU	Turb. Aeration Tank JTU	Turb. Final Tank JTU	Temp. Aeration Tank C	Air Flow LPM	Recycle Flow LPM
9/28/72	5.6	5.4	23	7	4	22.5	15	60
9/29/72	5.5	5.7	26	3	2	23.0	15	60
9/30/72	5.9	5.7	28	4	2	22.0	15	60
10/01/72	6.0	5.8	28	2	1	21.0	15	60
10/02/72	5.8	5.7	35	2	1	23.0	15	60
10/03/72	5.8	5.5	49	3	1	24.0	15	60
10/04/72	5.8	5.3	72	3	2	23.0	15	60
10/05/72	5.3	5.6	30	4	2	24.0	15	60
10/06/72	5.0	5.5	21	4	1	23.0	15	60
10/07/72	4.9	5.3	21	5	2	24.0	15	60
10/08/72	4.4	5.0	32	4	1	24.0	15	60

OPERATING PARAMETERS

Retention Time - 22 hours
Flow Rate - 600 ml/min

TABLE 6 (cont'd) RETENTION TIME - 22 HOURS

Date	Suspended Solids			BOD		
	P.E. mg/l	Aer. & Final Tanks mg/l	P.E. mg/l	Aer. & Final Tanks mg/l	P.E. mg/l	
9/28/72	37.0	8.0	5.0	68.0	22.0	10.0
9/29/72	38.0	5.0	2.0	80.0	17.0	7.0
9/30/72	42.0	6.1	1.6	76.0	15.0	7.0
10/01/72	41.0	2.4	1.0	72.0	12.0	9.0
10/02/72	51.0	2.3	0.9	106.0	14.0	6.0
10/03/72	69.0	3.1	1.1	122.0	15.0	5.0
10/04/72	114.0	2.9	1.0	106.0	17.0	4.6
10/05/72	49.0	3.7	1.6	96.0	14.0	4.2
10/06/72	31.0	3.9	1.2	64.0	15.0	6.0
10/07/72	34.0	4.7	1.9	84.0	17.0	7.0
10/08/72	42.0	3.9	1.2	88.0	12.0	5.0

maintain the excellent treatment. The retention time was lowered to 16 hours for two days, but during those two days the treatment deteriorated significantly as shown in Table 7, the turbidity of the final effluent increased from 1-2 JTU to 11-12 JTU. Due to the random arrangement of the plastic media, there were many areas within the media that were trapping the biological floc and preventing it from settling into the sludge storage area at the bottom of the unit. This reduced the effective surface area of the filter so that it was unable to provide full treatment at 16 hours retention time. The feed rate was therefore decreased to 600 ml/min ($t_r = 22$ hours) during the period from 10/12/72 to 11/2/72. Performance in general, was good but not as good as before as shown in Table 8. This was caused by the build-up of excess sludge in the media which was becoming more noticeable. Also of importance was perhaps the fact that the recycle rate was cut back to 30 LPM at the beginning of the operating period. This was done because as mentioned before, during the two days the filter was run at 12 hours retention, the suspended solids concentration in the final effluent had increased to 12 JTU. It was concluded then that possibly some sludge solids were passing through the media compartment due to the short exchange rate of only 8 minutes.

When the retention time was lowered to 17 hours, the suspended solids concentration increased significantly in the final effluent with the lower recycle rate of 30 or even 10 l/min (see Table 9). Inspection of the media compartment showed that

TABLE 7

Date		10/10/72	10/11/72	10/12/72
Aeration Tank D.O.	mg/l	4.5	4.7	4.6
Final Tank D.O.	mg/l	4.2	4.1	4.0
Turbidity PE	JTU	75.0	90.0	41.0
Turbidity Aeration Tank	JTU	17.0	17.0	15.0
Turbidity FE	JTU	12.0	10.0	11.0
Suspended Solids PE	mg/l	86.0	118.0	58.0
Suspended Solids Aeration Tank	mg/l	20.0	19.0	21.0
Suspended Solids FE	mg/l	14.0	11.0	12.0
BOD PE	mg/l	132.0	158.0	128.0
BOD Aeration Tank	mg/l	36.0	31.0	33.0
BOD FE	mg/l	17.0	14.0	12.0
Air Flow	LPM	15.0	15.0	15.0
Temp. Aeration Tank	C	20.0	22.0	22.0
Recycle Flow	LPM	60.0	60.0	60.0

Retention Time - 16 hours
Flow Rate - 800 ml/min

TABLE 8 RETENTION TIME - 22 HOURS

Date	Aer. Tank D.O. mg/l	Final Tank D.O. mg/l	BOD PE mg/l	BOD Aer. Tank mg/l	BOD FE mg/l	SS PE mg/l	SS Aer. Tank mg/l	SS FE mg/l	Turb. PE JTU	Turb. Aer. Tank JTU	Turb. FE JTU	Air Flow LPM	Temp. Aer. Tank C
10/13/72	4.9	4.3	126.0	12.0	9.0	38.0	14.0	10.0	26	12.0	10.0	15	22.0
10/14/72	5.1	4.6	94.0	27.0	12.0	28.0	12.0	8.0	17	10.0	7.0	15	22.0
10/15/72	5.5	4.8	74.0	14.0	10.0	30.0	11.0	8.0	19	9.0	6.0	15	20.0
10/16/72	5.8	5.0	96.0	20.0	9.0	30.0	10.0	6.0	20	8.3	5.9	15	21.0
10/17/72	5.7	5.0	126.0	17.0	9.0	78.0	10.0	8.0	60	8.0	5.5	15	21.0
10/18/72	5.9	5.2	118.0	15.0	7.0	36.0	10.0	4.0	24	7.7	5.5	15	22.0
10/19/72	5.7	5.0	104.0	14.0	8.0	32.0	9.0	5.0	20	7.4	5.3	15	22.0
10/20/72	5.3	5.2	106.0	13.0	6.0	40.0	10.0	6.0	23	7.4	5.2	15	22.0
10/21/72	5.2	5.4	98.0	12.0	7.0	46.0	11.0	5.0	27	7.0	4.6	15	22.0
10/22/72	5.2	5.0	64.0	17.0	4.0	72.0	12.0	3.1	60	9.0	3.0	15	20.0
10/23/72	5.4	5.1	82.0	15.0	5.0	60.0	14.0	3.0	45	8.0	4.0	15	19.0

TABLE 8 (cont'd)

Date	Aer. Tank D.O. mg/l	Final Tank D.O. mg/l	BOD PE mg/l	BOD Aer. Tank mg/l	BOD PE mg/l	SS PE mg/l	SS Aer. Tank mg/l	SS PE mg/l	Turb. PE JTU	Turb. Aer. Tank JTU	Turb. PE JTU	Air Flow LPM	Temp. Aer. Tank C
10/24/72	5.6	5.2	98.0	19.0	5.0	80.0	13.0	2.7	65.0	9.0	2.0	15	19.0
10/25/72	5.5	5.1	78.0	16.0	6.0	34.0	14.0	3.4	24.0	7.0	3.0	15	20.0
10/26/72	5.8	5.4	86.0	19.0	6.0	38.0	12.0	1.5	30.0	8.0	2.0	15	19.0
10/27/72	5.7	3.2	79.0	21.0	4.0	66.0	11.0	2.0	52.0	8.0	2.0	15	19.0
10/28/72	5.7	3.5	89.0	17.0	3.0	52.0	16.0	2.2	41.0	10.0	2.0	15	18.0
10/29/72	5.6	3.1	92.0	14.0	4.0	41.0	13.0	1.5	32.0	9.0	1.0	15	19.0
10/30/72	5.9	3.3	69.0	23.0	5.0	50.0	12.0	1.7	44.0	10.0	2.0	15	19.0
10/31/72	5.9	3.0	72.0	20.0	5.0	59.0	15.0	2.0	50.0	12.0	2.0	15	19.0
11/01/72	5.7	3.2	52.0	19.0	6.0	62.0	11.0	1.4	56.0	10.0	1.0	15	19.0
11/02/72	5.7	3.2	80.0	17.0	5.0	50.0	12.0	1.0	38.0	12.0	2.0	15	18.0

FILTER OPERATING DATA

Retention Time - 22 hours
Flow Rate - 600 ml/min
Aeration - Both Compartments until 10/26/72
Final Tank Air Flow - 5 LPM

TABLE 8 (cont'd) RETENTION TIME - 22 HOURS

Date	NH ₃ - N Primary Effluent mg/l	NH ₃ - N Aeration Tank mg/l	NH ₃ - N Final Effluent mg/l
10/22/72	14.3	8.5	0.3
10/23/72	12.7	7.2	0.2
10/24/72	15.1	6.2	0.1
10/25/72	13.0	5.9	0.3
10/26/72	11.3	7.2	0.2
10/27/72	10.9	8.1	0.4
10/28/72	12.3	6.0	0.1
10/29/72	10.2	5.8	0.2
10/30/72	11.7	6.2	0.3
10/31/72	13.1	7.0	0.2
11/01/72	12.0	7.2	0.2
11/02/72	11.2	7.1	0.3

TABLE 9 RETENTION TIME - 17 HOURS

Date	Aer. Tank D.O.	Final Tank D.O.	BOD PE mg/l	BOD Aer. Tank mg/l	BOD FE mg/l	SS PE mg/l	SS Aer. Tank mg/l	SS FE mg/l	Turb. PE JTU	Turb. Aer. Tank JTU	Turb. FE JTU	Air Flow LPM	Temp. Aer. Tank C	Recycle Flow LPM
11/03/72	5.9	3.0	74.0	19.0	7.0	44.0	14.0	1.7	40.0	14.0	2.0	15	19.0	30
11/04/72	5.5	2.1	72.0	16.0	11.0	40.0	11.0	3.0	30.0	11.0	4.0	15	19.0	30
11/05/72	5.6	1.7	72.0	16.0	11.0	40.0	14.0	2.7	30.0	13.0	7.0	15	19.0	30
11/06/72	5.7	1.3	92.0	21.0	17.0	56.0	15.0	3.8	43.0	13.0	9.0	15	18.0	30
11/07/72	5.4	0.9	80.0	20.0	16.0	56.0	12.0	3.7	45.0	15.0	11.0	25	20.0	30
11/08/72	5.6	3.4	74.0	17.0	10.0	40.0	11.0	4.0	34.0	11.0	8.0	25	19.0	30
11/09/72	5.7	4.2	82.0	22.0	11.0	34.0	16.0	3.0	24.0	15.0	10.0	25	19.0	30
11/10/72	5.5	4.4	92.0	24.0	9.0	40.0	17.0	4.2	26.0	15.0	9.0	25	19.0	30
11/11/72	5.2	4.0	76.0	20.0	10.0	32.0	15.0	2.9	28.0	13.0	7.0	25	19.0	30
11/12/72	5.3	4.2	66.0	28.0	10.0	38.0	14.0	3.3	32.0	14.0	9.0	25	18.0	30
11/13/72	5.6	4.7	78.0	30.0	12.0	50.0	12.0	3.9	35.0	14.0	11.0	25	17.0	10
11/14/72	5.8	4.2	98.0	26.0	11.0	56.0	10.0	3.2	45.0	12.0	7.0	25	17.0	10
11/15/72	5.9	4.8	-	24.0	12.0	-	17.0	2.9	-	12.0	4.0	25	17.0	10
11/16/72	5.9	4.6	-	29.0	11.0	-	19.0	3.0	-	16.0	5.0	25	17.0	10
11/17/72	5.6	4.9	106.0	30.0	10.0	48.0	19.0	5.0	35.0	15.0	6.0	25	17.0	10

OPERATING PARAMETERS

Retention Time - 17 Hours

Flow Rate - 700 ml/min

TABLE 9 (cont'd) RETENTION TIME - 17 HOURS

Date	Aer. Tank D.O. mg/l	Final Tank D.O. mg/l	BOD PE mg/l	BOD Aer. Tank mg/l	BOD FE mg/l	SS PE mg/l	SS Aer. Tank mg/l	SS FE mg/l	Turb. PE JTU	Turb. Aer. Tank JTU	Turb. FE JTU	Air Flow LPM	Temp. Aer. Tank C	Recycle Flow LPM
11/18/72	5.7	5.0	88.0	32.0	10.0	52.0	22.0	5.0	37.0	13.0	4.0	25	19.0	10
11/19/72	5.5	5.1	102.0	30.0	12.0	62.0	19.0	8.0	50.0	17.0	7.0	25	19.0	10
11/20/72	5.7	5.2	130.0	24.0	14.0	116.0	19.0	8.5	95.0	12.0	10.0	25	18.0	10
11/21/72	5.9	5.1	148.0	25.0	7.0	96.0	21.0	4.0	80.0	11.0	5.0	25	18.0	10
11/22/72	5.4	5.0	-	27.0	6.0	-	24.0	4.0	-	12.0	3.0	25	18.0	10
11/23/72	5.7	5.2	60.0	29.0	6.0	34.0	22.0	6.0	22.0	12.0	5.0	25	19.0	10
11/24/72	5.8	5.4	74.0	31.0	5.0	58.0	20.0	4.0	46.0	11.0	6.0	25	18.0	10
11/25/72	5.8	5.4	74.0	30.0	7.0	48.0	20.0	3.9	35.0	11.0	2.0	25	18.0	10
11/26/72	5.9	5.2	40.0	27.0	9.0	34.0	19.0	5.4	24.0	10.0	7.0	25	17.0	10
11/27/72	5.6	5.3	118.0	31.0	4.0	76.0	22.0	4.5	64.0	14.0	3.0	25	16.0	10
11/28/72	5.8	5.0	104.0	20.0	7.0	62.0	12.0	4.0	50.0	17.0	7.0	25	17.0	10
11/29/72	5.9	5.2	104.0	17.0	7.0	38.0	14.0	3.7	26.0	15.0	7.0	25	17.0	10
11/30/72	5.9	4.9	64.0	21.0	11.0	38.0	12.0	4.2	28.0	20.0	9.0	25	16.0	10
12/01/72	5.7	4.9	72.0	20.0	10.0	28.0	17.0	4.5	18.0	19.0	11.0	25	16.0	10
12/02/72	5.6	5.1	68.0	23.0	10.0	34.0	14.0	5.0	22.0	19.0	11.0	25	17.0	10
12/03/72	5.7	5.0	108.0	26.0	12.0	78.0	18.0	5.0	65.0	18.0	13.0	25	17.0	10

TABLE 9 (cont'd) RETENTION TIME - 17 HOURS

Date	NH ₃ - N PE mg/l	NH ₃ - N Aer. Tank mg/l	NH ₃ - N PE mg/l
11/03/72	12.0	7.5	0.2
11/04/72	9.7	6.0	0.4
11/05/72	10.1	9.0	0.5
11/06/72	10.4	7.0	0.5
11/07/72	12.1	6.0	0.4
11/08/72	13.0	5.9	0.6
11/09/72	10.9	4.7	0.5
11/10/72	9.1	5.1	0.5
11/11/72	8.7	5.7	0.6
11/12/72	10.1	7.0	0.4
11/13/72	11.0	7.3	0.4
11/14/72	12.0	6.9	0.5
11/15/72	10.5	7.0	0.6
11/16/72	11.1	7.7	0.7
11/17/72	12.5	8.1	0.7
11/18/72	9.8	6.75	0.6
11/19/72	10.7	7.2	0.6
11/20/72	10.0	7.2	0.6
11/21/72	11.1	7.5	0.6
11/22/72	12.0	8.3	0.6
11/23/72	12.5	6.7	0.5
11/24/72	12.0	6.0	0.4
11/25/72	11.7	5.9	0.6
11/26/72	11.5	5.0	0.7
11/27/72	10.9	5.7	0.4
11/28/72	11.2	7.1	0.6
11/29/72	11.3	7.4	0.6
11/30/72	12.0	7.5	0.7
12/01/72	10.9	5.7	0.7
12/02/72	10.9	5.0	0.7
12/03/72	11.0	6.2	0.8

the sludge build-up was getting progressively worse and was beginning to seriously affect the performance of the filter. The partitions between compartments had to be cleaned daily because the sludge would plug the holes and prevent an even distribution of water into the media compartment. In effect, part of the media chamber was shut off from the flow of waste water and of recycle flow and this resulted in poor treatment. It was therefore decided to drain the unit completely, clean out the accumulated sludge and to rearrange the plastic media so that any excess biological floc could move freely towards the bottom.

As shown in Figure 6 the plastic rings were arranged with their walls perpendicular so that if one were to look down on the media compartment, it would be possible to see straight through into the storage area. In this way the excess sludge could not be trapped and had to settle out into the storage area.

Operation of the unit started again on December 27, 1972. The tank was filled with primary effluent along with 5 gallons of mixed liquor from the plant, recycle flow was set at 20 LPM and the air supply at 15 l/min. No primary effluent was pumped into the unit until there were signs of biological film growing on the media.

For twelve days, 12/9/72--12/21/72, primary effluent was fed on alternate days at 250 ml/min to hasten the growth of floc on the media. Also, 5 additional gallons of mixed liquor

FIGURE 5 (MODE #1) RANDOM MEDIA ARRANGEMENT

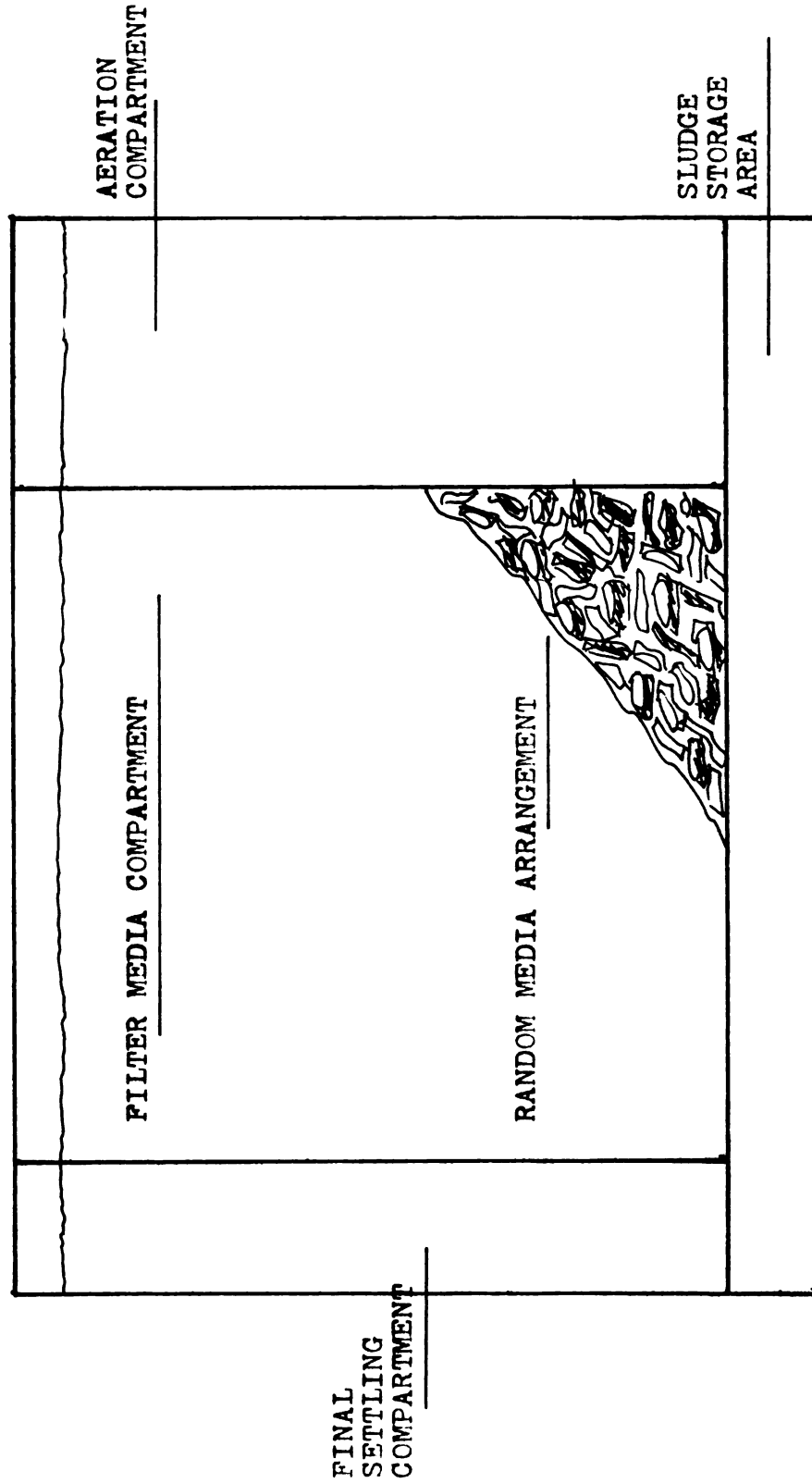
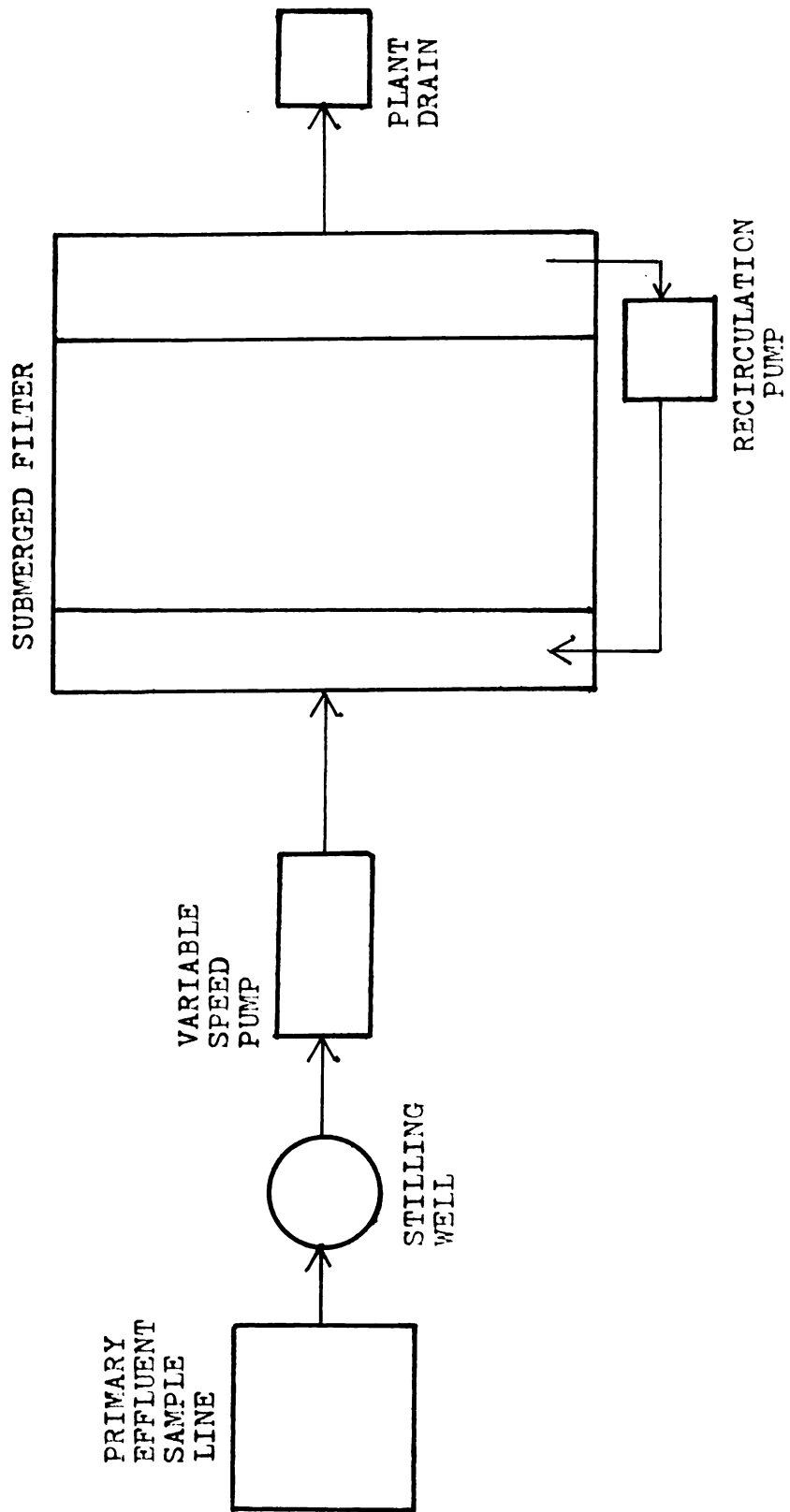




FIGURE 6 (MODE # 2) LAYERED FILTER MEDIA

FIGURE 7 FLOW DIAGRAM



were added to the filter as a supply of biological floc. The recycle flow was reduced to 10 l/min corresponding to an exchange rate of 48 min in the media compartment. After running for one week at this recycle rate, the dissolved oxygen concentration did not change significantly in the final compartment. This indicated that it was unnecessary to maintain a higher recycle flow than 10 LPM. At any rate, the recycle flow could always be increased if the increased growth of floc on the filter media required more oxygen.

Commencing on 12/21/72, primary effluent was continuously fed at the rate of 250 ml/min (48 hours retention) into the filter. Treatment was fair in the beginning but continued to get better with time. As shown in Table 10 at the end of a week and a half, over 90% removal was obtained for both BOD₅ and Suspended Solids. Ammonia concentrations in the final effluent averaged .3 mg/l; this represents a removal rate of better than 95%.

By using recirculation the time required to get the filter operating was effectively reduced by 2/3 compared to the first time. By maintaining a recirculation flow within the filter, dissolved oxygen is supplied to all parts of the filter media. In this manner, practically all of the surface area of the media is being used to treat the waste.

After collecting a sufficient amount of data at 48 hours retention, the retention time was decreased to 24 hours (540 feed rate ml/min), from January 24, 1973 through February 9, 1973. As shown in Table 11 the unit produced excellent removal for all determined parameters during this period.

TABLE 10

Date	Aer. Tank D.O. mg/l	Final Tank D.O. mg/l	BOD PE mg/l	BOD Aer. Tank mg/l	BOD FE mg/l	ODI PE mg/l	ODI Aer. Tank mg/l	ODI FE mg/l	COD PE mg/l	COD Aer. Tank mg/l	COD FE mg/l	Temp. Aer. Tank C
12/27/72	5.6	4.9	93.0	29.0	30.0	97.0	37.0	22.0	-	-	-	18.0
12/28/72	5.4	4.6	79.0	22.0	17.0	83.0	28.0	20.0	87.0	35.0	24.0	18.0
12/29/72	5.7	4.7	80.0	15.0	10.0	81.0	20.0	12.0	-	-	-	17.0
12/30/72	6.0	5.1	104.0	12.0	8.0	109.0	20.0	11.0	123.0	22.0	17.0	16.0
12/31/72	6.0	5.3	116.0	10.0	8.0	123.0	15.0	10.0	-	-	-	16.0
1/01/73	6.2	5.5	92.0	11.0	7.0	100.0	13.0	10.0	111.0	20.0	15.0	16.0
1/02/73	5.9	5.0	96.0	11.0	5.0	97.0	15.0	9.0	-	-	-	17.0
1/03/73	5.9	5.2	79.0	10.0	4.0	83.0	12.0	6.0	92.0	17.0	10.0	17.0
1/04/73	5.6	4.6	84.0	9.0	4.0	92.0	12.0	7.0	-	-	-	17.0
1/05/73	6.0	5.1	80.0	9.0	5.0	94.0	10.0	6.0	103.0	20.0	11.0	16.0
1/06/73	5.2	4.1	67.0	10.0	6.0	72.0	13.0	8.0	-	-	-	18.0
1/07/73	5.6	4.2	70.0	12.0	4.0	79.0	16.0	5.0	82.0	24.0	7.0	18.0
1/08/73	5.5	4.7	92.0	10.0	5.0	105.0	15.0	5.0	-	-	-	19.0
1/09/73	6.0	5.0	97.0	14.0	5.0	105.0	17.0	7.0	-	-	-	16.0

Retention Time - 48 hours
Flow Rate - 250ml/min
Aeration - Bubblewands in First Compartment

TABLE 10 (cont'd) RETENTION TIME - 48 HOURS

Date	Aer. Tank D.O. mg/l	Final Tank D.O. mg/l	BOD PE mg/l	BOD Aer. Tank mg/l	BOD FE mg/l	ODI PE mg/l	ODI Aer. Tank mg/l	ODI FE mg/l	COD PE mg/l	COD Aer. Tank mg/l	COD FE mg/l	Temp. Aer. Tank C
1/10/73	6.0	5.1	104.0	17.0	4.0	105.0	18.0	9.0	125.0	30.0	10.0	16.0
1/11/73	5.8	5.0	107.0	15.0	5.0	112.0	17.0	8.0	-	-	-	17.0
1/12/73	5.7	4.8	90.0	11.0	6.0	95.0	12.0	8.0	107.0	20.0	15.0	17.0
1/13/73	5.8	4.8	88.0	10.0	4.0	93.0	10.0	9.0	-	-	-	16.0
1/14/73	5.9	4.7	78.0	13.0	3.0	84.0	14.0	9.0	92.0	24.0	9.0	18.0
1/15/73	6.0	5.2	69.0	12.0	4.0	73.0	15.0	6.0	-	-	-	17.0
1/16/73	6.0	5.0	73.0	14.0	4.0	74.0	16.0	5.0	85.0	19.0	12.0	18.0
1/17/73	6.0	5.1	79.0	14.0	3.0	82.0	15.0	5.0	-	-	-	18.0
1/18/73	6.1	5.0	89.0	13.0	4.0	91.0	15.0	7.0	99.0	23.0	15.0	16.0
1/19/73	6.3	5.2	100.0	12.0	3.0	102.0	14.0	8.0	-	-	-	16.0
1/20/73	5.9	4.8	91.0	11.0	3.0	93.0	12.0	9.0	113.0	22.0	11.0	17.0
1/21/73	5.7	4.6	93.0	10.0	5.0	97.0	10.0	9.0	-	-	-	18.0
1/22/73	5.9	4.9	87.0	10.0	5.0	88.0	11.0	7.0	99.0	20.0	9.0	19.0
1/23/73	5.9	5.1	89.0	13.0	4.0	92.0	12.0	7.0	-	-	-	18.0

TABLE 10 (cont'd) RETENTION TIME - 48 HOURS

Date	Turb. PE JTU	Turb. Aer. JTU	Turb. FE JTU	Air Flow LPM	Recycle Flow LPM	SS PE mg/l	SS Aer. mg/l	SS FE mg/l	NH ₃ -N PE mg/l	NH ₃ -N Aer. mg/l	NH ₃ -N FE mg/l
12/27/72	42.0	12.0	4.7	15	10	52.0	17.0	7.0	11.8	6.9	0.9
12/28/72	39.0	10.0	4.4	15	10	46.0	16.0	5.0	10.7	7.0	0.7
12/29/72	55.0	15.0	3.0	15	10	62.0	12.0	4.5	12.2	6.8	0.7
12/30/72	70.0	12.0	3.2	15	10	81.0	10.0	2.7	11.5	6.2	0.8
12/31/72	69.0	9.0	4.0	15	10	84.0	11.0	2.1	10.7	5.8	0.7
1/01/73	53.0	10.0	2.0	15	10	66.0	11.0	2.0	11.8	6.3	0.6
1/02/73	61.0	10.0	2.0	15	10	70.0	13.0	1.5	12.1	7.1	0.5
1/03/73	57.0	7.0	2.0	15	10	65.0	15.0	1.7	12.0	6.9	0.4
1/04/73	60.0	7.0	1.7	15	10	70.0	10.0	1.7	12.1	6.3	0.4
1/05/73	40.0	9.0	1.6	15	10	52.0	14.0	1.4	11.6	5.9	0.3
1/06/73	34.0	10.0	1.0	15	10	45.0	12.0	1.3	11.7	6.0	0.3
1/07/73	39.0	10.0	1.0	15	10	55.0	12.0	1.2	12.2	6.8	0.4
1/08/73	51.0	10.0	1.0	15	10	62.0	10.0	1.0	11.8	5.8	0.2
1/09/73	60.0	10.0	3.0	15	10	74.0	15.0	1.7	11.9	6.0	0.2

TABLE 10 (cont'd) RETENTION TIME - 48 HOURS

Date	Turb. PE JTU	Turb. Aer. JTU	Turb. FE JTU	Air Flow LPM	Recycle Flow LPM	SS PE mg/l	SS Aer. mg/l	SS FE mg/l	NH ₃ -N PE mg/l	NH ₃ -N Aer. mg/l	NH ₃ -N FE mg/l
1/10/73	57.0	9.0	1.7	15	10	69.0	14.0	2.1	12.0	6.7	0.2
1/11/73	40.0	9.0	1.9	15	10	52.0	14.0	1.5	11.7	6.4	0.2
1/12/73	72.0	8.0	2.0	15	10	84.0	12.0	1.7	11.0	5.9	0.2
1/13/73	50.0	8.0	1.0	15	10	57.0	17.0	1.7	10.9	5.7	0.1
1/14/73	55.0	10.0	1.2	15	10	63.0	15.0	1.6	11.3	6.0	0.2
1/15/73	60.0	10.0	1.4	15	10	67.0	11.0	1.9	10.8	5.7	0.1
1/16/73	60.0	11.0	1.0	15	10	72.0	10.0	1.3	11.0	6.1	0.1
1/17/73	35.0	9.0	1.2	15	10	47.0	12.0	1.1	12.0	6.7	0.2
1/18/73	34.0	9.0	1.0	15	10	46.0	13.0	1.3	11.8	7.0	0.2
1/19/73	24.0	7.0	1.1	15	10	32.0	13.0	1.2	11.7	6.8	0.1
1/20/73	41.0	10.0	1.4	15	10	51.0	12.0	1.0	10.5	5.6	0.1
1/21/73	56.0	12.0	1.7	15	10	63.0	14.0	1.1	11.0	6.1	0.2
1/22/73	61.0	11.0	1.2	15	10	70.0	10.0	1.2	12.1	6.0	0.2
1/23/73	47.0	11.0	1.1	15	10	59.0	11.0	1.0	11.8	5.5	0.1

TABLE 11 RETENTION TIME - 24 HOURS

Date	Aer. Tank D.O. mg/l	Final Tank D.O. mg/l	Air Flow IPM	Temp. Aer. Tank C	NH ₃ -N PE mg/l	NH ₃ -N Aer. mg/l	NH ₃ -N PE mg/l
1/24/73	5.9	5.0	15	17.0	11.6	5.5	0.1
1/25/73	6.0	5.0	15	16.0	12.1	6.1	0.2
1/26/73	5.7	4.8	15	16.0	10.9	5.7	0.1
1/27/73	5.8	4.8	15	17.0	10.3	5.9	0.2
1/28/73	5.6	4.7	15	18.0	11.1	6.4	0.2
1/29/73	5.9	4.9	15	18.0	10.8	6.7	0.2
1/30/73	6.1	5.0	15	19.0	11.5	5.9	0.3
1/31/73	6.1	5.1	15	18.0	11.1	7.0	0.1
2/01/73	6.0	4.9	15	19.0	12.3	6.2	0.3
2/02/73	6.0	4.8	15	19.0	11.4	5.9	0.3
2/03/73	5.9	5.0	15	17.0	10.7	7.2	0.1
2/04/73	5.9	4.9	15	17.0	10.9	6.3	0.1
2/05/73	5.8	4.5	15	18.0	11.0	6.6	0.2
2/06/73	5.9	4.7	15	16.0	11.6	5.7	0.2
2/07/73	6.2	5.2	15	16.0	12.2	6.9	0.2
2/08/73	6.1	5.3	15	17.0	10.7	6.7	0.3
2/09/73	6.0	5.4	15	16.0	10.3	7.1	0.1

TABLE 11 (cont'd) RETENTION TIME - 24 HOURS

Date	BOD PE mg/l	BOD Aer. mg/l	BOD FE mg/l	ODI PE mg/l	ODI Aer. mg/l	ODI FE mg/l	SS PE mg/l	SS Aer. mg/l	SS FE mg/l	Turb. PE JTU	Turb. Aer. JTU	Turb. FE JTU	Recycle Flow LPM
1/24/73	94.0	14.0	4.0	97.0	20.0	7.0	88.0	12.0	1.3	70.0	20.0	1.5	10
1/25/73	101.0	17.0	5.0	105.0	22.0	9.0	76.0	12.0	1.1	65.0	15.0	1.0	10
1/26/73	94.0	11.0	4.0	96.0	16.0	9.0	66.0	11.0	1.0	51.0	17.0	1.0	10
1/27/73	76.0	15.0	4.0	79.0	17.0	8.0	59.0	10.0	1.0	44.0	12.0	1.0	10
1/28/73	62.0	19.0	3.0	65.0	19.0	7.0	62.0	11.0	0.9	55.0	15.0	1.0	10
1/29/73	67.0	14.0	4.0	72.0	15.0	6.0	89.0	12.0	1.1	73.0	15.0	1.0	10
1/30/73	94.0	11.0	4.0	97.0	17.0	6.0	70.0	9.0	1.0	60.0	11.0	1.0	10
1/31/73	96.0	12.0	6.0	99.0	15.0	6.0	68.0	12.0	1.2	50.0	17.0	1.0	10
2/01/73	88.0	13.0	5.0	90.0	15.0	8.0	55.0	10.0	1.3	42.0	13.0	1.2	10
2/02/73	80.0	10.0	5.0	82.0	12.0	7.0	59.0	14.0	1.0	45.0	16.0	1.0	10
2/03/73	82.0	12.0	4.0	85.0	13.0	7.0	69.0	10.0	1.0	57.0	15.0	1.0	10
2/04/73	96.0	14.0	7.0	99.0	14.0	7.0	78.0	12.0	0.9	65.0	17.0	1.0	10
2/05/73	98.0	14.0	6.0	106.0	17.0	9.0	89.0	10.0	1.0	75.0	12.0	1.0	10
2/06/73	72.0	10.0	5.0	79.0	12.0	10.0	87.0	9.0	1.1	71.0	10.0	1.3	10
2/07/73	110.0	17.0	4.0	119.0	22.0	7.0	90.0	10.0	1.0	81.0	10.0	1.4	10
2/08/73	104.0	18.0	5.0	107.0	21.0	6.0	46.0	9.0	1.0	35.0	12.0	1.0	10
2/09/73	91.0	14.0	5.0	92.0	17.0	6.0	59.0	9.0	1.2	49.0	13.0	1.0	10

A comparison of the data from 48 hours retention and 24 hours retention with the new media arrangement shows no decrease in treatment efficiency. Unfortunately, at the end of the week of February 5, 1973, the lucite tank developed a large crack which resulted in the cessation of all operations.

EXPERIMENTAL RESULTS

To facilitate comparison, the data have been divided into three modes of operation:

1. All data representing the operation of the filter with the random media arrangement and utilizing no recycle flow.
2. All data representing operation of the filter with the random media arrangement and using a recirculation flow within the filter.
3. All data representing operation of the filter with a layered filter media arrangement and using a recycle flow.

1. RANDOM MEDIA, NO RECIRCULATION

Referring to Figures 8-A and 9-A we can see graphically how the filter performed at the very beginning of our operation of the filter.

Figure 8-A illustrates the BOD₅ data obtained from operating the filter at the various retention times with a random media arrangement and with no recirculation. It is quite obvious from the graph that the best performance was obtained at a retention time of roughly 29-33 hours. However, it must also be stated that data from running the filter at 48 hours and 25 hours was not really representative because we had just begun operation and the necessary ingredient for good treatment was missing - a well developed floc. Not until the retention time was lowered to 30 hours was there a well developed floc. The result was excellent treatment.

The final point on the graph represented by a 32 hours retention time shows a slight increase in the final effluent BOD, up to 8.43 mg/l, but when we look at the ingoing BOD, we also have an increase of nearly 10 mg/l. In effect, the treatment had only deteriorated slightly.

The reason for this deterioration was that the floc build-up in the filter was becoming so heavy that it was utilizing all the dissolved oxygen in the water and creating anaerobic conditions; causing the floc to turn black. This resulted in incomplete treatment of the waste and is reflected in the increase in the final effluent BOD values. This

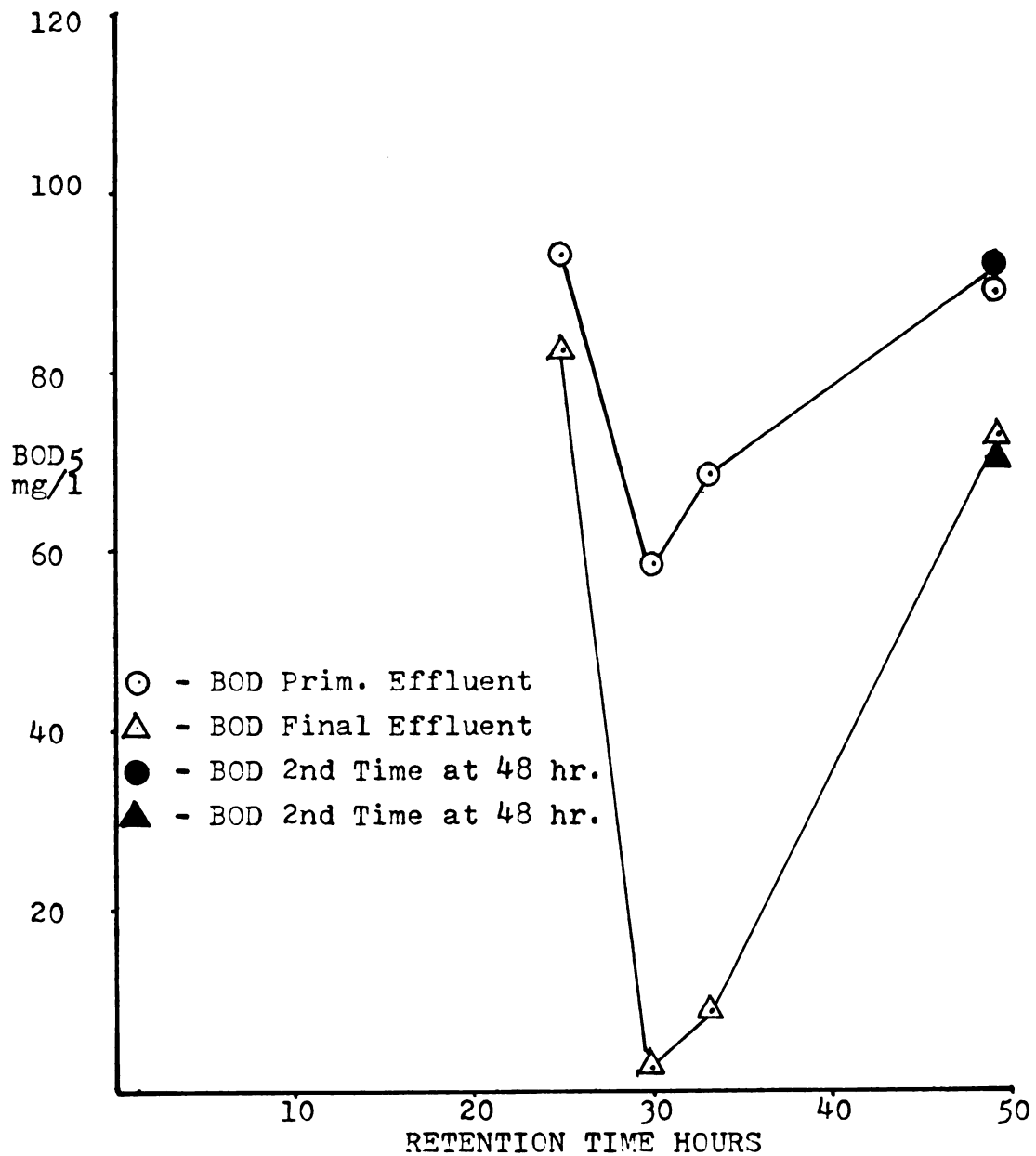


FIGURE 8-A; AVERAGE BOD VALUES OF INFLUENT AND EFFLUENT FOR RANDOM ARRANGEMENT OF FILTER MEDIA, NO RECIRCULATION

depletion of dissolved oxygen was also indicated by the low values of dissolved oxygen found in the final effluent.

Because the suspended solids removal is basically dependent on quiescent conditions within the filter, the removal of suspended solids does not necessarily have to be dependent on the good overall performance of the filter. It is possible to have good suspended solids removal when BOD removal is only fair to poor. Providing appropriate conditions exist, solids removal will be good.

As Figure 9-A shows, the suspended solids removal continued to get better throughout the operation of the filter; even though the other parameters did not. At 30 hours retention the final effluent was 2.22 mg/l (94.6% removal) and at 32 hours retention the final effluent was 1.92 mg/l (95.47% removal). With such small solids values, the removal becomes dependent on the floc's ability to adsorb these fine solids. Therefore, by the time 30 hours retention was employed in operating the filter, the floc was functioning as it should.

Throughout the period just described, the dissolved oxygen concentration of the final effluent was always at or close to the minimum concentration for aerobic conditions to exist (1.0 mg/l). Because of this condition it was highly probable that there were areas within the filter where anaerobic conditions were occurring. This means that those areas were creating a demand for oxygen and not capable of treating any of the waste material. In order to correct this problem a

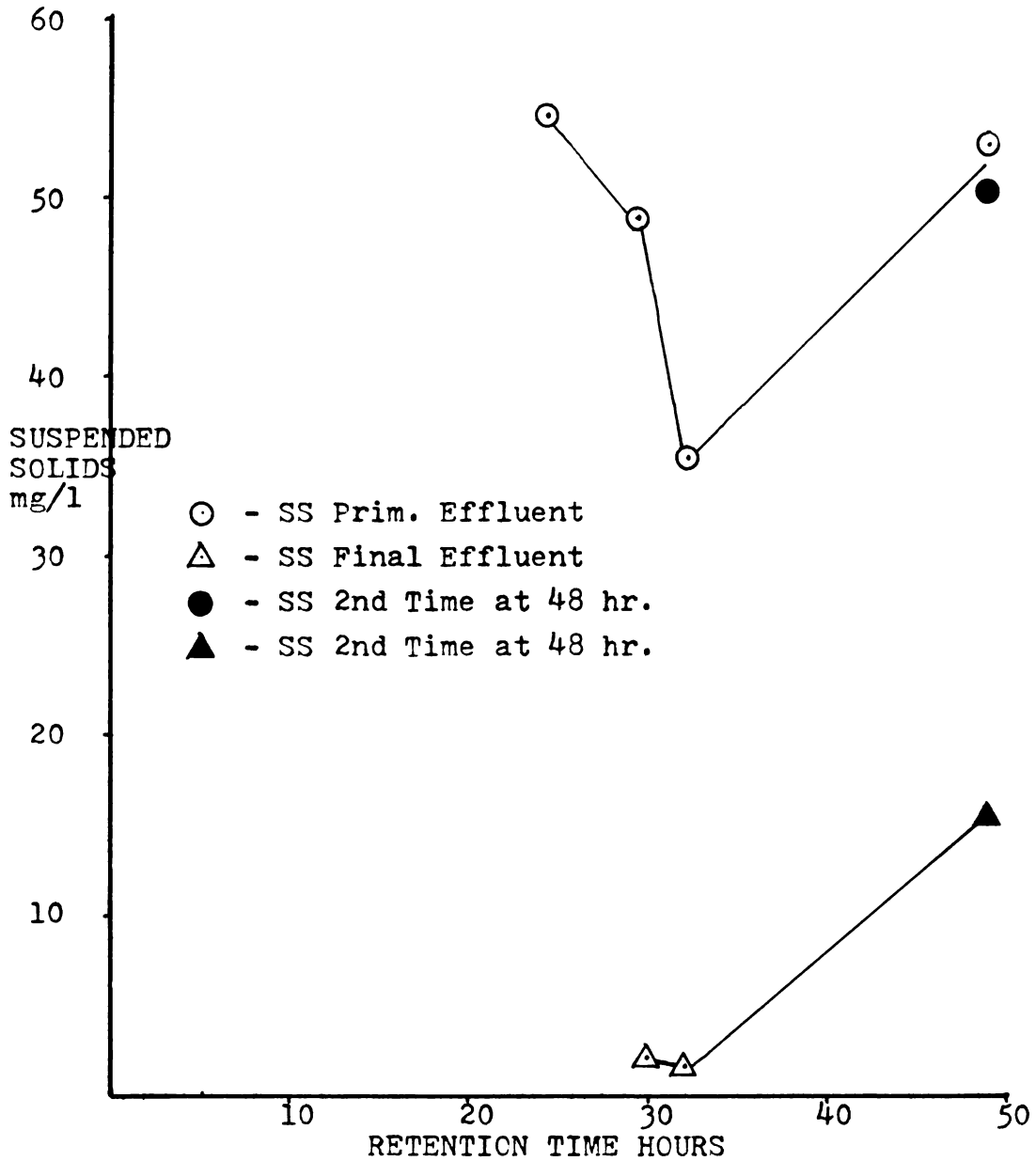


FIGURE 9-A; AVERAGE SUSPENDED SOLIDS VALUES OF INFLUENT AND EFFLUENT FOR RANDOM ARRANGEMENT OF FILTER MEDIA AND NO RECIRCULATION

recirculation pump was installed in the final compartment which was discharging into the first compartment. This produced an internal flow in the tank to supply fresh dissolved oxygen to all parts of the filter more rapidly.

2. RANDOM MEDIA WITH RECIRCULATION

Figures 10-A, 10-B, and 10-C represent the data obtained by operating the filter with a random filter arrangement and a recycle flow.

Looking at the graph of average BOD values (Figure 10-A), it is obvious that to obtain over 90% removal of BOD it is necessary to maintain a retention time of at least 22 hours. Although retention times of 16 and 17 hours still give good treatment in BOD removal, the turbidity and suspended solids measurements show a decrease in performance.

It must be mentioned here that the use of a recycle pump was a last effort to maintain operation of the filter. At this time, it was not known that the media arrangement of the filter was the real crux of the problem. It was not until the partitions between compartments started to clog with excess sludge that the problem was actually recognized.

All three graphs show a gradual increase in the final effluent parameters while the primary effluent values decreased. Since the dissolved oxygen concentration in the tank was being kept well above 1.0 mg/l, there was no chance that anaerobic conditions were causing this decrease in performance.

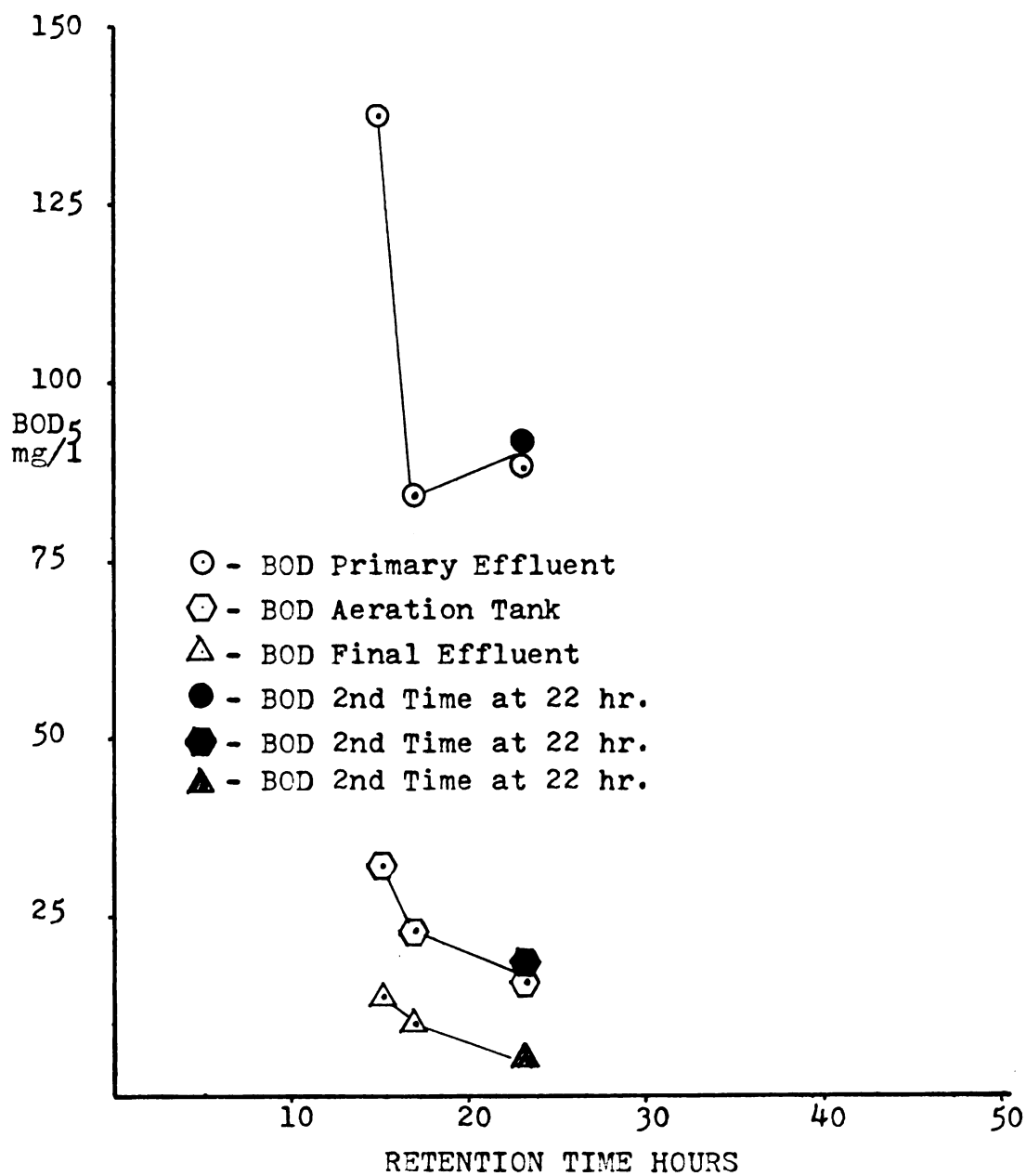


FIGURE 10-A; AVERAGE BOD VALUES FOR RANDOM ARRANGEMENT OF FILTER MEDIA WITH A RECYCLE FLOW

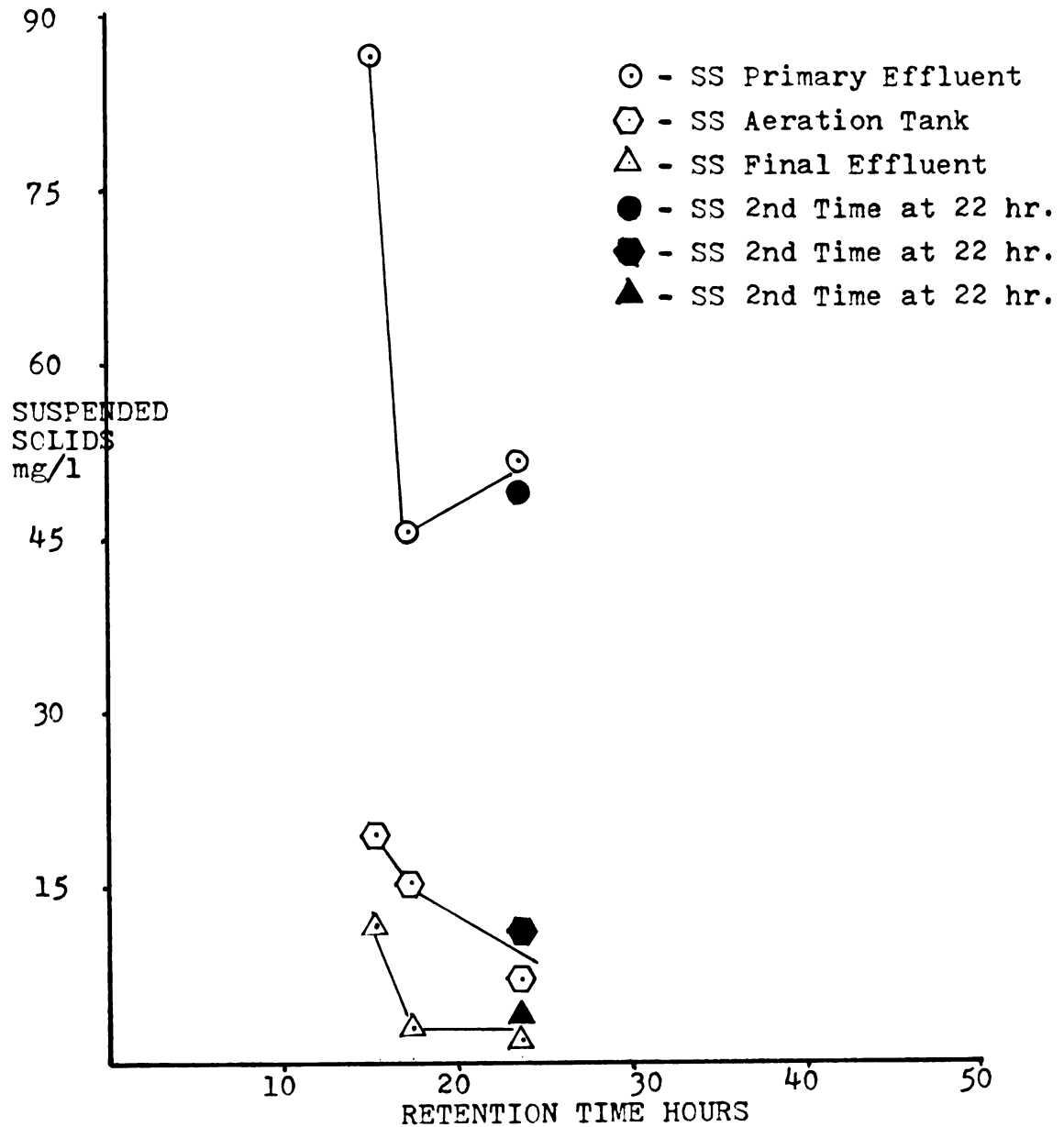


FIGURE 10-B; AVERAGE SUSPENDED SOLIDS VALUES FOR RANDOM ARRANGEMENT OF FILTER MEDIA WITH A RECYCLE FLOW

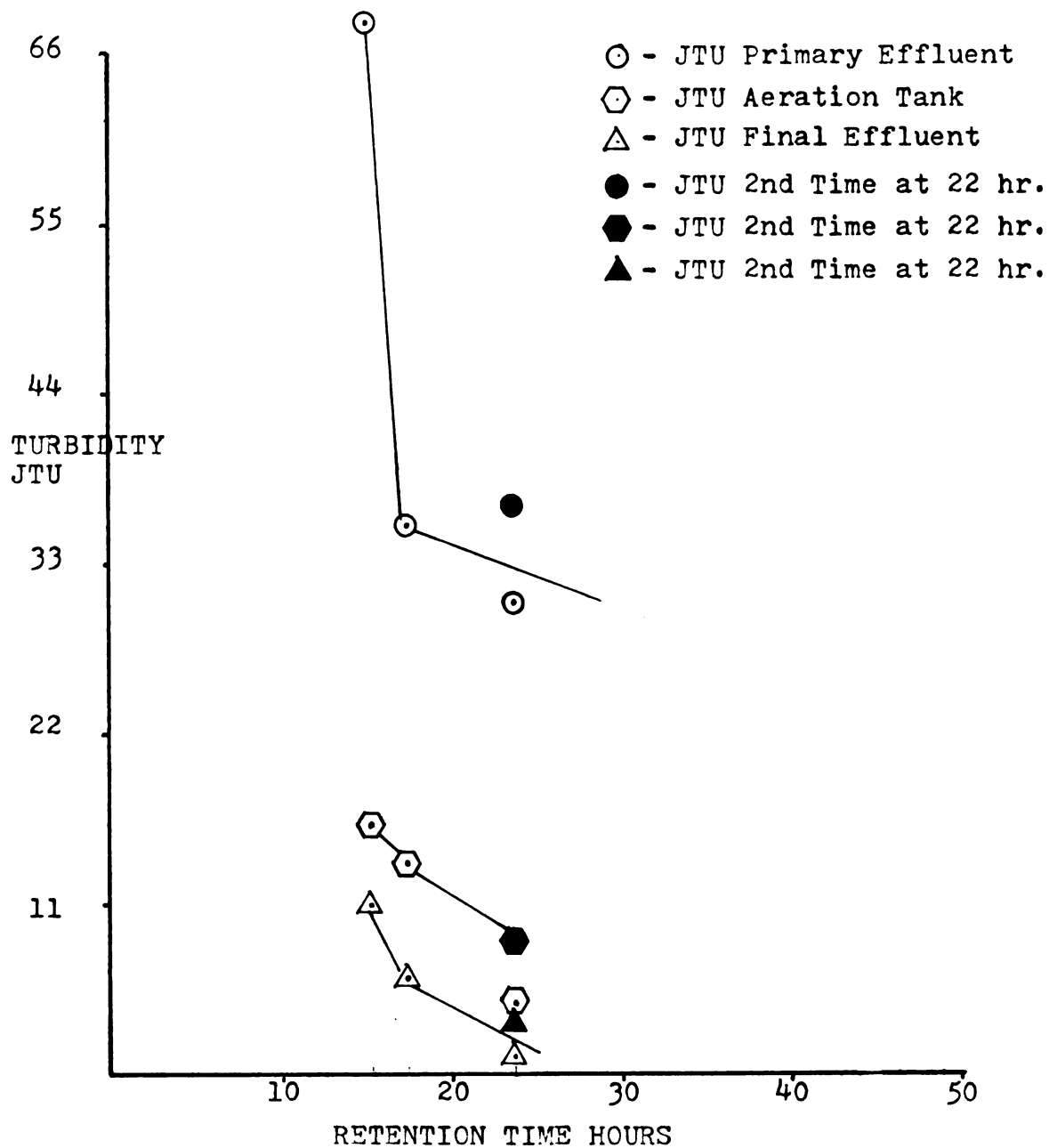


FIGURE 10-C; AVERAGE TURBIDITY VALUES FOR RANDOM ARRANGEMENT OF FILTER MEDIA WITH A RECYCLE FLOW

Rather the excess sludge build-up was closing off areas of the filter media and effectively reducing the active surface area. This would explain why the quality of treatment was deteriorating even though the organic loading to the unit decreased slightly. By the end of this operating period, the BOD removal decreased from 93% to 89%, the suspended solids removal decreased from 97% to 91%, the Turbidity removal decreased from 94% to 80%, and the Ammonia-Nitrogen removal decreased from 98% to 95%.

When it became necessary to clean the partitions daily due to the build-up of excess sludge blocking the holes in the partitions, the unit was shut down and cleaned out. The sludge had the appearance of a fine black floc, had the characteristic smell of hydrogen sulfide, and had very poor settling characteristics. The sludge volume index was only 330 ml/g. The total weight (approx.) of the accumulated sludge was surprisingly small, 3.2 lb. dry, for a total operating time of slightly less than nine months.

It was then decided to arrange the plastic media in layers so that the excess sludge would drop down into the sludge storage area and not have a chance to accumulate in the media compartment.

3. LAYERED MEDIA ARRANGEMENT WITH RECIRCULATION.

Data obtained by utilizing the layered media arrangement and the recycle flow yielded the best performance results. Referring to Figures 11-A, 11-B, and 12-A, it is obvious that the treatment obtained by using this arrangement was excellent.

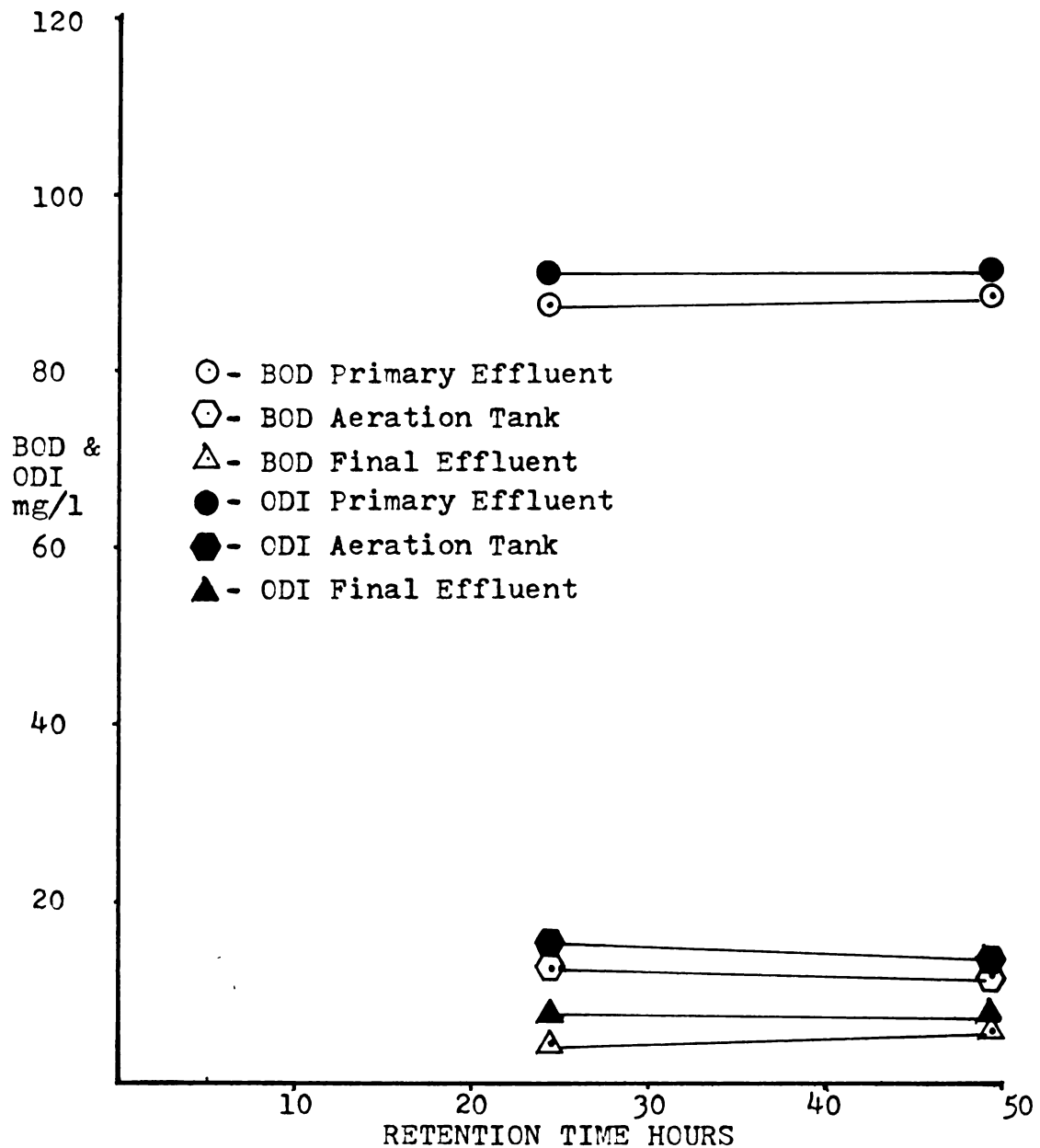


FIGURE 11-A; AVERAGE BOD AND ODI VALUES FOR VERTICAL ARRANGEMENT OF FILTER MEDIA WITH A RECYCLE FLOW

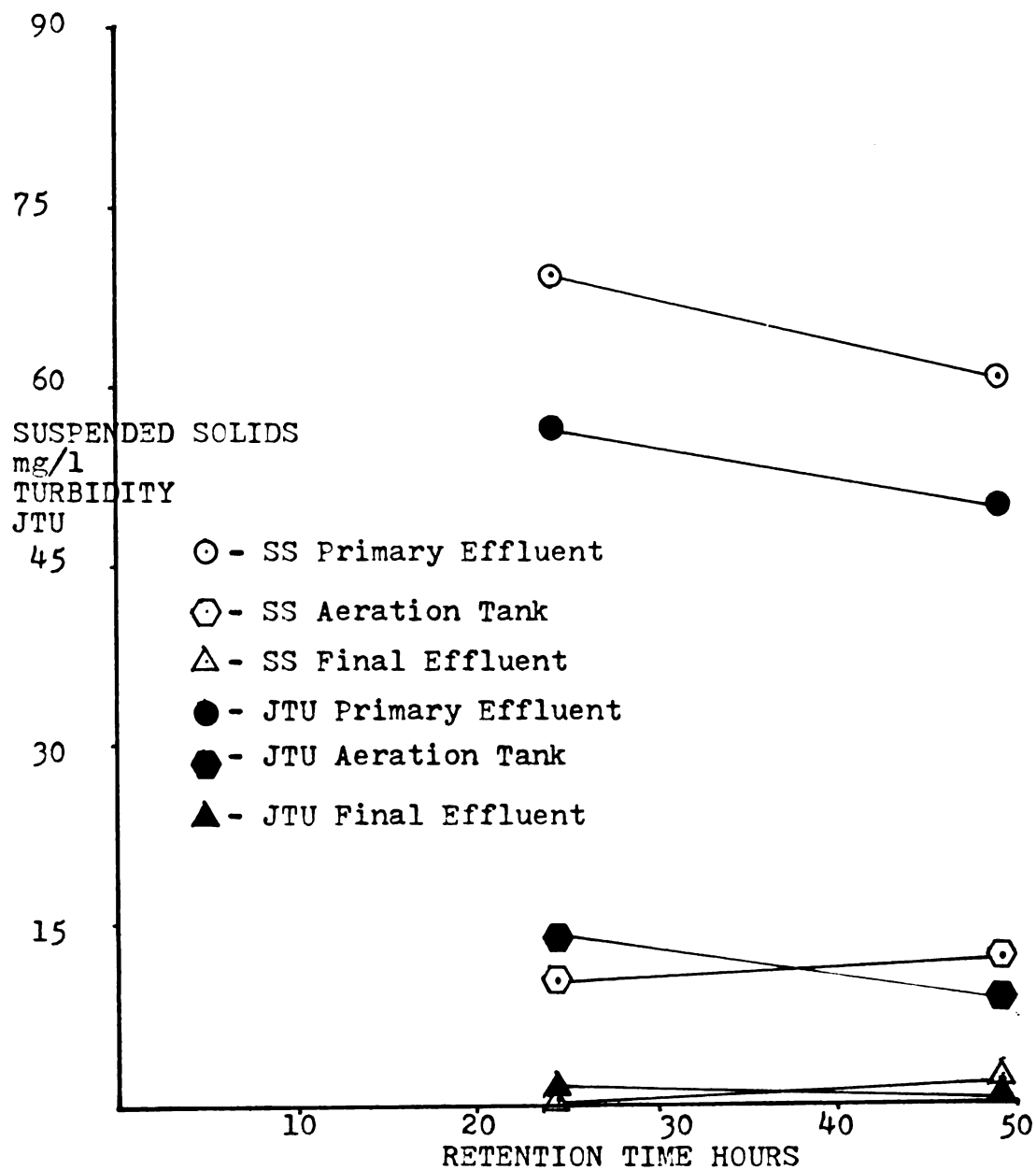


FIGURE 11-B; AVERAGE SUSPENDED SOLIDS AND TURBIDITY VALUES FOR VERTICAL ARRANGEMENT OF FILTER MEDIA WITH A RECYCLE FLOW

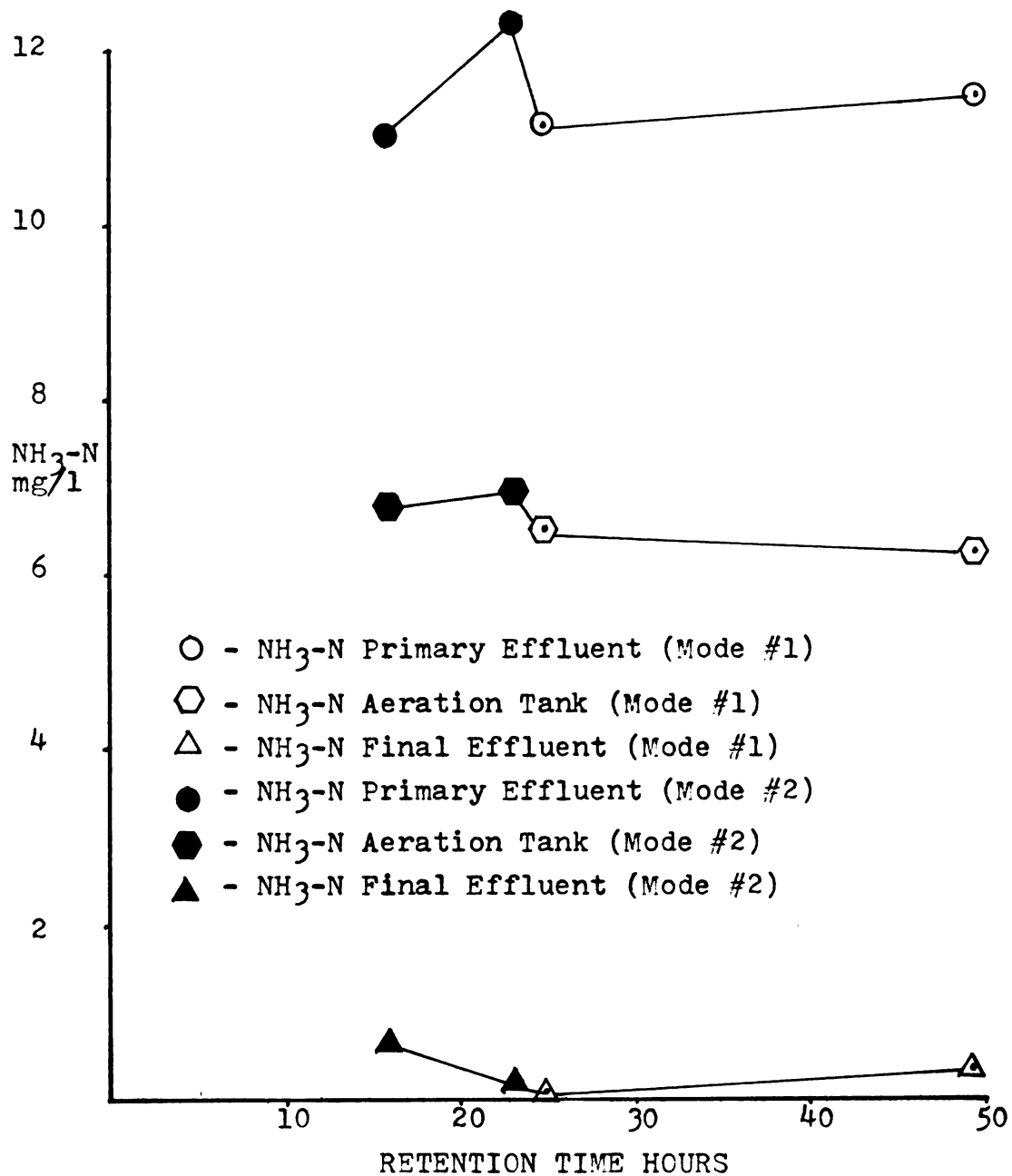


FIGURE 12-A; AVERAGE AMMONIA-NITROGEN VALUES FOR MODE 1 AND MODE 2 UNDER RECIRCULATION

In fact, the treatment at 24 hours retention was slightly better than at 48 hours. During operation of the filter at 24 hours retention, the final effluent averaged: 4.71 mg/l BOD (95% removal), 1.06 mg/l suspended solids (99% removal), 1.08 JTU (98% removal), and .19 mg/l $\text{NH}_3\text{-N}$ (98% removal).

The layered media arrangement used only 40 sq. ft. (approx.) of surface area compared to 150 sq. ft. (approx.) with the random arrangement. The data therefore, show that 40 ft.² of layered media can provide the same treatment that was obtained with 150 ft.² of randomly arranged media. In full scale application it would be advantageous to use less media per cubic foot of installation. But most important would be the fact that with the layered media arrangement it would not be necessary to interrupt the operation of the unit for removal of accumulated excess sludge. Another important factor is, of course, the use of the recycle pump. Supplying oxygen-laden water to all parts of the filter media is vitally important in oxidizing the waste and in evenly distributing the load throughout the filter.

One final area which must be discussed is the amount of aeration needed to maintain an effective treatment process. Table 17 shows large amounts of air were needed per lb. BOD to oxidize the waste effectively. Operation of the filter in Mode #1, which is the random arrangement of the media with no recycle flow, required the most amount of air per lb. BOD. This was expected because of two reasons:

TABLE 17 OVERALL AIR REQUIREMENTS

Mode #1									
Retention Time-hours									
Tot. Liters Air/Day-(ave.)									
1b/BOD/Ft ³ /Day (ave.)	18,514	23,200	35,400	36,000	41,538	32			
Liters Air/lb. BOD-(ave.)	.0025	.0053	.0026	.0028	.0029				
Cu. Ft. Air/lb. BOD-(ave.)	243,926	144,849	448,271	425,689	470,934				
(Overall Ave.)	8,610	5,115	15,831	15,033	16,631				
Cu. Ft. Air/lb. BOD			12,244						
% BOD Removal	16.00	11.00	20.00	91.79	87.88				

Mode #2									
Retention Time-hours									
Tot. Liters Air/Day-(ave.)									
1b. BOD/Ft ³ /Day (ave.)	21,600	21,600	21,600	34,141	17				
Liters Air/lb. BOD-(ave.)	.0055	.0118	.0057	.0072					
Cu. Ft. Air/lb. BOD-(ave.)	129,840	61,120	126,640	157,092					
(Overall Ave.)	4,585	2,158	4,472	5,547					
Cu. Ft. Air/lb. BOD		4,191							
% BOD Removal	92.60	89.71	92.83	88.59					

Mode #3									
Retention Time-hours									
Tot. Liters Air/Day-(ave.)									
1b. BOD/Ft ³ /Day	21,600	21,600							
Liters Air/lb. BOD-(ave.)	.0025	.0051							
Cu. Ft. Air/lb. BOD-(ave.)	286,503	142,507							
(Overall Ave.)	10,118	5,032							
Cu. Ft. Air/lb. BOD	7,575								
% BOD Removal	92.90	94.68							

1. It was necessary to supply dissolved oxygen in a concentration greater than 1.0 mg/l to 150 sq. ft. (approx.) of media surface area.

2. The retention time of the waste water in the media compartment was long so that the floc would deplete the dissolved oxygen in the water before it had a chance to pass through the media compartment. This is the reason that the final effluent was always low in dissolved oxygen. As the table shows, it was necessary to supply on the average about 15,500 cu. ft. of air per incoming lb. BOD₅ to obtain good treatment from the filter. This is extremely high and would not be feasible for a large-scale operation.

However, when the recirculation system was used, the air requirements dwindled to one-third that of before while the load on the filter lb. BOD/Ft³/Day more than doubled.

It is interesting to note that during the three days of operation at 16 hours retention the load on the filter was very high .3534 lb. BOD/Day. At the same time the air supply per lb. BOD was roughly one half of the average, 2158 cu. ft./lb. BOD versus an average of 4191 cu. ft./lb. BOD., because the air flow was not increased. However, the removal of BOD during those three days was not significantly lower. This would lend support to the idea that the air supply could be reduced while still maintaining a high level of treatment. This is only speculation, but it would be vital to investigate if the system were to be used full-scale.

When the plastic media was rearranged to facilitate better waste sludge removal, the air flow into the filter was not changed.

As shown in Table 11 the dissolved oxygen concentration in the final compartment continually ranged from 4.9 to 5.4 mg/l during these experiments. This indicates that the rate of air supply could have been reduced with no detriment to the degree of treatment.

TABLE 12 MODE OF OPERATION #1

Retention Time - hours	48	25	48	30	32
BCD (ave.) PE - mg/l	88.70	93.55	92.25	59.94	69.55
Standard Deviation	24.08	7.73	11.21	13.07	12.86
BOD (ave.) FE - mg/l	74.40	83.25	73.27	4.92	8.43
Standard Deviation	24.52	7.72	14.50	3.43	4.72
% Removal	16.00	11.00	20.00	91.79	87.88

TABLE 13 MODE OF OPERATION #1

Retention Time - hours	48	25	48	30	32
SS (ave.) PE - mg/l	53.14	54.88	50.64	35.83	49.11
Standard Deviation	13.43	8.31	13.81	19.36	15.48
SS (ave.) FE - mg/l	-	-	15.53	2.22	1.92
Standard Deviation	-	-	7.13	2.31	3.50
% Removal	-	-	69.00	94.60	95.47
Temp. (ave.) Aer. - C°	20.79	20.89	22.55	22.89	22.47
Standard Deviation	.65	1.20	.28	.63	.26
Turb. (ave.) FE - JTU	8.93	5.78	-	2.17	2.04
Standard Deviation	3.21	.36	-	.35	.56

TABLE 14 MODE OF OPERATION #2

Retention Time - hours	22	16	22	17
BOD (ave.) PE - mg/l	87.45	139.33	89.66	86.29
Standard Deviation	17.33	13.30	27.18	22.51
BOD (ave.) Aer. Comp. - mg/l	15.14	33.33	17.19	24.35
Standard Deviation	2.68	2.05	3.72	4.86
% Removal	82.33	76.07	80.82	71.77
BOD (ave.) FE - mg/l	6.44	14.33	6.43	9.84
Standard Deviation	1.73	2.05	2.26	2.94
% Removal	92.60	89.71	92.83	88.59
SS (ave.) PE - mg/l	49.82	87.33	48.66	46.06
Standard Deviation	22.57	24.51	15.83	18.74
SS (ave.) Aer. Comp. - mg/l	4.18	20.00	12.00	16.48
Standard Deviation	1.63	.85	1.79	3.79
% Removal	91.60	77.00	75.33	64.21
SS (ave.) FE - mg/l	1.68	12.33	3.14	4.19
Standard Deviation	1.11	1.25	2.77	1.38
% Removal	96.60	85.87	93.53	90.90
Turbidity (ave.) PE - JTU	31.36	68.66	36.81	35.77
Standard Deviation	14.53	12.85	15.21	18.16
Turbidity (ave.) Aer. Comp. - JTU	4.09	16.33	8.99	14.00
Standard Deviation	1.40	.94	1.55	3.11
% Removal	86.96	76.21	75.57	60.86

TABLE 14 (cont'd)

Retention Time - hours	22	16	22	17
Turbidity (ave.) FE - JTU	1.72	11.00	3.85	7.06
Standard Deviation	.86	.85	2.27	2.79
% Removal	94.49	83.97	89.52	80.28
NH ₃ - N (ave.) PE - mg/l	-	-	12.32	11.05
Standard Deviation	-	-	1.36	1.00
NH ₃ - N (ave.) Aer. Comp. - mg/l	-	-	6.87	6.65
Standard Deviation	-	-	1.27	6.65
% Removal	-	-	44.24	39.87
NH ₃ - N (ave.) FE - mg/l	-	-	.23	.60
Standard Deviation	-	-	.09	.13
% Removal	-	-	98.11	94.66
Temp. (ave.) Aer. Comp. - C°	23.09	21.33	20.09	18.48
Standard Deviation	.88	.94	1.41	.71

TABLE 15 MODE OF OPERATION #3

Retention Time - hours	48	24
BOD (ave.) PE - mg/l	88.07	88.53
Standard Deviation	11.77	12.98
BOD (ave.) Aer. Comp. - mg/l	12.82	13.82
Standard Deviation	4.13	2.64
% Removal	85.44	84.38
BOD (ave.) FE - mg/l	6.25	4.71
Standard Deviation	5.34	.96
% Removal	92.90	94.68
SS (ave.) PE - mg/l	61.29	71.18
Standard Deviation	12.37	13.42
% Removal		
SS (ave.) Aer. Comp. - mg/l	12.71	10.71
Standard Deviation	2.08	1.40
% Removal	79.25	84.95
SS (ave.) FE - mg/l	1.95	1.06
Standard Deviation	1.38	.12
% Removal	96.82	98.50
Temp. (ave.) Aer. Comp. - C°	17.75	17.29
Standard Deviation	1.13	1.03

TABLE 15 (cont'd)

Retention Time - hours	48	24
Turbidity (ave.) PE - JTU	50.78	58.12
Standard Deviation	12.25	12.86
Turb. (ave.) Aer. Comp. - JTU	9.82	14.12
Standard Deviation	1.69	2.77
% Removal	80.66	75.71
Turbidity (ave.) FE - JTU	1.91	1.08
Standard Deviation	1.05	.16
% Removal	96.25	98.14
NH ₃ - N (ave.) PE - mg/l	11.56	11.21
Standard Deviation	.51	.59
NH ₃ - N (ave.) Aer. Comp. - mg/l	6.29	6.34
Standard Deviation	.48	.52
% Removal	45.63	43.41
NH ₃ - N (ave.) FE - mg/l	.33	.19
Standard Deviation	.24	.08
% Removal	97.13	98.32
ODI (ave.) PE - mg/l	92.54	92.29
Standard Deviation	12.12	13.51
ODI (ave.) Aer. Comp. - mg/l	15.50	16.71
Standard Deviation	2.08	3.12
% Removal	83.25	81.89

TABLE 16 OVERALL PERFORMANCE

Mode of Operation - #	1	2	3
BOD (Overall Ave.) PE - mg/l	64.75	88.55	88.30
BOD (Overall Ave.) Aer. Comp. - mg/l	-	16.32	13.32
% Removal	-	81.57	84.92
BOD (Overall Ave.) FE - mg/l	6.68	6.43	5.48
% Removal	89.68	92.73	93.79
SS (Overall Ave.) PE - mg/l	42.47	49.24	66.24
SS (Overall Ave.) Aer. Comp. - mg/l	-	6.54	11.71
% Removal	-	86.72	82.32
SS (Overall Ave.) FE - mg/l	2.07	2.41	1.51
% Removal	95.13	95.11	97.72
Turb. (Overall Ave.) PE - JTU	-	34.09	54.45
Turb. (Overall Ave.) Aer. Comp. - JTU	-	6.54	11.97
% Removal	-	80.81	78.02
Turb. (Overall Ave.) FE - JTU	2.10	2.79	1.50
% Removal	-	91.81	97.25

CONCLUSIONS

After nearly nine months of operating the submerged filter it has been proven that the system works remarkably well. What remains now is to determine the various specifics involved in the filters' operation; such as air requirements for complete treatment, optimum retention times, and possibly different types of filter media and their effect on treatment. Unfortunately these very important areas were only slightly touched upon. However, the basic objective, namely to show that the submerged filter does give excellent treatment to a wastewater, was accomplished.

Looking at the system as a whole, it appears that it deserves more recognition as a treatment process and could be effectively used as a polishing unit for a secondary effluent from a treatment plant. The units' ability to effectively reduce suspended solids, BOD and ammonia-nitrogen make it a good candidate for tertiary treatment applications when federal and state regulations demand a high quality treated effluent from our wastewater treatment plants.

Another important factor which should not be overlooked is the fact that the filters' maintenance and operation costs would probably be low compared to a conventional system. The main cost factor involved would be for aeration and for recirculation. The simplicity of the system makes it suitable for even small communities which otherwise could not afford tertiary treatment facilities.

It is hoped that this study provides a basis for further research into the inner mechanisms of the submerged biological filter.

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