PHOSPHATE REMOVAL BY ACTIVATED SLUDGE

Amenability Studies at Pontiac, Michigan

by

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ABSTRACT

Phosphate removal by activated sludge was investigated at pilot and plant levels in the East Boulevard Sewage Treatment Plant, Pontiac, Michigan. These studies revealed erratic and low level soluble phosphorus removal, although plant design was similar to that found advantageous at the Rilling Plant in San Antonio, Texas[1/] and the Back River activated sludge plant in Baltimore, Maryland.[2/] Pilot-scale investigations of the amenability of waste and activated sludge to orthophosphate removal demonstrated that increasing the dissolved oxygen and suspended solids concentrations in the mixed liquor above existing plant conditions resulted in high levels of phosphate uptake. In contrast, test variations of orthophosphate, biochemical oxygen demand, and hardness loading on a pilot scale had less significant effects.

Considering amenability, design, and operation, the East Boulevard Plant has potential for soluble phosphate removal. With minor design and operational changes, it is suitable for full-scale demonstration of orthophosphate removal.

INTRODUCTION

The research summarized in this report was conducted at the East Boulevard Sewage Treatment Plant, Pontiac, Michigan and represents a continuation of a program investigating the removal of soluble phosphorus from sewage by conventional activated sludge treatment. Field research conducted at San Antonio, Texas[1/] demonstrated high removals of orthophosphate in the aeration tanks from the liquid phase to the mixed liquor suspended solids. The removal efficiency at San Antonio was controlled by the following design and operational parameters: dissolved oxygen and suspended solids concentrations in the mixed liquor, displacement times in the aeration tanks and final clarifiers, rapid solids-liquid separation with minimum sludge blanket depth, biochemical oxygen demand (BOD) and phosphate load, and no return of waste activated sludge to the process.

The purposes of the phosphorus removal studies conducted at Pontiac, Michigan were:

1. To determine if this facility contained waste and sludge amenable to biological removal of phosphorus, both on a plant and pilot scale.

2. To verify the controlling parameters of phosphorus removal identified at San Antonio by collecting data from an area of different geographic, population, and sewage characteristics.

3. To identify any additional parameters controlling phosphate removal.

4. To determine the expediency of this facility for plant-scale demonstration, wherein phosphorus removal will be monitored over a sustained period under desired operational conditions.

Aerated jugs of mixed liquor simulate the aeration tank process. This method was selected for testing the amenability of waste and activated sludge to phosphorus removal. Aerated jug tests circumvent many operational problems in activated sludge plants, in that aeration capacity, detention time, suspended solids concentration, and phosphorus and BOD load may be controlled easily. Sludge solids and sewage samples from various points in the secondary system may be studied conveniently. Detention time of the mixed liquor in the various unit processes may be controlled.

By deliberately varying operational parameters, the conditions for sludge response and maximum removal can be established. Test results may indicate necessary operational or design changes, or the period of acclimation required to achieve a process capable of high phosphate removal. Optimal operation can only be defined when plant limitations are considered in conjunction with aerated jug findings.

Plant Investigation

The plant was studied to determine pertinent design and operational characteristics. Plant sampling and tracer work together with jug studies defined plant performance.

Plant records were examined for type and frequency of sewage flow, BOD loading, suspended solids and orthophosphate ($O\text{-}PO_4$) concentrations, additional chemical and physical data, and performance characteristics. Plant personnel were questioned about sampling practices, analytical procedures, waste anomalies, and peculiarities of operational control. The wasting schedules of raw sewage and activated sludge were determined. Disposal methods for waste activated sludge, primary sludge, digester contents, and other waste streams were studied in anticipation of auxiliary, inhibitory, or latent effects on the phosphate removal process.

Tracer studies were conducted using Rhodamine WT dye on aeration tanks and final clarifiers to determine hydraulic characteristics such as displacement, short circuiting, and degree of longitudinal mixing.

Grab samples were collected throughout the plant to determine the phosphate concentrations and removal. These samples were analyzed for concentrations of orthophosphate and, occasionally, total phosphate ($T\text{-}PO_4$) and suspended solids. Chemically-fixed samples were transported to the Robert S. Kerr Water Research Center for total phosphate determination. The sample sources were raw sewage, primary effluent (PE), return sludge (RS), aeration tank influent, aeration tank (one-half point), aeration tank effluent, and final effluent. Dissolved oxygen (DO) measurements were made throughout the plant in conjunction with the sampling program.

Aeration Jug Studies

An aeration jug study usually consisted of six jugs. The quality of mixed liquor in each jug was unique.

Total suspended solids (TSS) concentrations were obtained for plant return sludge and mixed liquor as initial information for jug synthesis.

Return sludge, as such, or concentrated by flotation,* was mixed with primary and/or final effluent to obtain the desired range of suspended solids concentration. The mixture was placed in a 5-gallon polyethylene jug for subsequent aeration. Mixed liquor suspended solids (MLSS) concentrations were then measured.

A portable air compressor supplied air, which was delivered via plastic tubing to the jugs through a manifold containing individual needle valves and rotometers. Plastic tee fittings served as diffusers. Air flow throughout the experiment was regulated and maintained at 15 liters per minute per 15 liters of jug content.

The dissolved oxygen content and the temperature of the mixed liquor were monitored several times during each run.

Samples were withdrawn from the jugs usually at half-hour or hourly intervals. To purge the withdrawal tube, approximately 100 ml of mixed liquor was siphoned off and returned to the jug of origin. Thereafter, 100 ml was taken for orthophosphate analysis and 250 ml when more tests were planned. Samples were processed immediately to prevent orthophosphate release.

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*A pilot flotation device was designed specifically for amenability studies to provide a sufficient volume of concentrated return sludge to synthesize six jugs of mixed liquor of varying suspended solids concentrations. That volume of pure water representing 300 percent of the quantity of sludge to be concentrated was pressurized to 40 psi in a separate tank. Plant return sludge was placed in a 50-gallon drum serving as a flotation cell. The supersaturated water was rapidly released to atmospheric pressure beneath the sludge at the bottom of the flotation cell. Air bubbles were created by the pressure differential in such a turbulent fashion that the sludge and water were rapidly and completely mixed. In the cell, these bubbles rose to the surface carrying suspended matter with them in the form of a suspended float. Withdrawal of the subnatant liquid left behind a concentrated return sludge. The process effectively concentrated return sludge from 0.25 to 0.5 percent to 1 to 3 percent solids. Thickened sludge was stored under aeration until use in jug synthesis.

RESULTS AND DISCUSSIONS

Plant Characteristics*

The East Boulevard Sewage Treatment Plant in Pontiac, Michigan consists of one primary clarifier and two parallel activated sludge systems. The activated sludge systems contain two aeration tanks and two final clarifiers each and are operated independently with no intermixing of return sludge. A plant schematic is found in Figure 1.

Digested primary sludge and raw sewage in excess of 9.4 million gallons per day (mgd) is pumped to the Auburn Sewage Treatment Plant. In addition, waste activated sludge may be pumped to the Auburn Plant.

An average of 5.8 mgd of raw waste is treated at the East Boulevard Plant. Treatment consists of preliminary screening and degritting followed by primary clarification in one 0.5 million gallon circular tank. Primary effluent averages 58 mg/l BOD and 40 mg/l TSS. Waste activated sludge is recycled to the head of the primary clarifier. The average loading to the activated sludge process is 6 lbs. BOD/ 100 lbs. MLSS/day.

Venturi meters measure and valves control primary effluent, return sludge, and air to the aeration tanks. Each end-around tank has a volume of 590,000 gallons and a total length to width ratio of 18:1. Tapered aeration is used. Three tanks employ Pacific Flush Tank diffusers while the fourth uses Walker Process "Sparjar" diffusers. Standby blower capacity is available. Each aeration tank receives air at the rate of 2.1 million ft^3/day or 1.4 ft^3 of air per gallon of sewage.

There are two return sludge pumps in each half of the activated sludge process having respective ratings of 1,000 gallons per minute (gpm) and 600 gpm. The 600 gpm pumps are held in reserve. The 1,000 gpm pumps operate continuously, returning sludge at the rate of 1.4 mgd and maintaining MLSS levels near 2,000 mg/l. For each 200 mg/l increment in excess of 2,000 mg/l TSS, activated sludge is wasted for one hour at the rate of 200 gpm.

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*Conditions described in this section are those experienced during the two-week study and do not necessarily reflect yearly averages.

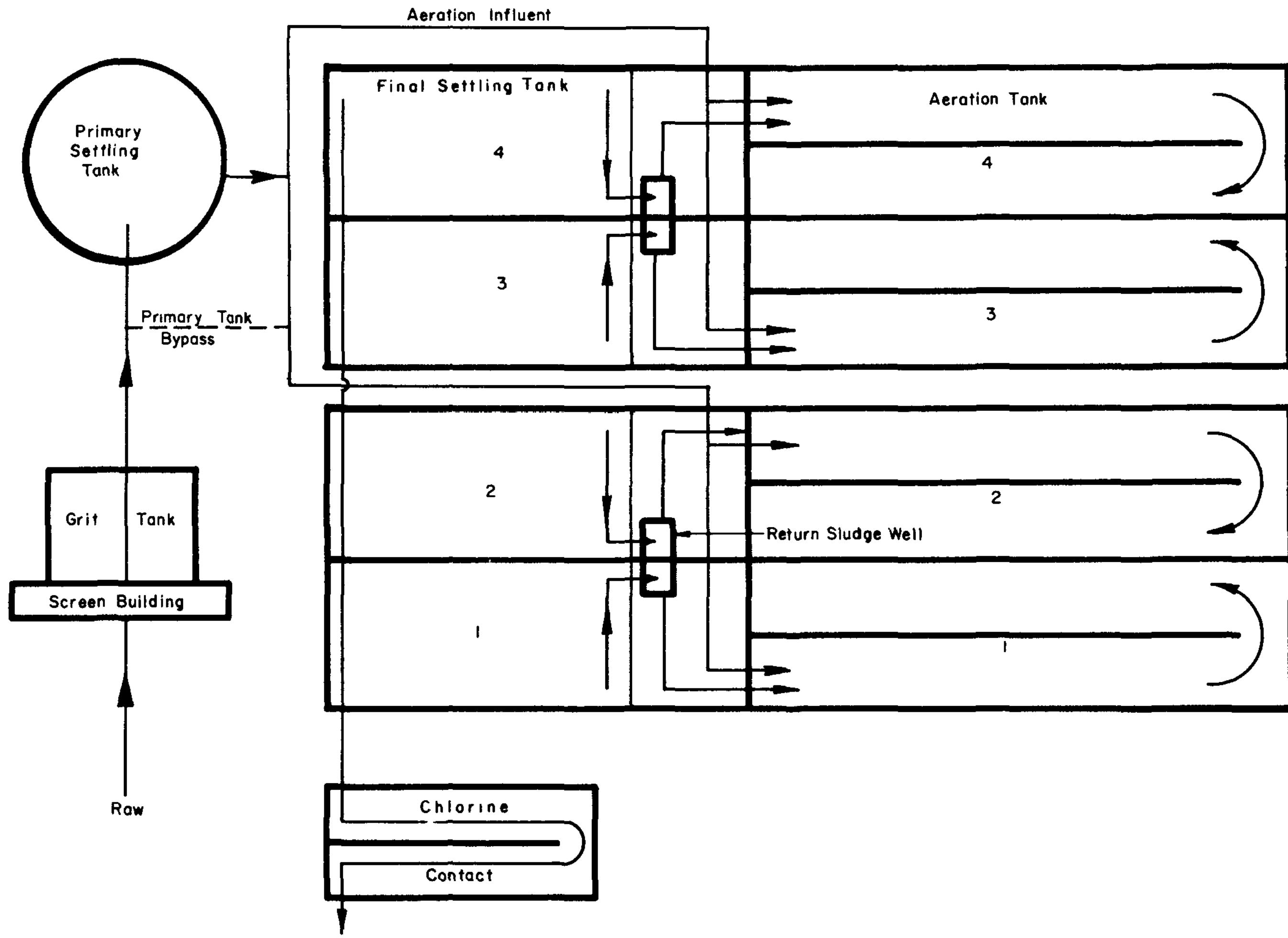

FIGURE I - EAST BOULEVARD SEWAGE WORKS, PONTIAC, MICHIGAN

Metal plating processes are the major sources of toxic metals found in the plant influent. Concentrations of free cyanide and hexavalent chromium are determined every hour. Concentrations rarely reach 0.5 mg/l and are normally $\leq$0.2 mg/l.

Dye Tracer Studies

Tracer studies were conducted on aeration tanks and final clarifiers on July 21 and July 29, 1967, respectively. Rhodamine WT dye* served as a tracer for determining hydraulic characteristics including displacement time, degree of mixing, and short circuiting.

1. Aeration Tanks

The theoretical displacement time for each tank was 6 hours. One and five tenths (1.5) liters of 20 percent Rhodamine WT was introduced at the influent end (beyond the point of entry of primary effluent and return sludge) of each aeration tank at 7:30 a.m. on July 21, 1967. Dye concentrations were monitored at the half-way and effluent points. Mixed liquor flow during the 8-hour period averaged 8.4 mgd.

Figure 2 represents dye dispersion curves of the four tanks obtained from effluent dye concentrations. These curves were not corrected for dye recycled by return sludge because this effect was insignificant within six hours after dye injection. Eighty-six percent of the dye introduced was recovered during eight hours of monitoring. A percent flow-through curve averaged from the areas under the four dye curves is shown in Figure 2.

The mode, median, t_{10}, and t_{90} (10 and 90 percent flow-through times) are 3.8, 4.0, 2.5, and 5.9 hours, respectively. The dispersion index (t_{90}/t_{10}) is 2.5, and the modal detention time is equal to 63 percent of the theoretical displacement time. The Pontiac aeration tanks have somewhat greater longitudinal mixing and less plug flow than the aeration tanks of the Rilling Plant[1] in San Antonio, Texas.

Based on Figure 2, 10 percent of the mixed liquor receives less than 2.5 hours aeration and 30 percent less than 3.5 hours. Such flow-through characteristics appear to be satisfactory for high phosphate (>80 percent) removal. Reducing hydraulic loading and adjustment of other operating parameters could increase phosphate removal.

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*LBS Rhodamine WT Solution (20%), E. I. DuPont de Nemours Company, Organic Chemicals Department, Dye and Chemical Division, de Nemours Building, Wilmington, Delaware 19898.

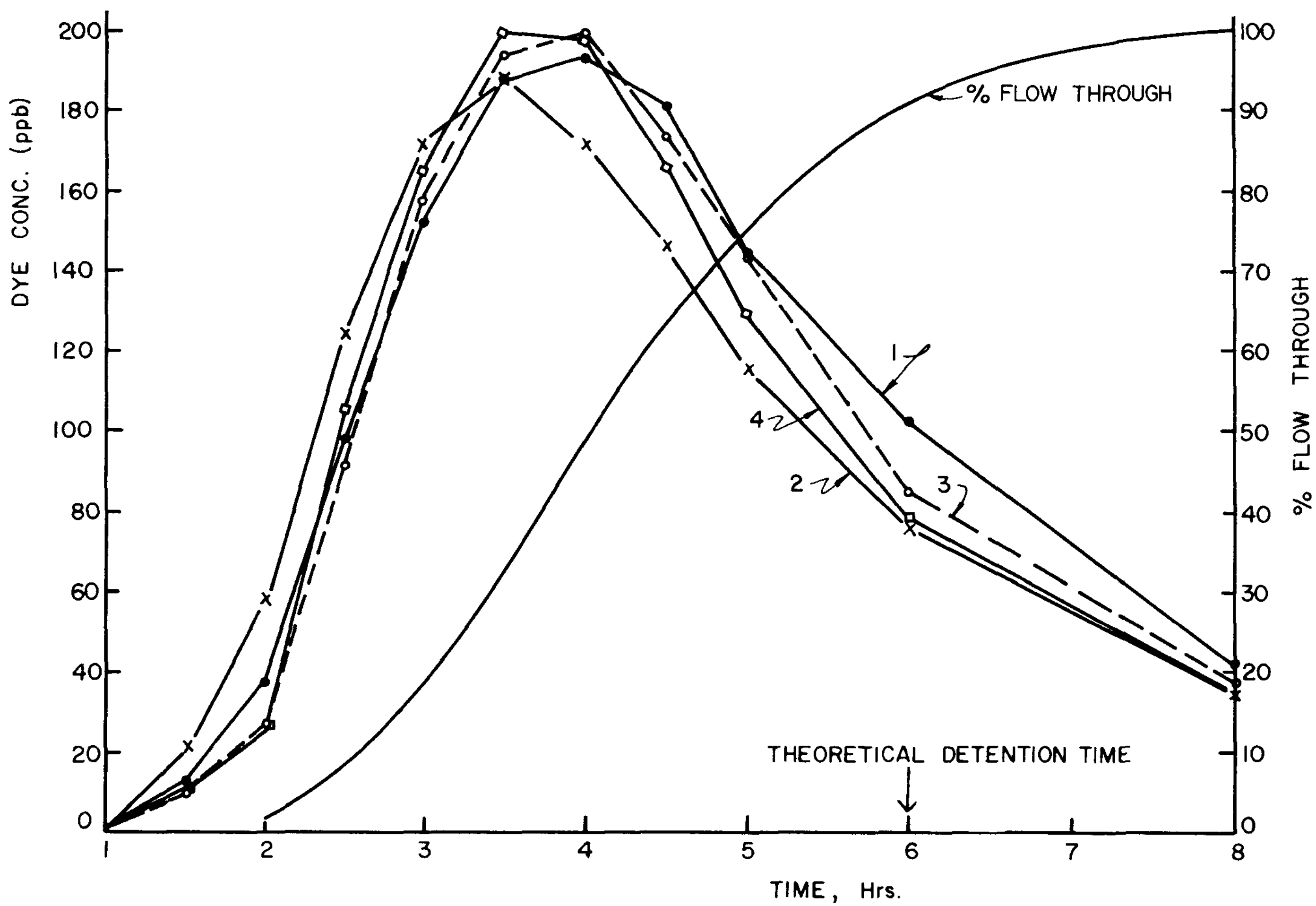


FIGURE 2 - DYE DETENTION IN AERATION TANKS

The following data are presented for comparison with two plants experiencing >80 percent phosphate removal, namely, the Baltimore, Maryland Back River activated sludge plant[2] and the San Antonio, Texas Rilling Sewage Treatment Plant.[1]

Aeration Tank	Pontiac	Baltimore	San Antonio
Length:Width	18:1	25:1	20:1
Volume (mg)	0.6	2.6	1.9
Type	2-pass	2-pass	2-pass
Theoretical Displacement (hrs)	6.3	4.6	8.6
Modal/Theoretical	0.6	1.0	0.9
Dispersion Index	2.5	2.4	3.5

2. Final Clarifiers

At 10:00 a.m. on July 29, 1967, 725 ml of 20 percent Rhodamine WT dye was injected at each influent of Final Clarifiers No. 1 and 3. Dye concentration was monitored in return sludge samples from both wet wells, the effluents from Final Clarifiers No. 1 and 3, and the combined final effluent at the head of the chlorine contact tank.

Based on primary flow and combined clarifiers (No. 1-4) volume, the theoretical detention time for final clarification was 2.8 hours. Figure 3 presents dye displacement curves for the two clarifiers studied. Superimposed on this graph is the percent flow-through curve averaged from dye curves of Clarifiers No. 1 and 3. Figure 4 presents dye detention curves for return sludge.

Figure 3 reveals that about 40 percent flow-through takes place in the first hour, and approximately 90 percent occurs at the time of theoretical displacement. The modal time is 27 percent of the theoretical detention time. Significant short circuiting of mixed liquor is evident in Figure 4.

Plant Performance

Erratic removal of soluble phosphorus occurred during the two-week study of the East Boulevard activated sludge process. Eight samples which allowed for displacement time indicated that Aeration Tanks No. 1 and 3 removed 10 percent from influent to effluent. Performance ranged from 40 percent removal to 30 percent release. Four samples taken with plug-flow consideration showed 3 percent

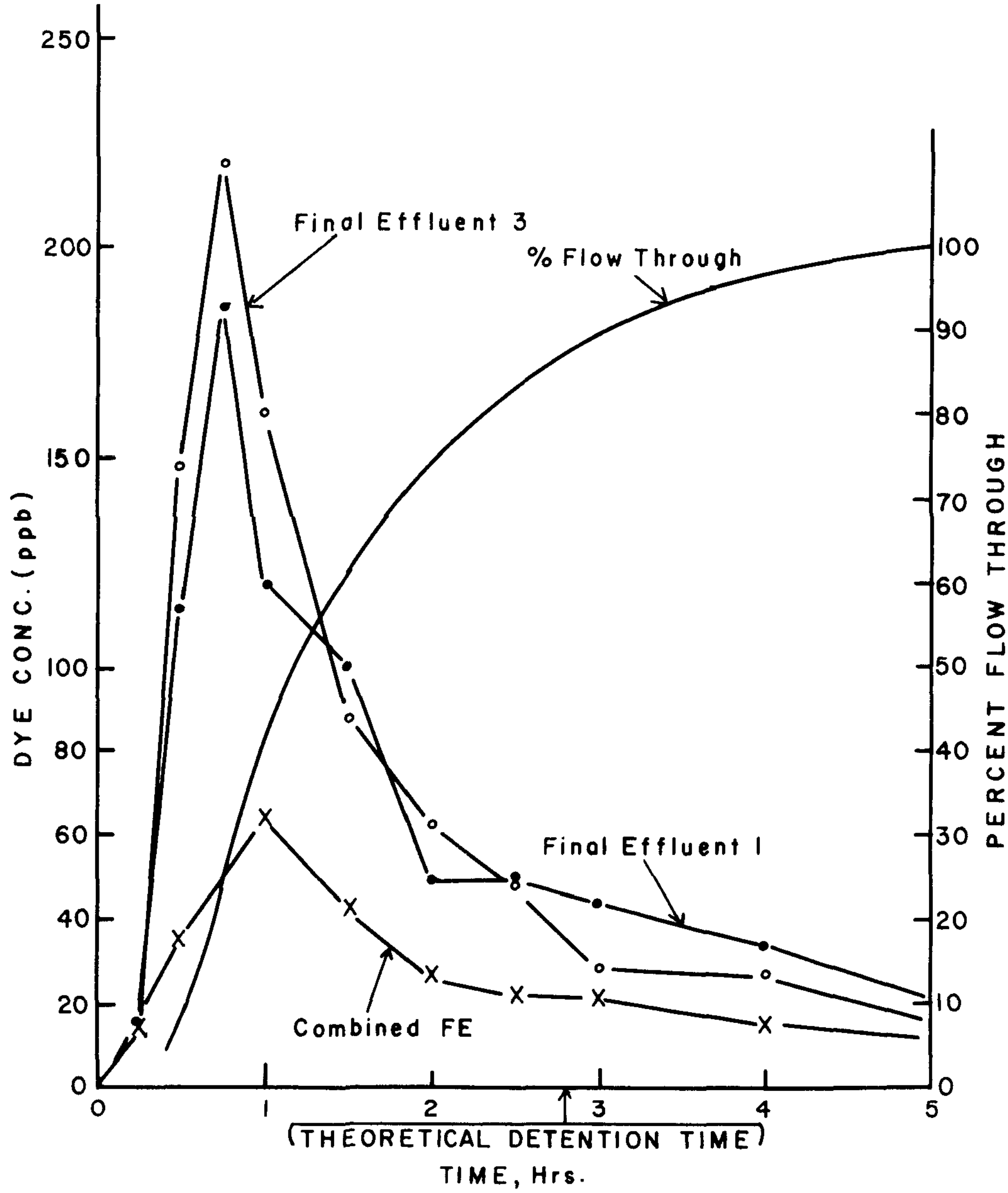


FIGURE 3 - DYE DETENTION IN FINAL CLARIFIERS

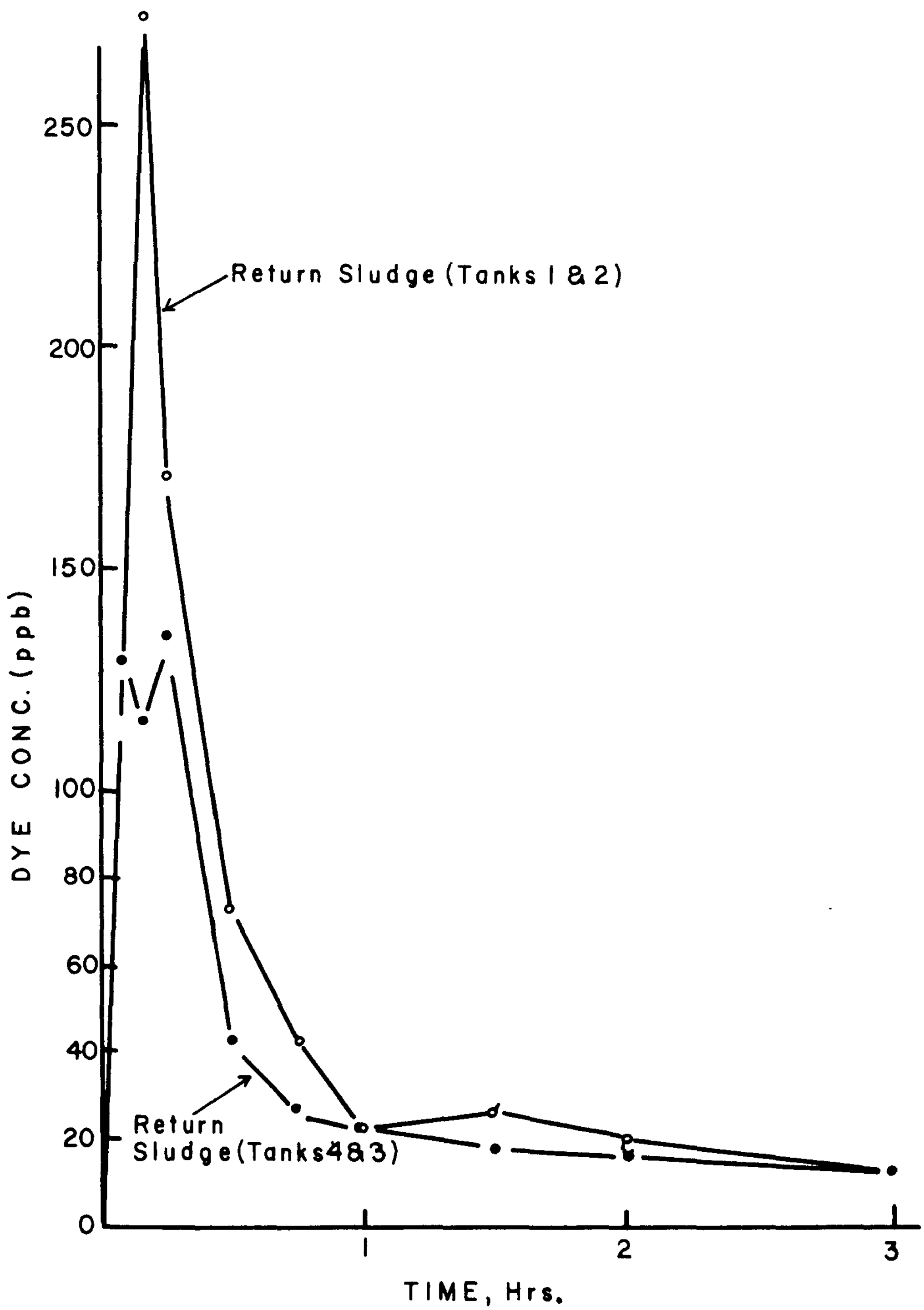


FIGURE 4 - DYE DETENTION IN RETURN SLUDGE

release of soluble phosphorus in Final Clarifiers No. 1 and 3. Clarifier performance ranged from no removal to 10 percent release. Plant orthophosphate results for the two-week study are shown in Table 1.

The plant analytical data obtained during this period are presented in Table 2. Several parameters have been abbreviated including total suspended solids (TSS), nonvolatile organic carbon (NVOC), soluble nonvolatile organic carbon (SNVOC), and total oxygen demand (TOD).

The average theoretical orthophosphate concentration in aeration tank mixed liquor at the influent end was 4.1 mg/l P. This value was based on soluble phosphorus content and relative volumes of primary effluent and return sludge. Mixed liquor influent averaged 4.8 mg/l P for two weeks of monitoring. Release of soluble phosphorus when primary effluent and return sludge mix was considered insignificant.

The four aeration tanks averaged 0.5 mg/l dissolved oxygen at the influent end and 0.8 mg/l at the effluent. Unchlorinated final effluent, primary effluent, and return sludge averaged 0.3 mg/l.

Two previously investigated activated sludge plants showed higher concentrations of dissolved oxygen in the mixed liquor effluent using an air supply similar in quantity to that at Pontiac and having higher primary effluent BOD concentrations:

Plant	Air Supply (ft^3/gal waste)	Avg. BOD of PE (mg/l)	DO Range in ML Effluent (mg/l)
East Boulevard, Pontiac, Michigan	1.4	58	0.1-3.8
Rilling, San Antonio, Texas[1/]	1.6	180	2.0-5.0
Back River Activated Sludge Plant, Baltimore, Maryland[2/]	1.1	200	2.5-7.0

These data indicate that the Pontiac plant experiences air transfer in the aeration tanks inadequate for high phosphate removal.

Phosphate (mg/l P) measured as follows in the raw sewage, primary effluent, and final effluent:

Table 1

PONTIAC EAST BOULEVARD PLANT
Plant Monitoring Summary
July 21-29, 1967
Orthophosphate (mg/l P)

Date - Time	Raw	PE	AT#1 in	AT#1 out	AT#2 in	AT#2 out	AT#3 in	AT#3 out	AT#4 in	AT#4 out	FE #1	FE #2	FE #3	FE #4	AT in comp	AT out comp	FE comp	RS 1&2	RS 3&4	RS comp
7/21 -11:45 am	2.8	2.8	4.3	3.4	4.3	3.6	3.8	3.6	4.0	4.0	-	-	-	-	-	-	4.2	5.5	5.0	-
7/22 -12:00 N	-	3.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.6	4.2	-	-
7/24 - 9:45 am	-	4.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11:00 am	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.0	-	-
11:30 am	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.1	-	-	-
2:30 pm	4.8	4.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3:00 pm	-	-	8.1	3.8	8.3	5.1	6.9	4.5	7.2	5.8	-	-	-	-	-	-	4.0	-	-	6.7
7/25 -10:00 am	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.0	-	-
10:30 am	-	2.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11:30 am	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.8	-	-	-
7/26 - 6:00 am	1.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7:00 am	2.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8:30 am	-	2.9	3.6	-	-	-	3.9	-	-	-	-	-	-	-	3.7	-	-	6.5	5.4	-
9:30 am	-	3.2	3.6	-	-	-	4.2	-	-	-	-	-	-	-	3.8	-	-	5.0	5.8	-
12:30 pm	-	-	-	2.2	-	-	-	3.6	-	-	-	-	-	-	-	2.8	-	-	-	-
1:30 pm	-	-	-	2.2	-	-	-	3.4	5.1	3.4	-	-	-	-	-	2.9	-	-	-	-
7/26 - 2:00 pm	-	-	-	-	-	-	-	-	-	-	2.4	-	3.8	-	-	-	2.8	-	-	-
3:00 pm	-	-	-	-	-	-	-	-	-	-	2.6	-	4.0	-	-	-	3.4	-	-	-
7/27 8:15 am	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.9	-	-
9:00 am	-	3.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5:00 pm	-	-	7.6	4.8	7.6	5.6	6.0	5.4	6.0	5.4	-	-	-	-	-	-	-	-	-	-
7/28 -12:00 N	2.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1:00 pm	2.7	2.6	3.9	-	-	-	3.8	-	-	-	-	-	-	-	4.0	-	-	-	-	5.5
2:00 pm	-	2.8	4.9	-	-	-	4.2	-	-	-	-	-	-	-	4.3	-	-	-	-	4.8
5:00 pm	-	-	-	4.1	-	-	-	5.0	-	-	-	-	-	-	-	4 9	-	-	-	-
6:00 pm	-	-	-	3.8	-	-	-	4.6	-	-	-	-	-	-	-	4.6	-	-	-	-
6:30 pm	-	-	-	-	-	-	-	-	-	-	4.1	-	5.1	-	-	-	5.1	-	-	-
7:30 pm	-	-	-	-	-	-	-	-	-	-	3.4	-	4.6	-	-	-	4.4	-	-	-
7/29 -10:00 am	1.7	2.9	3.8	3.9	4.0	4.3	3.5	4.9	3.7	5.4	4.5	5.5	5.7	5.3	-	-	-	8.1	5.8	-
2:00 pm	3.3	2.6	5.0	2.8	5.3	2.7	3.9	3.8	4.3	3.9	3.0	3.2	4.6	4.3	-	-	-	7.1	5.4	-

Table 2

Plant Monitoring Summary
July 21-29, 1967

Sample	Date	Time	TSS (mg/1)	Ortho P (mg/1)	Temp (°C)	DO (mg/1)	Carbon NVOC (mg/1 C)	Carbon SNVOC (mg/1 C)	TOD Whole (mg/1 OD)	TOD Filt. (mg/1 OD)	Total P (mg/1)	Total Hardness (mg/1 $CaCO_3$)	Total Plate Count (count/ml)
Raw	7/21	10:20 am	-	-	21.0	2.2	-	-	-	-	-	-	-
		11:45 am	422	2.8	-	-	-	-	-	-	8.8	-	4.2 x 10^5
		3:00 pm	-	-	-	-	-	-	-	-	-	280	-
	7/24	2:30 pm	-	4.8	-	-	-	-	-	-	-	-	-
	7/26	6:00 am	-	1.7	20.0	3.5	-	-	-	-	-	-	-
			74 1/	-	-	-	21.0 1/	17.0 1/	82 1/	-	2.4 1/	-	5.4 x 10^4 1/
		7:00 am	-	2.0	20.0	3.4	-	-	-	-	-	-	-
	7/28	12:00 N	-	2.9	22.5	2.8	-	-	324	-	7.9	-	3.1 x 10^4
			152 1/	-	-	-	110 1/	92 1/	-	-	8.3 1/	-	-
		1:00 pm	-	2.7	22.5	2.6	-	-	-	-	-	-	-
	7/29	10:00 am	-	1.7	-	-	-	-	-	-	-	-	-
		2:00 pm	-	3.3	-	-	-	-	-	-	-	-	-
PE	7/21	11:45 am	252	2.8	-	-	-	-	-	-	5.5	-	5.5 x 10^5
		3:00 pm	-	-	-	-	-	-	-	-	-	275	-
	7/22	12:00 N	48	3.2	-	-	85	71	105	70	5.0	-	-
	7/24	9:45 am	124	4.0	-	-	36.0	31.5	108	100	4.6	-	-
		2:30 pm	-	4.7	-	-	-	-	-	-	-	-	-
	7/25	10:30 am	116	2.8	-	-	36	32	142	70	3.4	-	-
	7/26	8:30 am	-	2.9	20.0	0.3	-	-	-	-	-	-	1.0 x 10^4
			72 1/	-	-	-	40.0 1/	29.5 1/	100 1/	-	3.6 1/	-	-
		9·30 am	-	3.2	20.0	0.3	-	-	-	-	-	-	-
	7/27	9:00 am	18	3.3	-	-	26	24.5	86	70	3.6	-	1.7 x 10^4
	7/28	1:00 pm	-	2.6	22.0	0.5	-	-	-	-	-	-	2.4 x 10^4
			80 1/	-	-	-	88 1/	67 1/	216 1/	-	6.4 1/	-	-
		2:00 pm	-	2.8	-	-	-	-	-	-	-	-	-
	7/29	10:00 am	-	2.9	-	-	-	-	-	-	-	-	-
		2:00 pm	-	2.6	-	-	-	-	-	-	-	-	-
AT#1 (in)	7/21	9:55 am	-	-	20.5	0.7	-	-	-	-	-	-	-
		11:45 am	-	4.3	-	-	-	-	-	-	-	-	2.7 x 10^5
	7/24	3:00 pm	-	8.1	24.0	0.6	-	-	-	-	-	-	-
	7/26	8·30 am	-	3.6	20.5	0.3	-	-	-	-	-	-	3.4 x 10^5
			1744 1/	-	-	-	-	15.0 1/	-	-	-	-	-
		9:30 am	-	3.6	21.0	0.2	-	-	-	-	-	-	-
	7/27	5:00 pm	-	7.6	22.0	0.2	-	-	-	-	-	-	-
	7/28	1:00 pm	-	3.9	21.5	0.5	-	-	1720	-	45	-	4.4 x 10^5
			1595 1/	-	-	-	-	-	-	-	-	-	-
		2:00 pm	-	4.9	22.0	0.4	-	-	-	-	-	-	-
	7/29	10:00 am	1110	3.8	20.5	0.3	-	-	-	-	-	-	-
		2:00 pm	-	5.0	-	-	-	-	-	-	-	-	-
AT#2 (1/2)	7/21	10:00 am	-	-	20.5	1.0	-	-	-	-	-	-	1.1 x 10^6
	7/26	10:30 am	-	2.5	21.0	0.4	-	-	-	-	-	-	1.1 x 10^5
		11:30 am	-	2.5	21.0	0.6	-	-	-	-	-	-	-
	7/28	3:00 pm	-	4.5	22.5	0.3	-	-	-	-	-	-	1.2 x 10^5
		4:00 pm	-	5.4	21.5	0.3	-	-	-	-	-	-	-

1/Composite figure of times sampled.

Table 2 (Cont'd.)

Sample	Date	Time	TSS (mg/l)	Ortho P (mg/l)	Temp (°C)	DO (mg/l)	Carbon		TOD		Total P (mg/l)	Total Hardness (mg/l $CaCO_3$)	Total Plate Count (count/ml)
							NVOC (mg/l C)	SNVOC (mg/l C)	Whole (mg/l OD)	Filt (mg/l OD)			
AT#1 (out)	7/21	9:50 am	-	-	20.5	0.8	-	-	-	-	-	-	-
		11:45 am	1852	3.4	-	-	-	-	-	-	-	-	2.4×10^5
	7/24	3:00 pm	-	3.8	22.0	0.6	-	-	-	-	-	-	-
	7/26	12:30 pm	-	2.2	21.0	1.4	-	-	-	-	-	-	9.0×10^4
			1620[1]	-	-	-	-	-	-	-	-	-	-
		1:30 pm	-	2.2	21.0	0.9	-	-	-	-	-	-	-
	7/27	5:00 pm	-	4.8	22.0	0.7	-	-	-	-	-	-	-
	7/28	5:00 pm	-	4.1	22.5	0.7	-	-	1720	-	-	-	1.0×10^5
			1605[1]	-	-	-	-	-	-	-	-	-	-
		6:00 pm	-	3.8	22.5	0.6	-	-	-	-	-	-	-
	7/29	10:00 am	-	3.9	21.0	0.9	-	-	-	-	-	-	-
		1:00 pm	-	-	22.5	1.5	-	-	-	-	-	-	-
		2:00 pm	-	2.8	-	-	-	-	-	-	-	-	-
AT#2 (in)	7/21	9:45 am	-	-	20.0	0.5	-	-	-	-	-	-	-
		11:45 am	-	4.3	-	-	-	-	-	-	-	-	-
	7/24	3:00 pm	-	8.3	23.0	0.3	-	-	-	-	-	-	-
	7/27	5:00 pm	-	7.6	22.0	0.3	-	-	-	-	-	-	-
	7/29	10:00 am	-	4.0	21.0	0.3	-	-	-	-	-	-	-
		2:00 pm	-	5.3	-	-	-	-	-	-	-	-	-
AT#2 (out)	7/21	9:50 am	-	-	20.5	0.5	-	-	-	-	-	-	-
		11:45 am	1704	3.6	-	-	-	-	-	-	-	-	3.5×10^6
	7/24	3:00 pm	-	5.1	22.0	0.1	-	-	-	-	-	-	-
	7/27	5:00 pm	-	5.6	22.0	0.3	-	-	-	-	-	-	-
	7/29	10:00 am	-	4.3	21.0	0.3	-	-	-	-	-	-	-
		1:00 pm	-	-	21.0	0.4	-	-	-	-	-	-	-
		2:00 pm	-	2.7	-	-	-	-	-	-	-	-	-
AT#3 (.n)	7/21	9:40 am	-	-	20.5	0.7	-	-	-	-	-	-	-
		11:45 am	-	3.8	-	-	-	-	-	-	-	-	-
	7/24	3:00 pm	-	6.9	22.0	0.3	-	-	-	-	-	-	-
	7/26	8:30 am	-	3.9	20.5	1.6	-	-	-	-	-	-	4.8×10^5
			1652[1]	-	-	-	-	-	-	-	-	-	-
		9:30 am	-	4.2	21.0	1.7	-	-	-	-	-	-	-
	7/27	5:00 pm	-	6.0	22.0	0.4	-	-	-	-	-	-	-
	7/28	1:00 pm	-	3.8	21.5	0.6	-	-	-	-	-	-	3.7×10^5
			1660[1]	-	-	-	-	-	-	-	-	-	-
		2:00 pm	-	4.2	21.5	0.3	-	-	-	-	-	-	-
	7/29	10:00 am	1645	3.5	21.0	1.1	-	-	-	-	-	-	-
		2:00 pm	-	3.9	-	-	-	-	-	-	-	-	-
AT#3 (1/2)	7/21	10:05 am	-	-	20.5	0.5	-	-	-	-	-	-	7.6×10^5
	7/26	10:30 am	-	3.7	21.0	0.3	-	-	-	-	-	-	1.4×10^5
		11:30 am	-	3.5	21.0	0.5	-	-	-	-	-	-	-
	7/28	3:00 pm	-	4.9	21.5	0.3	-	-	-	-	-	-	5.2×10^5
		4:00 pm	-	5.5	21.5	0.5	-	-	-	-	-	-	-

1/Composite figure of times sampled.

Table 2 (Cont'd.)

Sample	Date	Time	TSS (mg/l)	Ortho P (mg/l)	Temp (°C)	DO (mg/l)	Carbon: NVOC (mg/l C)	Carbon: SNVOC (mg/l C)	TOD: Whole (mg/l OD)	TOD: Filt. (mg/l OD)	Total P (mg/l)	Total Hardness (mg/l $CaCO_3$)	Total Plate Count (count/ml)
AT#3 (out)	7/21	9:35 am	-	-	21.0	0.4	-	-	-	-	-	-	
		11:45 am	1892	3.6	-	-	-	-	-	-	-	-	1.5×10^6
	7/24	3:00 pm	-	4.5	22.0	0.1	-	-	-	-	-	-	-
	7/26	12:30 pm	-	3.6	21.0	1.0	-	-	-	-	-	-	1.7×10^5
			1700[1/]	-	-	-	-	-	-	-	-	-	-
		1:30 pm	-	3.4	21.0	0.5	-	-	-	-	-	-	-
	7/27	5:00 pm	-	5.4	22.0	0.5	-	-	-	-	-	-	-
	7/28	5:00 pm	-	5.0	22.0	0.6	-	-	-	-	-	-	3.5×10^5
			1770[1/]	-	-	-	-	-	-	-	-	-	-
		6:00 pm	-	4.6	22.0	0.4	-	-	-	-	-	-	-
	7/29	10:00 am	-	4.9	21.0	0.5	-	-	-	-	-	-	-
		1:00 pm	-	-	21.5	0.8	-	-	-	-	-	-	-
		2:00 pm	-	3.8	-	-	-	-	-	-	-	-	-
AT#4 (in)	7/21	9:30 am	-	-	20.5	0.4	-	-	-	-	-	-	-
		11:45 am	-	4.0	-	-	-	-	-	-	-	-	-
	7/24	3:00 pm	-	7.2	22.0	0.1	-	-	-	-	-	-	-
	7/26	1:30 pm	-	5.1	-	-	-	-	-	-	-	-	-
	7/27	5:00 pm	-	6.0	22.0	0.4	-	-	-	-	-	-	-
	7/29	10:00 am	-	3.7	21.0	0.5	-	-	-	-	-	-	-
		2:00 pm	-	4.3	-	-	-	-	-	-	-	-	-
AT#4 (out)	7/21	9:30 am	-	-	20.5	0.4	-	-	-	-	-	-	-
		11:45 am	1348	4.0	-	-	-	-	-	-	-	-	-
	7/24	3:00 pm	-	5.8	22.0	0.1	-	-	-	-	-	-	-
	7/26	1:30 pm	-	3.4	-	-	-	-	-	-	-	-	-
	7/27	5:00 pm	-	5.4	22.0	1.8	-	-	-	-	-	-	-
	7/29	10:00 am	-	5.4	21.0	3.3	-	-	-	-	-	-	-
		1:00 pm	-	-	22.5	3.8	-	-	-	-	-	-	-
		2:00 pm	-	3.9	-	-	-	-	-	-	-	-	-
AT comp (in)	7/26	8:30 am	-	3.7	-	-	-	-	-	-	-	-	-
			1540[1/]	-	-	-	-	27.0[1/]	-	-	38.6[1/]	-	-
		9:30 am	-	3.8	-	-	-	-	-	-	-	-	-
	7/28	1:00 pm	-	4.0	-	-	-	-	-	-	-	-	8.2×10^5
			1650[1/]	-	-	-	-	30[1/]	-	-	30[1/]	-	-
		2:00 pm	-	4.3	-	-	-	-	-	-	-	-	-
AT comp (out)	7/26	12:30 pm	-	2.8	-	-	-	-	-	-	-	-	-
			1740[1/]	-	-	-	-	-	-	-	33.6[1/]	-	-
		1:30 pm	-	2.9	-	-	-	-	-	-	-	-	-
	7/28	5:00 pm	-	4.9	-	-	-	-	-	-	-	-	8.9×10^5
			1690[1/]	-	-	-	-	-	-	-	46[1/]	-	-
		6:00 pm	-	4.6	-	-	-	-	-	-	-	-	-
	7/24	3:00 pm	-	-	22.0	0.5	-	-	-	-	-	-	-
FE#1	7/26	2:00 pm	-	2.4	21.0	0.4	-	-	-	-	-	-	8.0×10^4
		3:00 pm	-	2.6	21.0	0.5	-	-	-	-	-	-	-
	7/28	6:30 pm	-	4.1	22.5	0.3	24	-	36	-	3.4	-	2.4×10^4
		7:30 pm	-	3.4	-	-	-	-	-	-	-	-	-
	7/29	10:00 am	-	4.5	-	-	-	-	-	-	-	-	-
		2:00 pm	-	3.0	-	-	-	-	-	-	-	-	-
FE#2	7/24	3:00 pm	-	-	22.0	0.3	-	-	-	-	-	-	-
	7/29	10:00 am	-	5.5	-	-	-	-	-	-	-	-	-
		2:00 pm	-	3.2	-	-	-	-	-	-	-	-	-

1/Composite figure of times sampled.

Table 2 (Cont'd.)

Sample	Date	Time	TSS (mg/1)	Ortho P (mg/1)	Temp (°C)	DO (mg/1)	Carbon NVOC (mg/1 C)	Carbon SNVOC (mg/1 C)	TOD Whole (mg/1 OD)	TOD Filt. (mg/1 OD)	Total P (mg/1)	Total Hardness (mg/1 $CaCO_3$)	Total Plate Count (count/ml)
FE#3	7/24	3:00 pm	-	-	22.0	0.2	-	-	-	-	-	-	-
	7/26	2:00 pm	-	3.8	21.0	0.2	-	-	-	-	-	-	3.0×10^4
		3:00 pm	-	4.0	21.0	0.2	-	-	-	-	-	-	-
	7/28	6:30 pm	-	5.1	22.5	0.4	-	-	-	-	-	-	2.5×10^4
		7:30 pm	-	4.6	-	-	-	-	-	-	-	-	-
	7/29	10:00 am	-	5.7	-	-	-	-	-	-	-	-	-
		2:00 pm	-	4.6	-	-	-	-	-	-	-	-	-
FE#4	7/24	3:00 pm	-	-	22.0	0.2	-	-	-	-	-	-	-
	7/29	10:00 am	-	5.3	-	-	-	-	-	-	-	-	-
		2:00 pm	-	4.3	-	-	-	-	-	-	-	-	-
FE comp	7/21	9:15 am	-	-	21.0	-	-	-	-	-	-	-	-
		11:45 am	-	4.2	-	-	-	-	-	-	4.0	-	1.6×10^3
	7/22	12:00 N	20	3.6	-	-	28.5	28.0	5	5	3.7	-	-
	7/24	11:30 am	54	4.1	-	-	19	16	49	40	3.3	-	-
		3:00 pm	-	4.0	-	-	-	-	-	-	-	-	-
	7/25	11:30 am	87	4.8	-	-	19.5	19.5	42	42	4.8	-	-
	7/26	2:00 pm	-	2.8	-	-	-	-	-	-	-	-	-
			23 1/	-	-	-	18.0 1/	13.5 1/	36 1/	-	2.8 1/	-	-
		3:00 pm	-	3.4	-	-	-	-	-	-	-	-	-
	7/28	6:30 pm	-	5.1	-	-	-	-	-	-	-	-	-
			3 1/	-	-	-	18 1/	16 1/	40 1/		4.6 1/	-	-
		7:30 pm	-	4.4	-	-	-	-	-	-	-	-	-
RS 1&2	7/21	11:45 am	3795	5.5	-	-	-	-	-	-	-	-	-
	7/22	12:00 N	2880	4.2	-	-	-	-	-		96.0	-	-
	7/24	9:20 am	5120	-	-	-	-	-	-	-	-	-	-
		11:00 am	5950	6.0	-	-	-	-	-	-	120	-	-
	7/25	10:00 am	6610	4.0	-	-	-	-	-	-	129	-	-
	7/26	8:30 am	-	6.5	20.5	0.3	-	-	-	-	-	-	6.7×10^5
			4550 1/	-	-	-	20.5 1/	15.0 1/	4440 1/	-	97 1/	-	-
		9:30 am	-	5.0	21.0	0.2	-	-	-	-	-	-	-
	7/27	8:15 am	3920	6.9	-	-	-	-	4640	-	99.5	-	3.2×10^5
	7/28	1:00 pm	-	-	22.0	0.3	-	-	-	-	-	-	1.8×10^5
		2:00 pm	-	-	21.5	0.3	-	-	-	-	-	-	-
	7/29	10:00 am	-	8.1	-	-	-	-	-	-	-	-	-
		2:00 pm	-	7.1	-	-	-	-	-	-	-	-	-
RS 3&4	7/21	11:45 am	4635	5.0	-	-	-	-	-	-	-	-	-
	7/26	8:30 am	-	5.4	20.5	0.3	-	-	-	-	-	-	5.2×10^5
			4620 1/	-	-	-	-	-	-	-	94.5 1/	-	-
		9:30 am	-	5.8	21.0	0.1	-	-	-	-	-	-	-
	7/29	10:00 am	-	5.8	-	-	-	-	-	-	-	-	-
		2:00 pm	-	5.4	-	-	-	-	-	-	-	-	-
RS (comp)	7/24	3:00 pm	-	6.7	-	-	-	-	-	-	-	-	-
	7/28	1:00 pm	-	5.5	-	-	-	-	-	-	-	-	-
			6780 1/	-	-	-	-	27 1/	4160 1/	-	131 1/	-	-
		2:00 pm	-	4.8	-	-	-	-	-	-	-	-	-

1/Composite figure of times sampled.

Source	Ortho Min	Ortho Max	Total Min	Total Max	Avg. (Ortho/Total)
Raw Waste	1.7	4.8	2.4	8.8	0.4
Pri. Effl.	2.6	4.7	3.4	6.4	0.7
Final Effl.	2.8	5.1	2.8	4.8	1.0

Orthophosphate loading was 0.4 lb. P/day/100 lbs. MLSS.

Temperatures in the aeration tanks averaged 21.5°C at both the influent and effluent ends. The average total bacterial plate count was 1.5 x 10^5 per ml for primary effluent, 3.8 x 10^5 per ml for aeration tank influent, 8.5 x 10^5 per ml for aeration tank effluent, and 3.3 x 10^4 per ml for unchlorinated final effluent.

Aeration Jug Studies

1. Suspended Solids Variation

Seven 5-gallon polyethylene aeration jugs were set up at 12:30 p.m. on July 22, 1967, to determine the effect of mixed liquor suspended solids concentrations on soluble phosphorus removal. Jug synthetic components are shown in Table 3. Jug No. 4 contained mixed liquor composited from the influent of each aeration tank.

Suspended solids concentrations ranged from about 700 to 6,000 mg/l. Initial soluble phosphorus concentrations showed minor variations with no apparent relationship to mixed liquor suspended solids (MLSS). Insignificant release of soluble phosphorus during mixed liquor preparation was attributed to preaeration of concentrated return sludge.

Soluble phosphorus removal after 4 hours aeration ranged from zero percent in the jug containing the low solids concentration to a maximum of 64 percent in the jug containing the high solids concentration. The jugs with $\geq$3,840 mg/l suspended solids concentrations removed 10 to 40 percent more than plant mixed liquor and other jugs containing lower suspended solids concentrations. Figure 5 is a plot of orthophosphate concentration versus aeration time for each jug. Analytical results are found in Table 4.

Percent phosphate removal versus suspended solids concentration is shown in Figure 6. This curve indicates that the optimum solids concentration for subsequent pilot studies is about 6,000 mg/l.

Table 3

Components of Aeration Jugs

Components	1	2	3	4	5	6	7	Ortho Phosphate (mg/l-P)	TSS (mg/l)
Suspended Solids Variation									
PE (liters)	10.0	10.0	10.0	--	10.0	10.0	10.0	3.2	60
RS (liters) a/	1.5	3.0	4.4	--	--	--	--	4.2	4005
RS (liters) b/	--	--	--	--	2.5	3.5	4.5	3.4	16090
ML (liters)	--	--	--	15.0	--	--	--	--	--
FE (liters)	3.5	2.0	0.6	--	2.5	1.5	0.5	3.6	50
Avg. TSS (mg/l)	670	1385	2360	3130	3840	4660	6170		
BOD Variation									
PE (liters)	7.0	10.0	10.0	10.0	10.0	--	--	4.0	124
RS (liters) b/	3.7	3.7	3.7	3.7	3.7	--	--	2.4	12260
FE (liters)	4.3	1.3	1.3	1.3	1.3	--	--	4.1	54
Metrecal (ml) c/	--	--	1.5	3.8	6.3	--	--	--	--
ML (liters)	--	--	--	--	--	15.0	--	--	--
Chemical Addition									
PE (liters)	5.0	10.0	10.0	10.0	4.6	0.5	10.0	2.8	116
PE (liters) d/	--	--	--	--	5.4	9.5	--	2.8	--
RS (liters) b/	4.0	4.0	4.0	4.0	4.0	4.0	4.0	2.8	12230
FE (liters)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	4.8	87
City Water (liters)	6.0	--	--	--	--	--	--	<0.1	--
Metrecal (ml)	2.	--	--	--	--	--	--	--	--
$FeSO_4$ (final conc. of Fe^{+2} in mg/l)	--	--	25.	--	--	--	--	--	--
$Al_2(SO_4)_3$ (final conc. of Al^{+3} in mg/l)	--	--	--	25.	--	--	--	--	--
Orthophosphate Variation									
PE (liters)	5.	11.	11.e/	11.	11.	--	--	3.3	18
RS (liters) b/	4.	4.	4.	4.	4.	--	--	2.5	10910
City Water (liters)	6.	--	--	--	--	--	--	<0.1	--
K_2HPO_4 (final conc. of P in mg/l)	--	8.3	--	--	--	--	--	--	--

a/Return sludge from wet well (Tanks No. 1 and 2).
b/Concentrated return sludge - 60 liters from wet well (Tanks No. 1 and 2) concentrated to approximately 20 liters.
c/BOD of Metrecal is 290 mg/ml.
d/Prim. effl. free of all hardness (normally total hardness = 280 mg/l $CaCO_3$).
e/Jugs No. 3, 4, and 5 had same make-up, and composite sample of these three jugs was considered the experimental control.

JUG	TSS (mg / l)
1	670
2	1385
3	2360
4	3130
5	3840
6	4660
7	6170

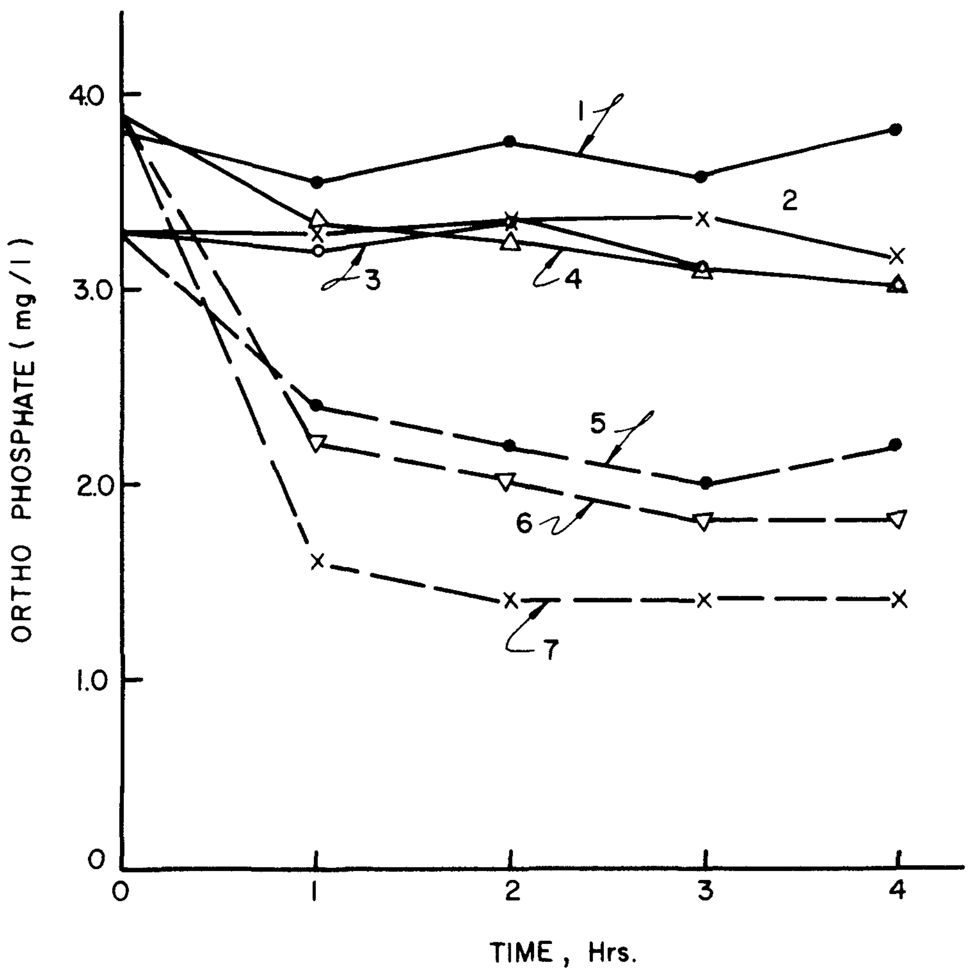


FIGURE 5 - SUSPENDED SOLIDS VARIATION

Table 4

Suspended Solids Variation
July 22, 1967

Sample	Time	TSS (mg/l)	Ortho P (mg/l)	Ortho PO_4 (mg/l)	Temp (°C)	DO (mg/l)	Carbon NVOC (mg/l c)	Carbon SNVOC (mg/l c)	TOD Whole (mg/l OD)	TOD Filt. (mg/l OD)	Total Plate Count (Count/ml)
Jug 1	12:30 pm	-	3.8	11.6	24.5	5.0	-	-	-	-	3.5×10^4
	1:30 pm	-	3.6	10.8	27.0	5.8	-	-	-	-	-
	2:30 pm	670	3.8	11.4	30.0	5.4	-	-	-	-	4.0×10^4
	3:30 pm	-	3.6	11.2	32.0	6.1	-	-	-	-	-
	4:30 pm	-	3.8	11.6	32.0	5.6	-	-	-	-	6.6×10^5
Settled Supernatant	5:00 pm	252	3.5	10.9	-	-	23.5	20.0	50.0	47.5	-
Settled Sludge	5:00 pm	-	4.9	15.0	-	-	-	-	-	-	-
Jug 2	12:30 pm	1480	3.3	10.0	25.5	6.3	-	-	-	-	-
	1:30 pm	-	3.3	10.0	27.5	6.3	-	-	-	-	-
	2:30 pm	1290	3.4	10.2	29.0	6.7	-	-	-	-	-
	3:30 pm	-	3.4	10.2	32.0	6.6	-	-	-	-	-
	4:30 pm	-	3.2	9.6	33.0	6.6	-	-	-	-	-
Settled Supernatant	5:00 pm	228	3.2	9.6	-	-	21.5	20.0	45.0	35.0	-
Settled Sludge	5:00 pm	-	4.8	14.8	-	-	-	-	-	-	-
Jug 3	12:30 pm	2250	3.3	10.0	24.0	5.8	-	-	-	-	-
	1:30 pm	-	3.2	9.8	25.0	5.5	-	-	-	-	-
	2:30 pm	2470	3.4	10.2	26.5	6.3	-	-	-	-	-
	3:30 pm	-	3.1	9.5	28.5	6.1	-	-	-	-	-
	4:30 pm	-	3.0	9.2	29.0	5.8	-	-	-	-	-
Settled Supernatant	5:00 pm	302	3.0	9.2	-	-	23.0	18.5	42.5	42.5	-
Settled Sludge	5:00 pm	-	4.8	14.8	-	-	-	-	-	-	-
Jug 4	12:30 pm	2800	3.9	11.9	23.0	5.6	-	-	-	-	4.7×10^5
	1:30 pm	-	3.4	10.2	24.0	5.2	-	-	-	-	-
	2:30 pm	3460	3.2	9.9	25.5	6.7	-	-	-	-	2.5×10^5
	3:30 pm	-	3.1	9.5	27.5	6.1	-	-	-	-	-
	4:30 pm	-	3.0	9.2	28.0	6.1	-	-	-	-	1.2×10^6
Settled Supernatant	5:00 pm	252	3.0	9.3	-	-	19.0	19.0	37.5	35.0	-
Settled Sludge	5:00 pm	-	4.7	14.4	-	-	-	-	-	-	-
Jug 5	12:30 pm	3680	3.3	10.[illegible]	24.0	4.5	-	-	-	-	-
	1:30 pm	-	2.4	7.3	25.0	4.9	-	-	-	-	-
	2:30 pm	4000	2.2	6.7	26.5	5.2	-	-	-	-	-
	3:30 pm	-	2.0	6.1	28.0	5.2	-	-	-	-	-
	4:30 pm	-	2.2	6.7	29.0	4.8	-	-	-	-	-
Settled Supernatant	5:00 pm	208	2.2	6.8	-	-	22.0	17.0	27.5	25.0	-
Settled Sludge	5:00 pm	-	4.4	13.5	-	-	-	-	-	-	-
Jug 6	12:30 pm	4550	3.9	11.9	24.0	4.0	-	-	-	-	-
	1:30 pm	-	2.2	6.9	25.5	3.7	-	-	-	-	-
	2:30 pm	4780	2.0	6.0	26.5	4.3	-	-	-	-	-
	3:30 pm	-	1.8	5.7	27.5	4.2	-	-	-	-	-
	4:30 pm	-	1.8	5.7	29.0	3.3	-	-	-		-
Settled Supernatant	5:00 pm	13[illegible]	1.9	5.8	-	-	19.0	19.0	17.5	17.5	-
Settled Sludge	5:00 pm	-	3.6	9.2	-	-	-	-	-	-	-
Jug 7	12:30 pm	6070	3.9	11.9	24.5	3.5	-	-	-	-	7.1×10^5
	1:30 pm	-	1.6	5.0	27.0	2.2	-	-	-	-	-
	2:30 pm	6270	1.4	4.3	28.0	2.8	-	-	-	-	9.2×10^5
	3:30 pm	-	1.4	4.1	29.5	2.6	-	-	-	-	-
	4:30 pm	-	.4	4.[illegible]	30.0	2.6	-	-	-	-	2.3×10^6
Settled Supernatant	5:00 pm	82	1.5	4.6	-	-	27.0	25.0	22.5	22.5	-
Settled Sludge	5:00 pm	-	3.5	10.7	-	-	-	-	-	-	-

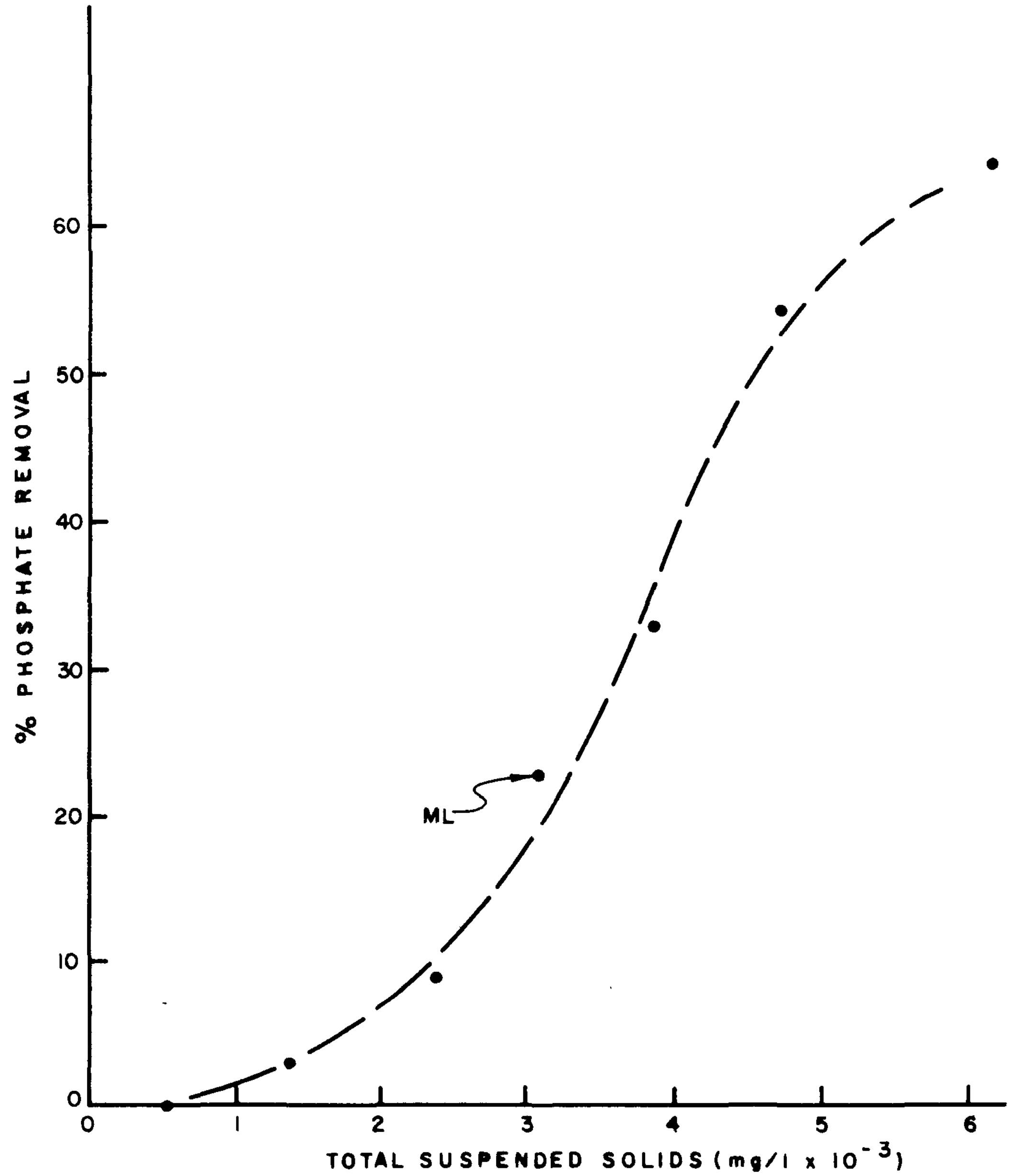


FIGURE 6 - SOLIDS VARIATION - REMOVAL VS. SOLIDS

Due to limitations in plant return sludge pumping capacity, 3,500 mg/1 MLSS was chosen for subsequent studies so that test results would be of practical value in plant selection and operation.

A marked increase in phosphate removal in Jugs No. 5 through 7 is evident in Figure 5. This elevated performance, disproportionate to the increased solids levels found in these jugs, requires explanation. These jugs were synthesized with thickened return sludge while Jugs No. 1 through 3 contained unconcentrated plant return sludge. The authors can only speculate about the enhanced capabilities of concentrated sludge by pointing out the differences between the two sources of jug solids:

a. Activated sludge taken from the secondary system averaged $\lesssim$1 mg/1 DO. During sludge thickening by air flotation, suspended solids contact water supersaturated with air. The resulting solids might be considered preaerated return sludge in contrast to plant return sludge which was essentially anaerobic at the time of jug synthesis.

b. Plant activated sludge contains dissolved interstitial substances, some of which might have a toxic influence in jug phosphate removal. Air flotation using city water undoubtedly removed a portion of these interstitial materials by elutriation.

c. Thickened sludge contained 20 percent less orthophosphate and 10 percent less total phosphate, per unit suspended solids, than unadulterated plant return sludge. This might account for its greater affinity for soluble phosphorus.

2. BOD Variation

Six jugs were set up on July 24, 1967, to determine the effect of BOD load on soluble phosphorus removal. Aeration commenced at 11:30 a.m.

According to plant records, the average BOD concentration for primary and final effluent during the two-week study was 90 and 7 mg/1, respectively. These figures were used in estimating jug BOD loadings in this experiment.

Each jug contained suspended solids (3.7 liters of concentrated sludge diluted with 1.3 liters of final effluent) and a BOD source which will be termed substrate in order to distinguish it from plant primary effluent. The substrate volume was 10 liters for each jug.

Jug No. 2 contained 10 liters of plant primary effluent as substrate and represented the synthetic control. It is termed the 100 percent substrate jug, in reference to the 10-liter substrate volume containing a BOD concentration equal to 100 percent of the primary effluent value. Substrate BOD was reduced to about 75 percent in Jug No. 1 by diluting primary effluent with final effluent (Table 3). Approximately 175, 300, and 400 percent substrate BOD concentrations were established in Jugs No. 3, 4, and 5, respectively, by the addition of a BOD supplement (Metrecal). Jug No. 6 contained mixed liquor composited from the influent ends of the aeration tanks and served as a control.

Suspended solids concentrations were about 3,500 mg/l for all jugs except Jug No. 6 (2,500 mg/l TSS). Experimental results are found in Table 5. The results of four hours aeration are presented in Figure 7.

Initial phosphate values were higher for those jugs having substrate BOD concentrations greater than 75 percent of the average primary effluent figure. The initial orthophosphate concentrations for all jugs, based on phosphate content of all jug constituents, were 20 to 30 percent below the observed concentrations. Similar results were observed in the suspended solids variation study.

The low BOD jug (75 percent of the primary effluent) showed 68 percent removal while synthetic jugs with higher BOD loading gave slightly higher results (72-78 percent). The mixed liquor control showed 29 percent removal of soluble phosphorus.

The similar removals observed with increasing BOD concentrations indicate that little could be gained by such practice at this facility on a plant scale. Accordingly, all future studies were performed with substrate BOD concentrations similar to that of plant primary effluent.

3. Chemical Addition

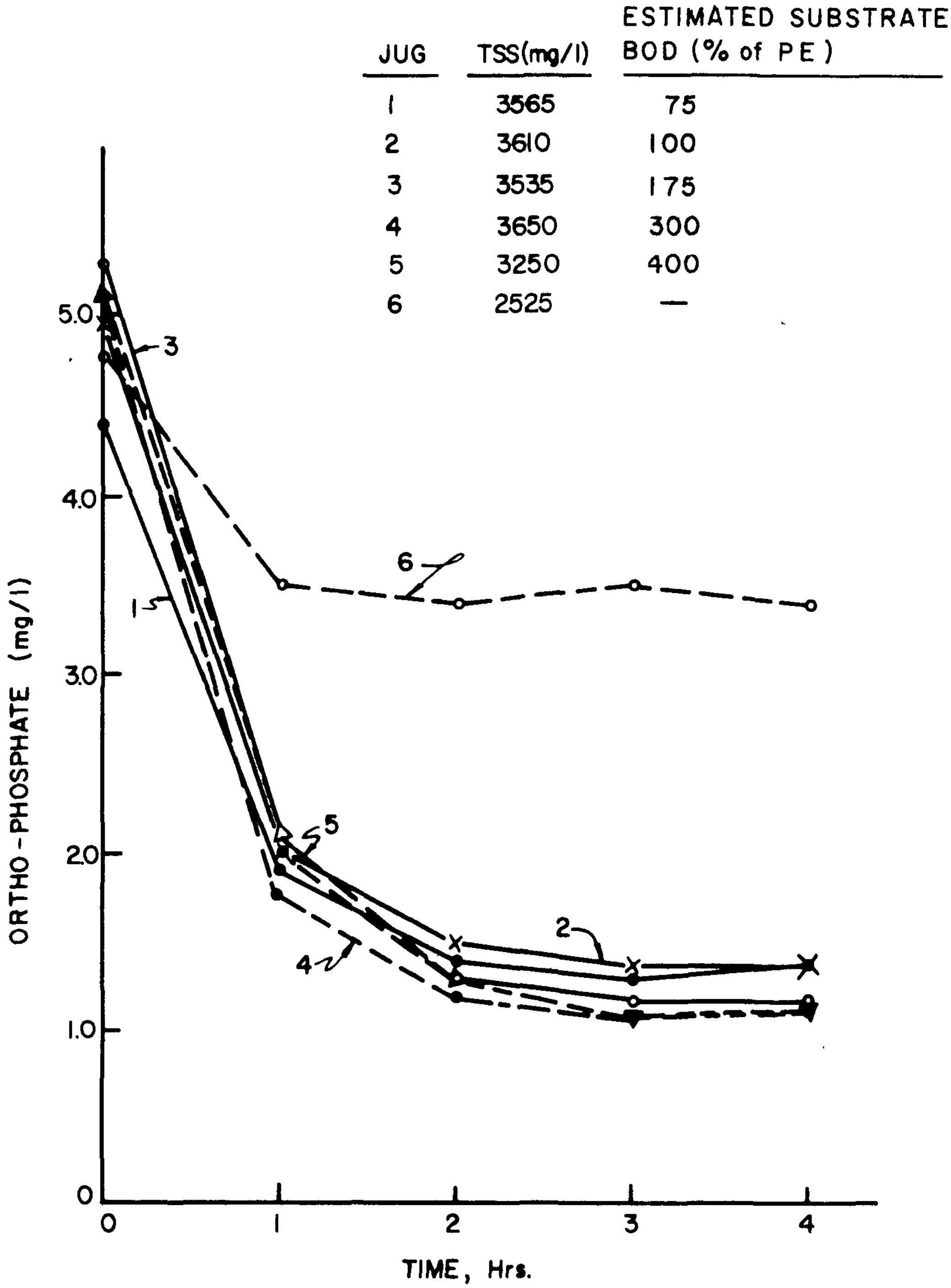
A set of jugs was prepared on July 25, 1968, to determine the effects of iron and aluminum salts, hardness, and low phosphate load on soluble phosphorus removal. Jug constituents are given in Table 3. The experimental results are summarized in Table 6 and shown graphically in Figure 8.

Theoretically, Jug No. 1 contained one-half the normal phosphate load contributed by primary effluent (Metrecal was added to this jug to restore the BOD lost by addition of final effluent and city water). High initial phosphate concentrations were found in Jugs No. 1, 2, 5, 6, and 7. Each was 50 percent greater than the

Table 5

BOD Variation
July 24, 1967

Sample	Time	TSS (mg/l)	Ortho P (mg/l)	Ortho PO_4 (mg/l)	Temp (°C)	DO (mg/l)	Carbon NVOC (mg/l c)	Carbon SNVOC (mg/l c)	TOD Whole (mg/l OD)	TOD Filt. (mg/l OD)	Total Plate Count (Count/ml)
Jug 1	11:30 am	3530	4.4	13.5	23.5	0.6	-	-	-	-	3.3×10^5
	12:30 pm	-	1.9	5.8	25.5	4.4	-	-	-	-	-
	1:30 pm	-	1.4	4.2	28.0	3.5	-	-	-	-	7.0×10^5
	2:30 pm	3600	1.3	4.0	29.5	3.9	-	-	-	-	-
	3:30 pm	-	1.4	4.3	-	-	-	-	-	-	6.7×10^4
Settled Supernatant	4:00 pm	226	1.5	4.5	-	-	23.0	21.0	25.0	22.5	-
Settled Sludge	4:00 pm	-	3.2	9.9	-	-	-	-	-	-	-
Jug 2	11:30 am	3470	5.0	15.3	24.0	0.2	-	-	-	-	1.4×10^6
	12:30 pm	-	2.0	6.1	25.5	4.5	-	-	-	-	-
	1:30 pm	-	1.5	4.5	27.0	4.2	-	-	-	-	6.2×10^6
	2:30 pm	3750	1.4	4.2	28.0	4.5	-	-	-	-	-
	3:30 pm	-	1.4	4.3	-	-	-	-	-	-	1.1×10^6
Settled Supernatant	4:00 pm	270	1.4	4.3	-	-	19.5	15.0	11.0	11.0	-
Settled Sludge	4:00 pm	-	2.2	6.7	-	-	-	-	-	-	-
Jug 3	11:30 am	3490	5.3	16.2	23.5	0.1	-	-	-	-	-
	12:30 pm	-	2.0	6.3	25.0	4.2	-	-	-	-	-
	1:30 pm	-	1.3	4.0	27.0	4.4	-	-	-	-	-
	2:30 pm	3580	1.2	3.5	27.5	4.6	-	-	-	-	-
	3:30 pm	-	1.2	3.6	-	-	-	-	-	-	-
Settled Supernatant	4:00 pm	212	0.7	2.3	-	-	15.0	15.0	17.5	15.0	-
Settled Sludge	4:00 pm	-	2.0	6.1	-	-	-	-	-	-	-
Jug 4	11:30 am	3440	5.1	15.6	23.5	0.1	-	-	-	-	-
	12:30 pm	-	1.8	5.6	25.0	4.2	-	-	-	-	-
	1:30 pm	-	1.2	3.7	27.0	4.5	-	-	-	-	-
	2:30 pm	3860	1.1	3.4	27.5	4.7	-	-	-	-	-
	3:30 pm	-	1.1	3.5	-	-	-	-	-	-	-
Settled Supernatant	4:00 pm	238	1.1	3.5	-	-	16.0	15.5	11.0	11.0	-
Settled Sludge	4:00 pm	-	1.8	5.6	-	-	-	-	-	-	-
Jug 5	11:30 am	3230	5.1	15.6	23.5	0.1	-	-	-	-	3.7×10^5
	12:30 pm	-	2.1	6.4	25.0	3.7	-	-	-	-	-
	1:30 pm	-	1.3	4.0	26.5	4.1	-	-	-	-	2.4×10^5
	2:30 pm	3270	1.1	3.4	28.0	4.4	-	-	-	-	-
	3:30 pm	-	1.1	3.3	-	-	-	-	-	-	3.3×10^5
Settled Supernatant	4:00 pm	220	1.1	3.4	-	-	18.0	18.0	11.0	11.0	-
Settled Sludge	4:00 pm	-	1.9	5.8	-	-	-	-	-	-	-
Jug 6	11:30 am	2470	4.8	14.7	23.5	3.2	-	-	-	-	2.1×10^6
	12:30 pm	-	3.5	10.8	25.0	5.8	-	-	-	-	-
	1:30 pm	-	3.4	10.5	27.0	5.8	-	-	-	-	6.5×10^5
	2:30 pm	2580	3.5	10.7	28.0	5.8	-	-	-	-	-
	3:30 pm	-	3.4	10.4	-	-	-	-	-	-	6.6×10^5
Settled Supernatant	4:00 pm	218	3.4	10.1	-	-	15.0	12.0	27.5	27.5	-
Settled Sludge	4:00 pm	-	4.7	14.4	-	-	-	-	-	-	-



JUG	TSS(mg/l)	ESTIMATED SUBSTRATE BOD (% of PE)
1	3565	75
2	3610	100
3	3535	175
4	3650	300
5	3250	400
6	2525	—

FIGURE 7 - BOD VARIATION

Table 6

Chemical Addition
July 25, 1967

Sample	Time	TSS (mg/l)	Ortho P (mg/l)	Ortho PO_4 (mg/l)	Temp (°C)	DO (mg/l)	Carbon NVOC (mg/l c)	Carbon SNVOC (mg/l c)	TOD Whole (mg/l OD)	TOD Filt. (mg/l OD)	Total Plate Count (Count/ml)
Jug 1	12:15 pm	4250	4.0	12.3	24.0	0.3	-	-	-	-	4.1×10^5
	1:15 pm	-	0.4	1.2	25.0	2.2	-	-	-	-	-
	2:15 pm	3940	0.2	0.5	27.0	2.0	-	-	-	-	2.4×10^5
	3:15 pm	-	0.3	0.8	29.5	4.4	-	-	-	-	-
Settled Supernatant	3:45 pm	30	0.4	1.1	-	-	-	-	24.0	24.0	-
Settled Sludge	3:45 pm	-	0.9	2.7	-	-	-	-	-	-	-
Jug 2	12:15 pm	3600	4.8	14.8	24.0	0.3	-	-	-	-	5.6×10^5
	1:15 pm	-	1.4	4.4	25.0	3.8	-	-	-	-	-
	2:15 pm	3540	0.6	1.8	26.5	3.9	-	-	-	-	7.1×10^5
	3:15 pm	-	0.3	1.0	28.5	4.2	-	-	-	-	-
	4:15 pm	-	0.6	1.7	27.5	4.2	-	-	-	-	3.7×10^5
Settled Supernatant	4:45 pm	34	0.6	1.7	-	-	20.0	19.0	22.0	16.0	-
Settled Sludge	4:45 pm	-	1.1	3.4	-	-	-	-	-	-	-
Jug 3	12:00 N[1]	-	2.9	8.8	-	-	-	-	-	-	-
	12:15 pm[2]	3750	0.7	2.3	24.0	0.7	-	-	-	-	1.9×10^6
	1:15 pm	-	0.2	0.6	25.0	4.1	-	-	-	-	-
	2:15 pm	3670	<0.1	0.2	26.0	4.1	-	-	-	-	6.8×10^5
Settled Supernatant	2:45 pm	30	<0.1	0.2	-	-	-	-	28.0	28.0	-
Settled Sludge	2:45 pm	-	0.2	0.6	-	-	-	-	-	-	-
Jug 4	12:00 N[1]	-	2.9	8.8	-	-	-	-	-	-	-
	12:15 pm[2]	3850	0.3	1.7	24.0	0.9	-	-	-	-	5.1×10^5
	1:15 pm	-	0.2	0.5	25.5	4.1	-	-	-	-	-
	2:15 pm	3510	<0.1	0.2	26.0	4.1	-	-	-	-	6.0×10^5
Settled Supernatant	2:50 pm	14	<0.1	0.2	-	-	-	-	42.0	32.0	-
Settled Sludge	2:50 pm	-	0.1	0.3	-	-	-	-	-	-	-
Jug 5	12:15 pm	3890	4.1	12.7	25.0	0.7	-	-	-	-	6.6×10^5
	1:15 pm	-	1.5	4.6	26.0	3.9	-	-	-	-	-
	2:15 pm	3530	0.7	2.3	26.0	5.6	-	-	-	-	7.4×10^5
	3:15 pm	-	0.4	1.2	27.5	4.5	-	-	-	-	-
	4:15 pm	-	0.2	0.6	27.0	4.2	-	-	-	-	1.0×10^6
Settled Supernatant	4:45 pm	22	0.4	1.3	-	-	21.0	21.0	16.0	16.0	-
Settled Sludge	4:45 pm	-	1.3	4.0	-	-	-	-	-	-	-
Jug 6	12:15 pm	3730	4.6	14.0	25.0	0.3	-	-	-	-	-
	1:15 pm	-	1.9	5.8	26.0	3.1	-	-	-	-	-
	2:15 pm	3620	1.0	3.0	26.0	3.9	-	-	-	-	-
	3:15 pm	-	0.3	1.0	27.0	4.2	-	-	-	-	-
	4:15 pm	-	0.2	0.6	27.0	3.9	-	-	-	-	-
Settled Supernatant	4:45 pm	48	0.7	2.1	-	-	32.0	32.0	20.0	16.0	-
Settled Sludge	4:45 pm	-	1.5	4.5	-	-	-	-	-	-	-
Jug 7	12:15 pm	3700	4.5	13.7	25.0	0.3	-	-	-	-	5.4×10^6
	1:15 pm	-	1.3	4.3	26.0	2.2	-	-	-	-	-
	2:15 pm	3550	0.6	1.8	26.0	3.9	-	-	-	-	2.9×10^6
	3:15 pm	-	0.2	0.7	27.0	4.2	-	-	-	-	-
	4:15 pm	-	<0.1	0.2	27.0	3.5	-	-	-	-	4.5×10^6
Settled Supernatant	4:45 pm	-	0.4	1.1	-	-	-	-	-	-	-
Settled Sludge	4:45 pm	-	1.1	3.3	-	-	-	-	-	-	-

1/Before metals addition.
2/After metals addition.

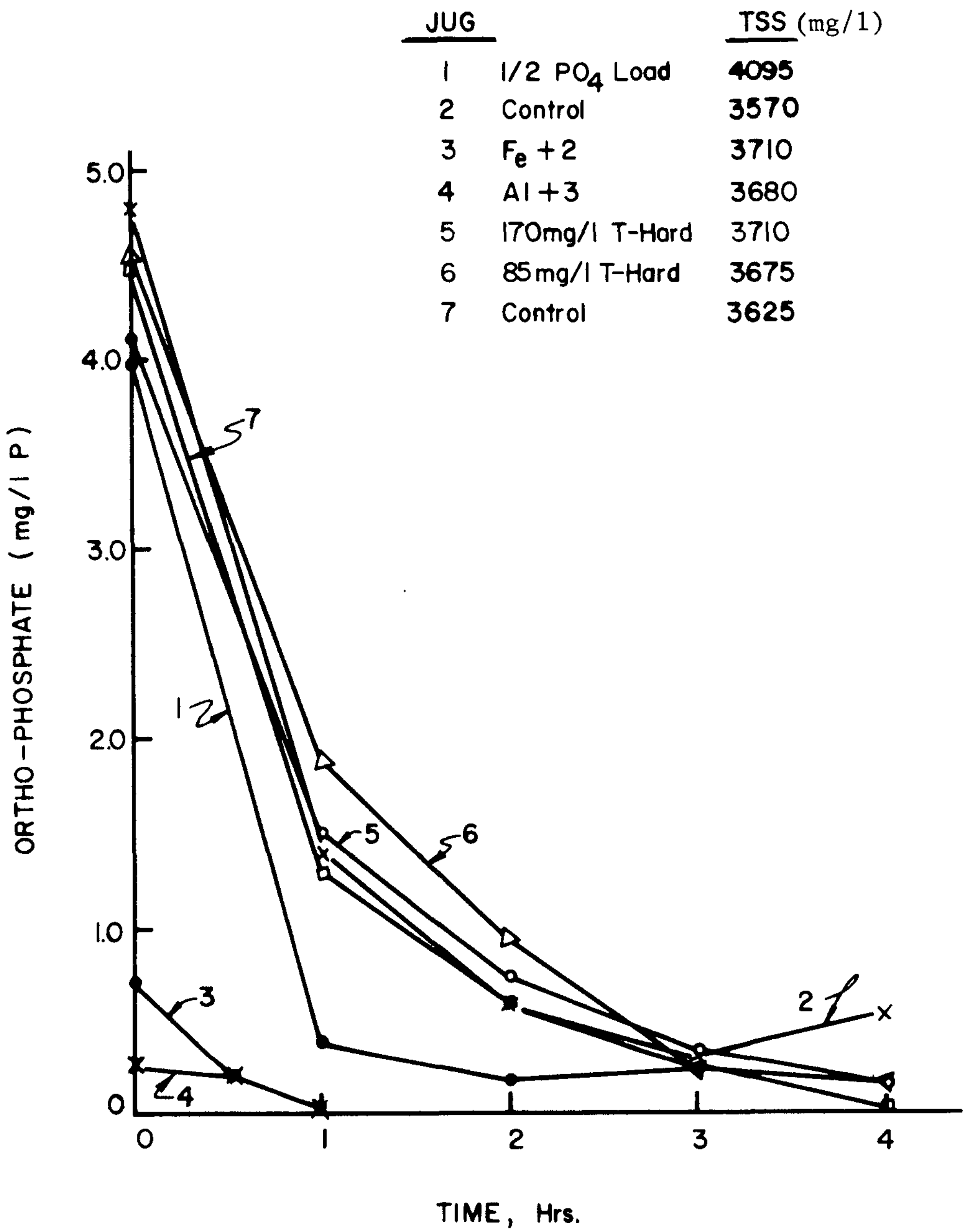


FIGURE 8-CHEMICAL ADDITION

theoretical value based on phosphate content of the jug components. The increase was attributed to release from the return sludge used in jug synthesis. Jugs No. 2 and 7 were used as controls.

After three hours aeration, Jugs No. 1, 2, and 7 showed greater than 90 percent soluble phosphorus removal. Jug No. 1 showed 90 percent removal within the first hour of aeration.

Jugs No. 5 and 6, synthesized with primary effluent deionized with respect to cations, contained less total hardness than was normal for raw waste (290 mg/l $CaCO_3$). These jugs, one with 170 mg/l hardness and the other with 85 mg/l, removed over 90 percent of the soluble phosphorus within 3 hours aeration. There was, however, no significant difference in phosphate removal between these and the control jugs.

Jugs No. 3 and 4 contained 25 mg/l Fe^{+2} and Al^{+3}, respectively. Each removed essentially 100 percent of the soluble phosphorus within one hour of metals addition. Apparently, the removal was by chemical precipitation before aeration commenced.

This experiment demonstrated that the hardness range studied had no effect on phosphate removal. The effect of decreased phosphate load on percent removal was not discernible, partly because initial phosphate concentrations were higher than anticipated. Addition of iron and aluminum salts brought about immediate reduction and essentially complete removal of soluble phosphorus within one hour.

4. Orthophosphate Variation

A set of jugs was prepared on July 27, 1967, to determine the effect of phosphate loading on orthophosphate removal. Jug No. 1 contained half the primary effluent of the control jugs. Phosphate-free city water served to dilute this jug to volume. Control Jugs No. 3 through 5 contained phosphate concentrations typical of the primary effluent. Samples from these jugs were composited since their constituents were identical. Jug No. 2 contained twice the normal phosphate load. Solids concentrations in all jugs were about 3,200 mg/l TSS. Jug constituents are seen in Table 3, and experimental results are found in Table 7.

Jug performances are seen in Figure 9. After three hours aeration, the jug having low phosphate concentration showed 82 percent removal, the control jugs 73 percent, and the jug with high phosphate concentration 50 percent removal. The data show that phosphate loading increases the magnitude of removal but decreases the percent removal under these test conditions.

Table 7

Orthophosphate Variation
July 27, 1967

Sample	Time	TSS (mg/l)	Ortho P (mg/l)	Ortho PO_4 (mg/l)	Temp °C	DO (mg/l)	Carbon NVOC (mg/l c)	Carbon SNVOC (mg/l c)	TOC Whole (mg/l OD)	TOC Filt. (mg/l OD)	Total Plate Count (Count/ml)
Jug 1	10:15 am	3150	2.8	8.6	21.5	4.1	-	-	-	-	5.5×10^5
	11:15 am	-	0.8	2.3	21.5	6.6	-	-	-	-	-
	12:15 pm	-	0.5	1.5	21.5	6.4	-	-	-	-	3.1×10^6
	1:15 pm	-	0.5	1.5	23.0	6.2	-	-	-	-	-
Settled Supernatant	1:45 pm	2	0.4	1.1	-	-	15.0	15.0	28.0	24.0	-
Settled Sludge	1:45 pm	-	1.5	4.6	-	-	-	-	-	-	-
Jug 2	10:15 am	3260	8.3	25.3	21.0	2.8	-	-	-	-	8.8×10^5
	11:15 am	-	5.2	14.9	21.5	5.7	-	-	-	-	-
	12:15 pm	-	4.8	14.7	21.5	6.0	-	-	-	-	3.1×10^6
	1:15 pm	-	4.1	12.5	22.5	5.7	-	-	-	-	-
Settled Supernatant	1:45 pm	2	4.5	13.8	-	-	20.0	15.0	22.0	22.0	-
Settled Sludge	1:45 pm	-	5.0	15.3	-	-	-	-	-	-	-
Jug 3, 4, 5 1/	10:15 am	3315	4.1	12.5	21.0 2/	3.3 ± 0.1 3/	-	15.0	3320	-	6.2×10^6
	11:15 am	-	1.6	5.0	21.0	6.1 ± 0.2 3/	-	-	-	-	-
	12:15 pm	-	1.3	4.0	21.5	6.3 ± 0.1 3/	-	-	-	-	-
	1:15 pm	-	1.1	3.3	22.5	6.1 4/	-	14.0	3480	-	3.5×10^6
Settled Supernatant	1:45 pm	-	1.3	4.0	-	-	15.0	-	30	-	-

1/Composite of Jugs 3, 4, and 5.
2/Temperatures ran same in Jugs 3, 4, and 5.
3/Average DO of Jugs 3, 4, and 5.
4/DO figure of Jug 3.

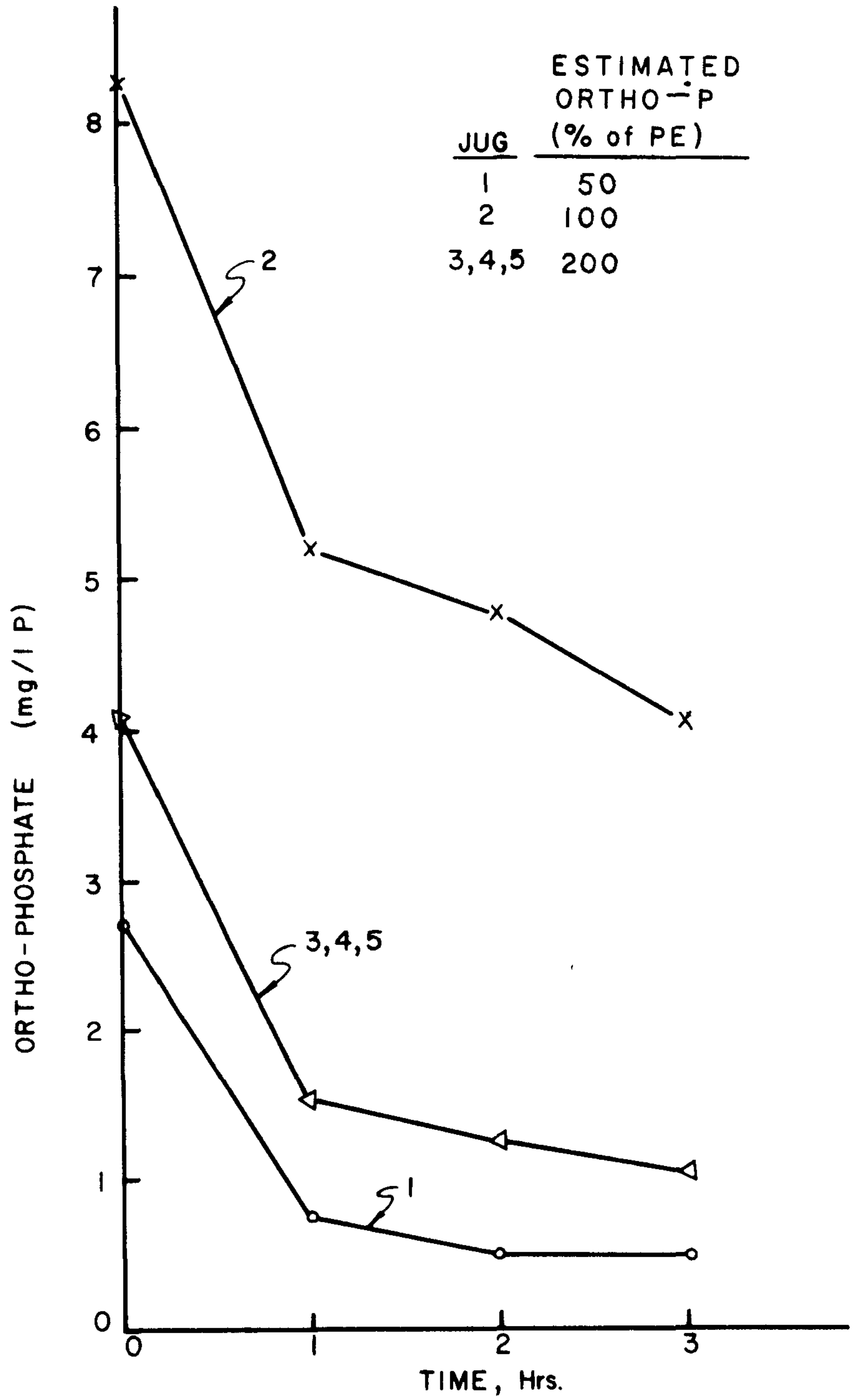


FIGURE 9 - ORTHOPHOSPHATE VARIATION

Sewage Characterization

A related purpose of the amenability program was to characterize samples collected at low and high flow from the various unit processes of activated sludge plants with regard to selected chemical paremeters. Additional samples from an aeration jug study were included in the characterization scheme. These samples were taken from a jug study whose operation and constituents were those which resulted in maximum phosphate removal. Primarily, the intention was to search for trends or correlatable functions within or between various chemical parameters which would be useful in defining the phosphate removal process. Frequently, phosphate removal realized from jug aeration was higher than that occurring in the aeration tanks. During such instances the probability of identifying gross differences of possible significance was greatly enhanced.

The samples were analyzed with and without solids to differentiate between the quantity of each respective chemical parameter associated with the solids and that associated with the liquid. Solids separation was accomplished by first decanting, then subjecting the resulting supernatant to further solids removal using a Sharples Ultra centrifuge. Samples resulting from such treatment are referred to as centrates of the original sample.

The significance of the results will not be discussed in this report since the basic purpose was for comparison with similar data from other plants studied. A separate report has been prepared.[3/]

Microbiological Studies

Microbiological studies conducted in conjunction with chemical and physical measurements were divided into two phases. Phase one consisted of bacterial isolation by the membrane filter technique and enumeration as total plate count. By this method, correlation was sought between bacterial population and both phosphate removal and mixed liquor suspended solids. The second phase involved selection of predominate colonial types isolated in phase one, transfer of the same to agar slants, and shipment to the Ada laboratory for identification. The final portion of this phase is under way. Results of the Pontiac study and all other amenability studies are reported under separate cover.[4/]

Data from the plate count determinations are recorded in Tables 2 and 4 through 7. There is no apparent relationship between total suspended solids concentrations and bacterial counts. Microbial populations remain essentially constant throughout the aeration tanks. In Jug Experiment No. 1 dealing with mixed liquor solids variation, total plate count increased with increasing solids and increasing time of aeration. Subsequent jug experiments revealed no trends in bacterial populations during the runs. From these data, it was concluded that bacterial counts and phosphate removal, if related, were not demonstrated by these measurement techniques.

SUMMARY

Studies at the East Boulevard Sewage Treatment Plant, Pontiac, Michigan, from July 21 through 29, 1967, showed inconsistent orthophosphate removals averaging 5 percent from aeration tank influents to final effluents.

Aeration tanks have a length to width ratio of 18:1 and employ tapered aeration. Dissolved oxygen concentrations average less than 1.0 mg/l in the activated sludge process. BOD loading was 6 lbs. BOD/100 lbs. MLSS/day. Mixed liquor suspended solids concentrations average 2,000 mg/l. Dye tracer studies point to short circuiting in the aeration tanks and final clarifiers. Modal detention times of about four hours for the aeration tanks were 60 percent of the theoretical. The dispersion index (t_{90}/t_{10}) was 2.5.

The effects of MLSS, phosphate, iron, and aluminum concentrations on phosphate removal were determined by pilot studies using aerated jugs. The optimum MLSS for satisfactory removal was 5,000 to 6,000 mg/l TSS. In considering MLSS versus phosphate removal, a figure of 3,500 mg/l TSS is practical for reasons of return sludge pumping capacity. Near this suspended solids level, variations in BOD and hardness caused little or no increase in percent phosphate removed. At the same concentration of suspended solids, increased levels of initial soluble phosphate effect a greater milligram uptake while decreasing the percent phosphorus removed. Addition of metals (aluminum and iron salts) brought about nearly complete removal of soluble phosphorus.

With sufficient dissolved oxygen concentrations in the mixed liquor, pilot studies pointed to mixed liquor suspended solids concentration as the significant factor limiting the amenability of Pontiac waste and sludge to satisfactory phosphate removal.

CONCLUSIONS

1. Plant removal of soluble phosphorus was limited to the level considered necessary for metabolic requirements.

2. Soluble phosphorus removal showed wide fluctuation within the aeration tanks during the study period as a result of present operation.

3. Displacement times within the aeration tanks are satisfactory for high orthophosphate removal based on observations at other plants.

4. Low levels of mixed liquor dissolved oxygen, when considered in light of a sufficient air supply and a low primary effluent BOD concentration, point to inefficient air transfer which may require modification if high orthophosphate uptake is to be obtained.

5. Pontiac waste and sludge demonstrated 30 to 90 percent orthophosphate removal in pilot studies at optimum MLSS concentrations.

6. Orthophosphate removal increased with increasing concentrations of total suspended solids.

7. Orthophosphate removal is independent of hardness concentrations within the range studied.

8. Within the range studied, increasing orthophosphate in the mixed liquor results in a greater quantity of phosphate removed and a decreased percentage uptake.

9. With adequate suspended solids concentrations in the system and a surplus of air supplied, increasing BOD concentrations in the mixed liquor increases phosphorus removal, but not significantly.

10. High phosphate removal resulting from metal ion addition to the mixed liquor concurred with results from studies at other plants.[1,2]

RECOMMENDATIONS

This plant is recommended for use as a research demonstration plant, provided:

1. The concentrations of mixed liquor suspended solids are adjusted, and at least 2 mg/l dissolved oxygen is established by remedying the air transfer system. Both changes should coincide with controlled flow and detention.

2. The effects on phosphorus removal of recycling waste activated sludge and digester supernatant to the main flow, thereby designing an effective treatment for handling recycle streams, should be considered in the demonstration.

3. The demonstration should cover a 12-month period to evaluate seasonal temperature influences.

APPENDIX

ANALYTICAL PROCEDURES

Sample Preparation

Samples collected for analyses in the field were processed as outlined in the respective analytical test procedures.

Samples sent to the Robert S. Kerr Water Research Center are referred to as whole, centrate, whole fixed, and centrate fixed.

The following table lists the treatment each type received preceding shipment to Ada.

	Sample	Treatment
1.	Whole	Shipped as is with no treatment.
2.	Whole fixed	Shipped as is plus 1 ml conc. sulfuric acid per liter.
3.	Centrate	The sample was passed through a Sharples motor driven, laboratory model continuous centrifuge, equipped with a clarifier bowl, at 23,000 rpm. The sample was delivered to the centrifuge by a peristaltic pump at a feed rate of 150 ml/min. The bowl was cleaned and rinsed with distilled water after each sample.
4.	Centrate fixed	The centrate sample plus 1 ml conc. sulfuric acid per liter.

All samples were shipped in either 250 ml plastic bottles or 1,000 ml cubetainers.*

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*Hedwin Corporation, 1600 Roland Heights Avenue, Baltimore, Maryland 21211.

Chemical Tests

1. Orthophosphate

In the field, initial samples for orthophosphate were filtered immediately using Schleicher and Schuell No. 588 paper. Subsequent handling by the stannous chloride procedure in Standard Methods[5] included the use of a spectrophotometer (Bausch and Lomb Spectronic 20) at 690 mμ.

A continuous automatic sampling device, built specifically to support jug-study phosphate analyses, supplied whole samples to a Technicon AutoAnalyzer platformed after Gales and Julian.[6] The manifold and reagents were modified to more closely approximate Standard Methods.[5] The arrangement, in order of sequence, was as follows:

a. A six-port peristaltic pump circulating jug mixed liquor continuously.

b. An open-shut solenoid valve regulating flow from a T-connection in each circulating jug line.

c. A stepping relay alternately activating one of six jug sample solenoids and one solenoid to a distilled water supply.

d. A master timer regulating the stepping relay over two-minute intervals.

e. A Technicon proportioning pump providing the flow of samples and distilled water to a Technicon continuous filter. This pump also diluted filtered samples with distilled water in the ratio of 1:40, respectively.

No significant orthophosphate bleedback occurred in unfiltered samples over a 30-minute period. Whole plant samples were run on the Technicon AutoAnalyzer using a Technicon Sampler II and continuous filter with samples reaching the filter within 30 minutes.

2. Total Phosphate

Fixed whole samples were analyzed at the Ada laboratory within 15 days of sample collection. Initially whole samples were blended for 3 to 5 minutes in a Waring Blendor and then analyzed by the persulfate procedure of Gales and Julian.[6] The procedure was modified to more closely approximate the procedure of Standard

Methods[5] for orthophosphate in that the samples were neutralized after digestion. Also the manifold design and reagents for the AutoAnalyzer were adjusted to deliver approximately the amount of reagents per sample outlined by Standard Methods.[5]

3. Carbon

Instrumentation and procedure for carbon analysis in the field followed that of Van Hall et al.[7,8] Preliminary homogenization in a Waring Blendor provided representative syringe sampling of whole samples. Two acidified and purged aliquots of each sample were injected into the Beckman Carbonaceous Analyzer--a whole homogenate and an homogenized filtrate.* Both results are nonvolatile organic carbon (NVOC). Whereas carbon figures for a S&S No. 588 filtrate and a 0.45 μ Millipore filtrate do not differ significantly, the carbon value for the S&S filtrate was reported as soluble nonvolatile organic carbon (SNVOC). Acetic acid standards provided instrument calibration.

4. Total Oxygen Demand

Samples were run by the method of Stenger and Van Hall[9] using the instrument and techniques described therein. Analysis of whole samples included preliminary homogenization. A homogenized portion of each sample received S&S No. 588 filtration before TOD analysis and was reported as "filtered TOD." Sodium acetate standards were used.

5. Total Hardness

In the field, hardness was performed by EDTA titrimetry according to Standard Methods[5] (Method B, pages 147-152).

Physical Tests

1. Solids

Tests for total suspended and total volatile suspended solids were conducted according to Standard Methods[5] (Methods C and D, pages 424-425). Reeve Angel 2.4 cm glass fiber filters, grade 934AH, were used in lieu of asbestos mats. Gooch crucibles were fired at 600°C, cooled, the filter mats placed in the crucibles and dried at 103°C for at least 1 hour before initial weighing. At intervals crucibles with

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*Schleicher and Schuell filter paper, No. 588.

filters were subjected to 600°C furnace temperatures to check for weight loss due to the filter. Total and total volatile solids were determined according to Standard Methods[5/] (Methods A and B, pages 423-424).

2. Dissolved Oxygen

Measurements were made in situ with a YSI Model 51 oxygen meter equipped with a Model 5103 oxygen/temperature probe. The meter was calibrated against the Azide Modification of the Winkler Method described in Standard Methods[5/] (Method A, pages 406-410). The meter was also calibrated against saturated air at the temperature of the test medium.

3. Hydrogen Ion Concentration

All pH measurements were made using a line current Beckman Zeromatic II equipped with a glass/calomel electrode system. Measurements were made on whole-untreated samples.

4. Temperature

Temperature measurements were made with a battery powered thermistor-thermometer.

5. Specific Conductance

Whole samples were measured using an Industrial Instruments Model RC 16B2 wheatstone bridge with cathode ray null indicator equipped with platinum electrode (cell constant 1). Resistance measurements at a constant temperature for both samples and a KCl standard gave specific conductances in μmhos/cm by calculation.

Mention of products and manufacturers is for identification only and does not imply endorsement by the Federal Water Pollution Control Administration or the U. S. Department of the Interior.

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ACKNOWLEDGEMENT

Gratitude is expressed for the generous participation of many individuals which contributed to this study. The field work was made possible by the cooperation of the city of Pontiac, Michigan. Special recognition is given to Mr. John Hennessey, Plant Superintendent. Staff members of the Robert S. Kerr Water Research Center are acknowledged as follows: Messrs. M. L. Cook and J. F. McNabb for analytical support in the field; Messrs. R. L. Cosby, K. F. Jackson, and B. D. Newport for analytical support at the Center; and Mr. Tommy Redman for drawing of the figures.

GLOSSARY

AT	Aeration Tank
BOD	Five-Day Biochemical Oxygen Demand
Comp.	Composite
DO	Dissolved Oxygen
FE	Final Effluent
ft^3	Cubic Feet
gal.	Gallon(s)
gpm	Gallons Per Minute
l	Liter(s)
mg	Million Gallons
mgd	Million Gallons Per Day
mg/l	Milligrams Per Liter
min.	Minutes
ml	Milliliter(s)
ML	Mixed Liquor
MLSS	Mixed Liquor Suspended Solids
mμ	Millimicrons
mv	Millivolt(s)
NVOC	Nonvolatile Organic Carbon (Whole Sample)
PE	Primary Effluent
ppb	Parts Per Billion = Micrograms Per Liter
psi	Pounds Per Square Inch

rpm	Revolutions Per Minute
RS	Return Sludge
SNVOC	Soluble Nonvolatile Organic Carbon (Filtered Sample)
TOD	Total Oxygen Demand
TS	Total Solids (Dissolved Plus Suspended)
TSS	Total Suspended Solids