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Title: The Effect of Elevated Pressure on the Activated Sludge Process

Abstract approved [redacted]
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A study of the effect of elevated pressure on the activated sludge waste treatment process is presented. The method of study involved a comparison of two laboratory, batch type, activated sludge units. One unit was operated at atmospheric pressure as a base control and the other operated at elevated pressures up to 60 psig. All other controllable parameters were kept constant. The units were compared on the basis of:

1. The type of biological growth present in the mixed liquor,
2. The mass growth rates of the biological organisms.
3. The removals of chemical oxidation demand.
4. The dissolved oxygen concentration in the mixed liquor.
5. The pH of the mixed liquor.

Results of this study showed that:

1. Elevated pressure of 60 psig does not affect the type of

biological growth present in the mixed liquor, but it does hinder the formation of long-chain filamentous growths.

2. The sampling methods used for determining the growth rates were not adequate and provided no basis for comparison.
3. Under the conditions of this study, elevated pressures have no effect on the removal of chemical oxygen demand in the activated sludge process.
4. The dissolved oxygen concentration in the mixed liquor increases with the pressure, but, under the conditions of this study, not in a direct relationship.
5. Elevated pressure of 60 psig does not adversely affect the pH of the mixed liquor.

This study is one phase of an investigation to determine the feasibility of increasing the reaction rates of the activated sludge process by subjecting the process to both high pressure and high shear mixing.

THE EFFECT OF ELEVATED PRESSURE ON THE ACTIVATED SLUDGE PROCESS

by

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INTRODUCTION

Since the inception of the activated sludge process of waste treatment, many modifications of the original design have been made to increase the efficiency and capacity of the process. During the past two decades, these modifications and the research involved have shown that one of the limiting factors in obtaining maximum efficiency in the process is the supply of oxygen to the biologically active sludge (9, p. 792). The research presented in this thesis is also directed towards solving the problem of oxygen supply, but in a different direction than has been previously taken. The direction to be taken herein is to elevate the pressure at which the activated sludge process operates, thereby increasing the free dissolved oxygen concentration available to the biological organisms.

Purpose and Scope. The purpose of this thesis is to study the effect of elevated pressure upon the activated sludge process as evidenced by:

1. The type of biological growth present in the mixed liquor.
2. The mass growth rates of the biological organisms.
3. The removals of chemical oxygen demand (COD).
4. The dissolved oxygen (D. O.) concentration in the mixed liquor.

5. The pH of the mixed liquor.

The effect of pressure on the above parameters was studied in a system in which only the pressure was varied and all other controllable parameters were kept constant.

This study is one phase of an investigation to determine the feasibility of increasing the reaction rates of the activated sludge process by subjecting the process to both high pressure and high shear mixing. Specifically, the long term goal is to determine the manner in which the biochemical oxidation rate will vary with pressure, aeration rate, degree of mixing, organic loading, and temperature.

Method of Study. The effect of elevated pressure upon the activated sludge process was determined by comparing results from two identical systems, one operated at atmospheric pressure as a base control and one pressurized. The pressure was varied between zero and 60 psig; the remaining controllable parameters, aeration rate, degree of mixing, organic loading, and temperature were held constant. An activated sludge was developed from a combination of settled sewage and seed material from an activated-sludge treatment plant and was acclimated to a synthetic, organic media having the general characteristics of a domestic sewage. The pressurized unit was operated at each pressure level for a sufficient period of time to allow the activated sludge to establish equilibrium with respect to the parameters being measured.

THE ACTIVATED SLUDGE PROCESS

The activated sludge process is a biological system in which a mass of microorganisms aerobically degrade organic wastes (6, p. 213). The process is schematically diagrammed in Figure 1. A biologically degradable waste which may have received preliminary treatment to remove settleable material is seeded with an actively growing mass of microorganisms. This mixture, called the mixed liquor, flows to an aeration tank where a sufficient quantity of air is diffused into the mixed liquor to provide both the oxygen necessary to maintain aerobic conditions and the mixing needed to maintain the biological growth in suspension. The mixed liquor then flows to a sedimentation tank where the biological growth is settled and the clarified liquid is removed. A portion of the biological growth which settles is recycled to seed the incoming waste stream.

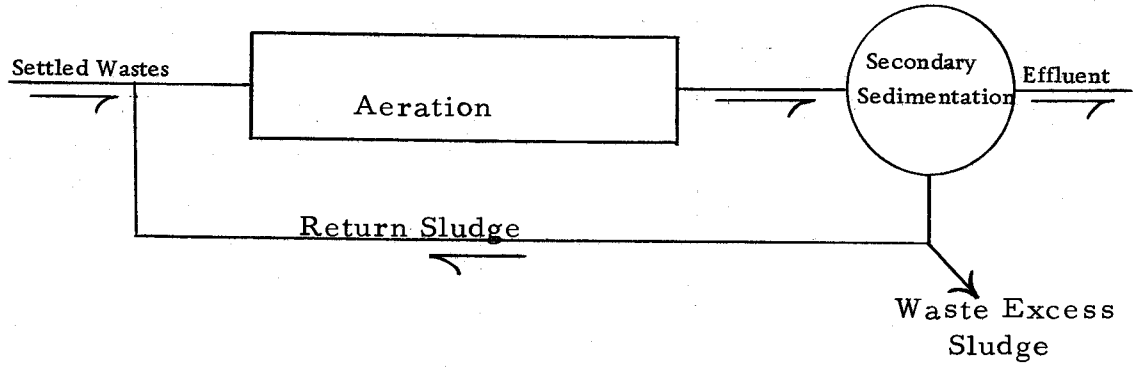


Figure 1. Schematic Diagram of a Conventional Activated Sludge System.

The biological process can be summarized by the following relationship:

$$\text{Organic matter} + O_2 \xrightarrow[\text{organisms}]{\text{micro-}} CO_2 + H_2O + \text{new microorganisms}$$

The microorganisms, in the presence of free dissolved oxygen, oxidize part of the organic matter. This oxidation supplies the organisms with the energy needed for the synthesis of new cellular material from the remainder of the organic matter (2, p. 14).

The above relationship indicates that the major factors influencing the activated sludge process are the microorganisms, the free dissolved oxygen, the organic matter, and the environment in which the process takes place.

The Microorganisms. Normal activated sludge is made up of bacteria, fungi, protozoa, rotifers, and sometimes nematodes or other forms of higher animal life. These organisms comprise a system in dynamic equilibrium in which food matter is utilized by bacteria and fungi; the bacteria and fungi are in turn utilized as a food source by rotifers and other forms of higher animal life.

Bacteria are the most important group of microorganisms, for they are primarily responsible for the stabilization of the organic

matter and for floc formation. Many different types of aerobic and facultative bacteria are found in the biological mass. The type inhabiting a particular operation depends on the nature of the organic compounds in the wastes being stabilized.

Fungi, as do bacteria, stabilize organic matter, but are usually not desirable in activated sludge since the filamentous forms which would thrive in the process prevent good floc formation and hinder the final settling operation. A carbohydrate, unusual organic compounds, low pH, and nutritional deficiencies all favor the development of fungi as the predominant biological growth.

Protozoa do not contribute directly to the stabilization of the organic matter in the wastes being treated, but are required for the sludge to have good settling characteristics. Since the organic concentration is usually too low to support animal growth, the protozoa will utilize the bacteria as a food source. In the low energy system, characterized by most activated sludge processes, stalked protozoa such as the Vorticella will be predominant.

The prevalence of rotifers in an activated sludge system is dependent upon the energy level. Since rotifers thrive in low energy systems, they are indicators of an extremely stable biological system (6, p. 214).

Oxygen Requirements. The demand for oxygen is a direct function of the biological metabolism of the microorganisms, and the supply of oxygen may be a limiting factor in activated sludge systems. If the demand for oxygen is greater than the supply, an anaerobic condition may develop which will hinder the development of the protozoans and increase the growth of filamentous bacteria. To maintain aerobic operation, a minimum dissolved oxygen concentration of approximately 0.5 mg/L is required (6, p. 221).

Nutrient Requirements. The microorganisms oxidize organic matter to form protoplasm and to produce energy. It is necessary that the organic matter contain essential elements for these functions to occur. Domestic sewage contains all of the required elements, but some industrial wastes are deficient in key elements. These elements can be added to the process to make up for the deficiency.

The primary nutrients required are nitrogen and phosphorous. Equally important are trace quantities of potassium, calcium, magnesium, molybdenum, cobalt, and iron. Natural waters supply sufficient trace elements to meet the needs of the microorganisms, but the quantities of nitrogen and phosphorous may have to be controlled.

One of the most important aspects of nutritionally deficient

wastes is their effect on the population balance between the biological organisms. Since fungi form protoplasm with a lower nitrogen content than bacteria, a partially nitrogen-deficient waste will stimulate the fungi over the bacteria. The same is true for a phosphorous deficiency (6, p. 224).

Environmental Factors. Two environmental factors of importance in activated sludge systems are pH and temperature. The pH of a system affects the type of growth that will develop. Normal bacterial predomination occurs between pH limits of 6.5 and 9.0. Below a value of 6.5 the metabolic functions of the bacteria are adversely affected while those of the fungi are not affected. At a pH of 4.5 the bacteria cease to function, allowing the fungi to dominate the biota. The rate of biological metabolism will be retarded with pH values above 9.0 (6, p. 226). Since it is important that the pH of a system be maintained at a proper level, the system must have sufficient buffer capacity to resist any pH change.

The temperature of the system affects the rate of biological reaction. An increase of 10°C between the limits of 0°C and 35°C will approximately double the reaction rate, and high temperatures will result in relatively high reaction rates while low temperatures will produce a slow rate of metabolism (2, p. 67).

Oxygen as a Limiting Factor. The transfer of oxygen from the diffused air to the microorganisms has long been considered one of the major engineering problems in the activated sludge process (6, p. 222). To become available to the microorganisms, the oxygen in the air must pass through three barriers. One or more of these barriers may control the rate at which oxidation of the organic material can take place (8, p. 28).

The barriers and the rates associated with these barriers are:

1. The gas-liquid interface and the rate at which oxygen is transferred from the air to the liquid.

2. The liquid phase and the rate at which oxygen is diffused through the liquid to the activated sludge floc.

3. The floc particles and the rate at which the oxygen is diffused into the floc particles.

Two theories, the penetration theory and the film theory, have been developed to explain the mechanism of gas transfer across the gas-liquid interface. Since application of the penetration theory to present technology is limited, the film theory has been used herein to explain the mechanism of oxygen transfer through the gas-liquid interface.

The film theory is based on a physical model in which two fictitious films exist at the gas-liquid interface, one liquid and one gas. The gas transfer mechanism is shown in Figure 2. The films

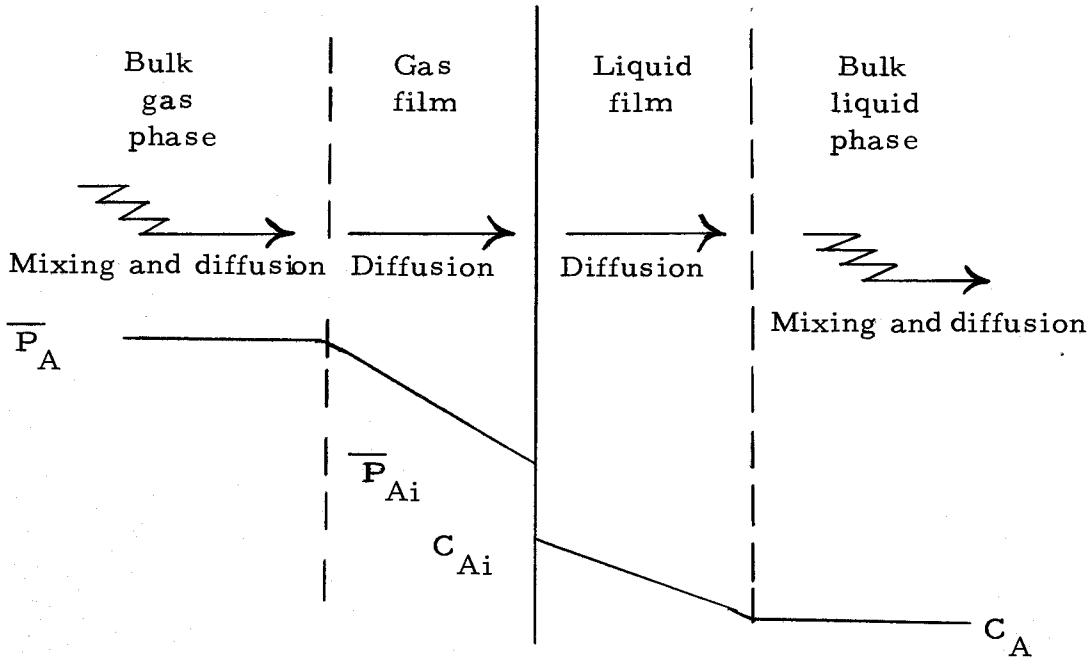


Figure 2. Schematic sketch of the gas transfer mechanism.

are considered to be stagnant, to furnish all resistance to gas transfer, and to persist regardless of how much turbulence is present in the gas and liquid. The turbulence, in this case, only serves to reduce the film thickness (10, p. 172).

The rate at which a gas is transferred across the fictitious boundary film, under steady-state conditions in which there is no

accumulation of diffusing molecules in either film, can be shown to be:

$$N_A = K_G A(\overline{P}_A - \overline{P}_{Ai}) = K_L A(C_{Ai} - C_A) \qquad (10, p. 174)$$

where N_A = local rate at which component A is transferred across a gas-liquid interface, $\frac{\text{lb mole}}{\text{hr.}}$

K_G, K_L = mass transfer coefficients for gas and liquid phases respectively, $\frac{\text{(lb mole)}}{\text{(hr) (ft}^2\text{) (atm)}}$ and ft/hr.

P_A, P_{Ai} = partial pressures of component A in the bulk gas phase and at the interface respectively, atm.

C_{Ai}, C_A = concentrations of A at the interface and in the bulk liquid phase respectively, $\frac{\text{lb mole}}{\text{ft}^3}$.

A = area of the gas-liquid interface, ft^2.

The terms enclosed in parenthesis in the above equation can be thought of as "potential differences" that motivate transfer across the boundary films. The concentration, C_{Ai}, is assumed to be in equilibrium with the partial pressure, P_{Ai}, and the two are related by Henry's Law.

Henry's Law states that "the mass of gas dissolved by a given volume of solvent, at a constant temperature, is proportional to the pressure of the gas in equilibrium with the solution" (4, p. 345).

In equation form Henry's Law states:

$$P_{Ai} = H\, C_{Ai}$$

where H is a proportionality constant and P_{Ai} and C_{Ai} are as defined previously.

The rate at which oxygen is diffused through the liquid phase to the floc particles depends on the diffusion properties of the liquid, the degree of turbulence in the liquid, and the quantity of oxygen that is bound in the floc particles. The diffusion process is accelerated by increasing both the turbulence and the amount of oxygen that is bound in the floc. Turbulence influences the diffusion process by physically transporting the dissolved oxygen through the liquid phase. Increasing the quantity of oxygen bound in the floc increases the "potential difference" across the liquid-floc interface.

Finally, the amount of oxygen per mass of organisms that is diffused into the floc particles is dependent upon the size of the particles. Considering spherical floc particles, the surface area per unit mass of floc increases with a decrease in particle diameter. Consequently, the amount of available oxygen per unit mass of organisms increases with the decrease in floc diameter. Also, the depth at which the diffusing oxygen must penetrate to completely saturate the floc decreases with decreasing particle size. Without this saturation, the oxidative processes will not proceed at maximum efficiency.

METHOD

To determine the effect of elevated pressure on the activated sludge process, a comparison was made of the results obtained from two laboratory activated-sludge test units which were operated under identical conditions, with the exception that one was subjected to elevated pressure and the other was maintained at atmospheric pressure. The following determinations were made to serve as a basis of comparison:

1. Type of biological growth in the mixed liquor.
2. Mass growth rates of the organisms.
3. Removal of organic material as measured by the chemical oxygen demand of the mixed-liquor filtrate.
4. Dissolved oxygen concentration in the mixed liquor.
5. pH of the mixed liquor.

Unless otherwise noted, the specific tests used in the preceding determinations were performed in accordance with the methods presented in Standard Methods for the Examination of Water and Wastewater (1).

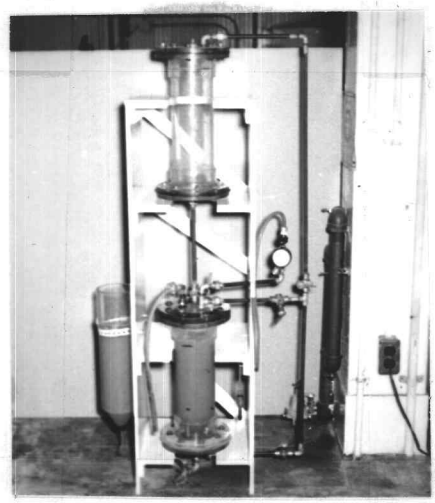
Apparatus. A laboratory activated sludge process was developed for the experimentation. The process consisted of two units-a control unit which was operated entirely at atmospheric pressure and a test

unit which was operated over a pressure range between zero psig and 60 psig. Figure 3 shows the units in operation, and Figure 4 shows a detailed diagram of the experimental apparatus.

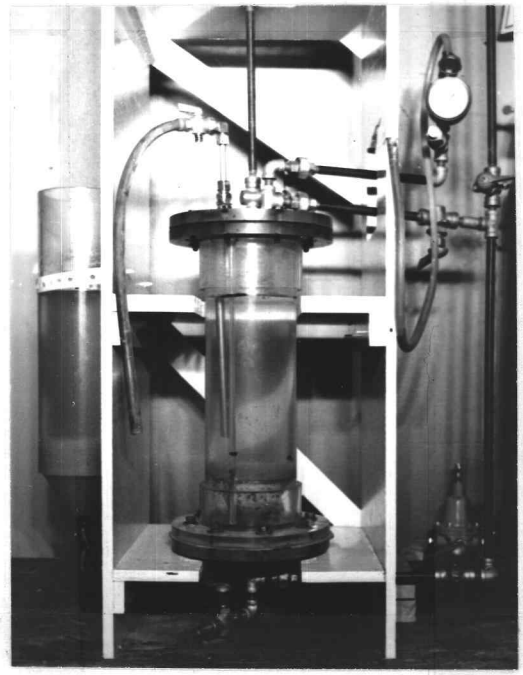
Both units were operated on a batch, fill and draw basis in which the aeration and settling processes were performed in the same chamber. The units were maintained on a twice-daily feeding basis. During one of the feedings, the activated sludge was settled, the clarified liquid decanted, the feed added, and the system made up to volume with distilled water.

Except for the closed ends of the test aeration chamber to permit pressurization, the aeration chambers were similar in design, each having a liquid capacity of two liters. In addition to the aeration chamber, the test unit included two feed chambers which were used to add the synthetic waste while operating under elevated pressure. The overall design of the test unit allowed for the addition of the organic waste without losing pressure in the aeration chamber. The clarified liquid could be removed without loss of pressure.

Controlled Parameters. Four parameters of the activated sludge process were controlled during the experimentation. These were the pressure (psig) at which the unit was operating, the concentration (mg/L) of suspended solids in the mixed liquor, the rate (ml/min, measured at atmospheric pressure) at which air was



Combined apparatus.



Control and test aeration chambers

Figure 3. Experimental Apparatus.

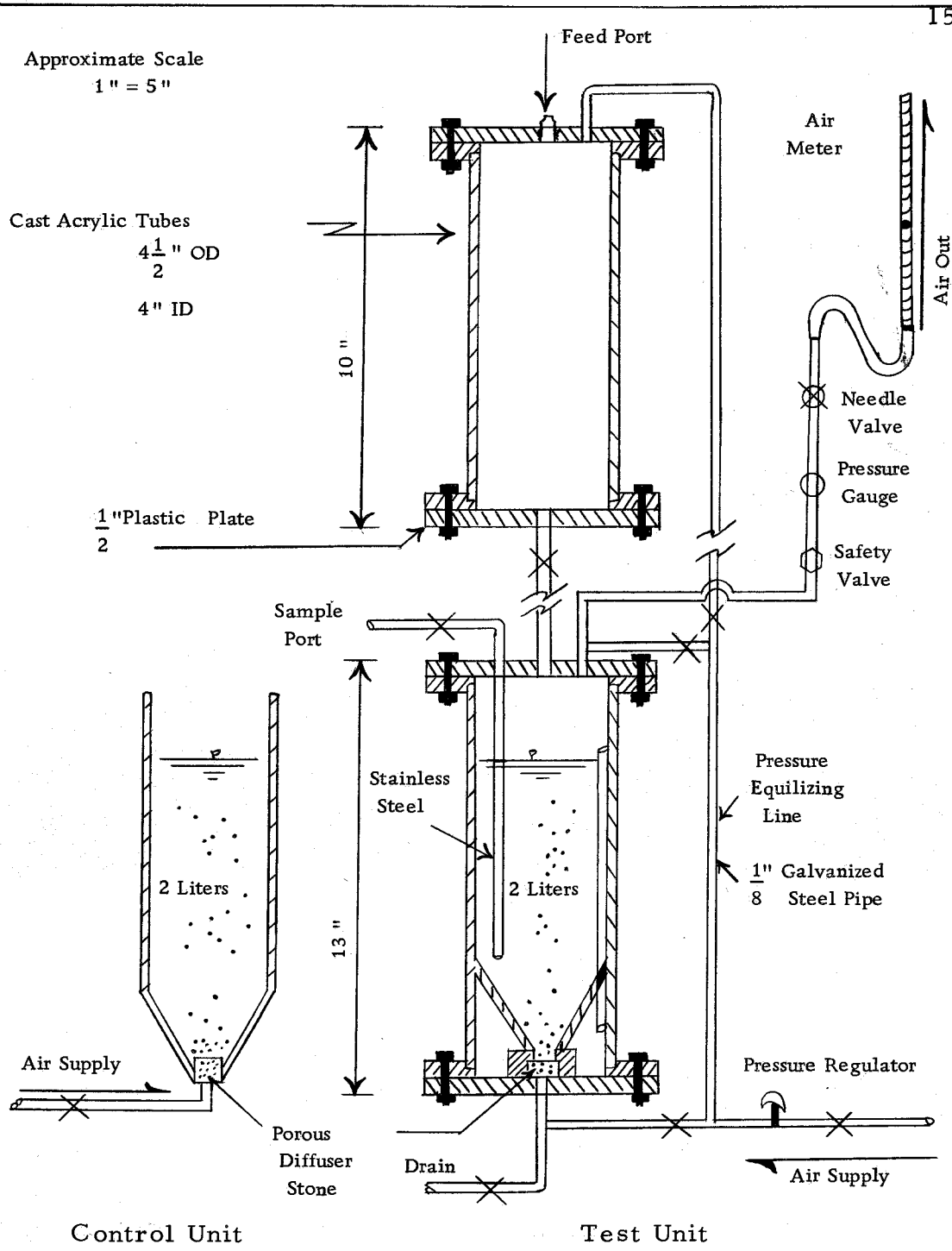


Figure 4. Experimental Apparatus.

passed through the aeration chamber, and the amount (mg/L COD) of synthetic waste that was fed to the mixed liquor.

The control unit was operated at atmospheric pressure, and the test unit was operated at pressures of zero psig, 30 psig, and 60 psig for the periods shown in Figure 5. One week was allowed for acclimation at each pressure level. Pressure measurements were made with a Marshalltown pressure gauge which was calibrated by standard weights to one psig accuracy.

The mixed liquor suspended solids concentration (MLSS) was kept between 2, 000 and 4, 000 mg/L during daily operation. These solids, which comprise the activated sludge, were cultured from a combination of raw settled sewage from the City of Corvallis sewer system and the mixed liquor of a Chicago Pump Company extended aeration plant at the Corvallis Trailer Park, Corvallis, Oregon. The test and control mixed liquor were both originally from this culture. Once experimentation was begun, no addition of new mixed liquor and no exchange between test and control mixed liquors was made. The only manipulation of the mixed liquor was the wasting of suspended solids to maintain the proper concentration.

The aeration rate was held constsnt at 1, 000±25 ml/min and was measured at atmospheric pressure. This rate is comparable to prototype activated sludge plants and provided adequate mixing of the

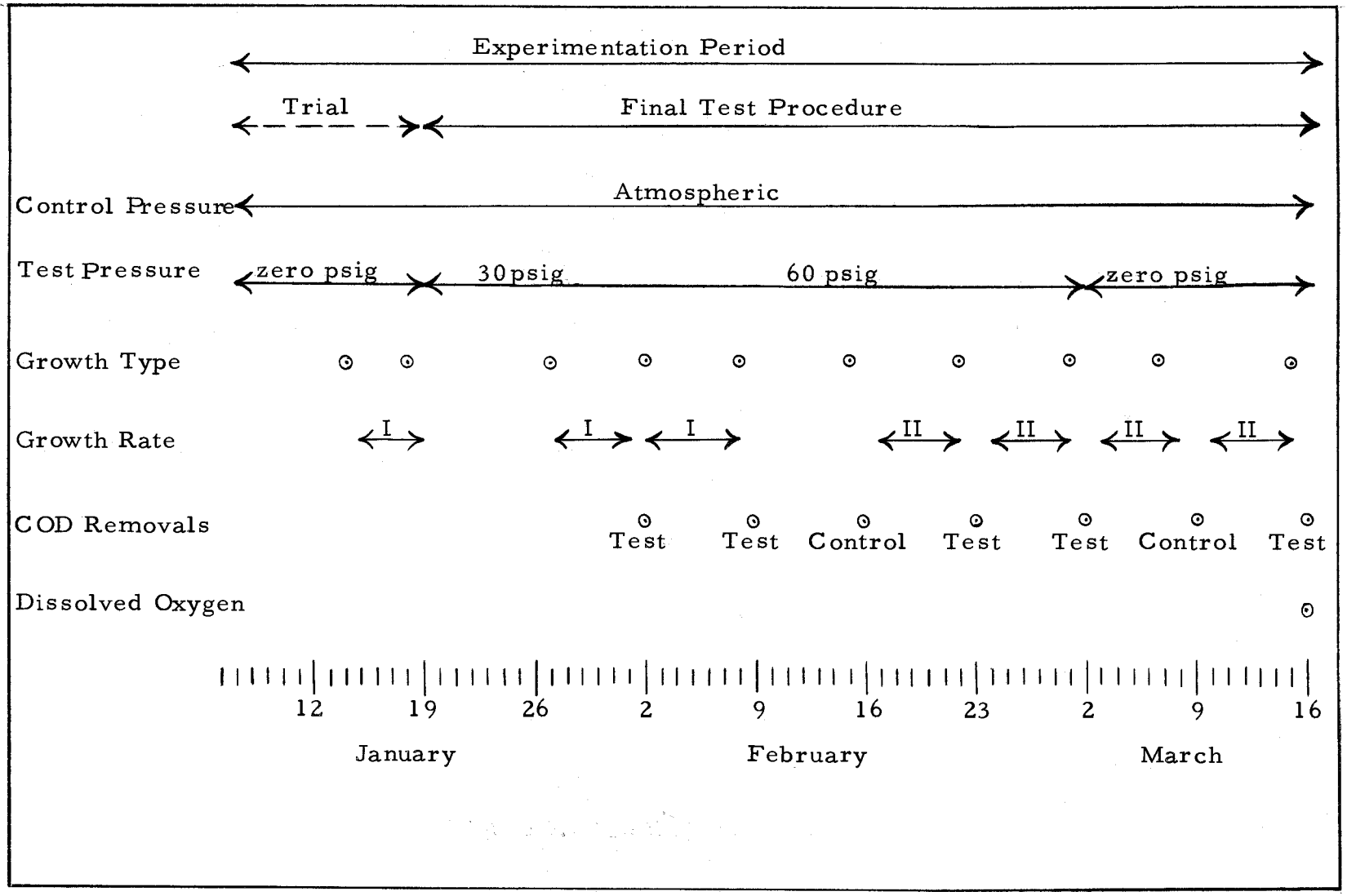


Figure 5. Testing Schedule

mixed liquor. A Roger Gilmont Instruments flowmeter, Catalog No. 63323-3, was used to measure the air rate.

The amount of synthetic waste, measured as mg/L COD, added to each unit was held constant during daily operation. The amount of synthetic waste added daily was designed to produce approximately 200 mg/L volatile solids in the mixed liquor per day. Also, an amount of buffer solution sufficient to produce an alkalinity of 150 mg/L, as $CaCO_3$, was added to the mixed liquor each day. The formulation of the synthetic waste and the buffer solution is presented in Table 1.

Table 1. Synthetic Waste Formulation.

1. Synthetic waste

Glucose	90 mg/L
Nutrient Broth	60 mg/L
Urea	25 mg/L
$NaHPO_4 \cdot 7H_2O$	15 mg/L
NaCl	20 mg/L
KCl	20 mg/L
$MgSO_4 \cdot 7H_2O$	20 mg/L
Castile Soap	10 mg/L

One Strength Solution = 177 mg/L COD

2. Buffer solution

Na_2CO_3 . . . . . 2 g/L

$NaHCO_3$ . . . . . 7 g/L

A 50 strength solution was prepared from which 664 mg/L COD were added to the system every twelve hours. Distilled water was used to replace the clarified liquid that was removed during the feeding operation.

Tests Performed. Figure 5 shows the schedule at which the following tests were performed.

The type of biological growth present in each unit was determined by weekly microscopic and visual observations. The microscopic observations were conducted with a Spencer monocular microscope at 100X and 430X. Both units were observed at the same time.

The mass growth rates were measured by the increase per day of the concentration of the mixed liquor volatile suspended solids (MLVS). Two sampling methods were used during the experimentation. (I) Each day for five days duplicate 25 ml samples were taken at a set time, the average value calculated, and the change in MLVS determined. This procedure measured the change during each day for five days. (II) At the beginning and the end of a five day period,

six 25 ml samples were made and an average value calculated. The two average values were subtracted and the change in MLVS determined for a five day period. This procedure gave an average per day growth rate.

Percent COD removal in the filtrate of the mixed liquor after 30 minutes contact of the mixed liquor with the synthetic waste was used as a measure of the system's ability to degrade the synthetic waste.

After a series of preliminary tests, the following procedure was adopted. First the mixed-liquor suspended solids concentration was adjusted to approximately 2,500 ml/L. Then a quantity of chloride-free, synthetic waste sufficient to provide 600 mg/L of COD was added to the system at each of the following times: 0, 1, 2, 2.5, 3, and 3.5 hours. The first two feedings were used to overcome any lag characteristics the system might have had. The last three feedings were used for the COD removal test. Each reduction test consisted of four individual thirty-minute tests successively performed. For these individual tests, one 50 ml sample was withdrawn from the aeration chamber immediately before the addition of the synthetic waste, and one 50 ml sample was withdrawn at five, ten, 15, 20, and 30 minutes after the addition of the waste. These samples were then filtered through a No. 40 filter paper, and duplicate

20 ml samples of the filtrate were analyzed for COD. A 0.100 N potassium dichromate solution and a 0.100 N ferrous ammonium sulfate solution were substituted in the test for the standard 0.250 N solutions. The percent removal of the COD added after thirty minutes was then calculated for each individual test.

The dissolved oxygen in the mixed liquor of the test unit was determined on the final day of experimentation by using a galvanic cell dissolved oxygen probe. Measurements were obtained at 0, 30, and 60 psig and were made at equilibrium conditions. The probe, with readings in microamperes, was calibrated by the Modified Winkler Method, using water from the City of Corvallis distribution system as a primary standard.

Temperature and pH measurements of the mixed liquors were made periodically. A Beckman glass electrode pH meter, Model #2, was used to determine pH, and the temperatures were recorded in degrees centigrade.

RESULTS

The following results were obtained from the test performed and provided the basis of comparison between the pressurized system and the non-pressurized system.

Growth Types. At the onset of the experimentation, microscopic examinations showed that both units contained in their mixed liquors a bacterial mass, free swimming paramecia, stalked ciliates, rotifers, and a filamentous growth. The rotifers were the predominating form of higher animal life, and there were comparatively few paramecia and ciliates. In the second and third weeks, the same organisms were observed except that no free swimming paramecia were noted. A species of water mite and a species of diatom developed in both units during the fourth and fifth weeks respectively, while the rest of the biota remained unchanged. For the remainder of the experimental period, the types of growth continued to be the same as those observed during the fifth week. However, the amount of filamentous material in the control unit was much less than in the test unit. Microscopic observations during the final week of experimentation showed that, while no change from the fifth week had occurred in the test unit, the control unit had become clear of filamentous material.

A significant change in the appearance of the mixed liquors in the test unit was noted during the experimentation. At the beginning, the mixed liquor consisted of brown flocculent material and clumps of black filamentous growth as long as two inches. After the test unit was pressurized, the large filamentous growth decreased in size and the mixture became gray. When the pressure was returned to atmospheric, the mixture returned to its original appearance.

The control unit began exactly like the test unit, but the clumps of filamentous growths gradually decreased in numbers. They finally disappeared after the fifth week, leaving a continuous mixture of brown flocculent material. During the sludge wasting procedure, it was observed that large clumps of filamentous material were removed from the control unit. This removal may account for the difference of filamentous material concentration between the two units.

Growth Rates. The results of the growth rate studies are presented in Table 2.

Table 2. Growth Rate Results

GROWTH RATES I

Date	Pressure	Change MLSS per day, mg/L Test Unit	Control Unit
1-16	0 psig	+91	+29
1-17	0 psig	+488	+399
1-18	0 psig	-254	+10
1-19	0 psig	+261	+12
	Average per day	+147	+113
1-28	30 psig	+214	-372
1-29	30 psig	+61	+156
1-30	30 psig	+961	+271
1-31	30 psig	-84	+576
2- 1	30 psig	-456	-792
	Average per day	+139	-32
2- 3	30 psig	+54	No sample
2- 4	30 psig	+43	No sample
2- 5	30 psig	+93	+61
2- 6	30 psig	-172	-7
2- 7	30 psig	-202	+25
2- 8	30 psig	+75	-105
	Average per day	-18	-6

GROWTH RATES II

Date	Pressure	Average Change MLSS per day, mg/L Test Unit	Control Unit
2-24 to 3-1	60 psig	+149	+52
3-3 to 3-8	0 psig	+134	+6
3-10 to 3-15	0 psig	+234	+103

COD Removals. The results of the COD removal tests are given in Figures 6 through 12. A summary of the percent removal for all tests is shown in Table 3.

Table 3. Summary of COD Removal Results

Percent COD Removal after 30 Minutes Aeration

	Test		
Control	0 psig	30 psig	60 psig
84.2	78.4	76.8	80.0
80.0	78.4	75.0	81.7
86.6	75.0	73.4	80.9
81.7	75.8	79.2	80.9
73.4		80.9	77.6
75.0		81.6	85.0
68.4		83.4	73.4
85.0		90.0	86.7
Mean 79.3	76.9	80.0	80.8

A completely randomized analysis of variance test was performed on these data to compare the effects of the different pressures (5, p. 151). The result of this test showed no difference between the four pressure conditions at the five percent level of significance.

Dissolved Oxygen. The results of the dissolved oxygen determinations, made by means of a galvanic cell, at equilibrium, are presented in Table 4.

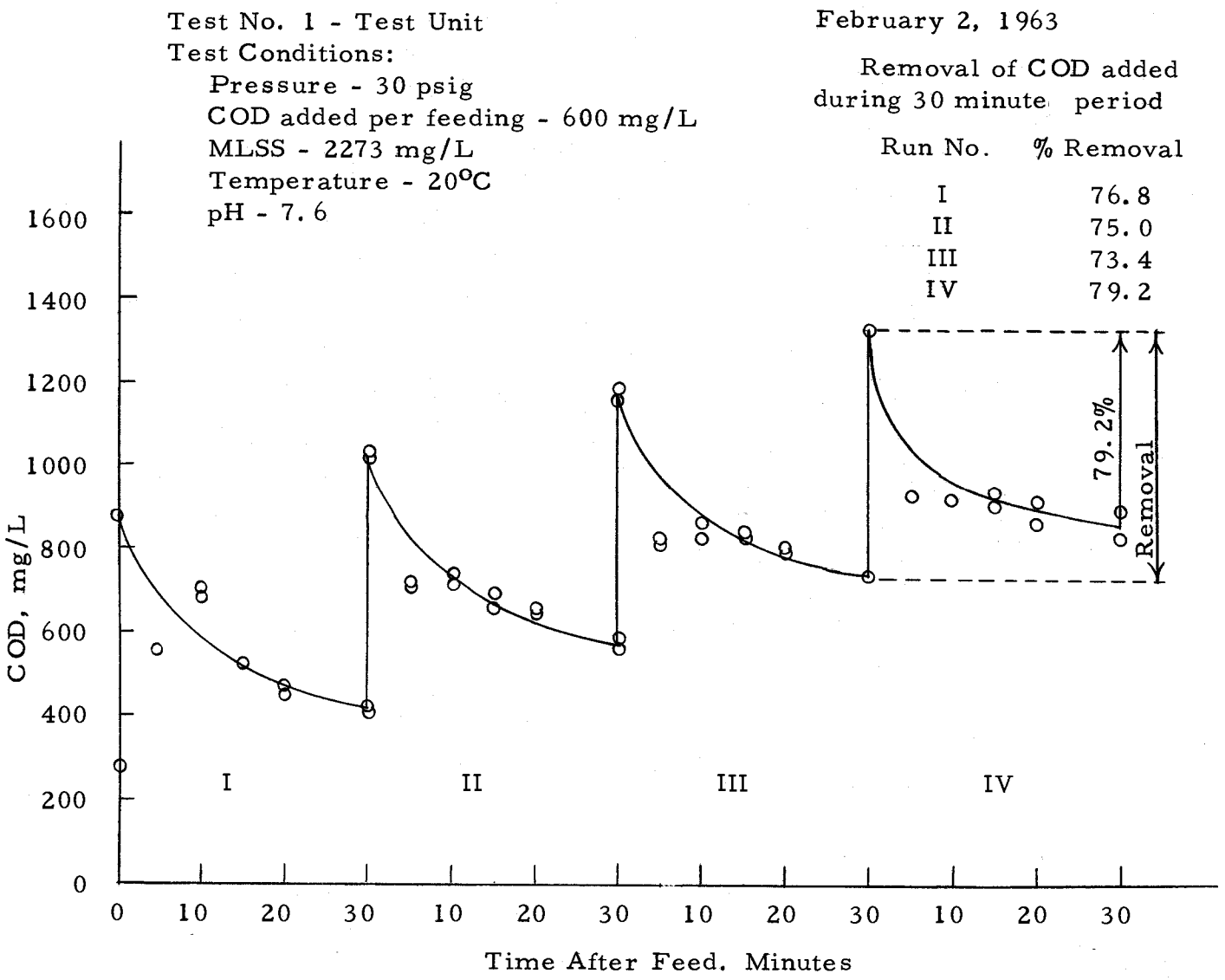


Figure 6. COD Removal After 30 Minutes Aeration

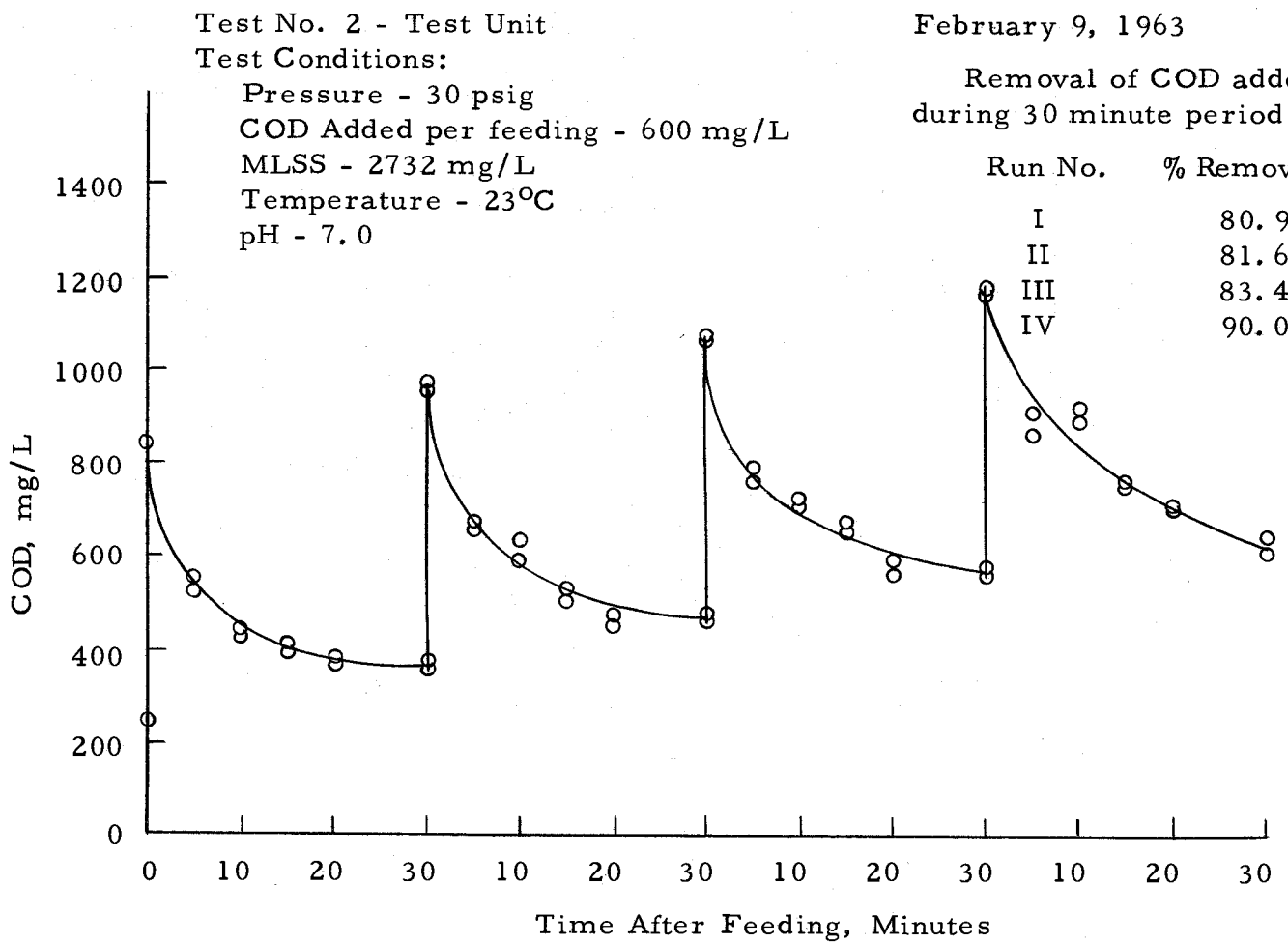


Figure 7. COD Removal After 30 Minutes Aeration.

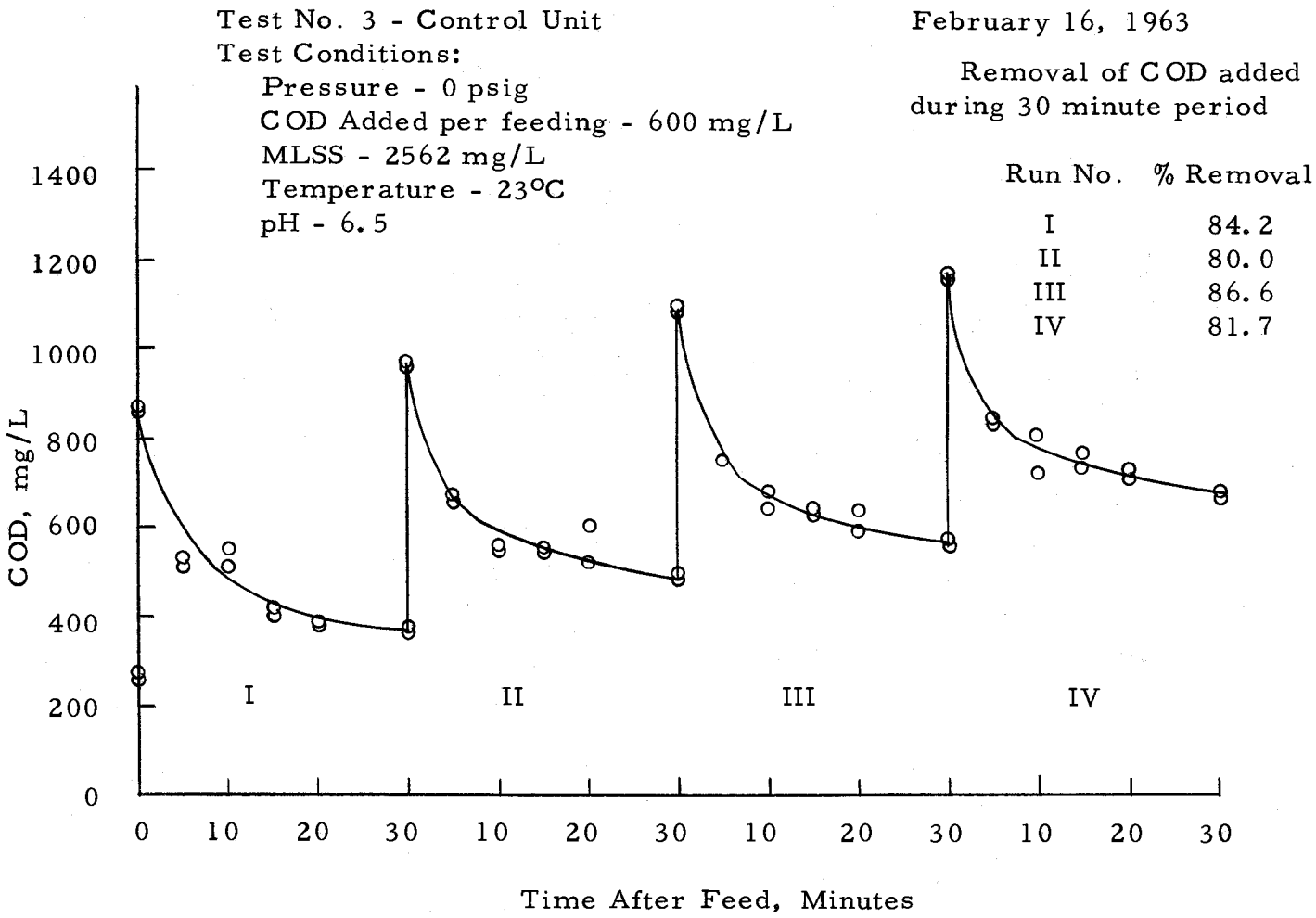


Figure 8. COD Removal After 30 Minutes Aeration.

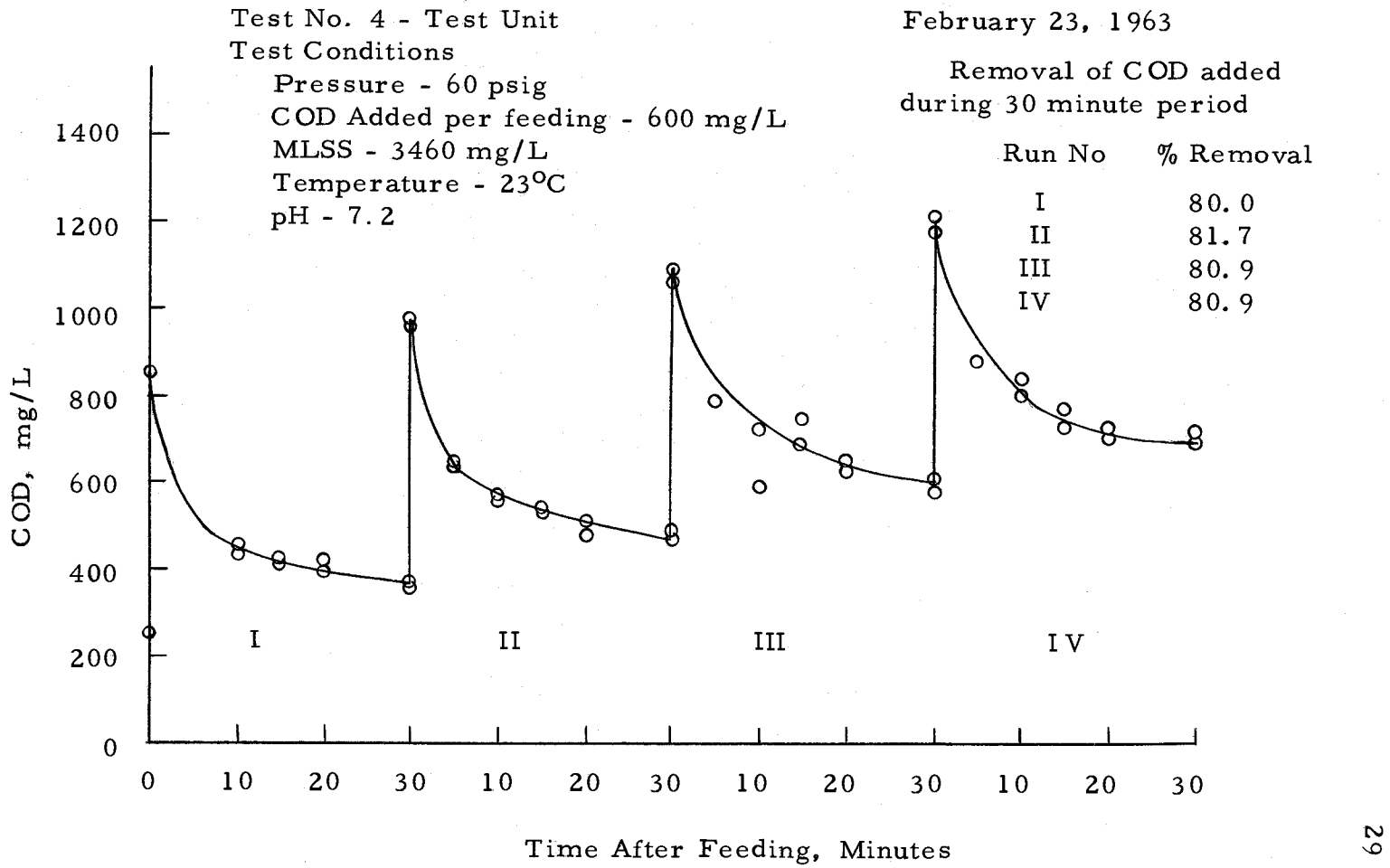


Figure 9. COD Removal After 30 Minutes Aeration.

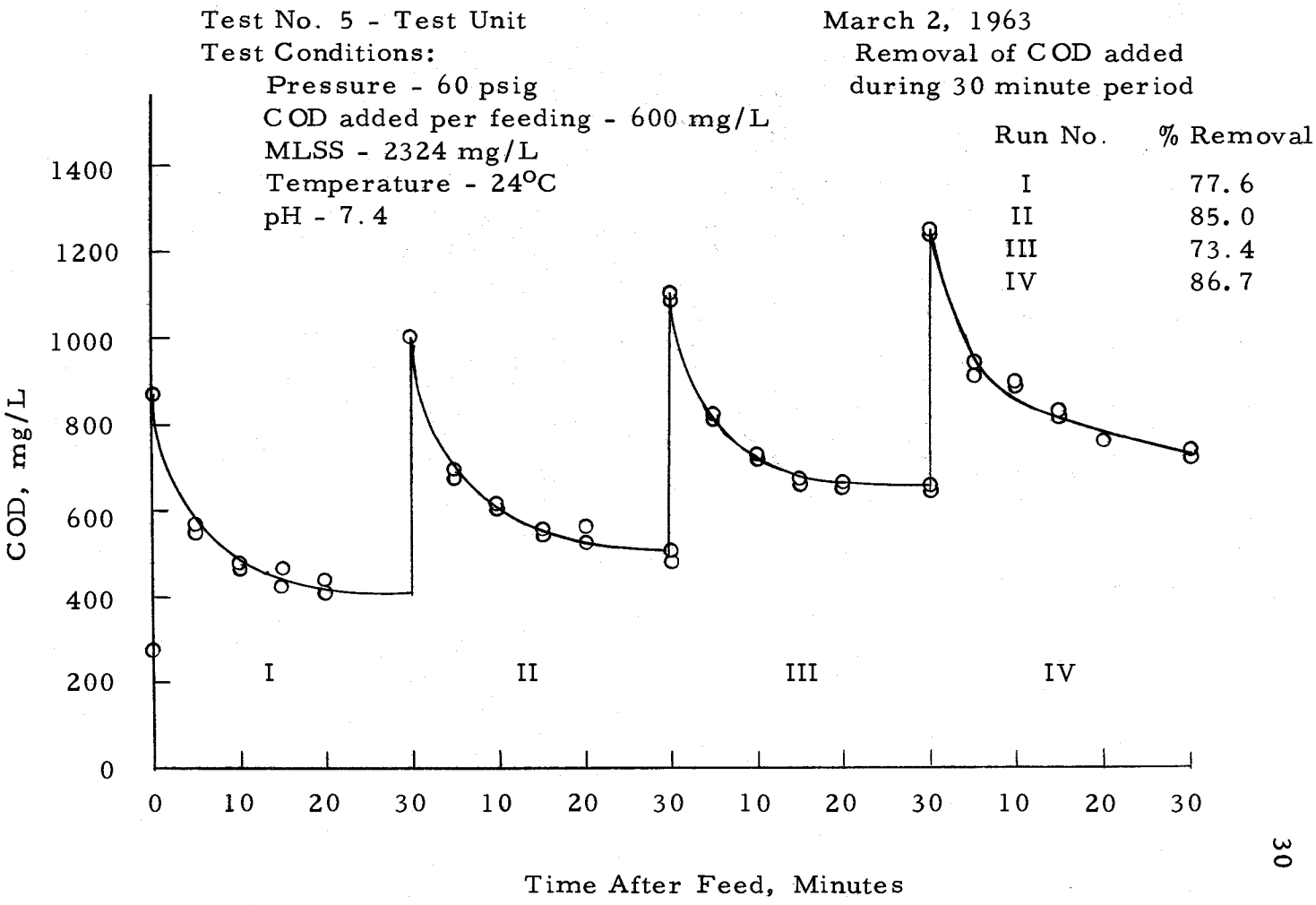
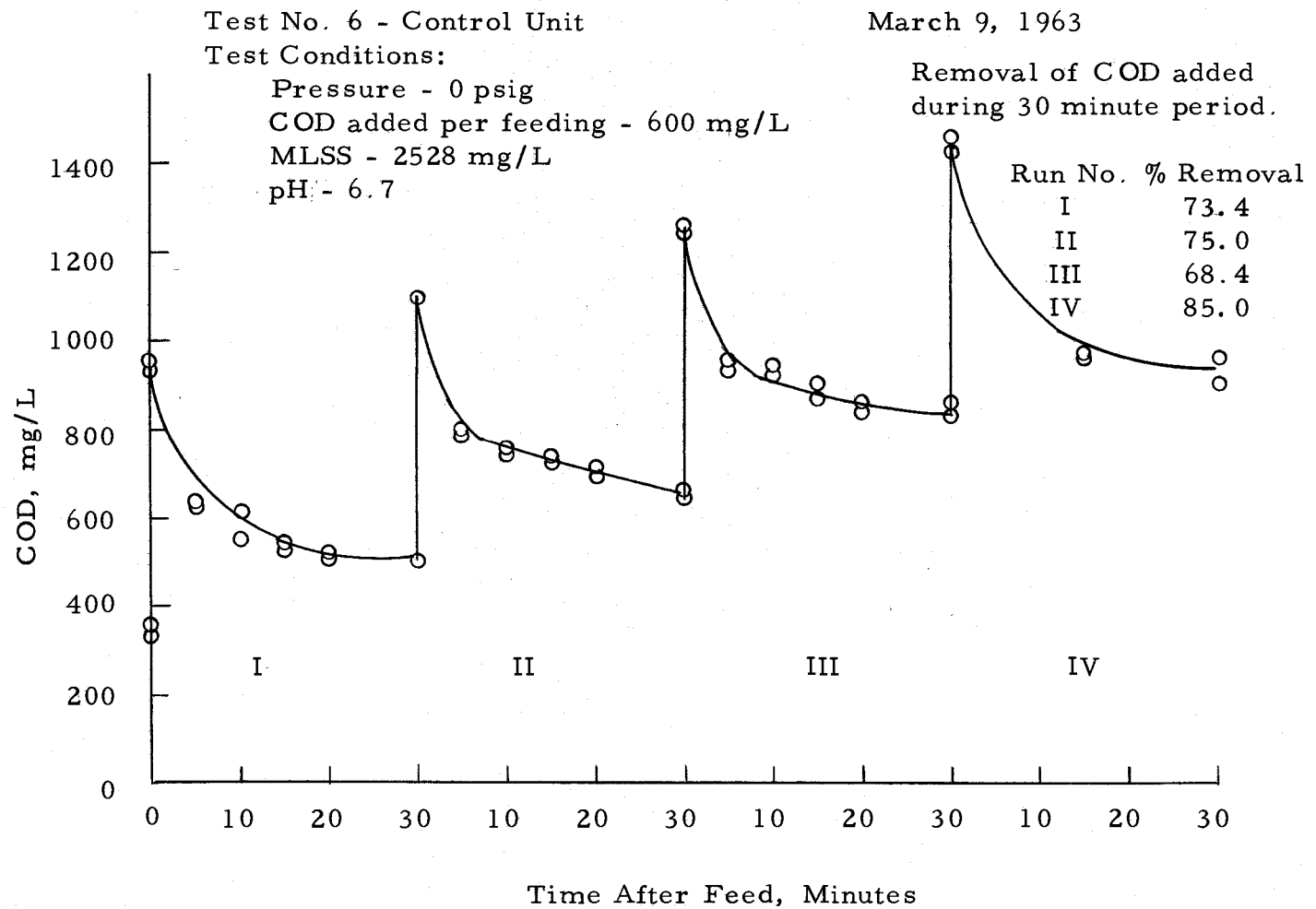


Figure 10. COD Removal After 30 Minutes Aeration.



Fugre 11. COD Removal After 30 Minutes Aeration.

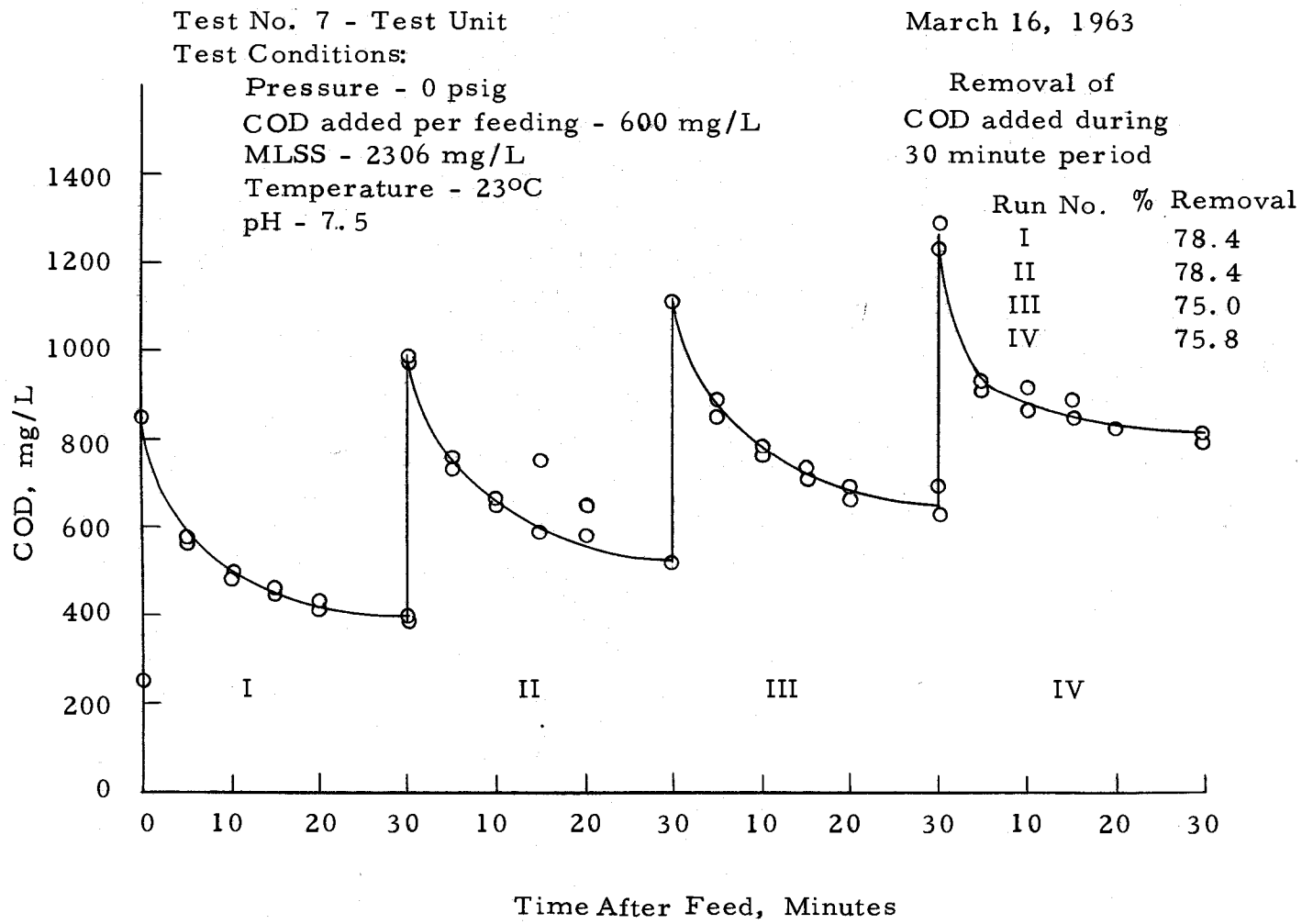


Figure 12. COD Removal After 30 Minutes Aeration.

Table 4. Dissolved Oxygen Results

	Pressure Level	Dissolved Oxygen, mg/L
Control Unit	0 psig	6.5
Test Unit	0 psig	6.5
	30 psig	14.8
	60 psig	18.0

pH and Temperature. The pH and temperature recordings are tabulated in the appendix. During the final experimentation period, the temperature varied between 22°C and 26°C, with most values between 24°C and 25°C. The pH of the test mixed liquor was consistently higher than that of the control unit, with the means being 7.3 and 6.9 respectively.

CONCLUSIONS

1. Elevated pressure of 60 psig does not affect the type of biological growth present in the mixed liquor, but it does keep filamentous growths, of the type found in this study, from forming large chains.
2. The sampling methods used for determining the growth rates were not adequate; therefore, no conclusion can be drawn from the growth rate results.
3. The results of the COD reduction tests showed that under the conditions of this study, elevated pressures have no effect on the removal of chemical oxygen demand in the activated sludge process.
4. The dissolved oxygen concentration in the mixed liquor increases with the pressure, but, under the conditions of this study, not in a direct relationship.
5. Elevated pressure of 60 psig does not adversely affect the pH of the mixed liquor.

RECOMMENDATIONS FOR FURTHER STUDY

1. Determine the effect of elevated pressure at higher organic loading rates by holding the pressure constant at 60 psig and increasing the organic loading above that used in this study.
2. Determine the limit of maximum chemical oxygen demand removal by varying both the organic loading and the pressure.
3. Determine the effect of increasing the surface area of the floc particles in conjunction with elevated pressure by subjecting the mixed liquor to high-shear mixing.

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APPENDIX

Table 1. Temperature and pH Data

Date		pH		Temperature °C	
		Control Unit	Test Unit	Control Unit	Test Unit
Jan	20	7.5	7.8		
	21	7.6	7.6	20	
	22	7.6	7.6		
	23	7.3	7.9		
	27	8.2	7.6		
	29	8.0	7.8	19	20
	31	7.6	7.6	20	20
Feb	1	7.2	7.0		
	2		7.6		20
	3	6.5			
	4	6.7	7.1	26	26
	5	7.2	7.6	24	
	6			25	
	7			24	
	8	7.1	7.0		23
	9		7.0	23	
	13	6.8	6.4		
	14	7.5	7.5		
	15	6.5	7.2	23	
	16	6.5		23	
	17	7.0	7.7	22	
	18	6.5	7.3	24	
	19	6.5	7.4		
	20	6.6	7.4		
	21	6.6	7.3	25	
	22	6.5	7.2	23	
	23		7.2		23
	24		7.3		
	25	6.7	7.3	25	
	26	7.0	7.3	25	25
	27	7.6	7.6	25	
	28	7.2	7.6	24	
March	1	7.0	7.4	24	
	2	7.0	7.4		24
	3	6.8	6.9		
	4	6.9	7.3	24	
	5	6.7	7.2	25	25

Table 1., Cont.

Date	pH		Temperature °C	
	Control Unit	Test Unit	Control Unit	Test Unit
7	6.9	7.3		
8	6.7	7.3		
9	6.7		24	
12	6.7	7.5		
13	7.1	7.6		
14	7.1	7.6		
15	7.0	7.5	23	23
16		7.5		23

Table 2. COD Removal Data

Date	Test No.	Time after Feeding, min	COD, mg/L Run Number I	II	III	IV
February 2, 1963	1 30 psig	0	269	420	578	725
			281	408	550	725
		5	566	705	815	926
			---	696	827	---
		10	677	725	824	---
			689	705	867	915
		15	526	697	840	902
			523	665	831	930
		20	471	630	795	915
			447	625	804	867
		30	420	578	725	820
			408	550	725	887
February 9, 1963	2 30 psig	0	240	368	472	568
			248	348	468	576
		5	556	672	796	868
			520	664	764	912
		10	440	628	716	896
			428	592	724	928
		15	396	500	656	752
			408	532	668	764
		20	360	476	560	708
			376	456	580	704
		30	368	472	568	612
			348	468	576	644

Date	Test No.	Time after Feeding, min	I	II	III	IV
February 16, 1963	3					
	Control	0	272	360	474	560
			264	364	496	568
		5	508	652	748	844
			532	668	---	836
		10	512	560	644	812
			552	548	684	724
		15	412	540	640	740
			408	548	636	772
		20	384	600	592	728
			388	524	640	708
		30	360	474	560	680
			364	496	568	668
February 23, 1963	4					
	60 psig	0	248	364	488	612
			248	372	468	580
		5	532	636	---	---
			---	644	792	884
		10	436	568	584	836
			456	556	728	804
		15	412	532	756	732
			424	536	684	776
		20	388	504	628	712
			420	480	644	724
		30	364	488	612	---
			372	468	580	716

Table 2, Cont.

Date	Test No.	Time after Feeding, min	COD, mg/L Run Number I	II	III	IV
March 2, 1963	5 60 psig	0	264	400	476	640
			264	400	500	656
		5	552	696	816	904
			556	676	812	940
		10	468	604	720	888
			460	604	724	900
		15	464	552	668	820
			428	540	664	828
		20	416	560	660	760
			432	528	656	---
		30	400	476	640	732
			400	500	656	728
March 9, 1963	6 Control	0	348	500	644	828
			332	500	660	856
		5	628	792	952	>1000
			632	800	928	>1000
		10	544	748	924	>1000
			604	752	940	>1000
		15	524	732	900	964
			540	724	872	968
		20	528	704	860	956
			516	688	844	956
		30	500	644	828	900
			500	660	856	960

Table 2, Cont.

Date	Test No.	Time after Feeding, min	COD, mg/L Run Number I	II	III	IV
March 16, 1963	7 zero psig	0	252	376	---	632
			---	384	---	696
		5	568	764	896	928
			572	732	844	912
		10	484	664	764	872
			484	648	784	924
		15	448	592	732	888
			460	748	708	852
		20	408	584	696	832
			432	648	668	832
		30	376	---	632	800
			384	---	696	808