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# The effects of pressure on the biodegradability of sanitary sewage in a model activated sludge reactor

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# THE EFFECTS OF PRESSURE ON THE BIODEGRADABILITY OF SANITARY SEWAGE IN A MODEL ACTIVATED SLUDGE REACTOR

BY

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A THESIS
PRESENTED IN PARTIAL FULFILLMENT OF
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## ABSTRACT

Based on existing information concerning the effects of pressure on the biodegradability of sanitary sewage, a model activated sludge reactor was used in conjunction with pressurization to determine the viability of pressurization as a primary sewage treatment process.

Municipal sewage samples were pressurized at 40 psig for one hour with an excess of oxygen. An air compressor and a steel drum were used for sample pressurization. A non-pressurized control sample was maintained. After pressurization, the samples were fed into separate model activated sludge reactors. Biodegradability of both types of effluent was measured by determining their five day biochemical oxygen demands (B.O.D.).

Other tests were performed on the samples to measure turbidity, ammonia content, and long term B.O.D.

It was found that after treatment in the reactor, no definitive measured effect due to pressurization was observed in the five day B.O.D. test. However, the pressurized effluent was found to be more turbid, and to have a higher ammonia content than the non-pressurized sample. The long term B.O.D. tests indicated some divergence between the pressurized and non-pressurized effluent B.O.D. curves.

# APPROVAL OF THESIS

# THE EFFECTS OF PRESSURE ON THE BIODEGRADABILITY OF SANITARY SEWAGE IN A MODEL ACTIVATED SLUDGE REACTOR

BY

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FOR

DEPARTMENT OF CIVIL ENGINEERING
NEW JERSEY INSTITUTE OF TECHNOLOGY

BY

FACULTY COMMITTEE

APPROVED: ____________________

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NEWARK, NEW JERSEY
APRIL, 1977

# PREFACE

The research for this thesis was carried out in the New Jersey Institute of Technology Civil Engineering Lab facilities located at 240 High Street, Newark. The author would like to extend his sincere thanks and appreciation to all of those people involved in the development of this thesis.

The author is grateful to Doctor Eugene Golub, who acted as Thesis Advisor from the Autumn of 1975 until the final write-up of this report in September of 1976. Doctor Golub's aid and guidance were responsible for the successful completion of this research.

On the few occasions when Doctor Golub was not available for consultation, Doctor Su Ling Cheng filled in as an advisor and friend whenever the need arose.

The author is also grateful to Doctor Thomas Olenik for his recommendation for monitoring the ammonia levels relative to pressurization effects.

Finally, the author would like to thank his wife, Virginia, whose help, encouragement, and understanding were always available.

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# INTRODUCTION

Today, many existing sewage treatment facilities have been found wanting in minimum treatment standards and have been declared inadequate, regardless of capacity. Recent regulations regarding degree of wastewater treatment required in conjunction with partial federal financing of treatment plant construction have added to the burden of municipalities in providing required facilities within limited time.

These factors, and other routine obstacles to wastewater plant construction such as land acquisition, financing, ecological problems, etc. have created problems which have forced the institution of building bans to prevent further overloading of existing facilities. Several New Jersey municipalities are currently experiencing such bans.

As environmental requirements become more stringent, it appears reasonable to assume that an increasing number of municipalities in the future will be faced with the aforementioned problems and building bans.

Since precise timing for construction of new treatment plants, and optimizing cost consideration and needs appears near impossible, a method of upgrading existing facilities to cover the time gap between need and availability of new treatment seems appropriate. Additionally, any viable upgrading methods could also be incorporated into new facilities. To this end, a method of treating wastewater by the use of pressure was researched.

Research conducted by John Chack at New Jersey Institute of Technology, Lawrence et al. at Purdue University, and Donald Nusser at New Jersey Institute of Technology, indicated that pressure does have an effect on the biodegradability of sanitary sewage. Conclusions reached by the aforementioned researchers included:

1. Moderately elevated pressures can stimulate biological activity.
2. The degradation of organic waste by microorganisms appeared to be an oxygen-limited process.
3. The highest reduction of first stage BOD obtained in a series of experiments on primary clarifier effluent was 25%. The varying parameters included pressure intensity, detention time, and air to sewage volume ratio.

Based on the above conclusions, an experiment to determine the effects of pressure on the biodegradability of sanitary sewage in a model activated sludge reactor was designed.

The purpose of the author's research was to compare the biochemical oxygen demand of pressurized and non-pressurized sanitary sewage effluent from a model activated sludge reactor. Municipal sewage (primary clarifier effluent) was subjected to a gauge pressure of 40 psi for one hour with an excess of oxygen. A Control sample (non-pressurized sewage) was maintained. Thereafter both samples were fed through separate model activated sludge reactors with controlled detention times, air flowrates, temperatures and settling times. The settling chamber effluents were tested for quality and residual biodegradability by determining the five day Biochemical Oxygen Demand (B.O.D.).

## LITERATURE REVIEW

Published data on the effects of pressure on the biochemical degradability of sewage is meager. The results of Jannash's field study of the microbial degradation of food materials from the sunken research submersible "Alvin" indicated that under 150 atmospheres of pressure at 4 degrees centigrade food was preserved equal to or better than it would have been preserved under normal refrigeration.[1] Further studies indicated that microbial degradation was ten to a hundred times slower under high pressure than under normal pressure with other parameters being identical. It was theorized that the high pressure raised the minimum growth temperature of the cell. Hence, under high pressure and low ambient temperature the pressure effect will cause the minimal growth temperature to exceed the ambient temperature, thereby repressing microbial growth.

John Chack showed that moderately elevated pressures (100 psi to 400 psi) will stimulate biological activity.[2] Chack found that the rate of oxygen demand of pressurized waste was greater than that of non-pressurized waste, but the total demand for both samples were nearly the same (as it should be). In further experiments, Chack found that in-

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[1] Jannash et al., Science, p. 672.

[2] Chack, Master's Thesis for Civil Engineering, 1972.

creased pressure produces a kill effect on coliform bacteria.

Lawrence et al.[3] at Purdue University performed a set of experiments to determine the effect of increased pressure on the overall rate at which bacteria would reduce waste to flocculent matter. Their conclusions were that the degradation of organic waste by microorganisms seemed to be an oxygen limited process, also that pressure had a beneficial effect in increasing the activity of microorganisms based on quantity of organic matter processed.

Donald O. Nusser conducted a series of experiments to determine in more detail the pressure effects on the biological degradation of primary sanitary sewage effluent.[4] Nusser's experiments were designed to vary the parameters of available oxygen, amount of pressure, and length of time for pressurization.

Nusser's experiments varied the gauge pressure intensity from 29 psi to 100 psi, the pressurization time from 10 minutes to 6 hours, and the ratio of volume of air to volume of sewage was varied from zero to 0.90. It was found that the optimum combination of parameters for the highest first stage BOD reduction (25.0%) occurred with 44.1 psig pressure for one hour with an air to

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[3] Lawrence et al., paper presented at the Middle West Regional Conference of Chemical Engineers, 1971.

[4] Nusser, Master's Thesis for Civil Engineering, 1975.

sewage volume ratio of 0.45. Additionally, Nusser found that, in general, the pressurized samples exerted the second stage BOD earlier than the non-pressurized samples.

Nusser found that the second stage B.O.D. of the pressurized samples was exerted 1 to 4 days earlier than in control samples, and he theorized that this phenomenon was independent of the amount of applied pressure, detention time, and available oxygen supply. If Nusser's theory is correct, the possibility exists that mere pressure may have an indirect influence on the activity of bacteria such as giving rise to a chemical or biological shift which favors a particular biochemical action.

In order to study more closely Nusser's findings with optimum parameters, a model activated sludge plant was constructed. Several models were considered, and a relatively simple but efficient model described by Ludzack[5] was chosen. After experimenting with the unit, Ludzack stated, "Performance with conventional loading compared favorably with that shown in records of plant units."[6] Furthermore, re-

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[5] F.J. Ludzack, "Laboratory Model Activated Sludge Unit," The Journal of the Water Pollution Control Federation, 32:6 (June, 1960).

[6] Ludzack, p.608.

garding the modeling capability of the unit, "Variables that commonly affect performance in large units show similar changes in this one but the changes appear to be more rapid and intense."[7]

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[7] Ludzack, p. 608.

# EXPERIMENTAL APPARATUS AND PROCEDURES

## Source of Samples

All of the sewage samples used for this study were obtained from the Township of Parsippany-Troy Hills Sewage Treatment Plant in New Jersey. At the time of writing, the plant provided treatment through the secondary level of approximately nine million gallons of municipal sewage per day. Samples used during the study were collected from the effluent end of the primary settling tank. The elapsed time between sample collection and commencement of flow through the reactors averaged approximately two and one half hours. Non-diluted samples were fed through the reactors.

## Pressurization Equipment Description

Sewage samples were pressurized in a fifteen gallon steel drum. The cap for the drum was machined for a fitting allowing an air pressure line to be connected from an air compressor (ITT, Pneumotive Model # SYCTGH91-W). The compressor was set to provide 40 psi gauge pressure through the line.

It was found that the line and drum seals were tight enough to hold to within 3 psi of the set gauge pressure after one hour. During the first pressurization, the flat ends of the drum bulged out to an alarming degree, however, thereafter no further physical problems occurred. It was deemed advisable to strictly limit the pressure in the drum to 40 psi.

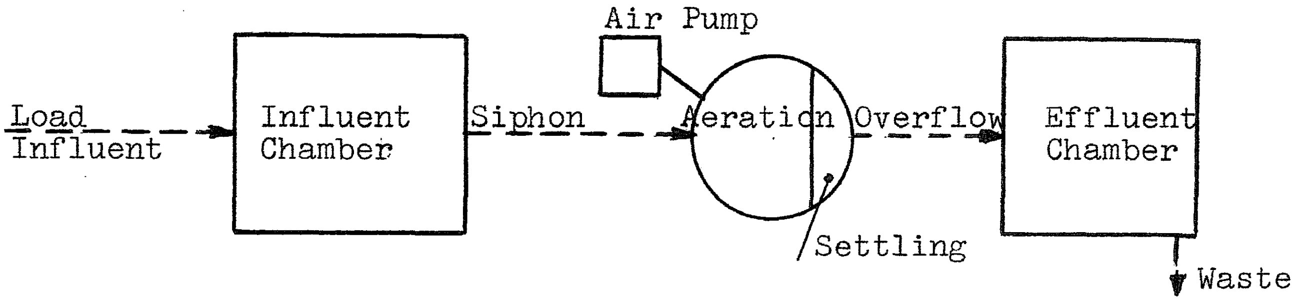
The pressure in the drum was released by opening the line valve in the compressor, and expelling the air.

### Model Activated Sludge Plant Description

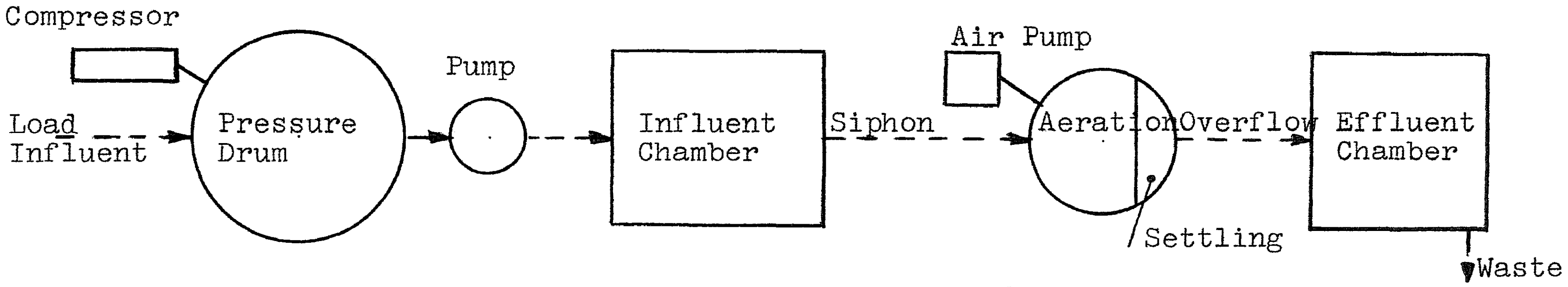
Two activated sludge plant models were in use: one for pressurized sewage and one for the non-pressurized control. The model consisted of an influent reservoir, a siphon line with a flow control valve from the influent reservoir to the aerator, an aerator chamber, a settling chamber, an air pump, and an effluent collection reservoir, (see Figure 1 and Figure 2).

The influent reservoir consisted of a 50 gallon fish tank mounted above and adjacent to the aerator unit. The tank geometry allowed for a large exposed surface area to allow oxygen transfer and minimize the possibility of the sewage becoming septic. In addition, the shallow depth of the sewage in the tank permitted a narrow range of flow velocity through the siphon tube so that the flow-rate variation could be minimized throughout the test period.

The siphon tube consisted of $\frac{1}{4}$ inch diameter plastic tubing with weighted ends and a pinch valve. One end of



Non-Pressurized Sewage Model



Pressurized Sewage Model

Figure 1 - Schematic Diagram of Experimental Apparatus

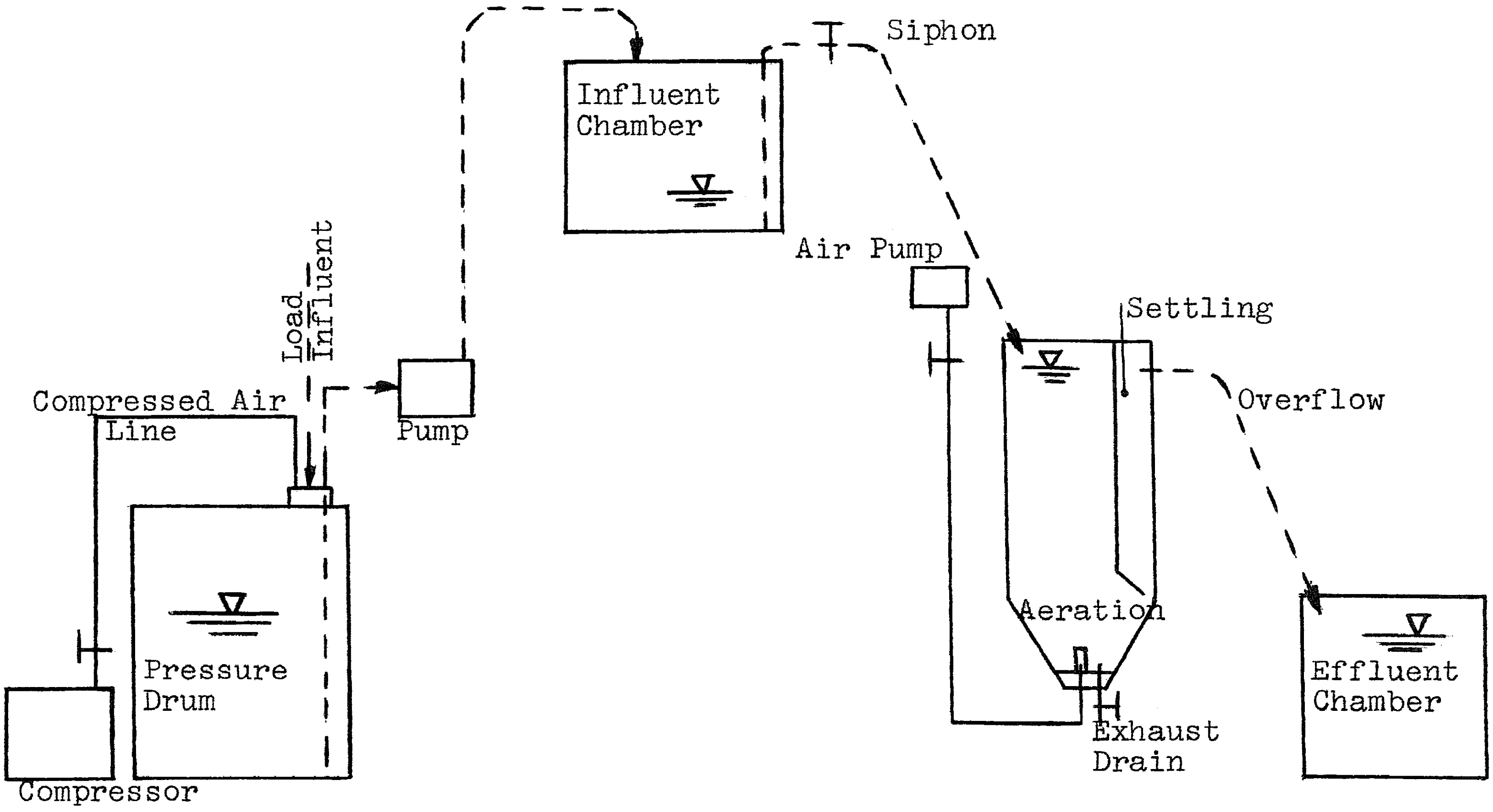
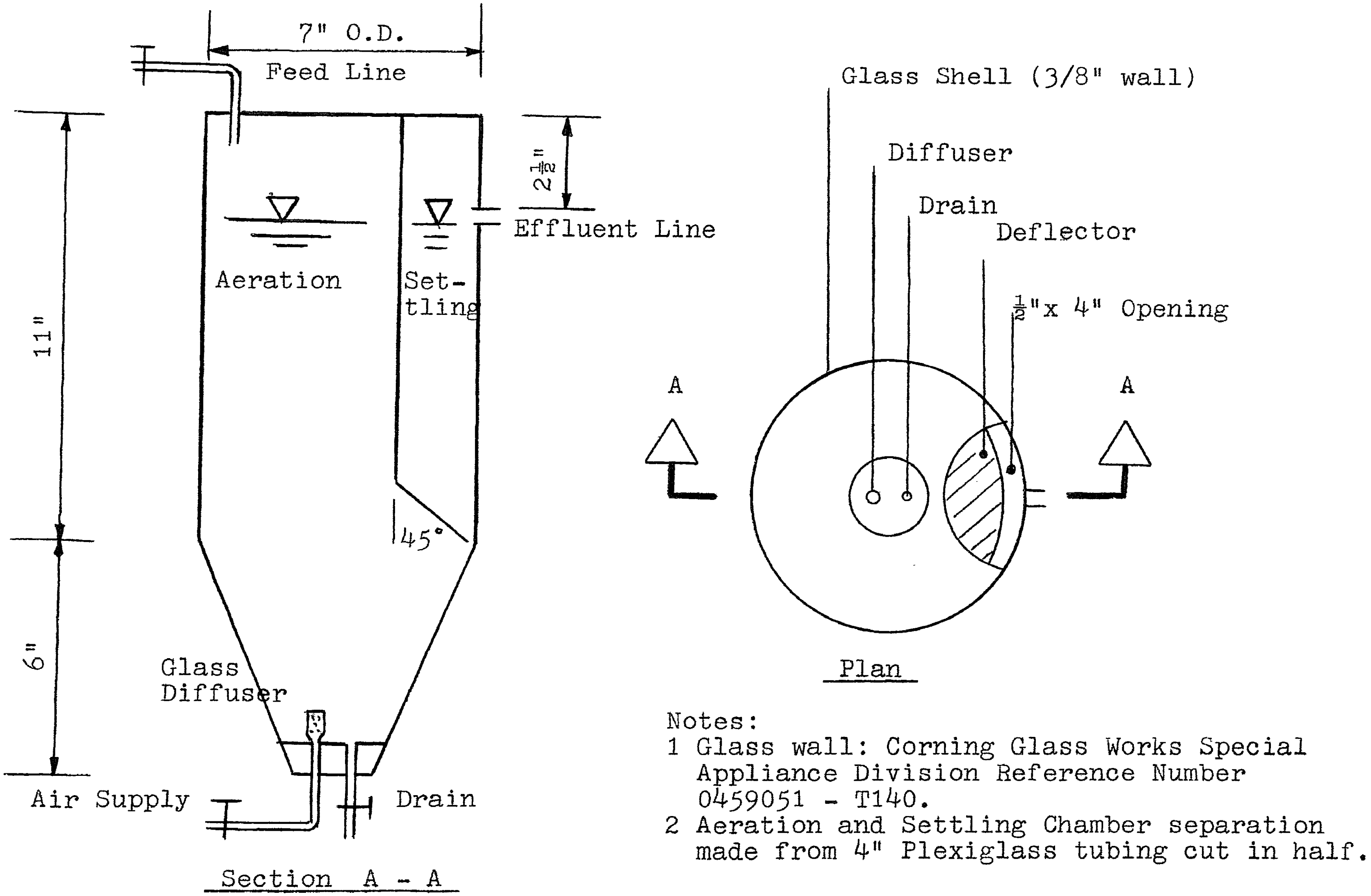


Figure 2 - Flow Diagram of Experimental Apparatus - Pressurized Model

the tube rested on the bottom of the influent reservoir, the other end rested inside the rim of the aeration chamber. Each day after influent loading, the siphon was started and the flowrate was controlled via the pinch valve. During the period of experimentation the flow was never drastically altered due to siphon clogging at the pinch valve. However, the flowrate had to be carefully set and checked repeatedly to assure reasonable accuracy.

The aerator chamber and the settling chamber were both located in a cylindrical pyrex tube with a conical end. A vertical partition parallel to the vertical axis of the cylinder separated the settling chamber from the aerator chamber (see Figure 3). The aerator chamber base at the conical end supported a diffuser through which air was bubbled from an aquarium air pump. The bubbled air provided oxygen, circulation, and mixing of return sludge with fresh influent. After a detention period in the aerator, the sewage fed into the settling chamber behind the baffle-like partition. Settled sludge accumulated behind the partition at the base, and the clear supernatant left the pyrex container via an overflow at the top end of the settling chamber.

From the overflow in the settling chamber, the treated sewage flowed by gravity to the effluent collection reservoir. The reservoir consisted of a ten gallon fish



Notes:
1 Glass wall: Corning Glass Works Special Appliance Division Reference Number 0459051 - T140.
2 Aeration and Settling Chamber separation made from 4" Plexiglass tubing cut in half.

Figure 3 - Detail of Aerator and Settling Chambers

tank which was emptied and the effluent was wasted once a day.

## Experimental Procedure

To achieve a steady-state condition in the activated sludge as quickly as possible in both the pressurized and non-pressurized models, an initial seed of primary clarifier effluent mixed with return activated sludge from the Treatment Plant was used. The mixed liquor was loaded into each aerator without pressurization. Thereafter each loading of the pressurized model influent reservoir was performed only with pressurized primary effluent.

A total of twenty gallons of primary clarifier effluent was brought from the Parsippany-Troy Hills Sewage Treatment Plant each day for the duration of the experiment. This permitted loading of each model with 40 liters of sewage plus some excess.

Ten gallons of the sewage was pressurized for one hour with 40 psig compressed air. The remaining ten gallons was set aside to be loaded into the non-pressurized model at the same time as the pressurized sample. During the pressurization process, the influent reservoirs were emptied of remaining sewage, and the sediment was cleaned out.

After pressurization, the pressurized sewage was pumped directly from the steel drum into the influent reservoir "A" (for pressurized sewage). At this time also, the remaining non-pressurized 10 gallons of sewage was loaded into influent reservoir "B". Immediately thereafter, the siphon from each influent reservoir was activated and the flowrate was set to allow a flow of about 1.5 liters per hour. The detention period in the aeration chamber would thereby be theoretically fixed at 4 hours. Some variation in the detention period (ranging from 3 to 6 hours), was always experienced. However, according to Ludzack, "Within an aerator detention period of 2 to 15 hours, no significant differences in performance were noted."[8] During the experiment, the mean detention period was 5 hours. Furthermore, an effort was made to minimize daily variations in aerator performance and consequent effluent quality.

In order to minimize effluent quality variations during a particular series of B.O.D. tests, a batch dilution technique for incubation was employed. Nusser had found during his experiments that diluting the sample seed in the total amount of dilution water (batch dilution) provided more consistent B.O.D. data than

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[8] Ludzack, p. 608.

selectively pipeting the sample seed into individual B.O.D. bottles.[9]

After the proper siphon flowrate was established, the pinch valve along the aerator air supply line was adjusted to provide 350 ± cc./min. air flow (approximately 1 cf/hr.). It was found that an air flowrate higher than 1 cf/hr. produced substantial foaming. Since the model was not monitored constantly, proper anti-foaming maintenance could not be effected, hence the air flowrate was set to 1 cf/hr., barely low enough to prevent excessive foaming.

Aerator maintenance included cleaning the sludge clinging to the glass wall and withdrawing approximately 900 cc. of mixed liquor from the base of each aerator once each day. It was found that an overabundance of sludge inhibited proper clarification in the settling chamber.

The return of sludge to the aeration chamber was effected by gravity. As the sludge build-up at the base of the settling chamber increased in weight, portions of the build-up would break off and slide through the half

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[9] Nusser, Master's Thesis for Civil Engineering, 1975.

inch wide opening between the baffle wall and the cylinder wall, and into the aerator.

The overflow for the clarified effluent consisted of the half inch diameter hole in the side of the pyrex cylinder wall near the top of the cylinder. The height of this overflow determined the fluid level in both the aerator and the settling chamber. A length of plastic tubing led the clarified effluent from the overflow to the effluent reservoir mounted below.

The samples for all tests were always taken from the line leading from the clarifier to the effluent reservoir. The effluent reservoir provided good visual observation of the turbidity of the treated sewage. The effluent reservoirs were pumped out once each day, and the effluent was wasted.

Initial Dissolved Oxygen (D.O.) tests were conducted on both the pressurized and control samples immediately after dilution. Dissolved oxygen content was determined using the Azide Modified Winkler method. Premeasured plastic powder pillow reagents were used and the final titration was performed with phenylarsineoxide using standard starch solution as the indicator.

Both pressurized and control samples were incubated in the dark at a constant temperature of 20°C. Subsequent D.O. tests were run at predetermined intervals (usually on a daily basis). Biochemical oxygen demand was calculated from the results of these D.O. tests. For a detailed description of this calculation, see page 494 of *Standard Methods for the Examination of Water and Wastewater* (Thirteenth Edition, 1971). Results of these B.O.D. calculations were plotted on graphs.

## EFFLUENT QUALITY COMPARISONS

The key role of most activated sludge reactors in waste treatment is the decomposition of organic matter. Organic waste is used by activated bacterial masses to obtain energy for further synthesis of waste into cellular material, formation of by-products prior to final oxidation, and the formation of the end products themselves.

The test used for effluent quality determination in terms of organic waste removal was the five day biochemical oxygen demand test. The effluent from the model reactor was also monitored for turbidity. The relative degrees of turbidity between pressurized and non-pressurized effluents appeared to be a quick, simple, and informal way of comparing general effluent quality between the samples.

### Five Day B.O.D. Determinations

Samples were taken from the settling chamber effluent line and the samples were batch diluted to 5 percent in anticipation of a five day B.O.D. of about 40 mg/l. The B.O.D. for untreated waste ranged from about 140 to 180 mg/l at the time of sample collection. This range is based on B.O.D. measurements made by the Treatment Plant. The samples were collected 6, 11, 12 and 13 days after reactor start-up, corresponding to Series A, B, C and D determinations respectively.

The results of the B.O.D. determinations are shown on Table 1. It was found that the B.O.D. values were substantially less than what was predicted. Hence in future tests, a much lower sample dilution should be used. The values also showed an abnormally large divergence between the different series of tests. This divergence was unexpected since all of the samples were collected about the same time of day, hence they all should have been about equal quality primary effluent. The inconsistent range of the five day B.O.D. results suggests that a more rigorous control of the model and daily monitoring of influent B.O.D. to compare with effluent B.O.D. is needed in future efforts to duplicate these experiments. The available flow control and filtering equipment prevented a satisfactorily precise control of the model's activity during these tests.

Based on Nusser's experiments with untreated pressurized and non-pressurized sewage, it was predicted that the pressurized five day B.O.D. values after treatment would be lower. Nusser's experiments showed that the effect of 44 psig of pressure applied for 1 hour with adequate or excess air would lower the first stage B.O.D. of the waste by about 25%. Nusser theorized that lower B.O.D. values indicated more efficient waste processing. It was expected that any improvement in waste processing due to pressurization

Table 1. - Five Day Biochemical Oxygen Demand Determinations

| Incubation Day after Reactor Start-Up | Description | Type | 0-Day D.O. (mg/l) | 5-Day D.O. (mg/l) | 5-Day B.O.D. (mg/l) |
|---|---|---|---|---|---|
| 7 | Series A | Press. | 7.0 | 6.3 | 14 |
| | | Non-Press. | 7.3 | 6.4 | 12 |
| 13 | Series B | Press. | 7.2 | 5.6 | 32 |
| | | Non-Press. | 7.3 | 5.6 | 34 |
| 14 | Series C | Press. | 7.2 | 6.0 | 24 |
| | | Non-Press. | 7.4 | 6.1 | 26 |
| 15 | Series D | Press. | 7.4 | 6.9 | 10 |
| | | Non-Press. | 7.6 | 7.0 | 12 |

should also be reflected in the biological treatment of the pressurized sewage.

The five day B.O.D. for the pressurized effluent from the model was consistently 2 mg/l lower than that of the non-pressurized effluent. Although the comparison favoring better B.O.D. removal for pressurized sewage was as expected, it appeared insignificant, (the difference did not approach the 25% range that Nusser's tests revealed).

It must be noted that Nussers' differences were observed on the basis of incubating directly after pressurization, whereas the author's differences were observed after a combination of pressurization and aeration in a model secondary treatment procedure. Hence the degree of difference in B.O.D. between Nusser's results and the author's results could be attributable to a leveling effect of the activated sludge process. That is, the biological rate during aeration could compensate to a large degree for any effects due solely to pressurization. Varying the detention periods and testing the mixed liquor in the reactors in future experiments could establish the cause for the apparent leveling effect in B.O.D. results following the activated sludge treatment.

### Turbidity

Relative turbidity measurements were made on the effluent throughout the modeling period. Since the effluent was too transparent for conventional turbidity measurements, a spectrophotometer was utilized to demonstrate the relative turbidity between pressurized and non-pressurized effluents. This also seemed a good way of monitoring apparent reactor efficiency throughout the testing period.

A preliminary check of the effluent in the spectrophotometer revealed that at the 500 mμ wavelength the meter needle showed maximum deflection away from 100% transmission. Therefore this wavelength was chosen as the basis for all turbidity measurements. The spectrophotometer was set to permit 100% transmission through distilled water and this served as an arbitrary standard.

Throughout the experimental period, the spectrophotometer transmission was consistently slightly higher through the non-pressurized effluent (see Table 2). This difference in the turbidity could also be visually observed in the effluent chambers. The range of spectrophotometer transmission values for non-pressurized effluent ranged from 85 to 95 percent. The values for pressurized waste ranged from 79 to 92 percent. Most of the lower transmission readings were taken during the first three days after reactor start-up. The best transmission readings were recorded on the last functional day of the reactor when the pressurized effluent transmission was 92 percent and the non-pressurized effluent

Table 2.-Relative Turbidity Determinations (Determinations performed on Spectrophotometer at 500 mμ wavelength).

| Day after Reactor Start-Up | Pressurized Effluent | | Non-Pressurized Effluent | |
|---|---|---|---|---|
| | Reactor Detention Time | Transmission | Reactor Detention Time | Transmission |
| 1 | -- | -- | -- | -- |
| 2 | 4.17 hrs. | -- | 3.53 hrs. | -- |
| 3 | 5.29 | 80.5% | 7.64 | 86% |
| 4 | 5.05 | 79 | 7.43 | 86 |
| 5 | 3.98 | 79 | 4.30 | 87 |
| 6 | 3.33 | 82 | 3.33 | 90.5 |
| 7 | 4.13 | 83 | 5.50 | 92 |
| 8 | 5.50 | -- | 8.21 | -- |
| 9 | 3.29 | 87.5 | 3.57 | 91 |
| 10 | 4.66 | 91 | 4.66 | 85 |
| 11 | 3.46 | 87 | 4.47 | 88 |
| 12 | 3.59 | 87 | 4.47 | 88 |
| 13 | 3.96 | 89 | 5.50 | 94 |
| 14 | 3.87 | 91 | 5.39 | 92 |
| 15 | 4.33 | 92 | 3.33 | 95 |

transmission was 95 percent.

If the turbidity recorded herein bore a relationship to B.O.D., then the turbidity and B.O.D. determinations yielded apparently contradictory results. However, a possible cause for the difference in turbidity could have been the generally greater settling period observed for the non-pressurized effluent. The settlement time depended on the influent rate to the aerator. The influent rate could not be precisely regulated with the available equipment in the laboratory. Future testing with the model should include a precision influent feed pump for better control of detention periods and settlement times. Hence, in the author's tests, although a trend was detected the results were inconclusive due to the limits of precision of the test equipment. Once the necessary precision is obtained in future experiments, a relationship between turbidity and five day B.O.D. should be investigated.

## AMMONIA DETERMINATIONS

Biochemical oxygen demand can also be exerted by inorganic compounds, the most important of them is ammonia. When ammonia is oxidized to nitrite, the biochemical reaction uses portions of the dissolved oxygen. Nitrites are converted to nitrates, and this reaction also exerts an oxygen demand. The nitrates are the stable end-products of nitrification .

Ammonia levels therefore can give an indication of sewage quality, and potential for exertion of second-stage oxygen demand. Any significant or consistent difference in ammonia levels between the pressurized and non-pressurized reactor effluent should indicate whether pressurization has any effect on the nitrification process. If nitrification is affected by pressurization, then the results of dissolved oxygen measurements on pressurized samples should be understood to reflect not only carbonaceous demand but influenced nitrification in these tests.

Ammonia determinations of reactor effluent were made on two separate occasions. The tests were performed in accordance with Section 132B-Nesslerization Method as outlined in Standard Methods for the Examination of Water and Wastewater, thirteenth edition. The ammonia colorimetric measurement was made on a spectrophotometer with the wavelength set at 500 mμ and the test samples were compared

Table 3. - Ammonia Determinations
(Determinations performed on Spectrophotometer at 500 mμ wavelength).

## Seventh Day after Reactor Start-Up

| | | | |
|---|---|---|---|
| Pressurized Effluent | Test #1 | 21.0 mg/l | |
| | Test #2 | 24.0 mg/l | |
| | Test #3 | 27.2 mg/l | |
| | Test #4 | 25.0 mg/l | |
| | Average | | 24.3 mg/l |
| Non-Pressurized Effluent | Test #1 | 16.0 mg/l | |
| | Test #2 | 21.0 mg/l | |
| | Test #3 | 20.8 mg/l | |
| | Average | | 19.3 mg/l |

## Ninth Day after Reactor Start-Up

| | | | |
|---|---|---|---|
| Pressurized Effluent | Test #1 | 28.8 mg/l | |
| | Test #2 | 26.0 mg/l | |
| | Average | | 27.4 mg/l |
| Non-Pressurized Effluent | Test #1 | 16.0 mg/l | |
| | Test #2 | 20.4 mg/l | |
| | Test #3 | 20.0 mg/l | |
| | Average | | 19.7 mg/l |

with standardized samples.

The ammonia determinations were made on the seventh and ninth day after reactor set-up. The effluent ammonia levels were found to be consistently higher in the pressurized effluent on both days, (see Table 3). Those levels ranged from 21 to 28.8 mg/l. The non-pressurized effluent ammonia levels ranged from 16 to 21 mg/l.

The available data indicated that pressurization does influence the ammonia levels in the wastewater. Hence dissolved oxygen levels in pressurized samples would be expected to be higher than in non-pressurized samples since the nitrification process in the pressurized sample appeared to be retarded. The dissolved oxygen levels in the Series B B.O.D. determinations (see Appendix) in fact do reflect such a difference. However, this influence should be investigated further to determine if the effect is biological, chemical, or physical. In addition, non-treated sample ammonia levels should be monitored for both pressurized and non-pressurized samples to determine the effects of pressure signs on the ammonia level of sewage.

## LONG TERM B.O.D. DETERMINATIONS

### Series "A" B.O.D. Tests

On the sixth day of operation of the model sewage treatment plant, sewage was collected from the effluent lines for incubation of the first series of B.O.D. bottles. The samples were collected approximately 18 hours after loading of the influent chamber. Enough sewage was collected from each model to provide for seeding for 32 B.O.D. bottles with a 5% batch dilution.

This series of B.O.D. tests consisted of testing the dissolved oxygen in two bottles per day each of pressurized and non-pressurized samples. It was decided to monitor the B.O.D. up to the sixteenth day to monitor any possible long-term effects of pressurization.

An inspection of the Series "A" dissolved oxygen curves (see Figure 4 and Figure 5) revealed an erratic series of points. Since the dissolved oxygen levels must decrease with time, and the data points do not all reflect this, an averaging of high and low values of D.O. would not provide reasonable data. Therefore, the data points were graphically averaged by neglecting the minority of data points which deviated from the necessary negative slope of the D.O. curve. The dissolved oxygen values used to calculate the B.O.D. values were

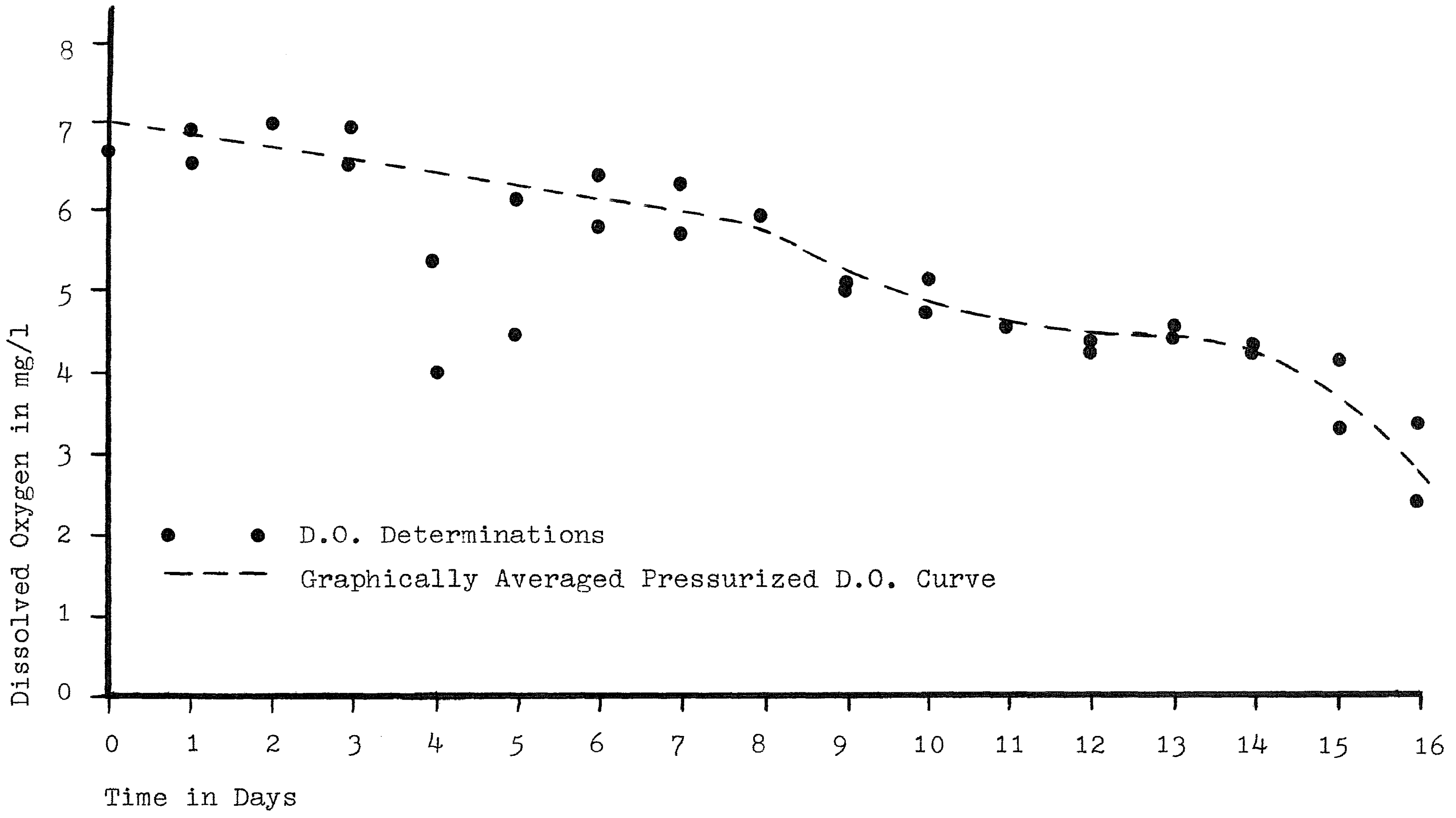

Figure 4 - Series "A" Graphically Averaged Dissolved Oxygen Curve for Pressurized Samples.

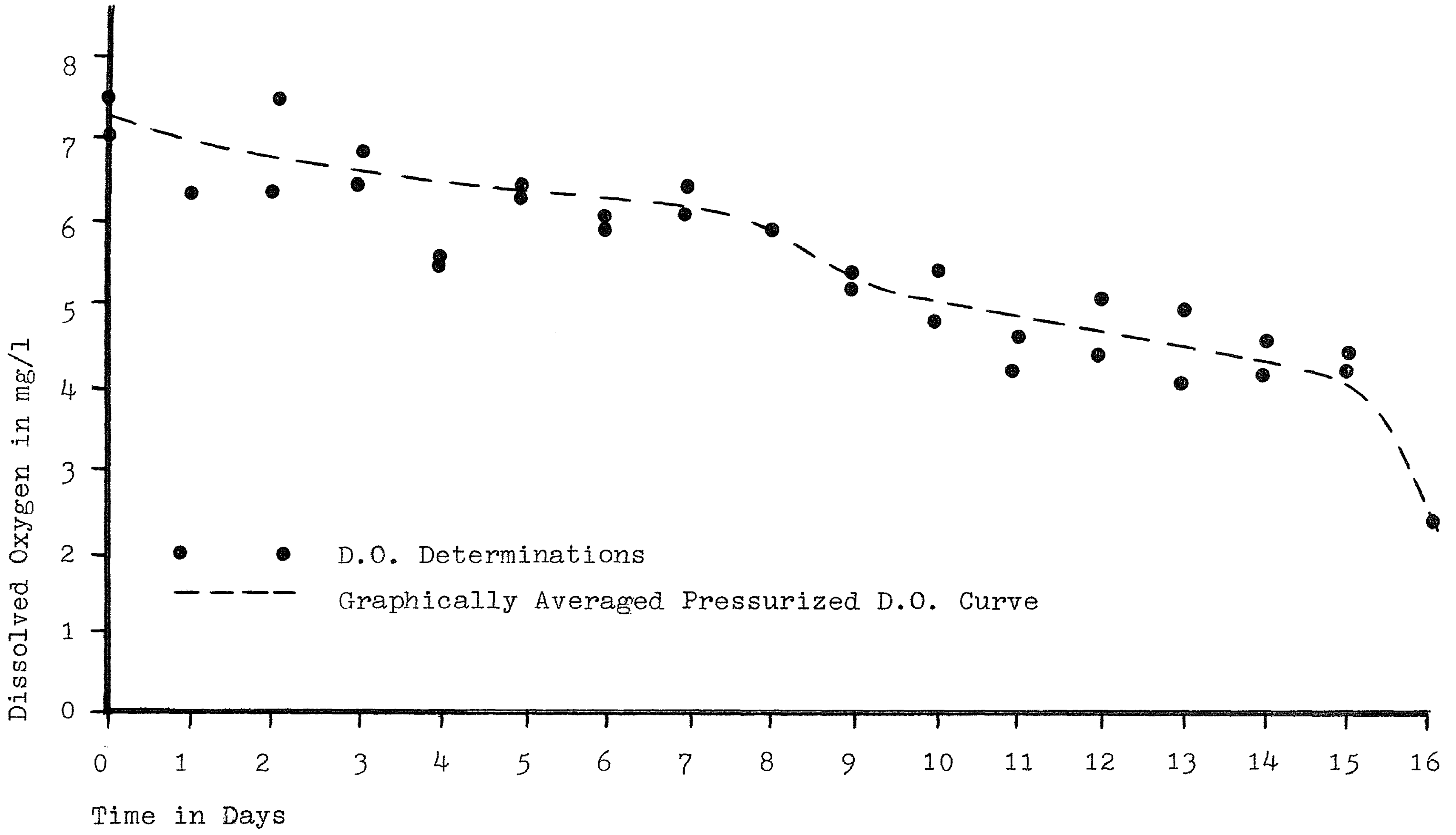

Figure 5 - Series "A" Graphically Averaged Dissolved Oxygen Curve for Non-Pressurized Samples.

taken from the curves depicting the graphical averages.

The Series "A" B.O.D. curve (see Figure 6) for pressurized effluent approximated a mild Logarithimic bacterial growth curve from the date of incubation (day zero) to day nine. In contrast, the non-pressurized effluent exhibited a declining growth curve from incubation to day seven. These results could indicate that the reactor did not sufficiently oxidize the organics, or that a form of second atage B.O.D. was being exerted, or that the 5% dilution used for long-term B.O.D. measurements was insufficient to yield good results during the initial days of incubation.

The most probable cause for the declining growth curve for the non-pressurized sample appeared to be organics, but the log growth in the pressurized effluent suggested nitrogen fixing bacteria (probably from the reactor) to be the cause. The higher ammonia level in the pressurized sample would provide a more available nutrient source for the nitrifying bacteria, hence a log growth curve yield would not be surprising. To determine the nature of the declining growth and the log growth curves future testing of reactor effluents should include nitrogen and non-oxidized organic determinations.

From day seven through day nine, both types of ef-

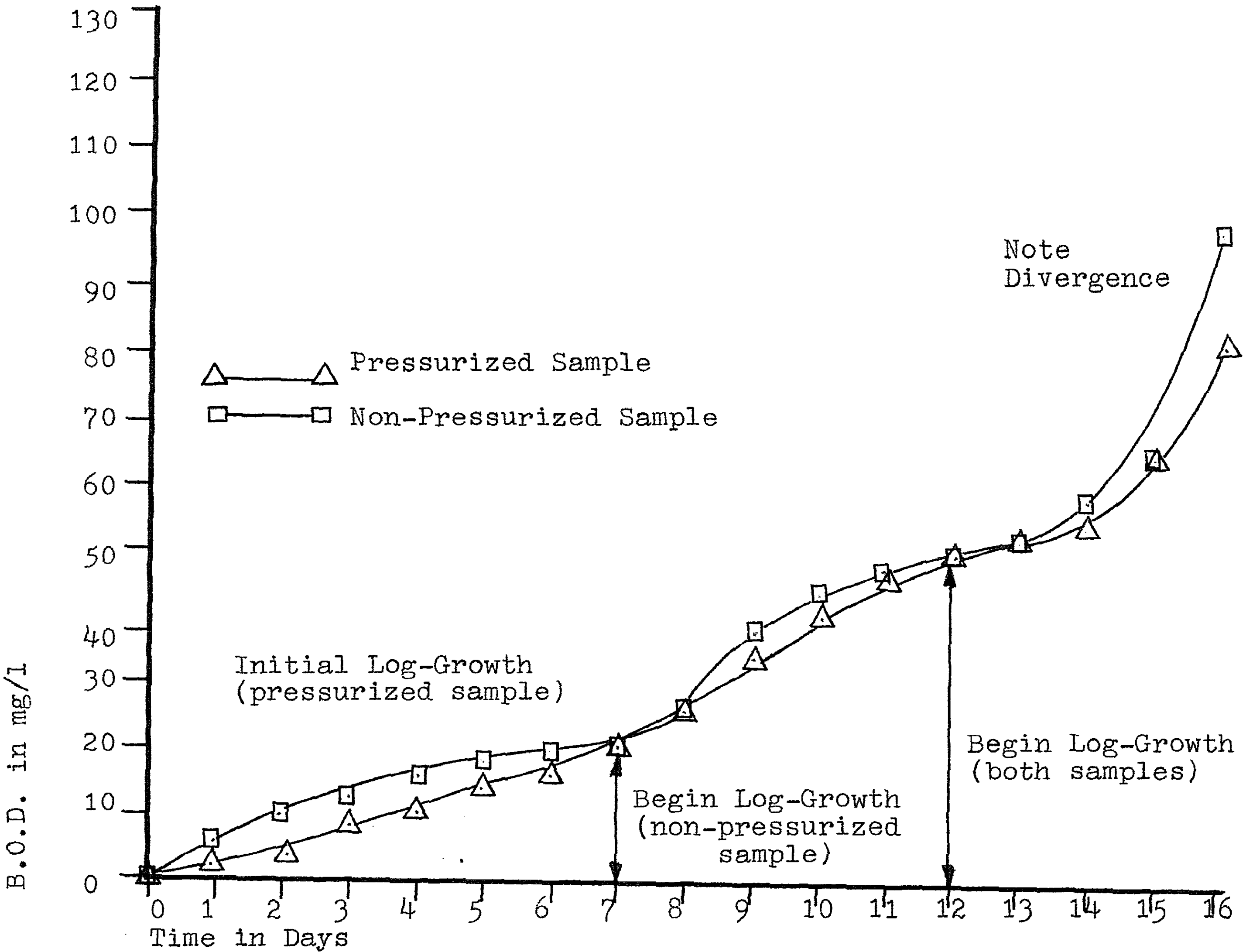

Figure 6 - Series "A" Biochemical Oxygen Demand Determinations
Pressure: 40 psig for 1 hour
Incubation: 7 Days after Reactor Start-Up

fluents exhibited a log growth curve. During this period the second stage B.O.D. would normally be expected to assert itself.

On about the ninth day, both pressurized and non-pressurized samples demonstrated a declining growth curve which ended for both samples on the twelfth day. The twelfth day marked the beginning of another log growth curve which increased in intensity to the end of the incubation period, the sixteenth day.

The most likely cause for the two separate log growth phases in each type of sample appeared to be nitrifying bacteria. Since the conversion of ammonia occurs in two phases (ammonia to nitrites and nitrites to nitrates), and two separate types of organisms perform the conversions, it would not be unexpected to find two growth curves. Again, nitrite and nitrate determinations are needed in future tests to help establish the probable cause of the log growth curves.

It should be noted that the dissolved oxygen levels in the Series "A" tests were still at 4.3 ppm for both pressurized and non-pressurized samples on the fourteenth day of incubation. This was an unexpected result indicating that bacteria population growth in both pressurized and non-pressurized samples was limited by factors other than oxygen availability. Further, testing seems appropriate to determine if the cause was due to an inadequate bacterial population in the seed or if it was due to the nature of the bacteria present in the samples.

The erratic points on the dissolved oxygen curves could have been due to several factors. Since this was the first series of tests to be performed, inadequate laboratory precautions could have accounted for some variations. Secondly an inspection of the curves shows D.O. levels on some days to be inconsistent with levels on adjacent days, and this could be due to incubator malfunctions. Thirdly, since these samples were taken from the reactor on the sixth day after seeding, it is possible that a consistent model effluent was not yet achieved due to inadequate time for the reactor to reach a steady state condition.

### Series "B" B.O.D. Tests

In an attempt to duplicate the results of the Series "A" tests, a second set of B.O.D. bottles were were incubated. The samples for this series were taken from the effluent line eleven days after reactor start-up.

Again, the samples were diluted to 5%. Enough bottles were incubated and timewise spaced to afford dissolved oxygen readings up to the 15th day.

The dissolved oxygen curves for the Series "B" tests (see Figure 7 and 8) were more uniform than the corresponding Series "A" curves, however, both sets of curves were erratic during the initial six days of incubation. The same method of graphical averaging to determine the dissolved oxygen levels to be used for biochemical oxygen demand determinations was used for both Series "A" and Series "B" curves.

An inspection of the Series "B" B.O.D. curves (see Figure 9) revealed that the initial log growth curve from day zero was exhibited by the non-pressurized sample rather than the pressurized as was the case in the Series "A" test. The contradictory results appear to stem from the graphical interpretation of the erratic oxygen demand readings during the first six days of sample incubation in both Series "A" and Series "B" tests. The 5% dilution used for long-term B.O.D. determinations was too dilute to yield good results in the initial portion of the D.O. and hence the B.O.D. curves.

A major difference between the Series "A" and "B"

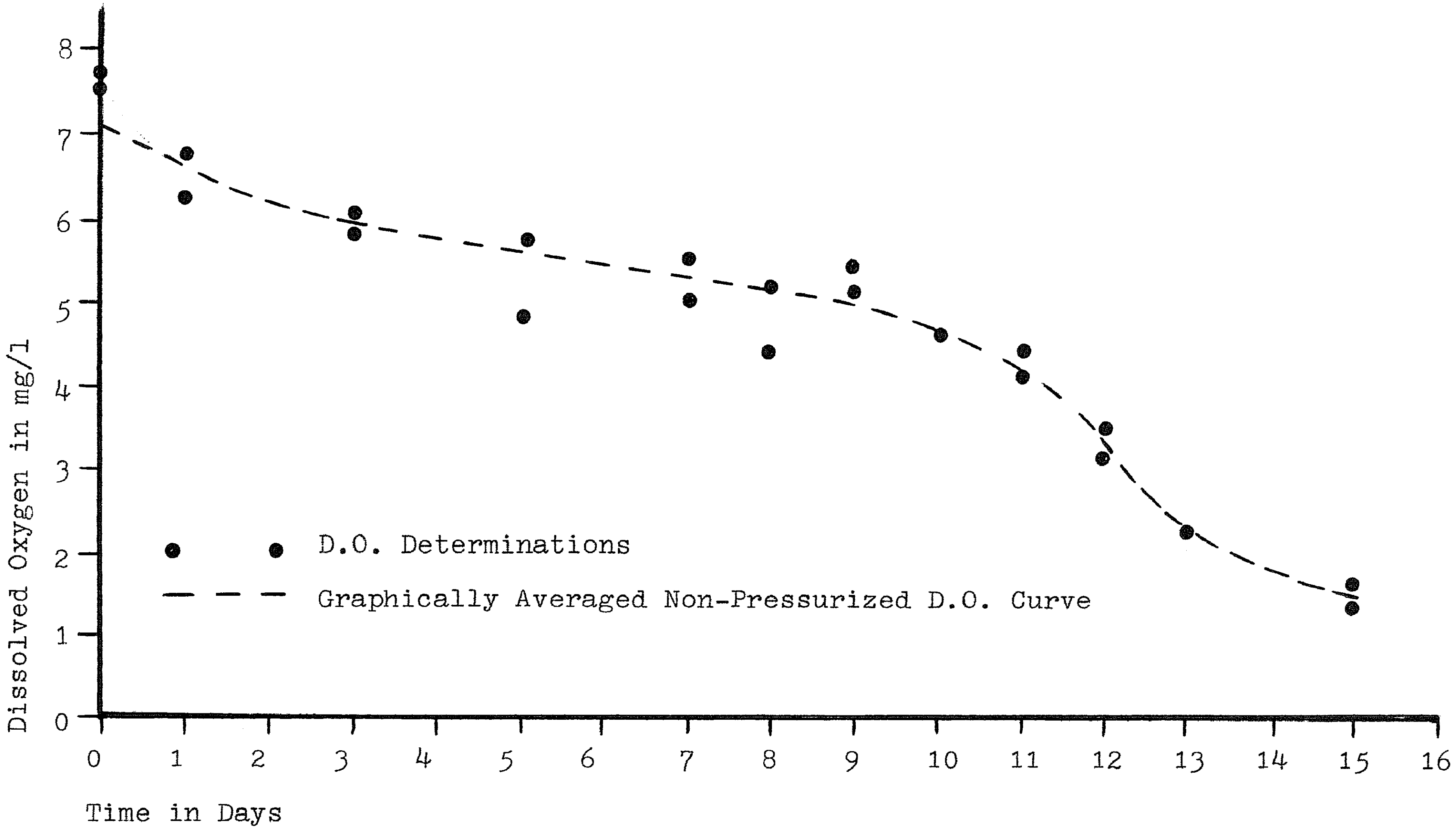

Figure 7 - Series "B" Graphically Averaged Dissolved Oxygen Curve for Pressurized Samples.

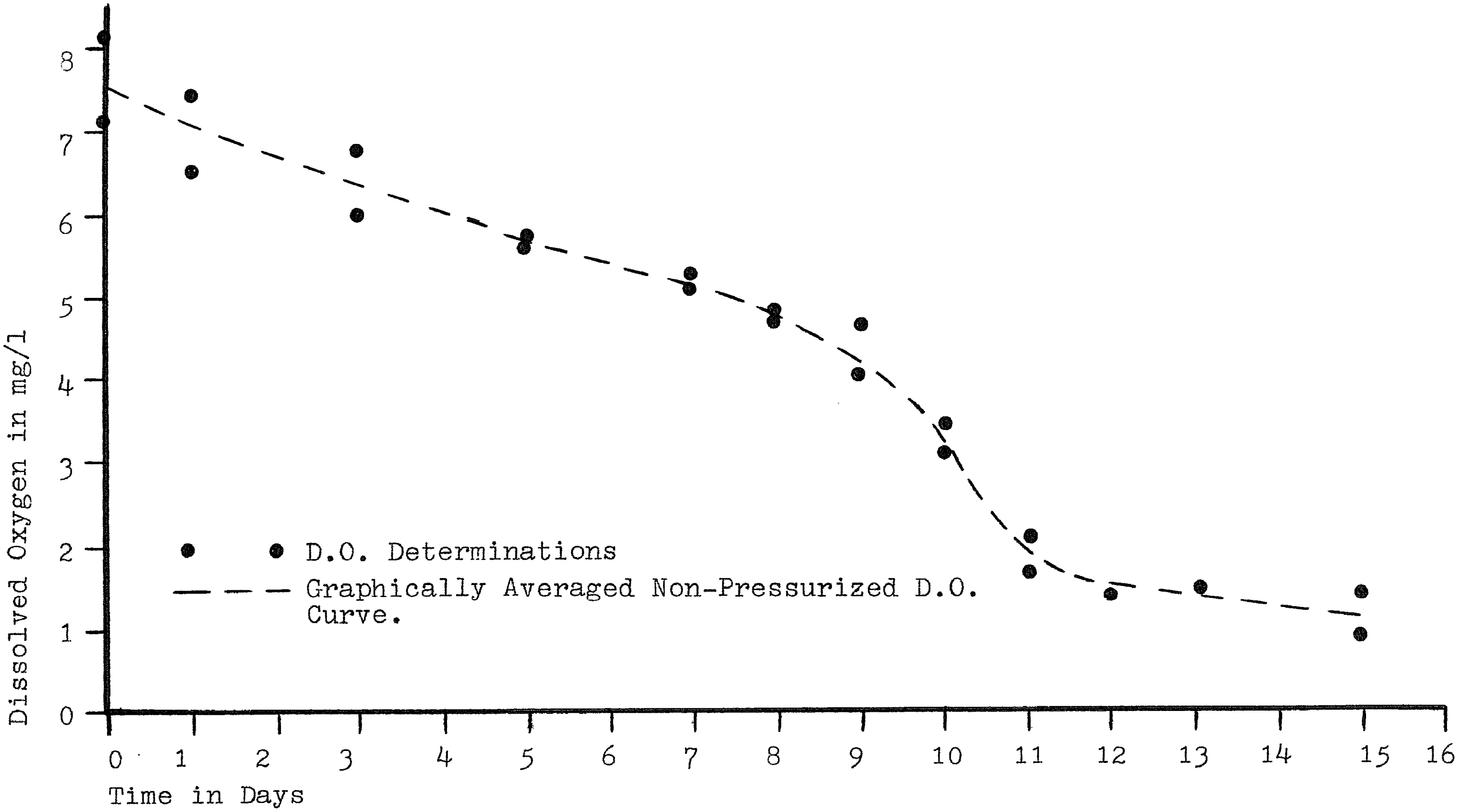

Figure 8 - Series "B" Graphically Averaged Dissolved Oxygen Curve for Non-Pressurized Samples.

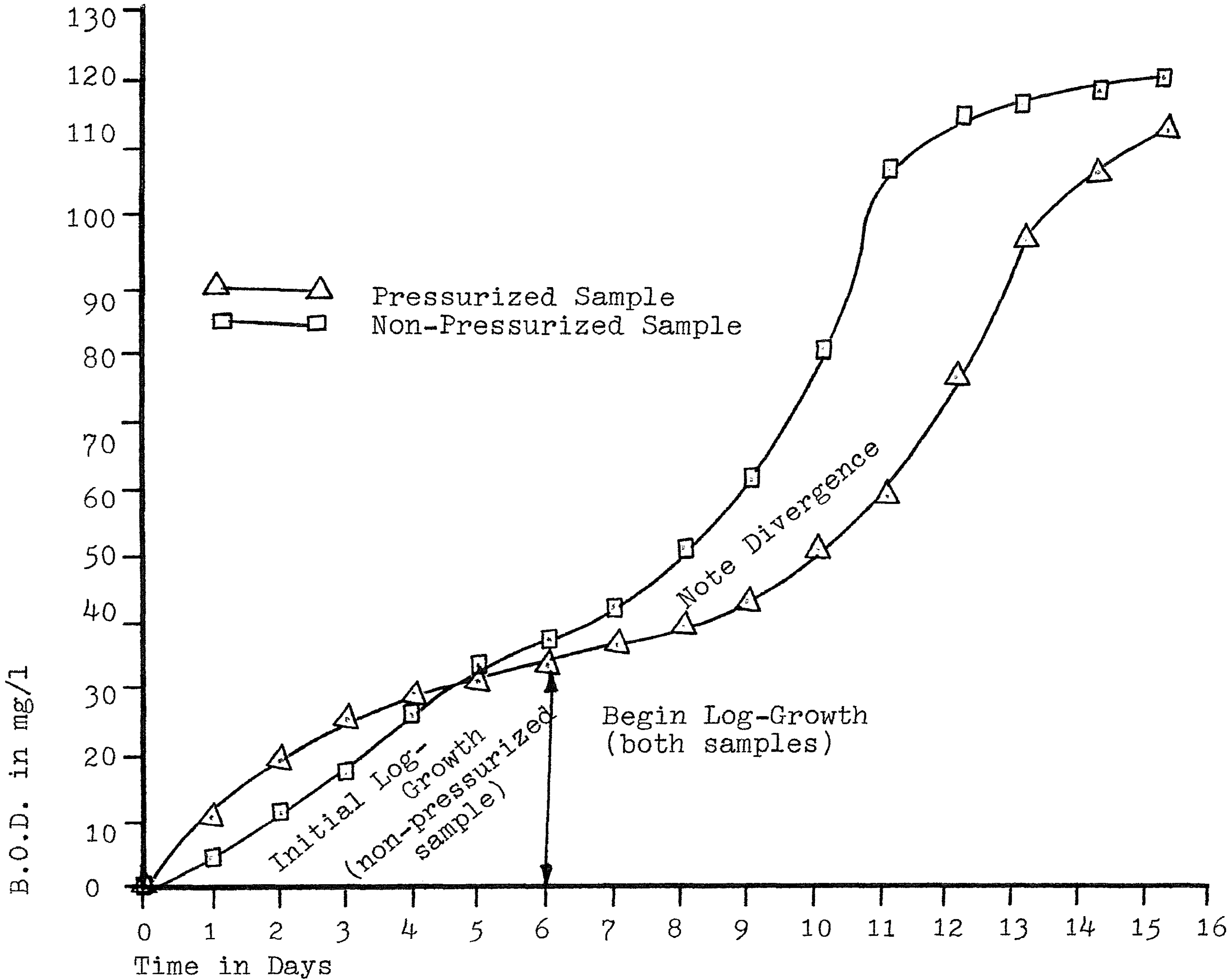

Figure 9. - Series "B" Biochemical Oxygen Demand Determinations
Pressure: 40 psig for 1 hour
Incubation: 13 days after Reactor Start-Up

curves was the separation of the pressurized curve from the non-pressurized curve in Series "B". The Series "A" curves began to separate only on the last day of incubation, whereas the Series "B" curves began separating drastically on the seventh day of incubation. The separations in both series indicated a faster bacteria growth rate in the non-pressurized effluent.

It was expected that since the Series "B" incubations were performed eleven days after reactor start-up, the reactor was producing a more consistent effluent than the earlier run Series "A". As a byproduct of the more stable reactor, it was expected that the activated sludge contained a maximum population of organic and nitrifying bacteria. Hence it was expected that the secondary clarifier effluent used for B.O.D. incubation seed would contain a greater bacterial population in Series "B" than in Series "A". A comparison of the B.O.D. curves for Series "A" and Series "B" in fact showed that the rate of B.O.D. exertion was markedly greater in Series "B", indicating a probable greater bacterial population in the Series "B" seed. Furthermore, a comparison of the dissolved oxygen levels on the fourteenth day of incubation revealed that while the Series "A" levels were still at 4.3 ppm, the Series "B" levels were 1.8 and 1.3 ppm.

Therefore, the Series "B" B.O.D. results appear to be more valid for determining the long range effects of pressurization on the biodegradability of sanitary sewage. The separation of the Series "B" pressurized and non-pressurized B.O.D. curves seemed to indicate that either the non-pressurized effluent was less polished hence more bacterial nutrients were available, or that an original exertion took place during pressurization, or that the non-pressurized activated sludge contained a greater amount of nitrifying bacteria which passed into the incubation seed. Future monitoring, especially of the solids and of specific bacteria population of the reactor effluents and the mixed liquor could more accurately pinpoint the cause of the long range effects of pressurization on the biodegradability of sanitary sewage.

# CONCLUSIONS

Based on the data generated by performing determinations of five day B.O.D. relative turbidity, ammonia contents, and long term B.O.D., the following conclusions can be made regarding the effects of pressure on the biodegradability of sanitary sewage in a model activated sludge reactor:

1. Sanitary sewage, pressurized for 1 hour at 40 psi gauge, then fed through a model activated sludge reactor and settling chamber (pressurized and treated) exhibited a lower five day biochemical oxygen demand than sanitary sewage undergoing similar treatment without prior pressurization.

2. Pressurized treated sewage exhibited greater turbidity than sanitary sewage undergoing similar treatment without prior pressurization.

3. Pressurized and treated sewage exhibited higher ammonia levels than sanitary sewage undergoing similar treatment without prior pressurization.

4. The long term B.O.D. curves for treated sewage revealed two distinct log growth phases for non-pressurized sewage, and milder log growth phases

for pressurized sewage.

5. A time period of at least ten days after start-up is required to approach a consistent effluent quality as measured by relative turbidity results in the model activated sludge reactor described herein.

6. A precise influent flowrate control is necessary with the model activated sludge reactor described herein in order to provide a consistent settling chamber effluent so that reliable comparisons between pressurized and non-pressurized samples can be made.

# RECOMMENDATIONS

The experiments performed with the model activated sludge reactors were intended to determine if the pressurization of sewage can be shown to be a practical treatment procedure. Based on the five day biochemical oxygen demand results, pressurization appears to hold little promise for practical applications as a unit process prior to activated sludge treatment. However, these experiments should be performed repeatedly to establish a greater data base for any final conclusions.

On the other hand, the Series "B" long term B.O.D. determinations suggested the possibility of utilizing pressurization to control second stage biochemical oxygen demand. The actual cause for the effects pressure exerts on sewage is still not understood, but further testing in the area of nitrification and pressurization could produce information possibly leading to its use in tertiary treatment. In conjunction with this possibility, it is suggested that in future tests the mixed liquor and effluents from the model reactors should be monitored microscopically to determine the predominant microorganisms. Effluent nitrite and nitrate determinations are also recommended. The model reactors should be run for at least ten days to establish a consistent effluent before any testing is performed on the sewage. In addition, a precisely controlled influent flowrate should be employed to control settling chamber detention time.

It is also suggested that the influent and effluent sewage samples in future experiments be monitored for total carbon, total nitrogen, and total and volatile solids. Pressurization should also be considered and tried in treatment phases other than prior to the activated sludge process, (more specifically as a form of secondary or tertiary treatment) if future test results confirm the ammonia test results herein.

It is the author's opinion that this thesis points to the direction of the required work which should be performed in the use of pressure as a unit treatment process. It is hoped that future work will establish the nature of the effect of pressurization on the biodegradability of sanitary sewage so that practical unit process experimentation could be planned, designed, and used to maximum advantage.

# APPENDIX

## Series "A" Dissolved Oxygen Determinations

Incubation Day: seventh day after aerator start-up
Dilution : 5%, batch mixed
Pressure : 40 psig

| Day | Pressurized | | Non-Pressurized | |
|---|---|---|---|---|
| | Bottle | D.O. (mg/l) | Bottle | D.O. (mg/l) |
| 0 | 137 | 6.7 | 117 | 7.0 |
| | 206 | 6.7 | 122 | 7.5 |
| 1 | 134 | 6.9 | 365 | 6.3 |
| | 136 | 6.5 | 364 | 6.3 |
| 2 | 132 | 7.0 | 341 | 7.5 |
| | 133 | 7.0 | 356 | 6.3 |
| 3 | 129 | 6.9 | 210 | 6.4 |
| | 130 | 6.5 | 338 | 6.8 |
| 4 | 128 | 5.3 | 209 | 5.5 |
| | 127 | 4.0 | 207 | 5.4 |
| 5 | 125 | 6.1 | 168 | 6.4 |
| | 126 | 4.5 | 205 | 6.3 |
| 6 | 121 | 5.8 | 170 | 6.0 |
| | 124 | 6.4 | 173 | 5.9 |
| 7 | 104 | 5.7 | 183 | 6.4 |
| | 110 | 6.3 | 181 | 6.1 |
| 8 | 114 | 5.9 | 179 | 5.9 |
| | 113 | 5.9 | 177 | 5.9 |
| 9 | 115 | 5.0 | 176 | 5.2 |
| | 120 | 5.1 | 175 | 5.3 |
| 10 | 44 | 4.8 | 137 | 4.8 |
| | 49 | 5.2 | 140 | 5.4 |
| 11 | 50 | --- | 142 | 4.6 |
| | 51 | 4.6 | 141 | 4.2 |
| 12 | 52 | 4.4 | 144 | 4.9 |
| | 54 | 4.3 | 143 | 5.1 |
| 13 | 59 | 4.6 | 149 | 4.1 |
| | 57 | 4.5 | 163 | 5.0 |
| 14 | 60 | 4.3 | 164 | 4.6 |
| | 65 | 4.4 | 167 | 4.2 |
| 15 | 66 | 4.2 | 189 | 4.2 |
| | 70 | 3.4 | 198 | 4.4 |
| 16 | 103 | 2.5 | 187 | --- |
| | 100 | 3.4 | 188 | 2.4 |

Series "A" Biochemical Oxygen Demand Determinations

Incubation Day : seventh day after aerator start-up
Dilution : 5%, batch mixed
Pressure : 40 psig

| Day | Pressurized D.O. graphically averaged (mg/l) | Non-Press. D.O. graphically averaged (mg/l) | B.O.D. | |
|---|---|---|---|---|
| | | | Press. (mg/l) | Non-Press. (mg/l) |
| 0 | 7.0 | 7.3 | 0 | 0 |
| 1 | 6.9 | 7.0 | 2 | 6 |
| 2 | 6.8 | 6.8 | 4 | 10 |
| 3 | 6.6 | 6.7 | 8 | 12 |
| 4 | 6.5 | 6.5 | 10 | 16 |
| 5 | 6.3 | 6.4 | 14 | 18 |
| 6 | 6.2 | 6.3 | 16 | 20 |
| 7 | 6.0 | 6.3 | 20 | 20 |
| 8 | 5.7 | 6.0 | 26 | 26 |
| 9 | 5.3 | 5.4 | 34 | 38 |
| 10 | 5.0 | 5.1 | 40 | 44 |
| 11 | 4.7 | 4.9 | 46 | 48 |
| 12 | 4.5 | 4.8 | 50 | 50 |
| 13 | 4.4 | 4.6 | 52 | 54 |
| 14 | 4.3 | 4.4 | 54 | 58 |
| 15 | 3.8 | 4.1 | 64 | 64 |
| 16 | 2.9 | 2.4 | 82 | 98 |

## Series "B" Dissolved Oxygen Determinations

Incubation Day: thirteenth day after aerator start-up
Dilution : 5%, batch mixed
Pressure : 40 psig

| Day | Pressurized | | Non-Pressurized | |
|---|---|---|---|---|
| | Bottle | D.O. (mg/l) | Bottle | D.O. (mg/l) |
| 0 | 121 | 7.5 | 170 | 8.1 |
| | 124 | 7.7 | 173 | 7.1 |
| 1 | 136 | 6.7 | 365 | 7.4 |
| | 141 | 6.2 | 360 | 6.5 |
| 2 | -- | -- | -- | -- |
| | -- | -- | -- | -- |
| 3 | 142 | 5.8 | 367 | 6.0 |
| | 143 | 6.0 | 368 | 6.7 |
| 4 | -- | -- | -- | -- |
| | -- | -- | -- | -- |
| 5 | 134 | 4.8 | 338 | 5.6 |
| | 135 | 5.7 | 356 | 5.7 |
| 6 | -- | -- | -- | -- |
| | -- | -- | -- | -- |
| 7 | 133 | 5.5 | 209 | 5.1 |
| | 131 | 5.0 | 207 | 5.2 |
| 8 | 129 | 5.1 | 205 | 4.6 |
| | 130 | 4.4 | 206 | 4.7 |
| 9 | 127 | 5.4 | 190 | 4.1 |
| | 128 | 5.1 | 193 | 4.6 |
| 10 | 126 | 4.6 | 168 | 3.1 |
| | 124 | 4.6 | 171 | 3.4 |
| 11 | 123 | 4.1 | 165 | 1.7 |
| | 122 | 4.4 | 166 | 2.7 |
| 12 | 117 | 3.1 | 162 | 1.4 |
| | 120 | 3.5 | 140 | 1.4 |
| 13 | 101 | 2.2 | 137 | 1.5 |
| | -- | -- | -- | -- |
| 14 | -- | -- | -- | -- |
| | -- | -- | -- | -- |
| 15 | 99 | 1.6 | 121 | 0.9 |
| | 100 | 1.3 | 132 | 1.4 |

## Series "B" Biochemical Oxygen Demand Determinations

Incubation Day : thirteenth day after aerator start-up
Dilution : 5%, batch mixed
Pressure : 40 psig

| Day | Pressurized D.O. graphically averaged (mg/l) | Non-Press. D.O. graphically averaged (mg/l) | B.O.D. Press. (mg/l) | B.O.D. Non-Press. (mg/l) |
|---|---|---|---|---|
| 0 | 7.2 | 7.3 | 0 | 0 |
| 1 | 6.6 | 7.1 | 12 | 4 |
| 2 | 6.2 | 6.7 | 20 | 12 |
| 3 | 5.9 | 6.4 | 26 | 18 |
| 4 | 5.7 | 6.0 | 30 | 26 |
| 5 | 5.6 | 5.6 | 32 | 34 |
| 6 | 5.5 | 5.4 | 34 | 38 |
| 7 | 5.3 | 5.2 | 38 | 42 |
| 8 | 5.2 | 4.7 | 40 | 52 |
| 9 | 5.0 | 4.2 | 44 | 62 |
| 10 | 4.6 | 3.2 | 52 | 32 |
| 11 | 4.2 | 1.9 | 60 | 108 |
| 12 | 3.3 | 1.5 | 78 | 116 |
| 13 | 2.3 | 1.4 | 98 | 118 |
| 14 | 1.8 | 1.3 | 108 | 120 |
| 15 | 1.5 | 1.2 | 114 | 122 |

# REFERENCES

Anderson, Donald R., "A Study of the Effects of Positive and Negative Pressures on the Anaerobic Microbial Decomposition of Sewage Sludge," Master's Thesis for Civil Engineering, Purdue University, West Lafayette, Indiana, 1960.

Bloodgood, Donald E., and Anderson, Donald R., "A Study of the Effects of Negative Pressure on Sludge Digestion," Water and Sewage Works, January, 1963.

Burnett, William E., "The Effect of Salinity Variations on the Activated Sludge Process," Water and Sewage Works, March, 1974.

Chack, John J., "Biodegradability and Coliform Die-Away in a High Pressure Ocean Environment," Master's Thesis for Environmental Engineering, New Jersey Institute of Technology, Newark, New Jersey, 1972.

Jannash, Holger W.; Eimhjellen, Kjell; Wirsen, Carl O.; Farmanfarmaian, A.; "Microbial Degreadation of Organic Matter in the Sea," Science, 171(3972), February, 1971, pp. 672-675.

Lawrence, Richard; Reynolds, Robert; Schilling, Robert; "The Effects of Pressure on the Degradation of Organic Wastes by Microorganisms," paper presented at the Middle West Regional Conference of Chemical Engineers, 1971, p.11 ff.

Ludzack, F.J., "Laboratory Model Activated Sludge Unit," The Journal of the Water Pollution Control Federation, June 1960.

Metcalf and Eddy, Inc., Wastewater Engineering, New York: Mc Graw-Hill Book Company, 1972.

Nusser, Donald O., "The Effects of Pressure on the Biodegradability of Sanitary Sewage," Master's Thesis for Civil Engineering, New Jersey Institute of Technology, Newark, New Jersey, 1975.

Pelczar, Michael J., and Reid, Roger D., Microbiology, New York: Mc Graw-Hill Book Company, 1972.

Sawyer, Clair N., and Mc Carthy, Perry L., Chemistry for Sanitary Engineers, New York: Mc Graw-Hill Book Company, 1967.