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DEVELOPMENT AND VERIFICATION OF A LABORATORY MODEL FOR  
USE IN THE STUDY OF A CONTINUOUS FLOW PRESSURIZED  
ACTIVATED SLUDGE PROCESS

*New Jersey Institute of Technology*

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By

WAYNE FREDRICK NOLTE

A DISSERTATION  
PRESENTED IN PARTIAL FULFILLMENT OF  
THE REQUIREMENTS FOR THE DEGREE

Of

DOCTOR OF ENGINEERING SCIENCE

At

NEW JERSEY INSTITUTE OF TECHNOLOGY

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## ABSTRACT

Investigations concerning the responses of domestic wastewater treated at elevated pressures have demonstrated an acceleration in the rate of biological assimilation of the waste material. The literature is not extensive, but presents much conflicting data. There has been a lack of a coherent approach to the investigation of pressure in wastewater treatment. This demonstrates the need for standard testing apparatus and procedures.

A bench scale pressurized activated sludge process was designed and constructed. The apparatus was tested over a broad range of conditions and was found to give reproducible results. Kinetic responses of the pressurized process are presented.

APPROVAL OF DISSERTATION

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LABORATORY MODEL FOR USE IN THE STUDY OF A  
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By

WAYNE FREDRICK NOLTE

For

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING  
NEW JERSEY INSTITUTE OF TECHNOLOGY

By

FACULTY COMMITTEE

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Newark, New Jersey  
December 1979



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## I. INTRODUCTION

Advances in water pollution control technology can occur in two areas. The first, equipment or hardware, offers less scope for change than does the second, process alteration. Frequently, the introduction of basic changes in process brings about the need for new hardware. The use of elevated pressures in the treatment of domestic wastewater has gotten little attention. The few investigations on its use have presented conflicting observations. The need for a more understandable approach to investigation was overdue.

Wastewater treatment research begins with the design and operation of a model from which the prototype is later developed. Further investigations of the responses of domestic wastewater treated at elevated pressures is an area of wastewater treatment research requiring the need for a laboratory model if its practical applications are to be examined.

The major operational parameter by which wastewater treatment plant efficiency is evaluated is Biochemical Oxygen Demand (BOD). Efficiency is derived from the percent reduction in 5-day BOD ( $BOD_5$ ) between the untreated and treated wastewater. Previous work involving the application of pressure to wastewater indicated that the rate at which organic material is decomposed is increased by as much as 36%. This demonstrates a possible utility in wastewater treatment because more of the oxygen required for the aerobic decomposition of organic material can be supplied during the wastewater retention period within

the treatment plant, thus reducing the oxygen demand upon discharge into the receiving water (stream or river).

The work reported in this paper was approached in two distinct phases. The first portion was the selection of the treatment process to be used in the investigation. For this, the activated sludge process was chosen. Among the design considerations were that it be a complete-mix, flow-through, pressurized process. The second phase commenced upon completion of the laboratory model. It involved a description of the reaction kinetics of the effluent wastewater for operating pressures of 0 to 40 psig and Mixed Liquor Suspended Solids (MLSS) concentrations of 1000 mg/L to 3000 mg/L. The MLSS is a measure of the concentration of organisms making up the activated sludge.

The data presented in this paper are not to be considered as the resolution of all confusions appearing in the literature, but as a starting point for a more cohesive approach to future investigations.

## II. LITERATURE REVIEW

There is not an extensive literature on pressure effects in wastewater treatment. Published and unpublished reports are more qualitative than quantitative and contain much conflicting data. Below are discussed the previous works and the conflicts that exist.

### PRESENTATION OF PREVIOUS WORK EXAMINING THE EFFECTS OF ELEVATED PRESSURES TO WASTEWATER TREATMENT

#### Jannach

An investigation, by Jannach (1), examining the effects of pressure on a biological environment was inspired by the lack of degradation in the food materials recovered after one year from the Woods Hole Oceanographic Institute's submersible ALVIN which sank in about 5000 ft. (2165 psig) of water, 135 miles southeast of Woods Hole, Massachusetts. When food from the submersible was placed in a refrigerator at 3°C, it spoiled in only a few weeks. Subsequent to these discoveries, tests were conducted in which organic materials were submerged at depths of 5000 ft. (2165 psig) for periods of two to five months. These tests indicated that microbial degradation was 10 to 100 times slower in the deep sea. It was postulated that this slow-down is caused by pressure exerting an effect on the cells, which in turn raises their minimal growth temperature. In an environment of low temperature and elevated pressure as found in the deep sea, microbial activity will decrease and eventually cease; increased pressure causes the minimal growth temperature to rise and finally surpass the environmental temperature.



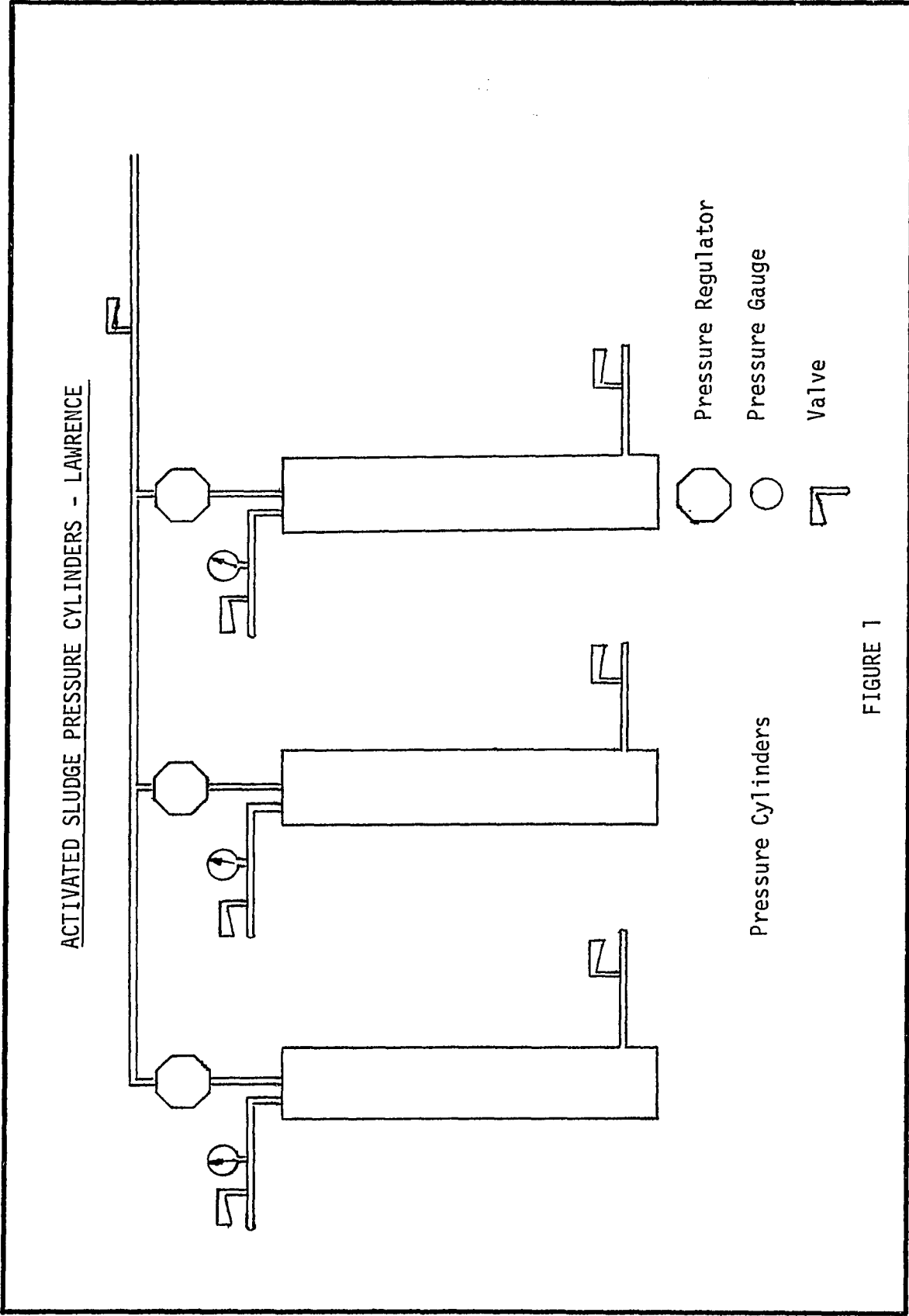
### Lawrence

Lawrence (2) investigated the effects of pressure on the biological degradation of organic wastes. Prior to Lawrence (2), Anderson (3) examined the effects of positive and negative pressures on the anaerobic microbial decomposition of sewage sludge. pH corresponding to maximum microbial activity was found to lie between 6.4 and 7.3; at a pressure of 5.3 psig, the pH is 7.2.

Based on Anderson's (3) observation of pH control with pressure, Lawrence (2) had constructed three pressure cylinders from 3 inch standard black pipe 18 inches high. Each cylinder was equipped with a hydraulic release valve, an air release valve, a pressure regulator and a pressure gauge as shown in Figure 1.

Waste sludge from a nearby treatment plant was collected and diluted with distilled water. Two weeks of aeration were necessary to acclimate the organisms before testing. The pressure cylinders were filled with a mixture of wastewater and activated sludge and pressurized to one, two and three atmospheres (14.7, 20.4 and 44.10 psig) respectively. At regular time intervals of 30 minutes, samples were withdrawn and analyzed for COD (Chemical Oxygen Demand). Each run lasted about three hours after the first sample was taken. Runs were separated by three to four days to allow the system to return to the conditions existing at atmospheric pressure before pressurizing again.

Figure 2 illustrates the results obtained by Lawrence (2). A beneficial effect caused by pressure is seen in the degradation of



COD ANALYSIS OF THREE PRESSURIZED SAMPLES - LAWRENCE

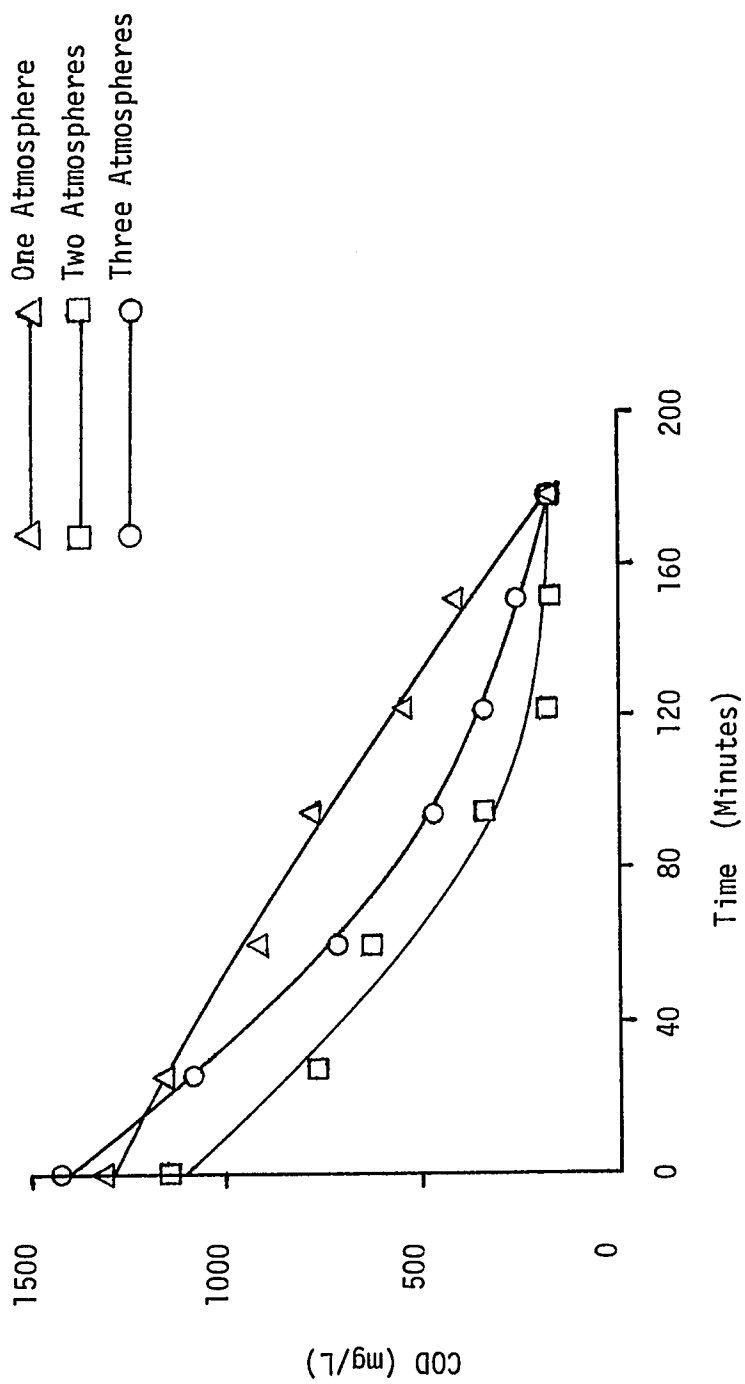


FIGURE 2

organic waste by the microorganisms. At pressures of two and three atmospheres, the percentage of COD removed is greater than that at one atmosphere (56% at two atmospheres and 38% at three atmospheres).

#### Kaplan and Klei

An investigation of reaction kinetics of a complete-mix activated sludge process operating at pressures of 0 to 100 psig was conducted by Kaplan and Klei (4). The flow-through pressure cylinder was constructed from stainless steel and was equipped with instruments for monitoring dissolved oxygen, temperature, pH and flowrate. Activated sludge from a wastewater treatment plant was adjusted to pH 6.8 to 7.2 and temperature of 68<sup>0</sup>F to 72<sup>0</sup>F and placed in the pressure cylinder. Samples of influent and effluent wastes were analyzed for COD. Detention times of 1 to 2 hours resulted in the best operating conditions. Kaplan and Klei (4) reported that little quantitative data was obtained due to the unsteady state conditions in the reactor. However, it was concluded that the growth yield coefficient decreased with increased pressure and that the kinetics of the biological reaction with pressure seemed to follow second order kinetics.

#### Chack

The observations made by Lawrence (2) and the team of Kaplan and Klei (4) are in complete disagreement. Chack (5) investigated the effects of high pressures (100 psig to 400 psig) on the biodegradation of organic waste material and coliform-bacteria die-away in the ocean environment in an effort to resolve this conflict.

His work was performed in three phases:

1. The effects of pressure on sewage samples diluted in prepared nutrient water.
2. The effects of pressure on sewage samples diluted in seawater, and
3. The effects of pressure on coliform die-away.

In each phase, pressurized and unpressurized samples were compared.

Sewage samples diluted in nutrient water were pressurized from 100 to 400 psig for one, three and five days. Samples were then analyzed for BOD. Maximum BOD removal occurred at 100 psig and decreased slightly with increasing pressure up to 400 psig as shown in Figure 3. In time, the total BOD exerted was relatively the same for pressurized and unpressurized samples. Figure 4 shows the difference in BOD exertion between an unpressurized sample and one pressurized for one day. The rate of BOD exertion is seen to be faster for the pressurized sample and to have a complete absence of the two-stage BOD characteristic.

The second phase of Chack's (5) work was the investigation of the effects of pressure on sewage samples diluted in seawater. A comparison was made between samples diluted in freshwater and seawater. Higher BOD values were obtained for the freshwater samples at atmospheric pressure while at 100 psig the seawater samples had higher BOD values.

BOD ANALYSIS OF THREE WASTEWATER SAMPLES PRESSURIZED FOR ONE DAY - CHACK

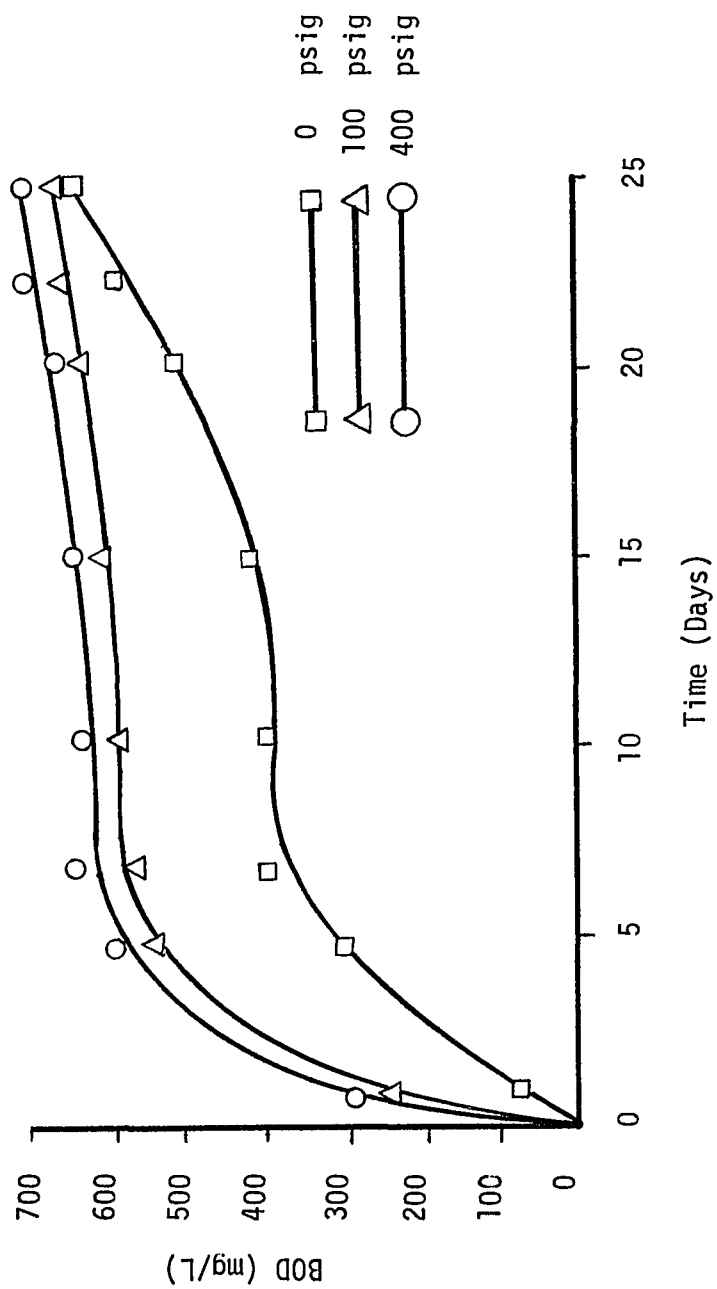


FIGURE 3

DIFFERENCE IN BOD BETWEEN A PRESSURIZED AND UNPRESSURIZED SAMPLE - CHACK

( 30 PSIG FOR 24 HOURS )

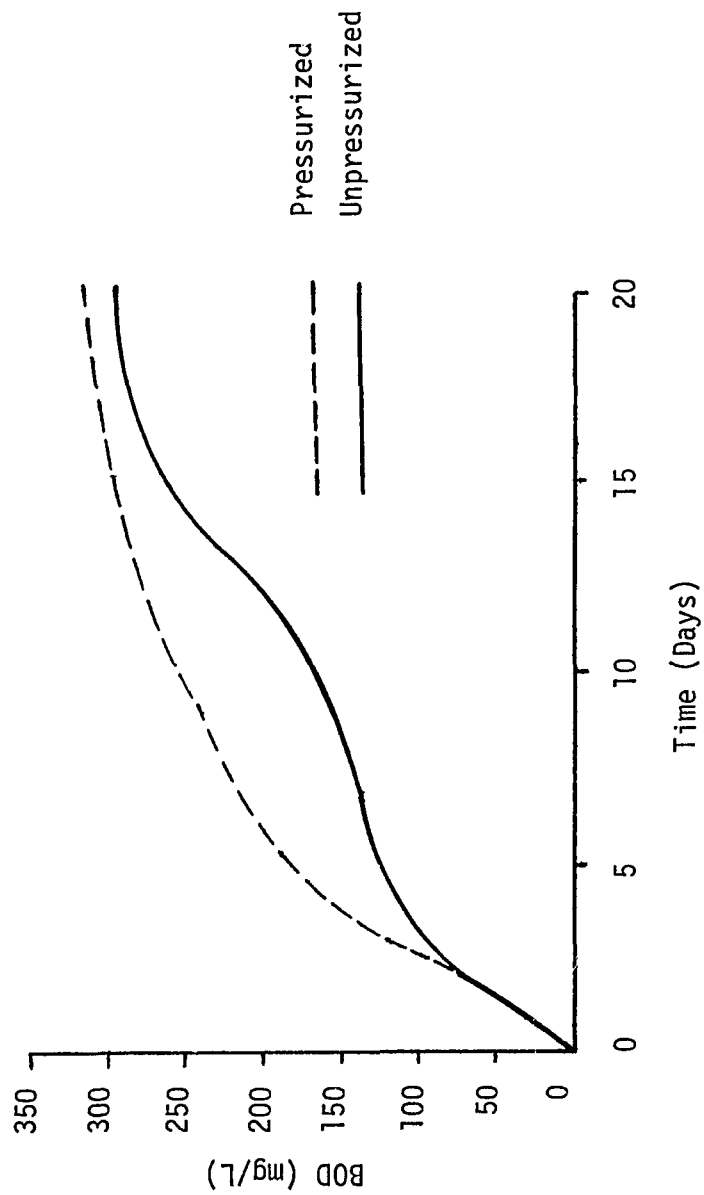


FIGURE 4

In the final portion, estimates of coliform die-away were made by the Most-Probable-Number (MPN) method for organism enumeration. Sewage samples diluted in freshwater and seawater were subjected to pressures from 0 to 400 psig for two, four and eight days. At 0 psig, freshwater samples contained a greater number of organisms than did the seawater samples. Enumerations made on the samples at 100 psig and 400 psig showed overall decrease with increasing pressure. Also, opposite to what occurred with the 0 psig samples, the elevated pressure samples had MPN values which showed more bacteria present in the seawater samples than in the freshwater samples. This is shown in Figure 5.

Chack's (5) work, rather than supporting any previous investigation, added but another observation; this being the increase in the rate of BOD exertion with pressures of 100 psig and 400 psig.

#### Nusser

Nusser (6) attempted to complete the study started by Chack (5) by observing the responses to pressures from 29.4 to 100 psig. This pressure range included the range studied by Lawrence (2). Nusser (6) used a Soils Triaxial Testing Cylinder to pressurize wastewater. All samples were compared to similar unpressurized samples.

The first series of samples were pressurized at 100 psig for 10, 30, 60 minutes and six hours. At 10 minutes there was no reduction of BOD. Reductions of 12% and 16% were observed with pressurization periods of 30 minutes and 60 minutes, respectively.



COLIFORM DIE-AWAY IN FRESHWATER AND SEAWATER AT PRESSURES OF 0,  
100 AND 400 PSIG - CHACK

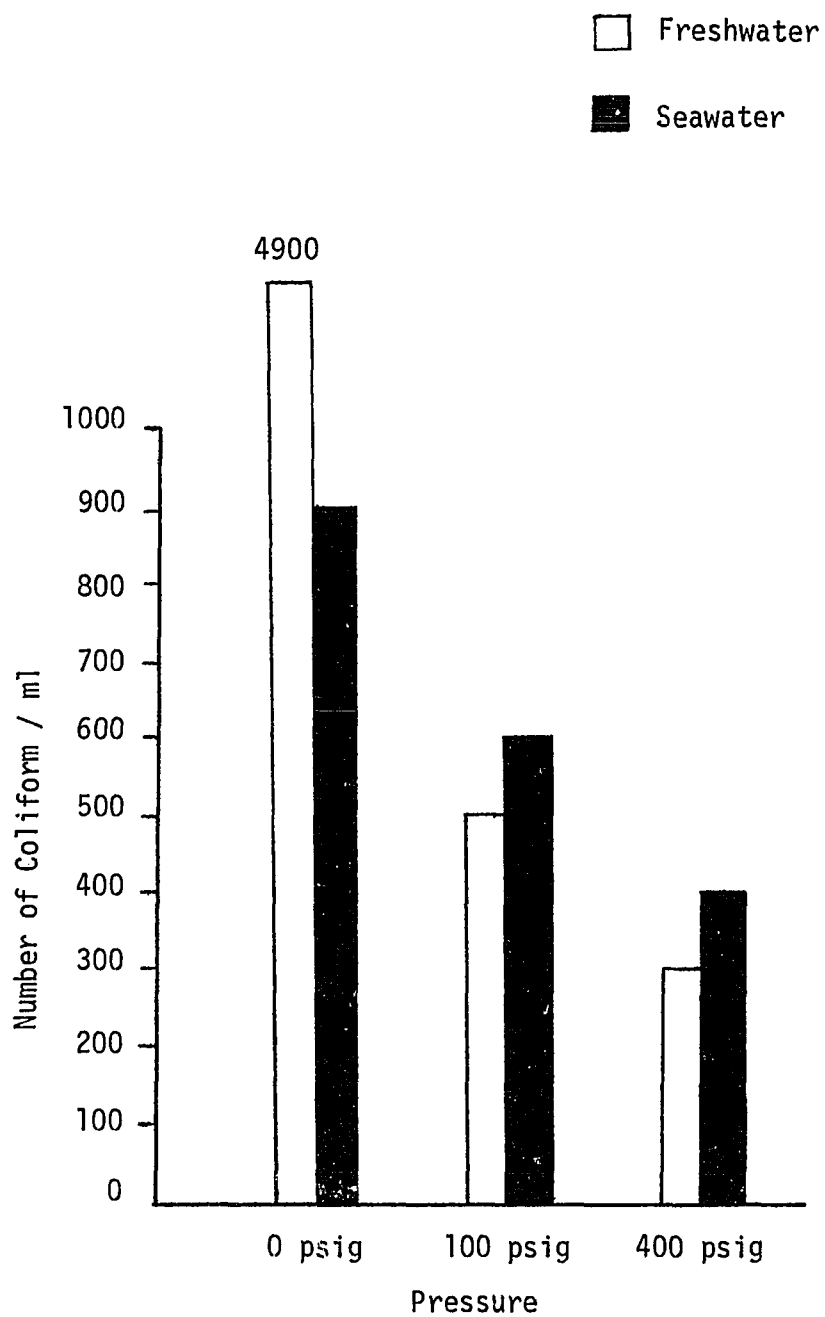


FIGURE 5

Also, the occurrence of the second-stage BOD was three days earlier than in the unpressurized samples in both cases. The six hour pressurization period caused a 19% reduction in BOD with a complete absence of the two-stage distinction. This is shown in Figure 6.

Another portion of Nusser's (6) work investigated the responses of wastewater to pressures of 14.7, 29.4, and 73.5 psig (two, three and five atmospheres) applied for one hour. A 12.5% reduction was obtained with 73.5 psig, while 21.3% and 25% reductions were obtained with 14.7% psig and 29.4 psig, respectively. These observations are presented in Figures 7, 8, and 9.

Nusser's (6) final set of tests were designed to observe the effects of varying the air/wastewater ratio (air to wastewater ratio) within the pressure cylinder. Ratios of 0.00, 0.45, and 0.90 were used. Wastewater pressurized in the absence of air (air/wastewater ratio = 0.00) showed no significant difference in ultimate first-stage BOD between pressurized and unpressurized samples. When pressurized with air, the second-stage BOD appeared up to three days earlier than wastewater samples exposed to air at atmospheric pressure. No appreciable reduction in BOD was gotten by increasing the amount of available air.

#### Mezei

Two model activated sludge processes were constructed by Mezei (7) in order to investigate the process responses to a pressurized influent. One process was fed an unpressurized wastewater, while the

BIOCHEMICAL OXYGEN DEMAND EFFECTS OF 100 PSI PRESSURE APPLIED FOR 6 HOURS - NUSSER

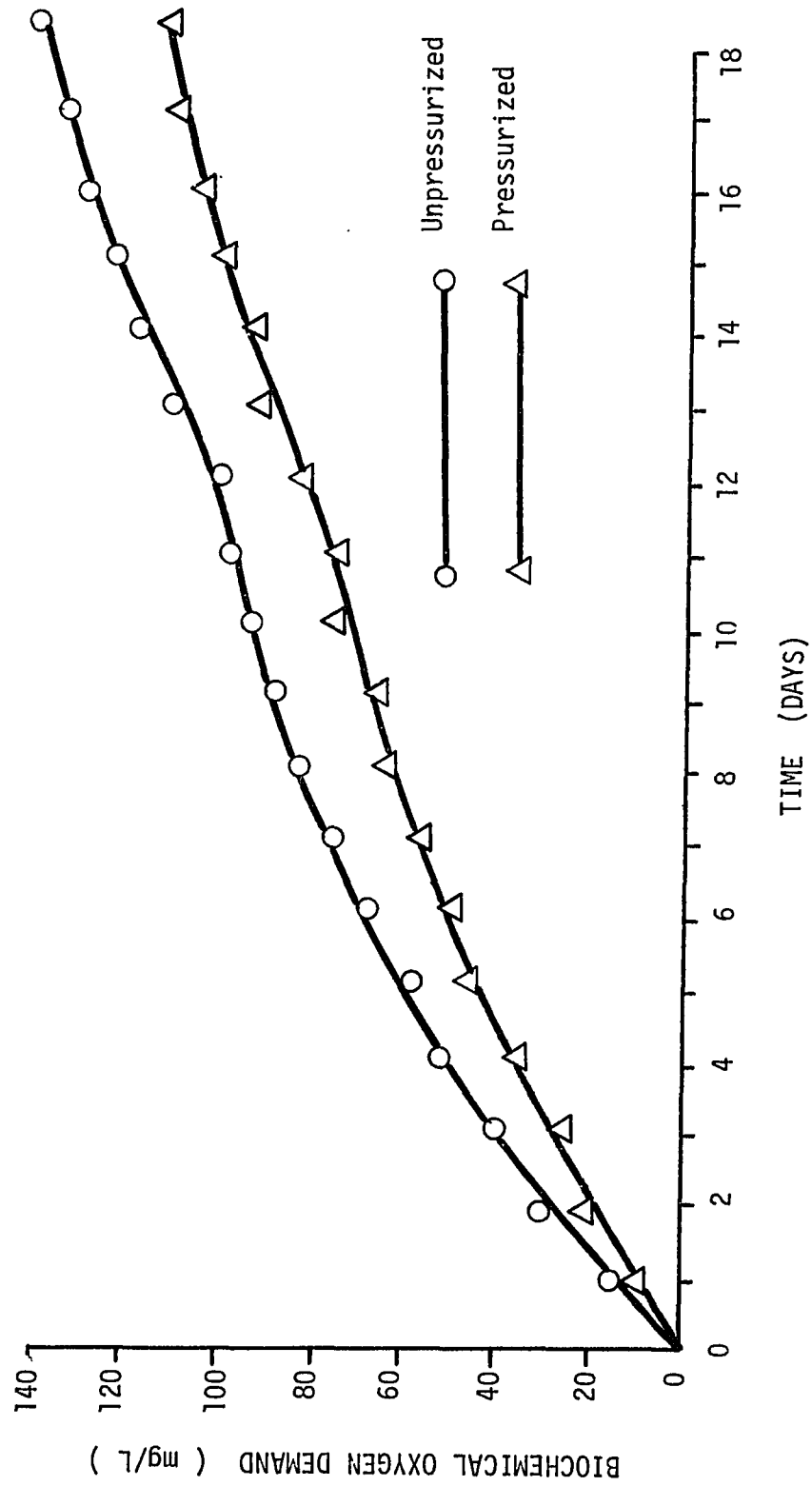


FIGURE 6

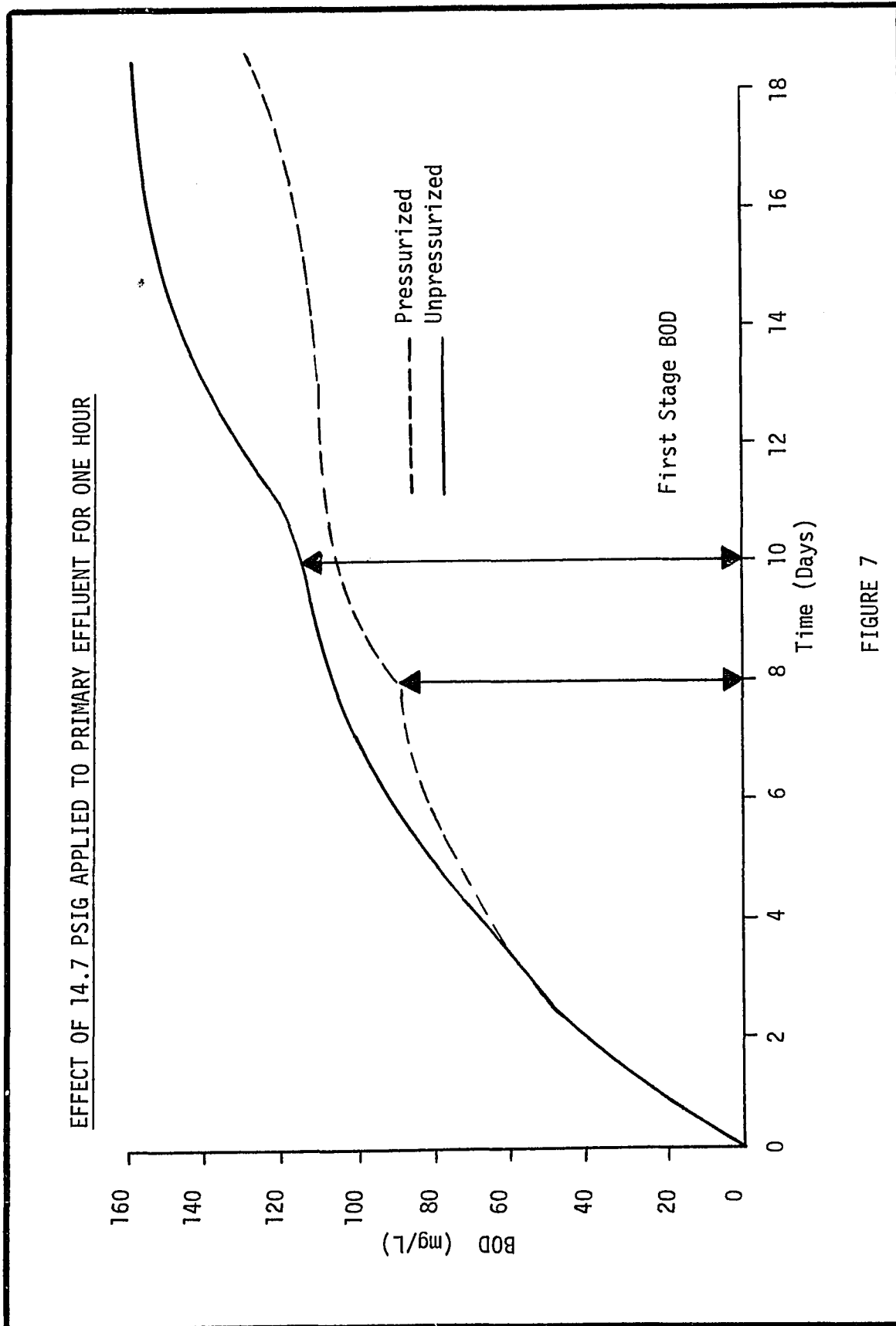


FIGURE 7

EFFECT OF 29.4 PSIG APPLIED TO PRIMARY EFFLUENT FOR ONE HOUR

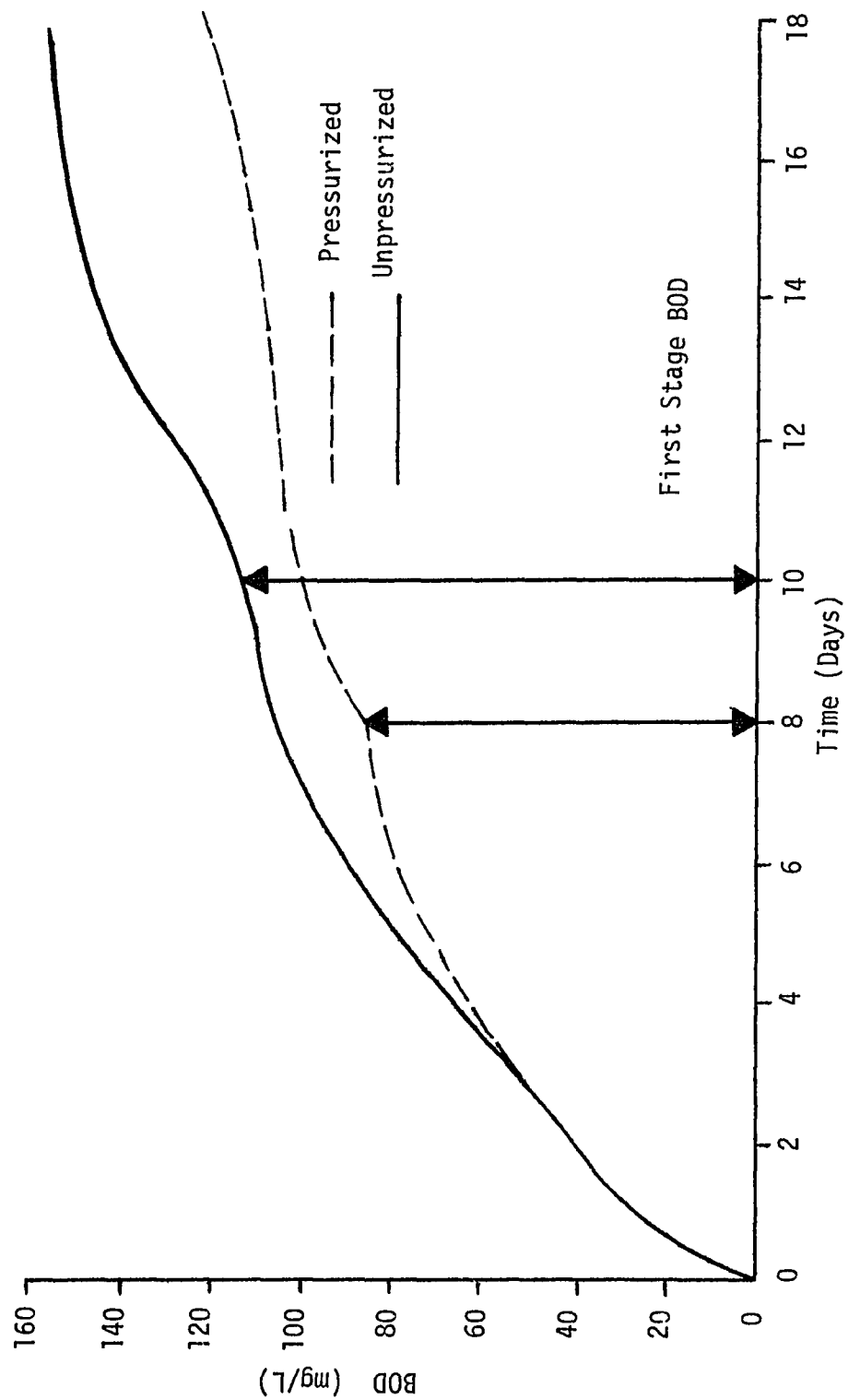
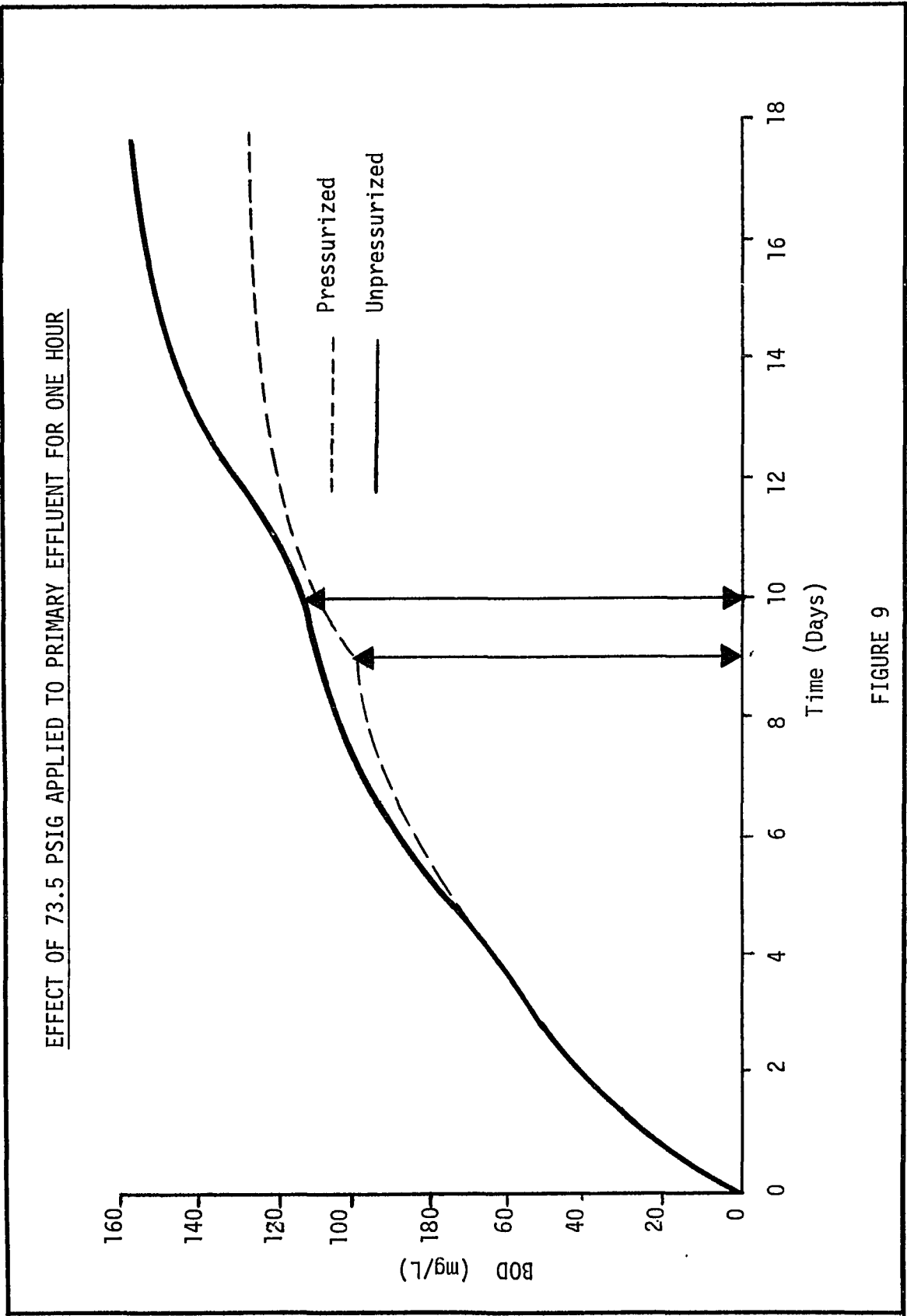


FIGURE 8



other was fed a pressurized portion of the same waste. An overall 2% reduction in ultimate first-stage BOD was obtained with the use of pressure. This, Mezei concludes, could be due to experimental error.

#### Mazzei

Mazzei (8) investigated the enumeration of general and nitrifying bacteria in pressurized and unpressurized wastewaters. This work is an extension of that begun by Chack (5) on coliform bacteria die-away. Although Mazzei's data is very erratic, it does show the growth of nitrifying bacteria and the appearance of second-stage BOD to be concurrent.

#### DISCUSSION OF PREVIOUS WORK EXAMINING THE EFFECTS OF ELEVATED PRESSURES TO WASTEWATER TREATMENT

Studies investigating the responses of wastewater to elevated pressures appear in the literature as individual studies not extending any previously conducted work. Although some of the works overlap in content, their conclusions are but convincing. A discussion of the conflicts, along with the similarities, is presented.

Lawrence (2) observed that at a pressure of 14.7 psig (2 atmospheres), the greatest reduction in COD is gotten (56%). This could indicate that microorganism activity is stimulated by pressure. However, COD is a measure of the oxygen consumption for the oxidation of biologically oxidizable and biologically inert organic matter. No tests were performed by Lawrence (2) to support the conclusion that

oxygen was strictly utilized by microorganisms for the oxidation of biologically oxidizable matter and not for the oxidation of biologically inert matter. At the same pressure, Nusser (6) indicates a 21.3% reduction in BOD and a 25% reduction at 29.4 psig (3 atmospheres). Lawrence (2) and Nusser (6) drew the same conclusions from their investigations. The rate at which waste material is oxidized is faster when pressure is applied. Kaplan and Klei (4), however, investigated the use of pressure in the activated sludge process in the same pressure range as Lawrence (2) and Nusser (6) and concluded that increased pressure tends to slow the rate of oxidation.

The manner in which pressure was applied in wastewater treatment is different in each work reported. Lawrence (2) mixed wastewater and activated sludge and placed it in a pressure cylinder where it was pressurized as a batch process. Nusser (6) did not mix activated sludge with wastewater. Here, wastewater receiving only gravity settling (primary effluent) was pressurized as a batch. Kaplan and Klei (4) pressurized a mixture of primary effluent and activated sludge in a flow-through reactor.

Tests performed by Lawrence (2) and Nusser (6) exposed microorganisms to pressure for shorter periods of time than did the tests by Kaplan and Klei (4). Here, organisms remained in the pressure environment for as much as 20 days.

It is possible that organisms subjected to long periods of pressure eventually die. Kaplan and Klei (4) present no attempt to



investigate this matter.

Pressures investigated by Chack (5) were in the range of 100 psig to 400 psig. The highest pressure investigated by Nusser (6) was 100 psig. At this pressure, he observed a 16% reduction in BOD for a pressurization period of one hour. At these same conditions, Chack (5) reported a BOD reduction of 36%. According to Nusser (6), the greatest BOD reduction was 25% and occurred at 29.4 psig (3 atmospheres) applied for one hour. Table 1 is presented as an aid to summarize the reported findings.

The model activated sludge process constructed by Mezei (7) attempted to demonstrate the utility of pressure in a wastewater treatment process. Although only a 2% reduction in BOD was obtained, this should not discourage the use of pressure in wastewater treatment. The position of pressurization in the treatment process is an unknown which needs further consideration. Previous work has emphasized the stimulation of microbial activity by pressure. If this is considered correct, Mezei (7) should have pressurized the activate sludge tank; thus stimulating a larger number of organisms than contained in the influent wastewater.

At this time, reports indicate that wastewater has a definite response to pressure. However, there are too many conflicting conclusions and a too diverse research approach to the investigation.

TABLE 1  
SUMMARY OF PRESSURE INVESTIGATIONS

RESEARCHER	PRESSURE	% REDUCTION	PERIOD OF PRESSURIZATION	MANNER OF PRESSURIZATION
Lawrence	14.70 29.40	56.00 37.00	Samples removed from test cylinder every 30 minutes for 3 hrs.	Batch -- Wastewater/Activated Sludge mixture
Chack	100.00	34.00	60 minutes	Batch -- Wastewater only
Nusser	14.70 29.40 58.80	21.30 25.00 12.50	60 minutes	Batch -- Wastewater only
	100.00 100.00 100.00	16.00 12.00 00.00	60 minutes 30 minutes 10 minutes	
Mezei	40.00	2.00	60 minutes	Batch -- Pressurization of primary effluent prior to activated sludge treatment

### III. SIGNIFICANCE OF FUTURE INVESTIGATION

Findings reported in the literature on the response of wastewater to elevated pressures indicates that pressure satisfies an immediate oxygen demand as seen by the increased rate of biodegradation. If, in fact, pressure does stimulate microorganism activity to a level which would warrant its use in a treatment process, then further investigation is necessary. The data reported to date supports this need.

In order that pressure be viewed as a practical approach to wastewater treatment, a new process or process modification must be investigated. The work performed by Mezei examined the responses of an activated sludge process to pressurized influent. It is felt that the proper location of pressure is not to the influent wastewater, but to the activated sludge. Although the influent wastewater does contain microorganisms, their numbers are greater in the activated sludge. Since more organisms can be stimulated by the application of pressure to the activated sludge, the investigation reported here will only examine that location of pressure.

#### IV. OBJECTIVE

The stimulation of microbial activity, and in turn, the faster removal of organic matter, by pressure, presents a phenomenon which warrants further investigation of its utility in wastewater treatment. The objective of this study was two-fold: First, the development of the testing apparatus which would simulate a wastewater treatment process. For this, a complete-mix, flow-through, pressurized activated sludge cylinder was constructed. Secondly, a description of the first order Biochemical Oxygen Demand rate constant,  $k_1$ , of the effluent waste stream for various cylinder pressures.

The specifications for the testing apparatus were drawn from the examination of many pilot-plant wastewater treatment processes. (9, 10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32, 33). Below are the specifications:

1. Simulation of the complete-mix activated sludge process.  
(The activated sludge process was selected over the trickling filter process because of the ease of pressurizing and its ability to handle larger volumes of widely varied waste concentrations).
2. Pressurization of the activated sludge.
3. Control of the pressure within the activated sludge cylinder.
4. Use of gases other than air for future investigations.
5. Control of air (or other gases) flowrate into the cylinder.

6. Hydraulically maintain a flow-through process.
7. Measurement of air and wastewater flowrates.
8. Measurement of the dissolved oxygen concentration of the cylinder's content.
9. Measurement of the contents pH.
10. Mixing paddle of variable speed.

The work performed in this study was not meant to resolve all confusions existing about the use of pressure in wastewater treatment. However, the purpose was to develop the necessary laboratory equipment for a more practical and understandable approach to the use of pressure in wastewater treatment and to describe the kinetic responses of the treated effluent.

## V. THE COMPLETE-MIX ACTIVATED SLUDGE PROCESS

The activated sludge process can be described as an aerobic biological process in which microorganisms decompose a portion of organic waste material into carbon dioxide and utilize the remaining portion for the production of new microorganisms. Proper aeration causes a mass of settleable solids. This microbial mass is regarded as activated sludge. A schematic of the basic process is shown in Figure 10.

The activated sludge process has experienced only minor modifications in design since its inception in 1913. Among the various activated sludge processes available are:

- Conventional
- Step Aeration
- Modified Aeration
- Tapered Aeration
- Contact Stabilization
- Extended Aeration
- Krauss Process
- Pure Oxygen
- High Rate/Complete-Mix

The hydraulics of a complete-mix activated sludge process parallels that of a mechanically stirred reactor. Primary effluent and return activated sludge are mixed and introduced into the aeration tank in a manner which will result in optimum contact between microorganisms and waste material (commonly referred to as substrate). As

SCHEMATIC OF A COMPLETE-MIX ACTIVATED SLUDGE PROCESS

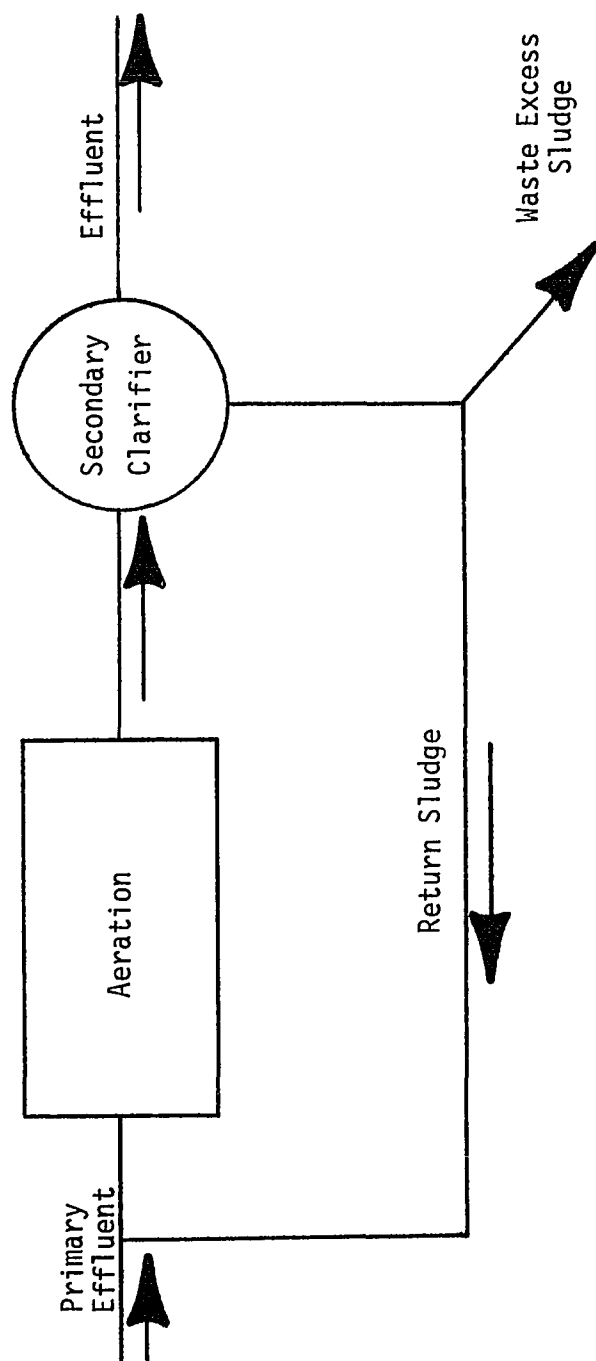


FIGURE 10

the mixture of activated sludge and primary effluent passes through the aeration tank, the dissolved and colloidal organic content decreases.

Effluent drained from the aeration tank enters the sedimentation tank (secondary clarifier) where flocculation of the activated sludge occurs and eventually settles. Flocculation is caused by a reduction in organism energy. The clarified liquid which remains is regarded as secondary effluent and is low in organic content. The settled activated sludge is either used as return sludge to mix with the primary effluent or is wasted to the sludge digester where it is decomposed under anaerobic conditions.

#### A. Theory of Operation

The availability of substrate to the microbial mass determines the quality of treatment achieved. At the aeration tank inlet port, the food-microorganism (food to microorganism) ratio is large. Initially, due to the availability of food, the microorganism population increases. This is regarded as logarithmic growth, or simply, log growth and is illustrated in Figure 11. During the log growth phase, organic matter is utilized at its maximum rate for the production of organisms. A point is reached at which the availability of substrate is limited. Population growth will not proceed at the same rate as when substrate is in abundance. The growth is said to have passed from log growth to declining growth. Further growth is now directly proportional to the substrate remaining. As more and more organisms lack the



MASS GROWTH PATTERN OF MICROORGANISMS

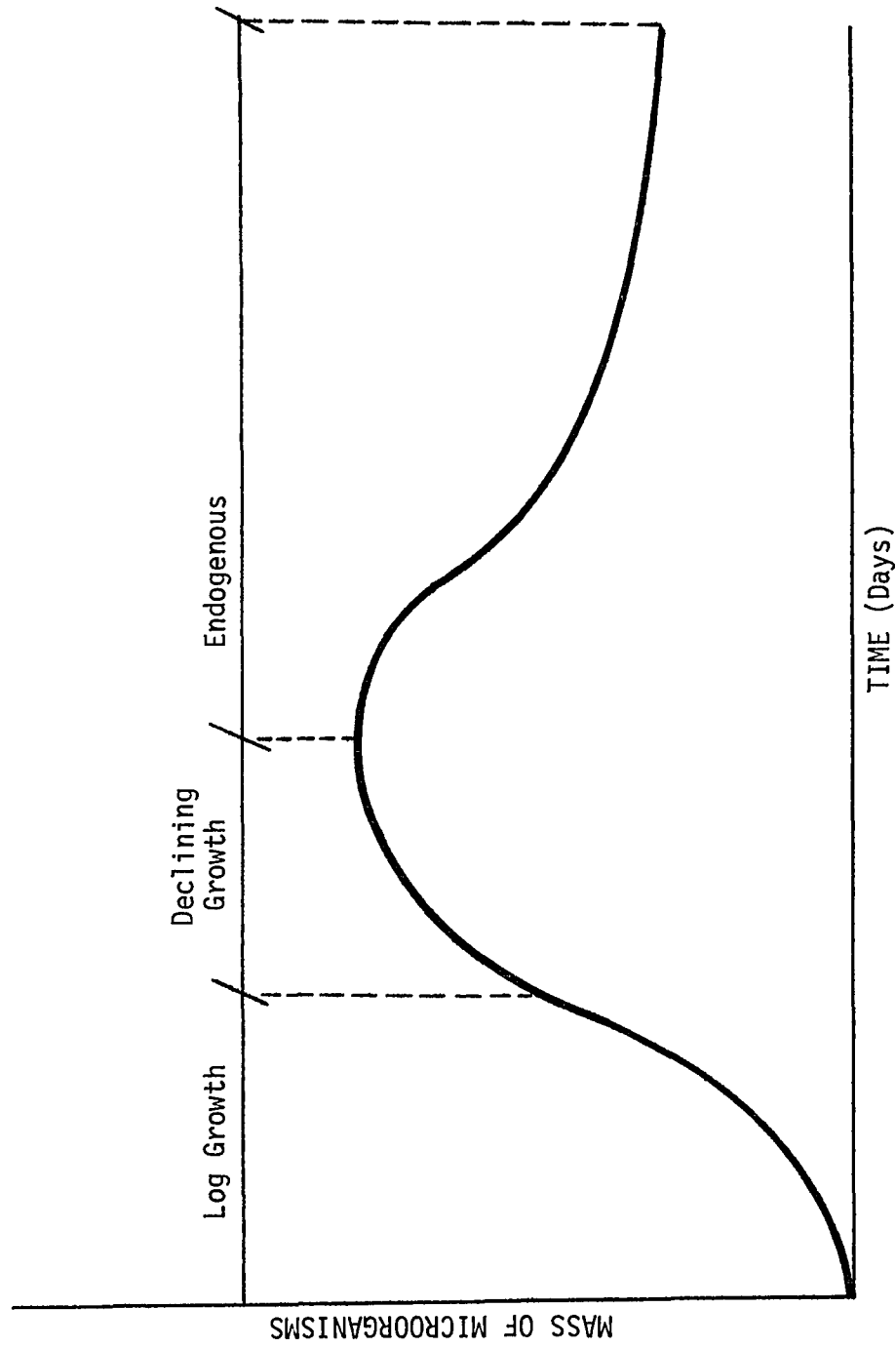


FIGURE 11

sufficient energy to overcome the forces of attraction, a floc develops.

In a well operated activated sludge process, organisms will be in equilibrium with the remaining substrate. This ensures that organisms will flocculate upon entrance to the secondary clarifier.

#### B. Nutritional Requirements and Environmental Factors

All biological waste treatment processes require that the microbial mass have all the necessary elements to form protoplasm. The primary nutritional elements are nitrogen and phosphorus. A partially nitrogen-deficient waste will stimulate fungi growth over bacterial growth, since fungi form protoplasm with a lower nitrogen content than bacteria. Fungi are filamentous and prevent good settling. The same is true of a phosphorus deficiency.

Environmental factors of importance in the activated sludge process are temperature and pH. Increases in temperature of 5 to 10°C above the desirable operating temperature of 20°C hastens the biological reactions. Greater increases cause organism death thus slowing the reaction. The desirable pH range is between 6.5 and 9.0. Below pH 6.5, fungi formation occurs and above pH 9.0 metabolic retardation is observed.

## VI. EQUIPMENT DESIGN AND OPERATION

Construction of the complete-mix, flow-through, pressurized activate sludge process followed the specifications outlined in the OBJECTIVE. The activated sludge cylinder was constructed from a clear plastic cylinder 1 foot in diameter and 3 feet in height. Clear plastic plates 2 inches thick were grooved and O-ringed to securely cap each ends of the cylinder. The cylinder was supported upright on four aluminum legs which passed through the lower plate to the upper plate. The upper ends of the legs were threaded so that nuts could be fastened in order to compress the end plates against the cylinder.

The cylinder was partitioned into an aeration chamber and settling chamber by mounting one-half of a longitudinally cut 6 inch diameter clear plastic cylinder to the inner wall. The settling chamber extended from the fluid surface to 6 inches above the floor of the cylinder. An inclined chute on the bottom of the settling chamber directed settled sludge to the center of the aeration chamber where it was resuspended by a variable speed paddle. A schematic of the activated sludge cylinder is illustrated in Figure 12.

Wastewater was stored in a 55 gallon feed tank (drum) and delivered to the activated sludge cylinder via a pump and solenoid valve mechanism. A diagram of the process layout is shown in Figure 13. Because of the pressure within the cylinder the influent wastewater had to be pumped in. A  $\frac{1}{4}$  inch plastic tube routed the influent from

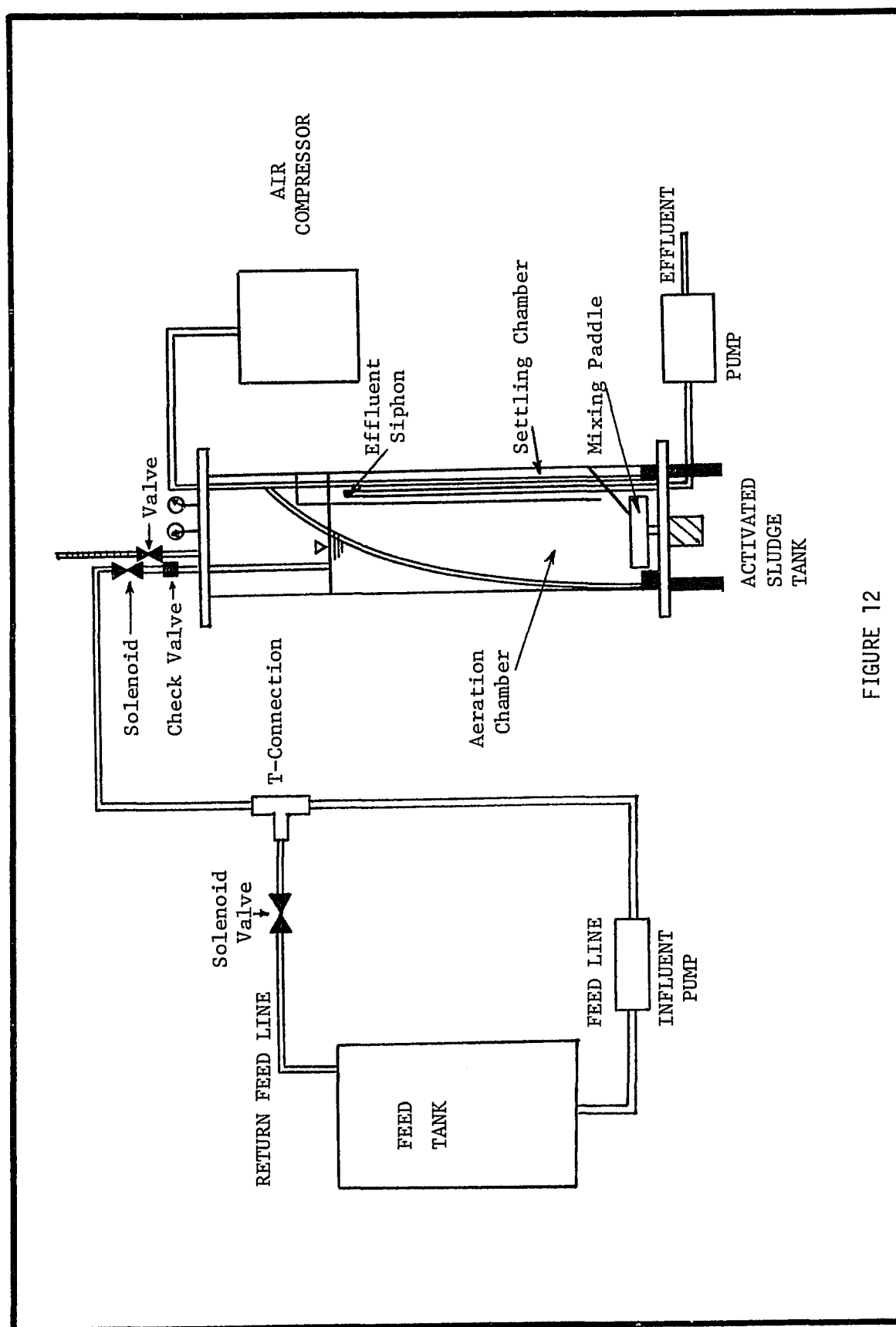


FIGURE 12

# FLOW THROUGH PRESSURIZED ACTIVATED SLUDGE PROCESS

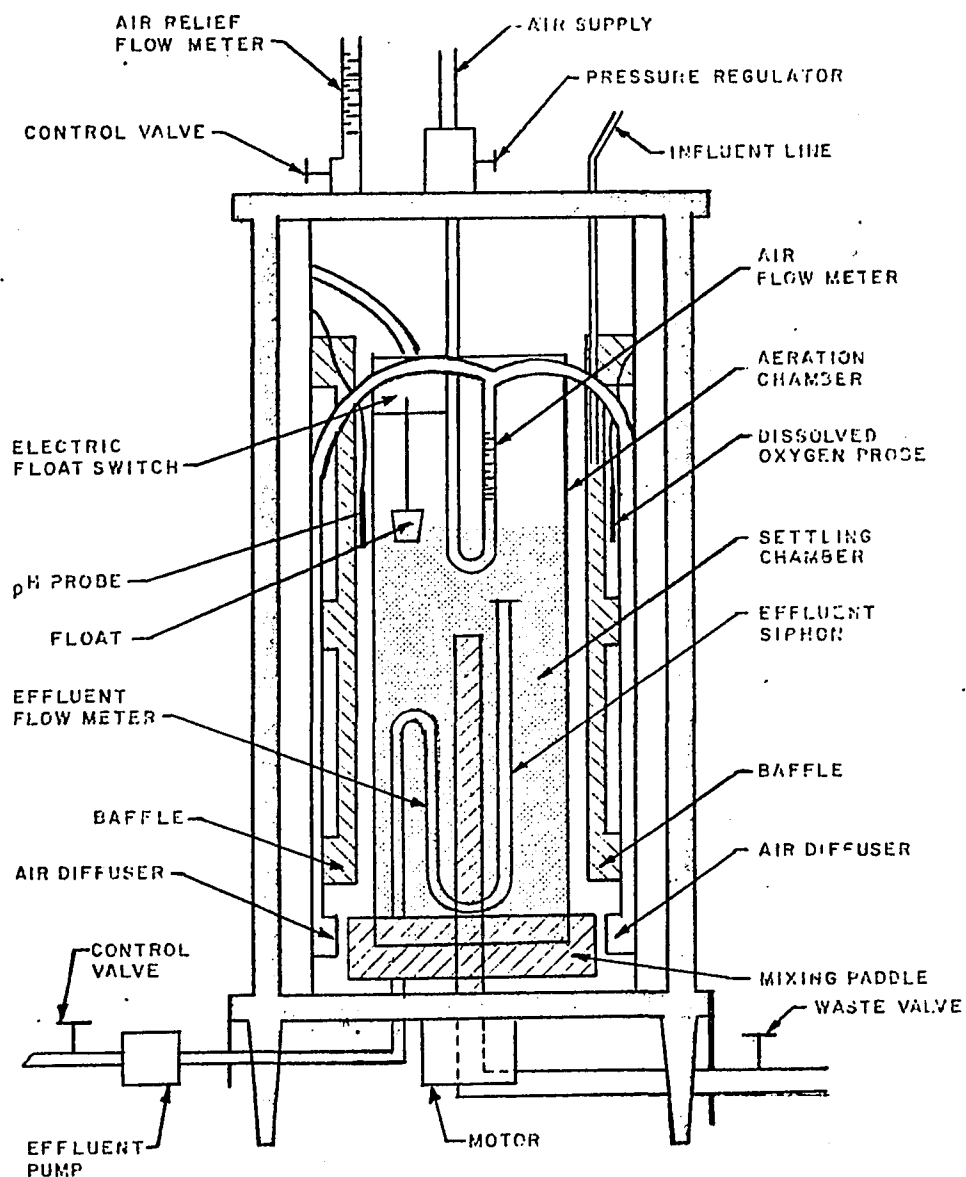


FIGURE 13

the feed tank to the influent pump. This pump was a gear-driven type with a Net Discharge Head of 350 psig. Beyond the pump was a T - connection where the influent line divided in two. One line returned to the feed tank while the other section of line conveyed wastewater to the activated sludge cylinder. A solenoid valve on the return line operated in parallel with the solenoid valve on the cylinder. As the solenoid valve on the cylinder opened to allow wastewater to enter, the solenoid valve on the return line closed. After filling the cylinder to a predetermined level, the solenoid valves directed the flow of wastewater back to the Feed Tank. This mechanism maintained a continuous flow of wastewater through the influent pump, thus eliminating excessive on-off cycling.

The influent line, from T-connection to cylinder, included a  $\frac{1}{4}$  inch polyurethane coil, solenoid valve with a  $\frac{1}{4}$  inch orifice and a check valve with opening pressure of 3 psig. An 8 inch section of  $\frac{1}{4}$  inch tubing, fastened to the inner side of the upper plate, deposited wastewater at the mixed liquor surface so that aeration prior to contact with the activated sludge would not occur. Capacity of the aeration chamber was ten gallons and settling chamber capacity was two gallons.

Wastewater flow in the pressure cylinder paralleled that of an activated sludge treatment plant. As wastewater entered the cylinder, it was completely mixed with the contents (mixed liquor) and aerated. After retention in the aeration chamber, the mixed liquor entered the

settling chamber. Clarified effluent was gathered at an effluent siphon located 1 inch below the liquid surface in the settling chamber. The 1 inch depression was needed so that pressure was not released.

A plastic tube connected between the effluent siphon and effluent port at the bottom of the cylinder included a flowmeter as shown in Figure 13. The meter was mounted to the wall of the cylinder so that it could be read from the outside. The rate of flow through the cylinder was controlled by an externally mounted gate valve on the effluent line. As the level of fluid in the cylinder lowered, a float switch opened the solenoid valve on the influent line so that wastewater entered the cylinder to refill. Once refilled, the float switch closed the solenoid valve, directing wastewater back to the feed reservoir. It was found necessary to mount a pump between the effluent port and gate valve in order to create suction in the effluent line to prevent solids from settling.

Air was supplied by an air compressor. The air line, from air compressor to aeration stones, included a pressure regulator, pressure gauge and flowmeter. Air was diffused through porous stones placed on the bottom of the cylinder. In order that a continuous flow of air be maintained through the activated sludge, a relief valve was mounted on the upper plate.

## VII. EXPERIMENTAL PROCEDURE

A study of an engineering process requires that operational and testing procedures parallel those of the full scale system in order that an accurate assessment of its utility be made. Therefore, in this investigation, activated sludge from a nearby activated sludge treatment plant was collected and stored in a laboratory aeration tank. This material was ready for use in the laboratory as required. Because of the problem encountered with the variation of pollutional strength of the wastewater taken from the treatment plant, a synthetic wastewater was prepared (see Table 2). The flowrate was maintained at 2 gallons per hour for all testing.

Before activated sludge was pumped to the pressure cylinder, it was acclimated to the synthetic wastewater for one week. A portion of the activated sludge was then pumped into the cylinder. Once filled, wastewater pumping began.

The parameters routinely monitored were dissolved oxygen, temperature, MLSS concentration and pressure within the cylinder. The MLSS concentration was varied from 1000 mg/L to 3000 mg/L in increments of 500 mg/L for each of the cylinder pressures 0, 10, 20, 30, and 40 psig. Each pressure was maintained for several days before data was taken. Between runs, the pressure within the cylinder was released. It was necessary to readjust the MLSS concentrations during this time. Fresh sludge was introduced as required. This procedure yielded adequate data for process description.



TABLE 2  
SYNTHETIC WASTEWATER

---

Ammonium Sulfate	9.00	grams
Potassium Monobasic	2.50	grams
Ferric Chloride	0.25	grams
Magnesium Sulfate	7.50	grams
Sodium Carbonate	9.00	grams
Sodium Nitrate	2.70	grams
Succrose	45.00	grams

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(Per 50 gallons of tap water)

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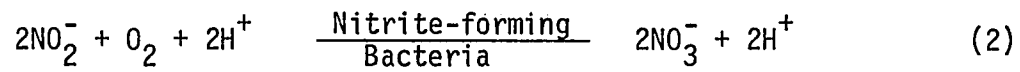
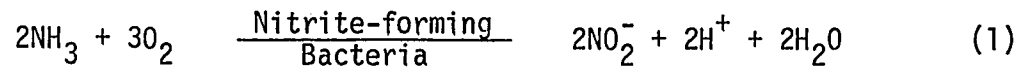
After much data was gathered with use of the synthetic wastewater, wastewater which received only primary treatment was brought to the laboratory from a nearby domestic wastewater treatment plant. The process operational procedure was followed with the domestic wastewater as had been followed with the synthetic wastewater. Because of the difficulty in transporting large volumes of domestic wastewater to the laboratory, only one MLSS concentration (2160 mg/L) was investigated. The data gathered with the use of domestic wastewater followed very closely that obtained with the synthetic wastewater.

### VIII. DATA ANALYSIS

The 5-day BOD is the accepted parameter by which the strength of a pollutional waste is measured. It is essentially a measure of the oxygen utilization in the stabilization of the organic waste by the microorganisms over a 5-day period at 20°C. With domestic sewage, the 5-day BOD values represent 65 to 70 percent of the total biologically oxidizable organic matter of the carbonaceous phase. The BOD test is considered to be a wet oxidation procedure in which living organisms serve as the means of oxidation of the organic matter to carbon dioxide, water and new organisms. The oxidative reaction involved is a result of biological activity, and the rate at which the reaction proceeds is governed by the availability of substrate, microbial population which is dependent on the availability of substrate and temperature.

BOD is not a single response. Domestic wastewater contains nitrifying bacteria which oxidize ammonia-nitrogen to nitrate-nitrogen. At 20°C, their reproductive rate is such that their populations do not become sufficiently large to exert an appreciable demand for oxygen until about 8 to 10 days have elapsed in the regular BOD test.

The following two equations (1 and 2) describe the mechanism by which nitrifying bacteria oxidize ammonia-nitrogen to nitrite-nitrogen and then to nitrate-nitrogen.



The BOD reaction can be fairly well described as "first order" in character, or the rate of the reaction is proportional to the amount of oxidizable organic matter remaining at any time. This reaction may be expressed as shown in Equation (3):

$$\frac{dy}{dt} = k_1' (L - y) \quad (3)$$

$\frac{dy}{dt}$  = BOD exertion in the time increment  $dt$

$k_1'$  = Reaction Rate Constant

$L$  = Ultimate First Stage BOD

$y$  = BOD exerted in time  $t$

Integration of this equation yields:

$$y = L (1 - e^{-k_1' t}) \quad (4)$$

$$y = L \overset{\text{or}}{(1 - 10^{-k_1' t})} \quad (5)$$

In the work reported here, values of  $k_1$  were calculated for the effluent wastestream. Data are not always well behaved in the real world and pure first order responses can seldom be expected. This is particularly true when the nitrogenous phase follows the carbonaceous phase. Fortunately, the early stages of the carbonaceous phase do reasonably well follow a first order. It is necessary, therefore, to use as the basis of analysis the "well behaved" portion of the curve. The value of  $L$  associated with this curve was selected as to produce a straight line on a semi-log plot.

For the biological response:

$$y = L ( 1 - 10^{-k_1 t} ) \quad (6)$$

taking logarithms of both sides and rearranging:

$$\log ( 1 - y/L ) = k_1 t \quad (7)$$

A typical plot of  $\log (1-y/L)$  versus  $t$ , the elapsed time, is displayed as a semi log plot. The more closely a straight line is followed, the more closely a pure first order exponential response is indicated. In analysis of experimental data values of  $L$  were assumed and semi-log plots of the quantity  $\log (1-y/L)$  against arithmetic time were prepared for each combination of pressure and MLSS concentration previously mentioned. These plots are shown in Appendix C. The slope of the straight line gives the reaction rate constant  $k_1$  and can be directly calculated in the following manner. If a time interval  $t_{1/2}$  is taken such that the value of  $(1 - y/L)$  falls

to one-half its initial value, the rate constant is expressed as shown in Equation 8.

$$k_1 = \frac{\log 2}{t_{1/2}} = \frac{0.301}{t_{1/2}} \quad (8)$$

This was proposed by Roots and his co-workers (34). Rate constants for the pure first order response were calculated. All experimental points were calculated using the values of  $k_1$  and  $L$  as outlined above. In addition, the traditional Method of Moments proposed by Moore, Thomas and Snow (35) was used as an independent check of the values obtained from the above procedure.

## IX. DISCUSSION OF EQUIPMENT OPERATION

The model complete-mix, flow-through, pressurized activated sludge process constructed for the investigation of the responses of the activated sludge process to elevated pressures operated satisfactorily. Future apparatus construction will require modifications be made and are outlined in FUTURE INVESTIGATIONS.

Bulking of the sludge (floating sludge) presented a problem but was later found to be caused by the high oxygen concentration of the activated sludge and wastewater in the pressure cylinder, the settling chamber located in the pressure cylinder and the speed of mixing.

Stopping the mixing paddle for 10 minutes each half hour allowed the sludge enough time to flocculate and settle, thus creating a clear effluent. During mixing, however, the sludge would collect at the surface of the settling chamber where it would enter the effluent siphon. The siphon tube was one-half inch in diameter and was easily clogged. An effluent pump was mounted externally at the effluent port in order to create enough suction so that the sludge would not settle in the line.

Two air stones at the bottom of the aeration chamber unevenly distributed dissolved oxygen through the Mixed Liquor. Four additional air stones were included and appeared to more evenly distribute the dissolved oxygen. Dissolved oxygen profiles within the Mixed Liquor could not be plotted because the probe and meter used in

the cylinder design was incapable of measuring dissolved oxygen concentrations in excess of 15 mg/L.

Mechanical mixing of the sludge is necessary for sufficient contact between microorganisms and waste. However, too much mixing can create a highly turbulent environment in which microorganism and waste contact is diminished to the point where no decomposition of the waste takes place. A paddle speed of 30 rpm's was used for the first few runs but was quickly lowered to 18 rpm's where better contact was made.

Except for the few problems discussed above, it operated well. Duplication of data was obtainable from its operation.

## X. DISCUSSION OF EXPERIMENTAL WORK AND CONCLUSIONS

Evaluation of an engineering process often includes an examination of its efficiency. However, increases in efficiency may be prohibitive due to economic reasons. The assessment of a new process or an improvement of an existing process can initially require substantial investment. It is only after much investigation of a process capability that economic feasibility can be considered.

The work reported in this paper examines the responses of the activated sludge process to elevated pressures and does not consider the economic feasibility of its utility. The pressurized activated sludge process was designed with regard to similarity in operation to the complete-mix activated sludge process found in domestic wastewater treatment plants. The equipment used in the construction of the pressurized process was selected only for its operational capabilities while optimization of design was not considered.

Experimental investigation of the operational parameters of the complete-mix pressurized activated sludge process was undertaken upon completion of the laboratory model. The purpose of this investigation was three-fold:

1. To describe the operation of a complete-mix, flow through, pressurized activated sludge.
2. Describe the kinetic responses of an activated sludge process to elevated pressure.



3. Observe any changes in process efficiency obtained through the use of pressure.

The work undertaken in this investigation is unique in that based on the results obtained by previous investigators, testing apparatus necessary for a more understandable approach to the use of pressure in wastewater treatment was developed. No investigation had considered the practical application of pressure to domestic wastewater treatment. The most important part of work reported in this paper is the systematic approach used to collect the data necessary for describing the kinetic responses of the activated sludge process to pressure. In the following paragraphs, the results are discussed.

Kinetic responses of the effluent synthetic wastewater treated in the pressurized activated sludge process was obtained by BOD analysis. For each sample taken, three dilutions were made. In three 300 ml BOD bottles were placed 5, 10, and 15 mls of wastewater respectively, and diluted with nutrient water until full. Dissolved oxygen concentrations were taken daily for fourteen days. The curves presented in Appendix I illustrate the percent reduction in Effluent BOD between the pressurized and unpressurized samples of the synthetic wastewater. The MLSS concentrations within the cylinder were 1000, 1500, 2000, 2500, and 3000 mg/L. Table 3 summarizes the reductions. Each MLSS concentration examined indicates an increase in BOD removal with an increase in pressure. The greatest removal (45.9%) occurred at 2500 mg/L and 40 psig.

Greater removals of BOD in a given period of time corresponds to an acceleration in the rate of organic decomposition. The reaction rate was quantified by computing values of the first order reaction rate constant,  $k_1$ . Appendix II presents semi-log plots of the quantities  $(1-y/L)$  vs. time for the determination of  $k_1$  as explained in the DATA ANALYSIS. A summary of the reaction rate constants is given in Table 4. Figure 14 graphically illustrates the data presented in Table 4. Appendix III contains the individual curves which are shown as a composite in Figure 14.

Reaction rate constants for the treated synthetic wastewater varied from 0.170 per day at 0 psig to 0.295 per day at 40 psig. The greatest increase in the reaction rate from 0 psig to 40 psig was observed at a MLSS concentration of 2500 mg/L -- the rate constant of 0.170 per day at 0 psig increased to 0.288 per day at 40 psig. All increases in reaction rate were accompanied by reductions in First-Stage BOD.

Table 5 presents the results of the overall process efficiency for the various pressures and MLSS combinations examined. Process efficiency increased with increasing pressure. The greatest overall increase observed was 90.90% which was obtained at 40 psig, and 2500 mg/L. This reflects a 10% increase in process efficiency.

Tables 6, 7, and 8 presents domestic wastewater data similar to that presented in Tables 3, 4, and 5. At a MLSS concentration of 2160 mg/L, and a pressure of 40 psig, a 20% reduction in effluent

REACTION RATE CONSTANT AS A FUNCTION  
OF PRESSURE AND MLSS.

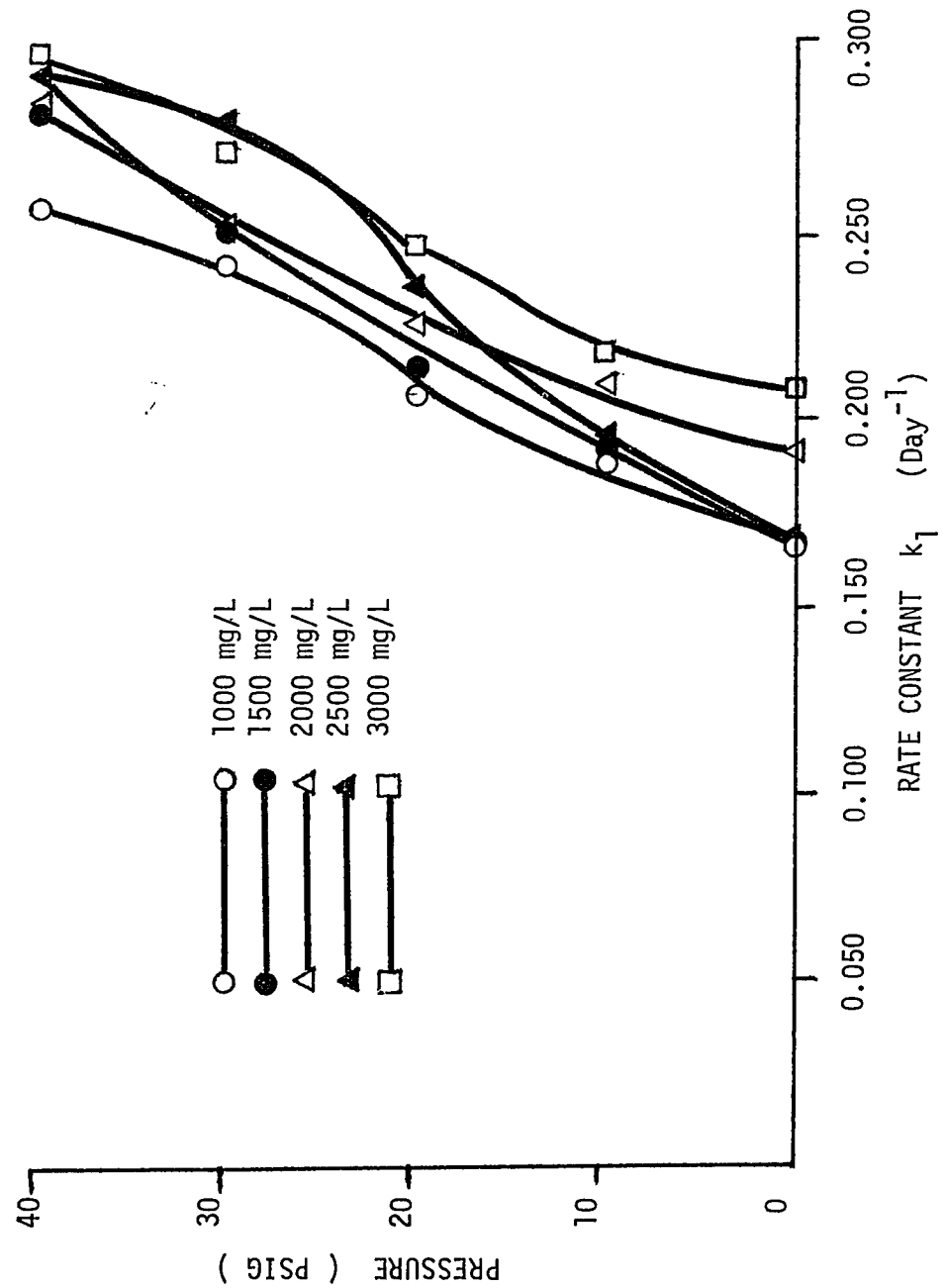


FIGURE 14

BOD was obtained. The fastest reaction rate occurred at a pressure of 40 psig -- similar to the synthetic wastewater observation. Process efficiency did not increase as much with the domestic wastewater as it did with the synthetic wastewater. Here, only a 4% increase in efficiency was observed. The overall process efficiency at 40 psig was 84.18% as compared to 90.90% with the synthetic wastewater.

The equipment necessary to investigate the use of pressure in the activate sludge process has been constructed and shown to have operated satisfactorily. The data obtained from the model process offers a preliminary description of its capabilities. Extensive operation of the equipment is necessary.

TABLE 3  
PERCENT REDUCTION IN  
EFFLUENT ULTIMATE FIRST-STAGE BOD AT ELEVATED PRESSURE  
SYNTHETIC WASTEWATER

MLSS (mg/L)	0 PSIG VS. ELEVATED PRESSURE (PSIG)	REDUCTION %
1000	0 - 10	20.90
	0 - 20	23.10
	0 - 30	32.00
	0 - 40	40.00
1500	0 - 10	15.00
	0 - 20	18.00
	0 - 30	27.00
	0 - 40	35.00
2000	0 - 10	20.60
	0 - 20	23.30
	0 - 30	28.20
	0 - 40	31.20
2500	0 - 10	20.70
	0 - 20	28.10
	0 - 30	35.70
	0 - 40	45.90
3000	0 - 10	27.00
	0 - 20	37.80
	0 - 30	43.00
	0 - 40	44.80

TABLE 4  
REACTION RATE CONSTANTS FOR  
SYNTHETIC WASTEWATER

MLSS (mg/L)	PRESSURE (PSIG)	REACTION RATE ( Day <sup>-1</sup> )
1000	00.00	0.170
	10.00	0.193
	20.00	0.214
	30.00	0.244
	40.00	0.256
1500	00.00	0.170
	10.00	0.198
	20.00	0.214
	30.00	0.278
	40.00	0.280
2000	00.00	0.190
	10.00	0.208
	20.00	0.225
	30.00	0.249
	40.00	0.285
2500	00.00	0.170
	10.00	0.198
	20.00	0.239
	30.00	0.278
	40.00	0.288
3000	00.00	0.209
	10.00	0.218
	20.00	0.247
	30.00	0.267
	40.00	0.295

TABLE 5ACTIVATED SLUDGE PROCESS EFFICIENCY AT ELEVATED PRESSURESYNTHETIC WASTEWATER

MLSS (mg/L)	PRESSURE (PSIG)	EFFICIENCY %
1000	0	82.02
	10	85.79
	20	86.18
	30	87.75
	40	89.21
1500	0	82.02
	10	84.72
	20	85.28
	30	86.85
	40	88.31
2000	0	81.46
	10	85.28
	20	85.79
	30	86.69
	40	87.25
2500	0	83.15
	10	86.63
	20	87.87
	30	89.16
	40	90.90
3000	0	82.02
	10	86.85
	20	88.82
	30	89.78
	40	90.06

TABLE 6  
PERCENT REDUCTION IN  
EFFLUENT ULTIMATE FIRST-STAGE BOD AT ELEVATED PRESSURES  
DOMESTIC WASTEWATER

MLSS (mg/L)	0 PSIG VS. ELEVATED PRESSURES	REDUCTION %
2160	0 - 10	9.44
	0 - 20	12.50
	0 - 30	16.94
	0 - 40	20.00



TABLE 7  
REACTION RATE CONSTANTS FOR  
DOMESTIC WASTEWATER

MLSS (mg/L)	PRESSURE (PSIG)	REACTION RATE ( Day <sup>-1</sup> )
2160	00.00	0.150
	10.00	0.180
	20.00	0.220
	30.00	0.250
	40.00	0.270

TABLE 8ACTIVATED SLUDGE PROCESS EFFICIENCY AT ELEVATED PRESSUREDOMESTIC WASTEWATER

MLSS (mg/l)	PRESSURE (PSIG)	EFFICIENCY %
2160	0	80.22
	10	81.81
	20	82.69
	30	83.57
	40	84.18

## XI. FUTURE INVESTIGATION

Investigation of the responses of wastewater treated in a pressurized activated sludge process supports the need for further work. Control of the rate of organic waste decomposition appears to be obtainable by the MLSS concentration and the pressure within the activated sludge cylinder.

The laboratory model activated sludge process constructed for the investigation reported herein has mainly treated synthetic wastewater with only limited operation with domestic wastewater. Future operation should be made with domestic wastewater. However, since the volume of wastewater required to operate the process 24 hours each day is so great, it is recommended that the model be taken to a treatment plant. Initially, a data baseline should be established by operating the apparatus at atmospheric conditions with elevated pressures being examined later.

The model activated sludge process operated with only a few difficulties. The most significant difficulty was the model size. The 10 gallon cylinder capacity dictated that the flowrate through the cylinder be small, thus requiring the periodic filling process as described in the EQUIPMENT DESIGN AND OPERATION. Although the process operation paralleled that of an activated sludge process, it is felt that a larger volume would allow higher flowrates so that continuous flow could be achieved. The plumbing on the model often

clogged due to its size and could be eliminated with a larger process.

A working laboratory model of a complete-mix, flow-through, pressurized activated sludge process has been developed and tested. Its operation parallels that of existing activated sludge processes. The data gathered clearly indicates that pressure causes a definite response in the rate of oxygen utilization. Further investigation is needed to determine the mechanism causing this response.

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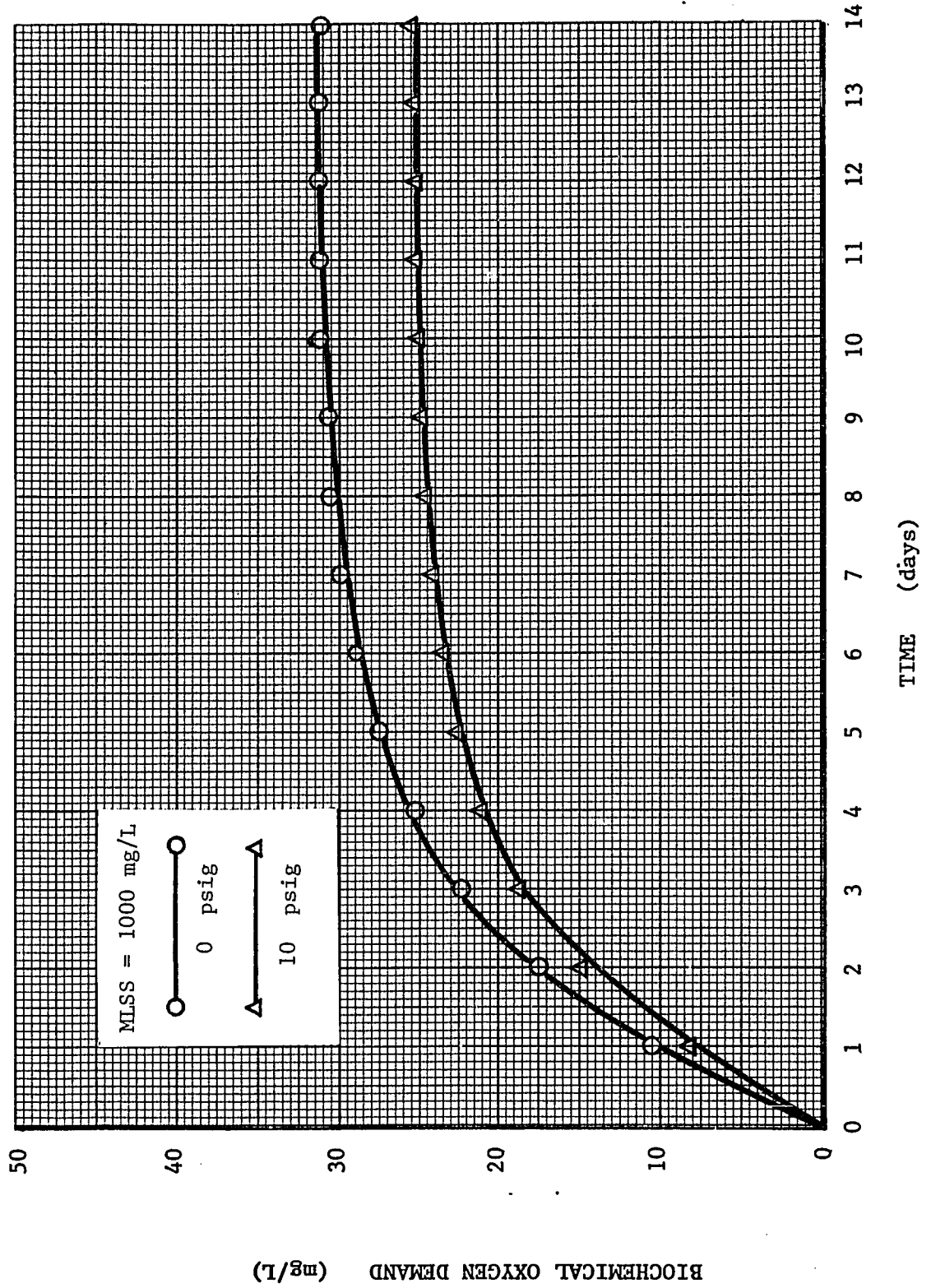
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34. Roots, W.K., M. Shridhar, R.H. Tull and J.R. Pfafflin, "Mode Dependent Time Constants in Three Forms of Space Heating," IEEE Transactions on Industry Applications, vol. 1A-10, no. 6, 1974, pp. 699-702.
35. Moore, E.W., H.A. Thomas and W.B. Snow, "Simplified Method for Analysis of BOD Data," Sewage and Industrial Wastes, vol. 22, 1950, pp. 1343-1345.



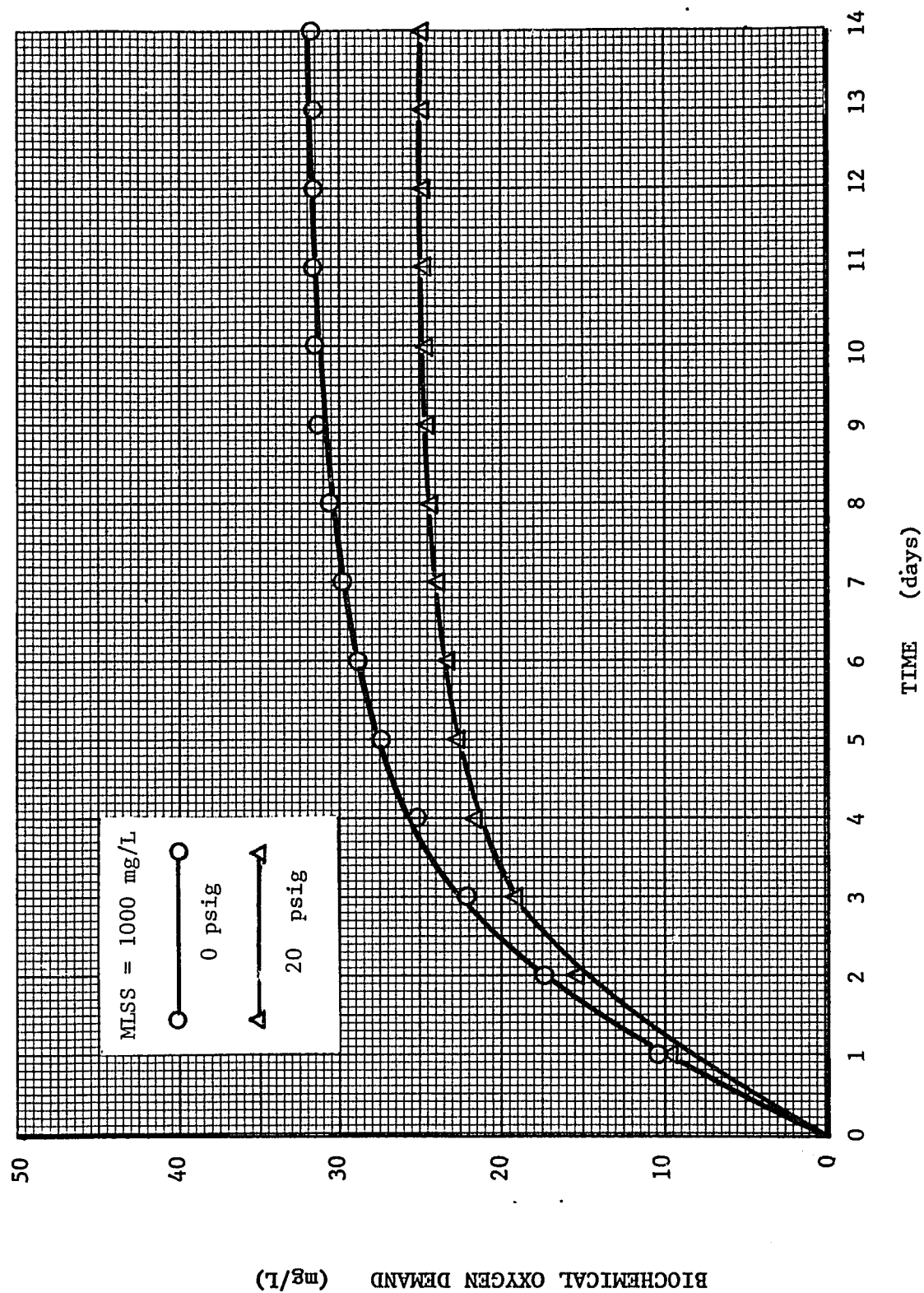
### APPENDIX I

THE FOLLOWING GRAPHS ILLUSTRATE THE DIFFERENCE IN  
EFFLUENT BOD FOR A SYNTHETIC WASTEWATER TREATED  
AT 0 PSIG AND PRESSURES GREATER THAN 0 PSIG

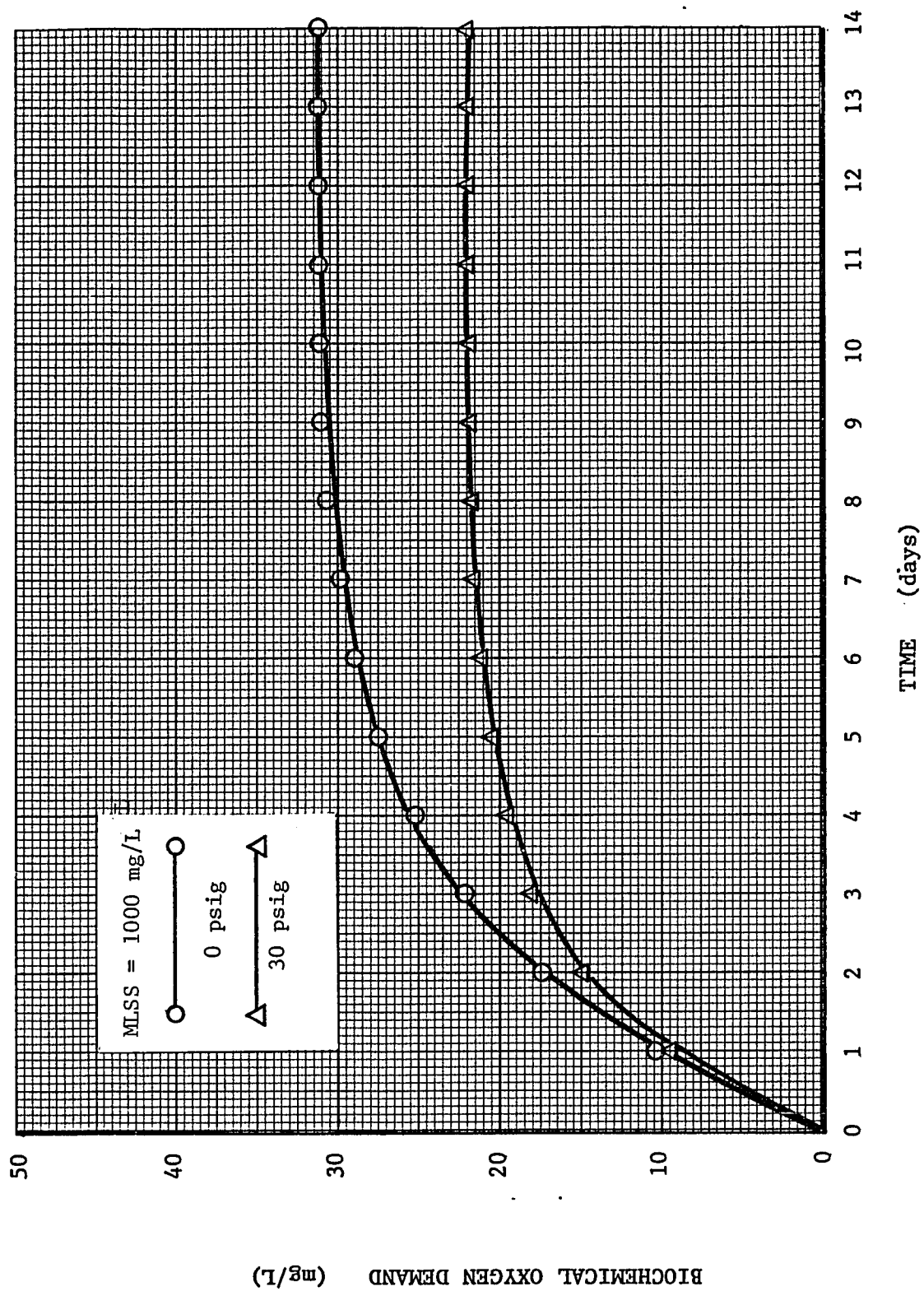
## BIOCHEMICAL OXYGEN DEMAND



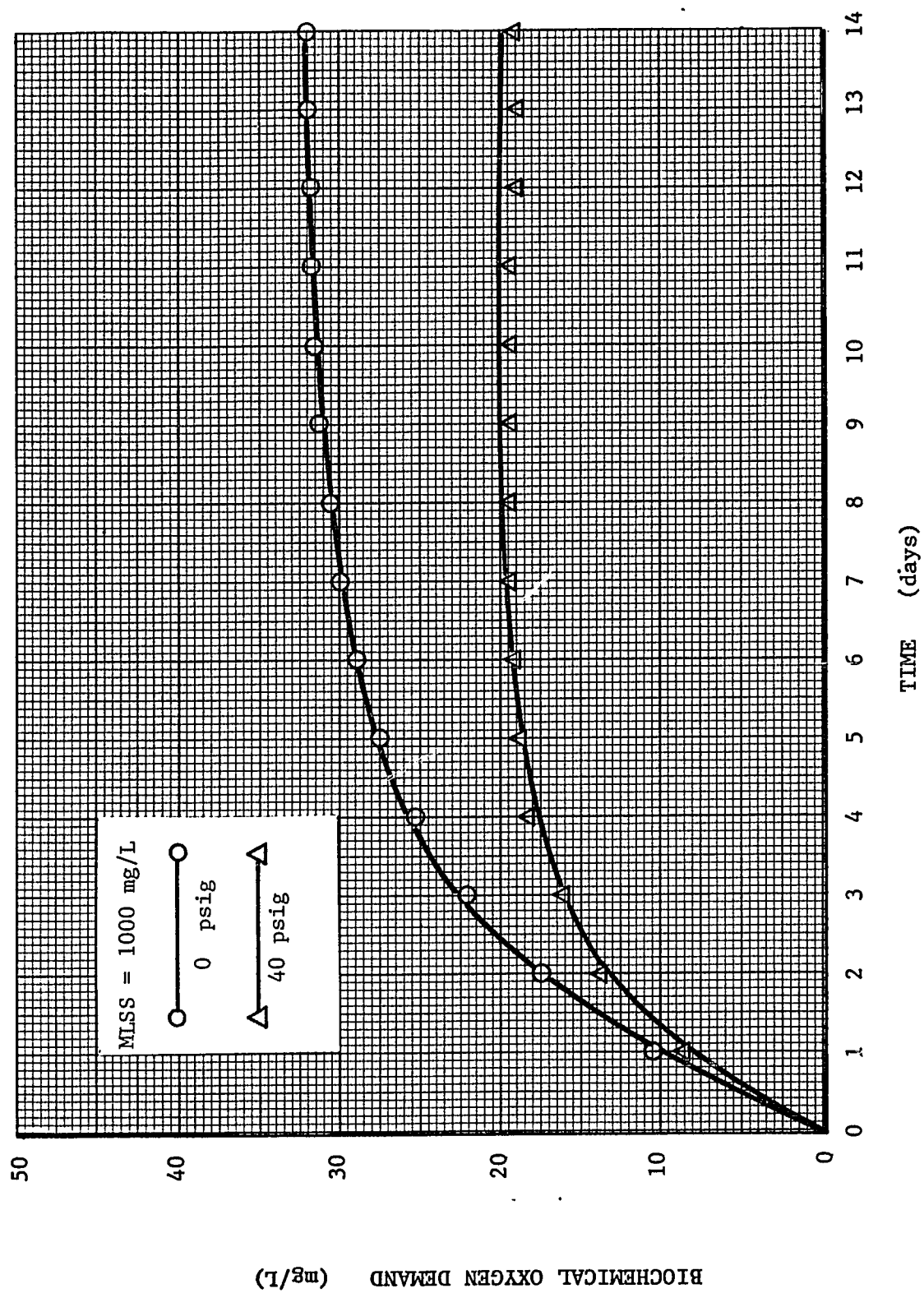
## BIOCHEMICAL OXYGEN DEMAND



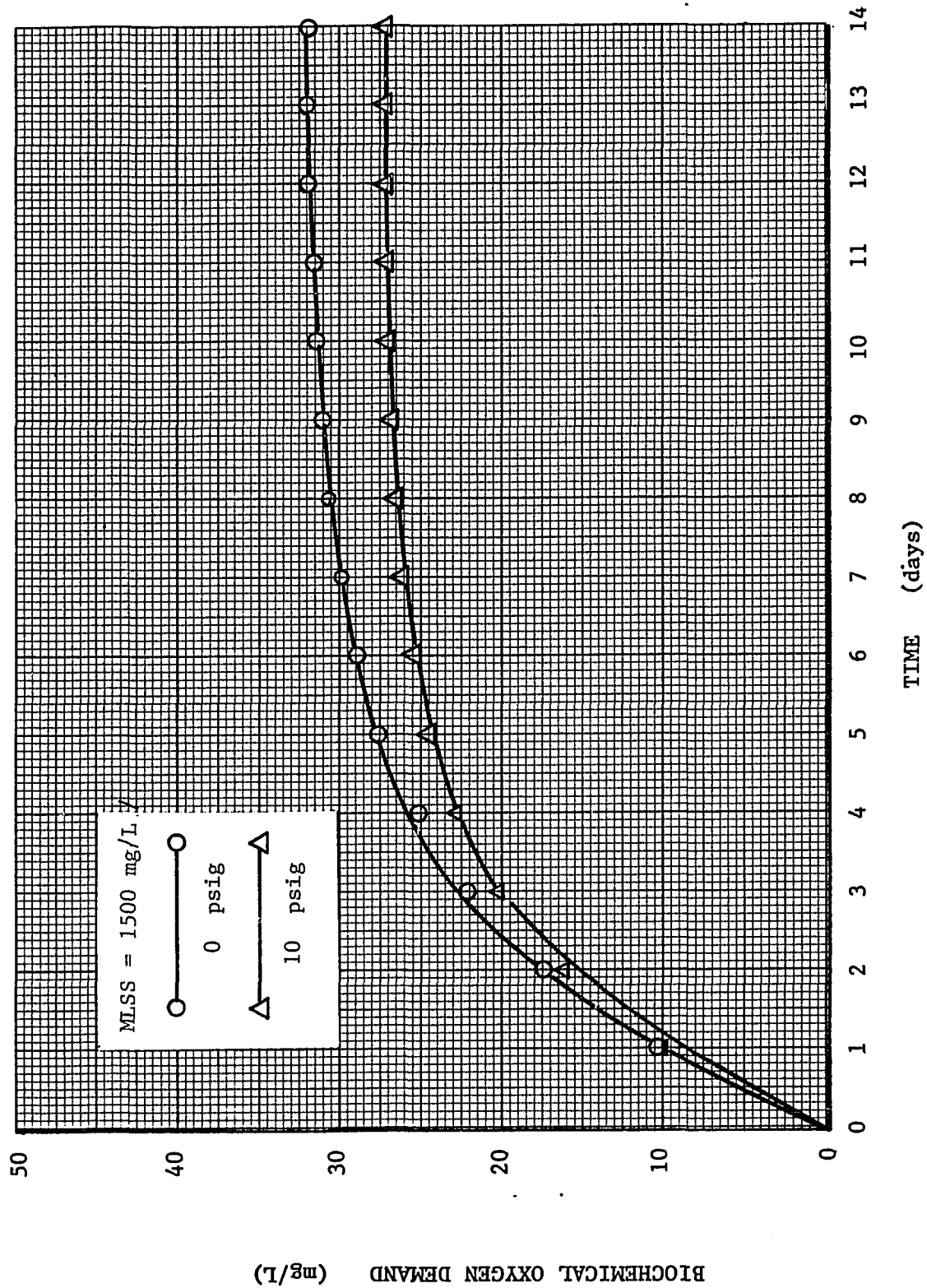
## BIOCHEMICAL OXYGEN DEMAND



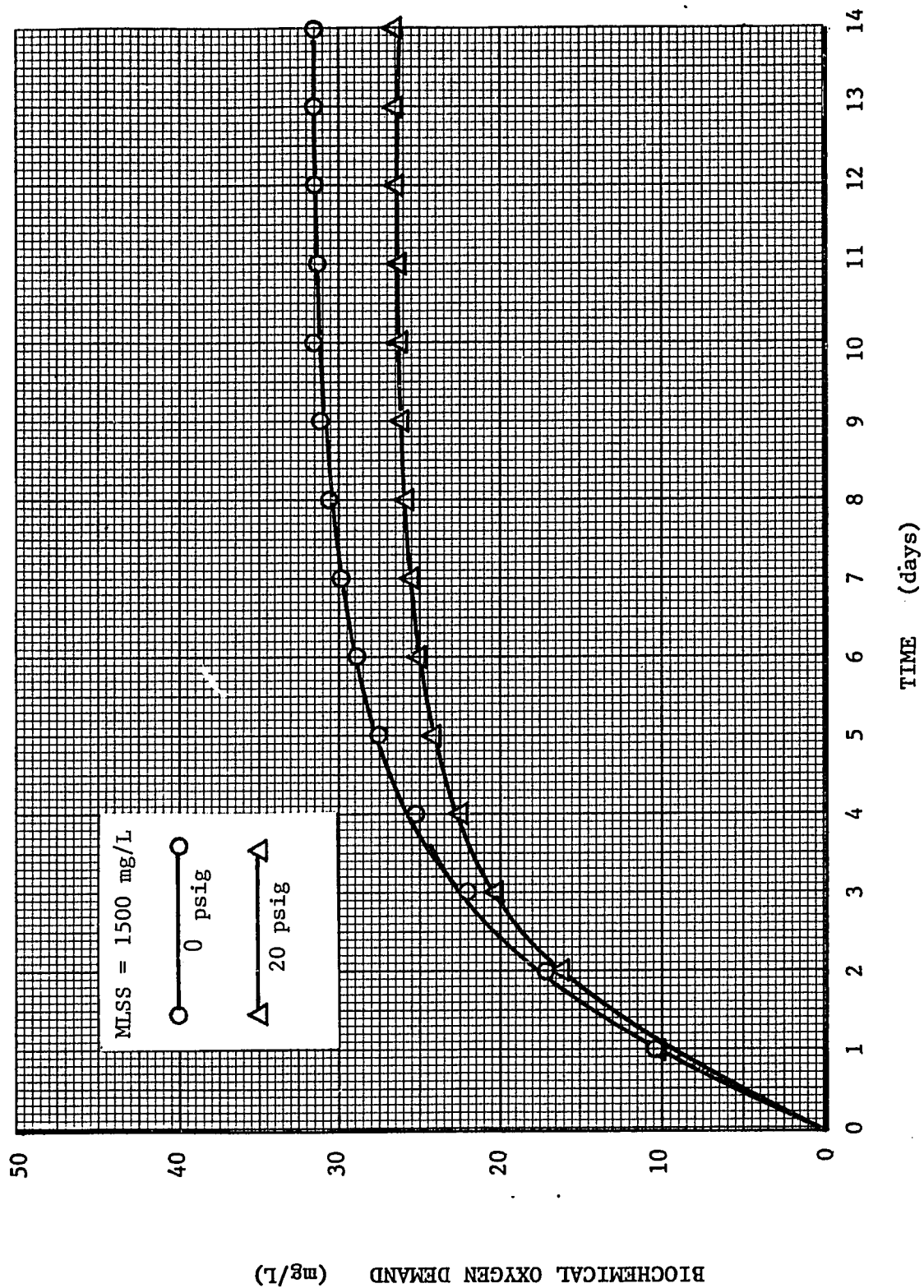
## BIOCHEMICAL OXYGEN DEMAND



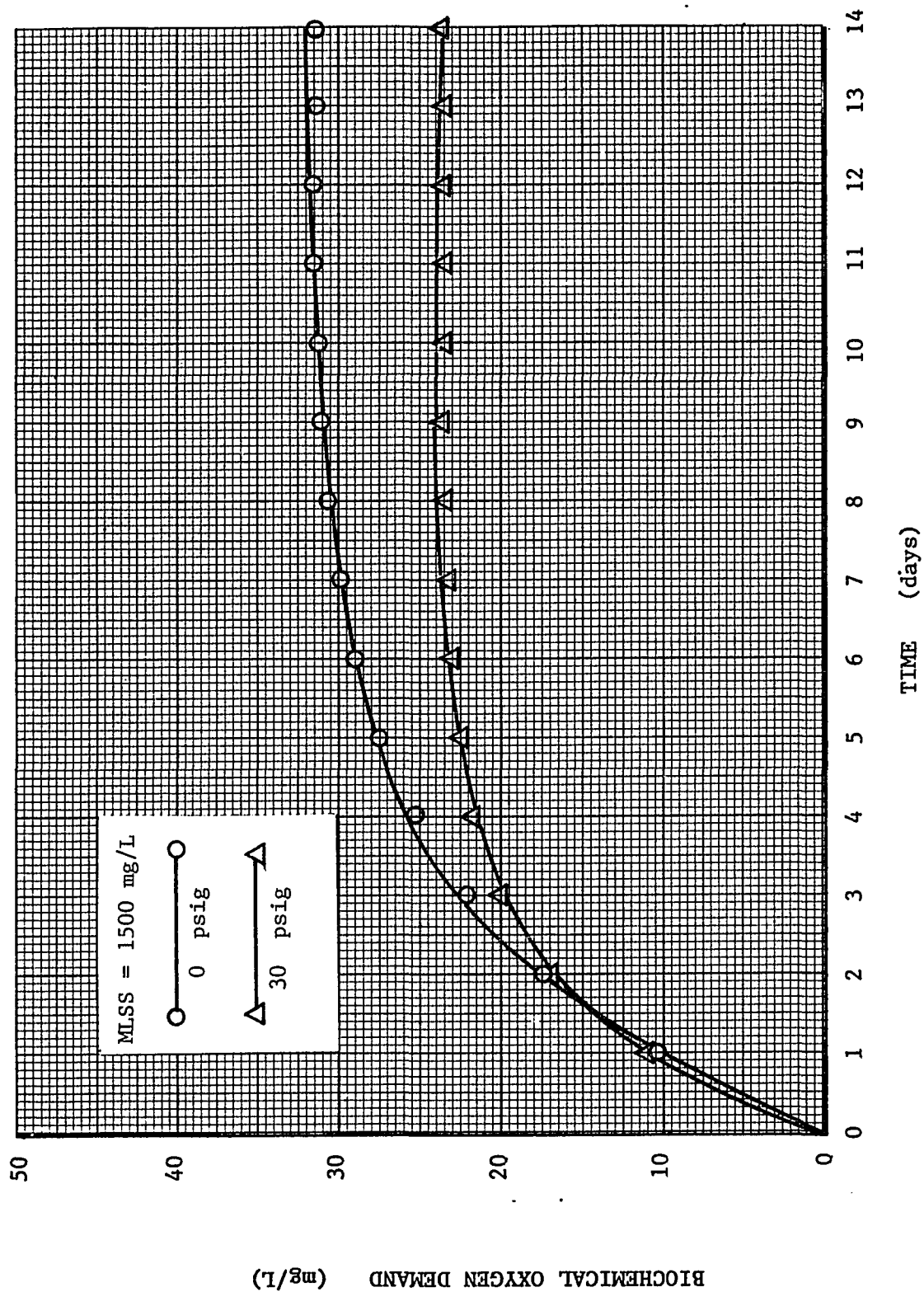
# BIOCHEMICAL OXYGEN DEMAND



## BIOCHEMICAL OXYGEN DEMAND

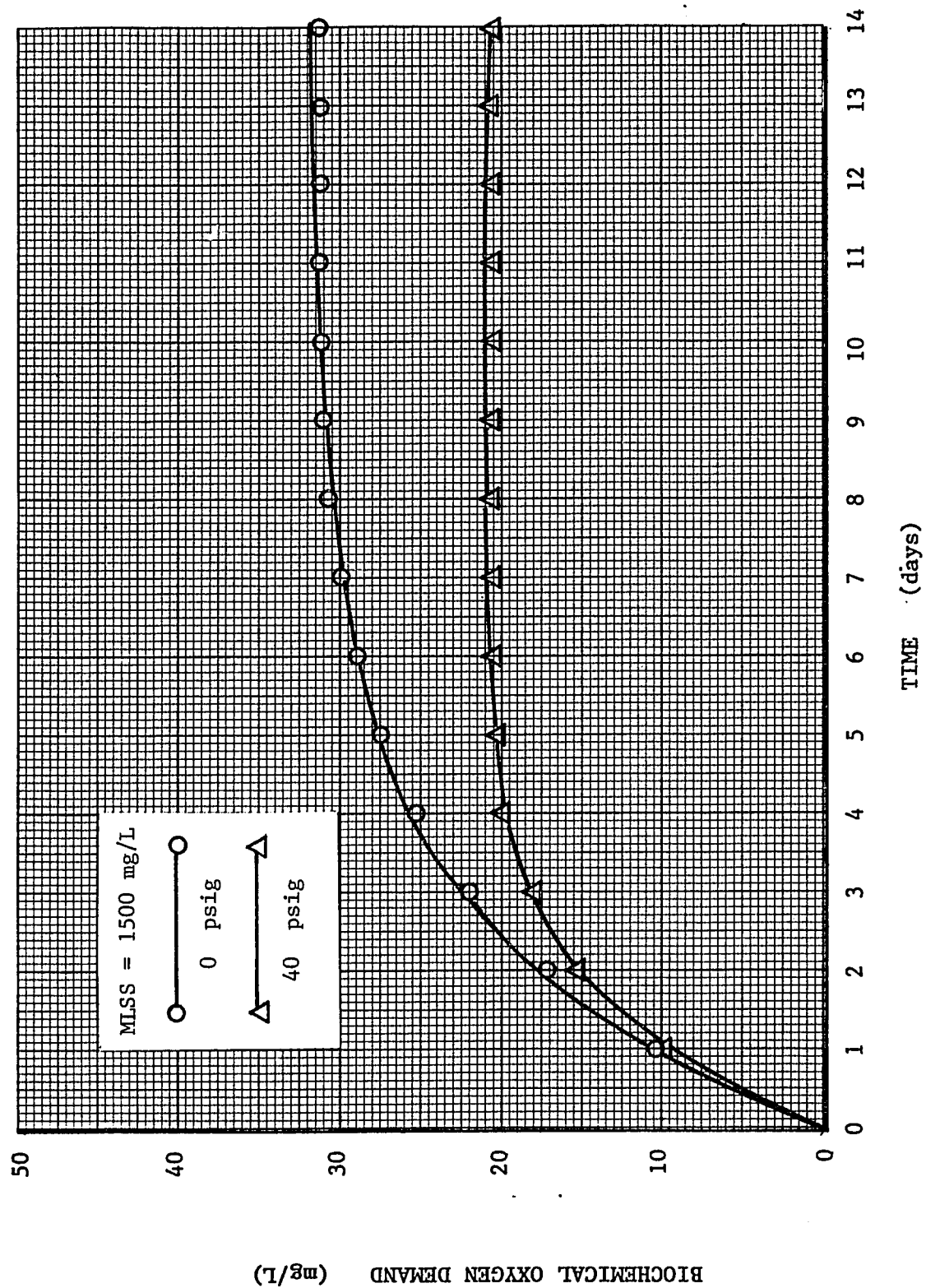


## BIOCHEMICAL OXYGEN DEMAND

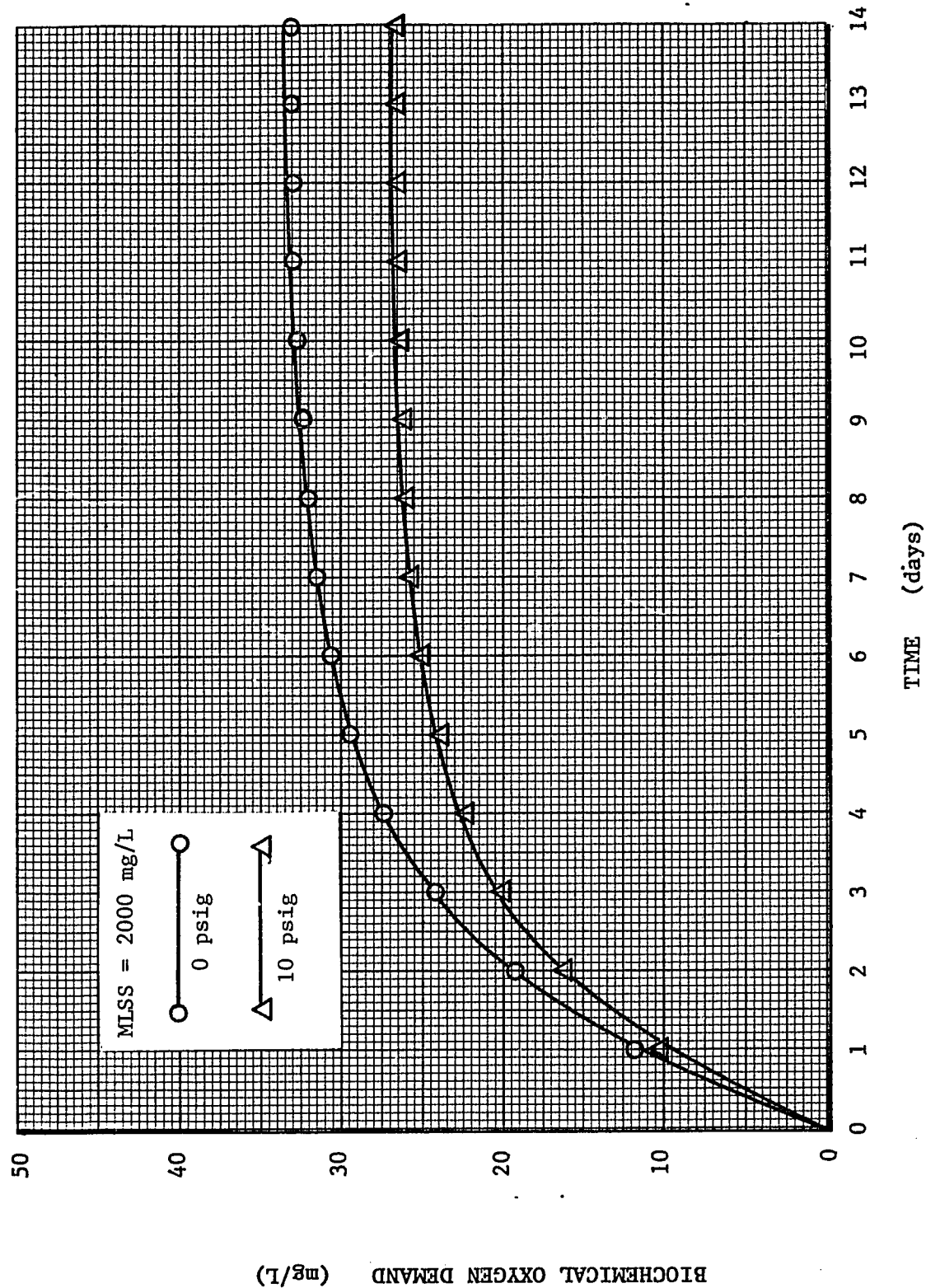




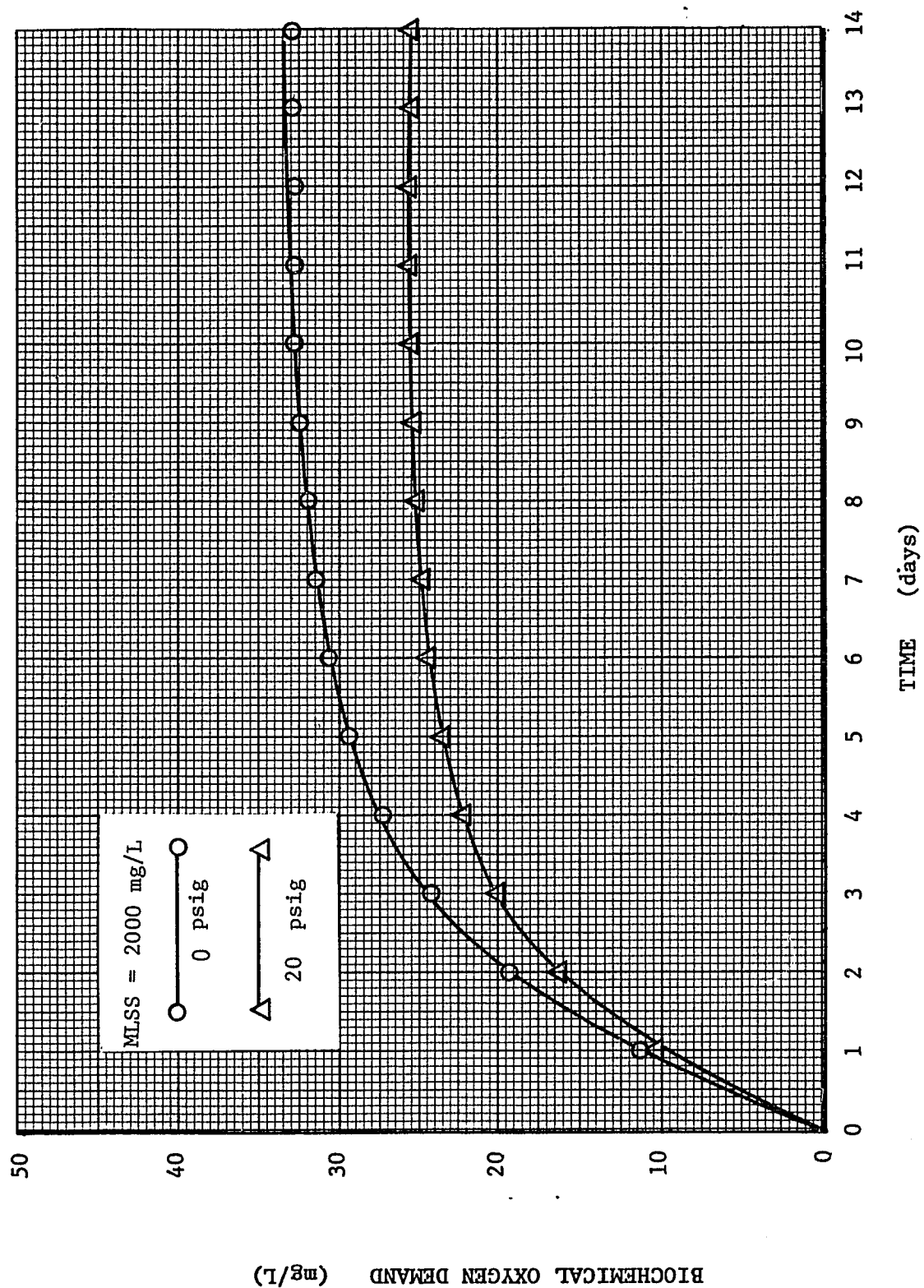
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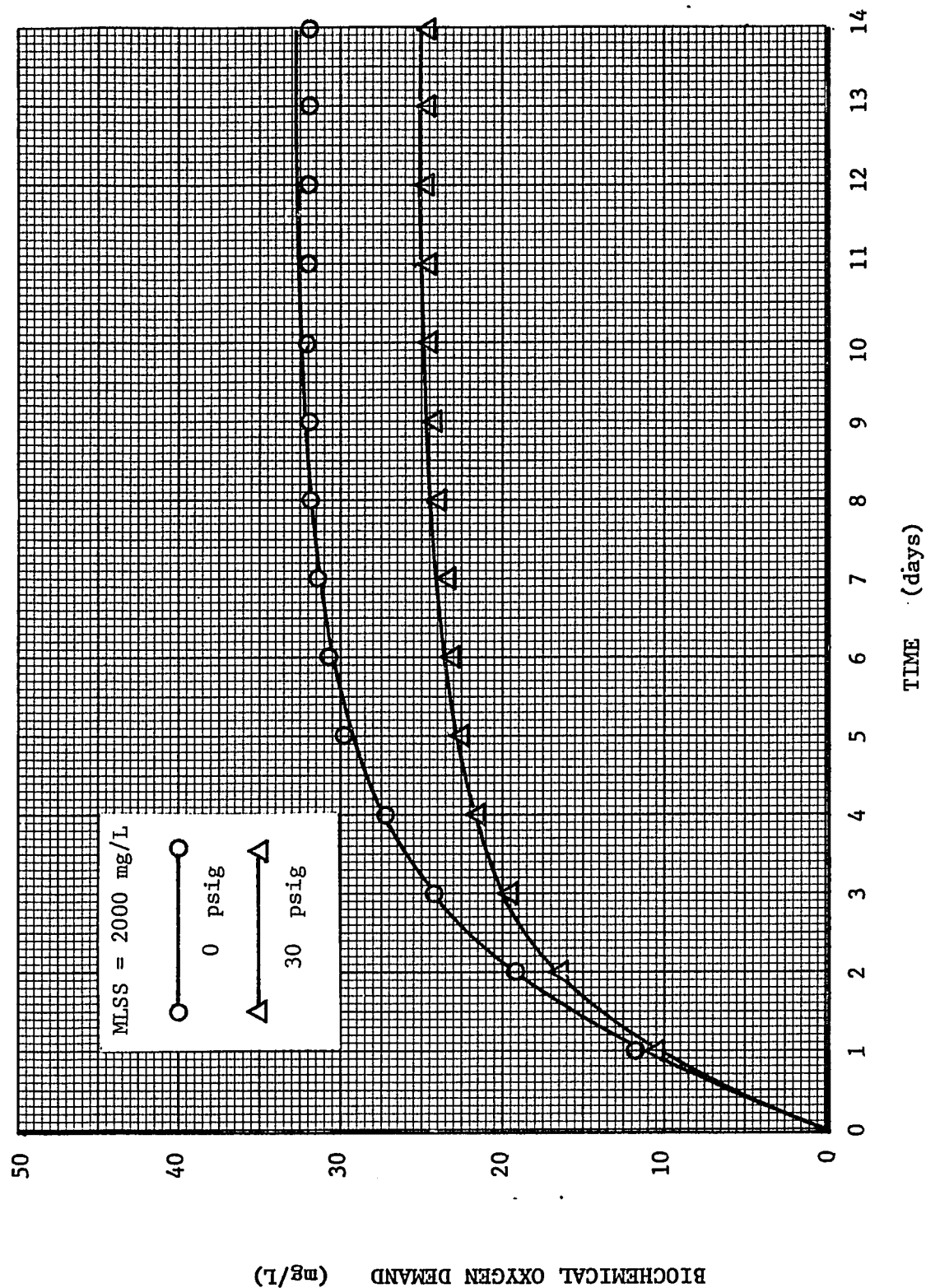
BIOCHEMICAL OXYGEN DEMAND



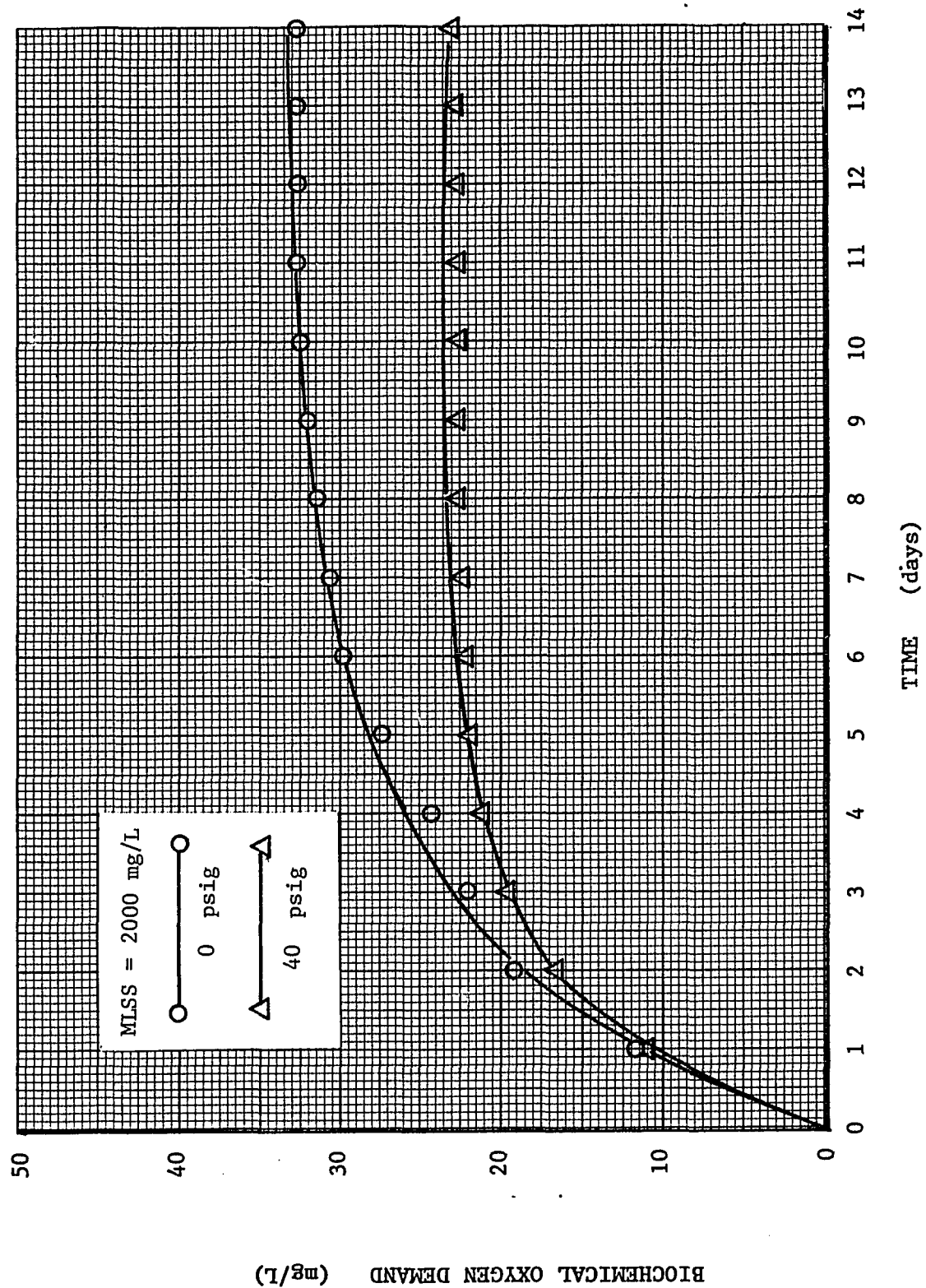
## BIOCHEMICAL OXYGEN DEMAND



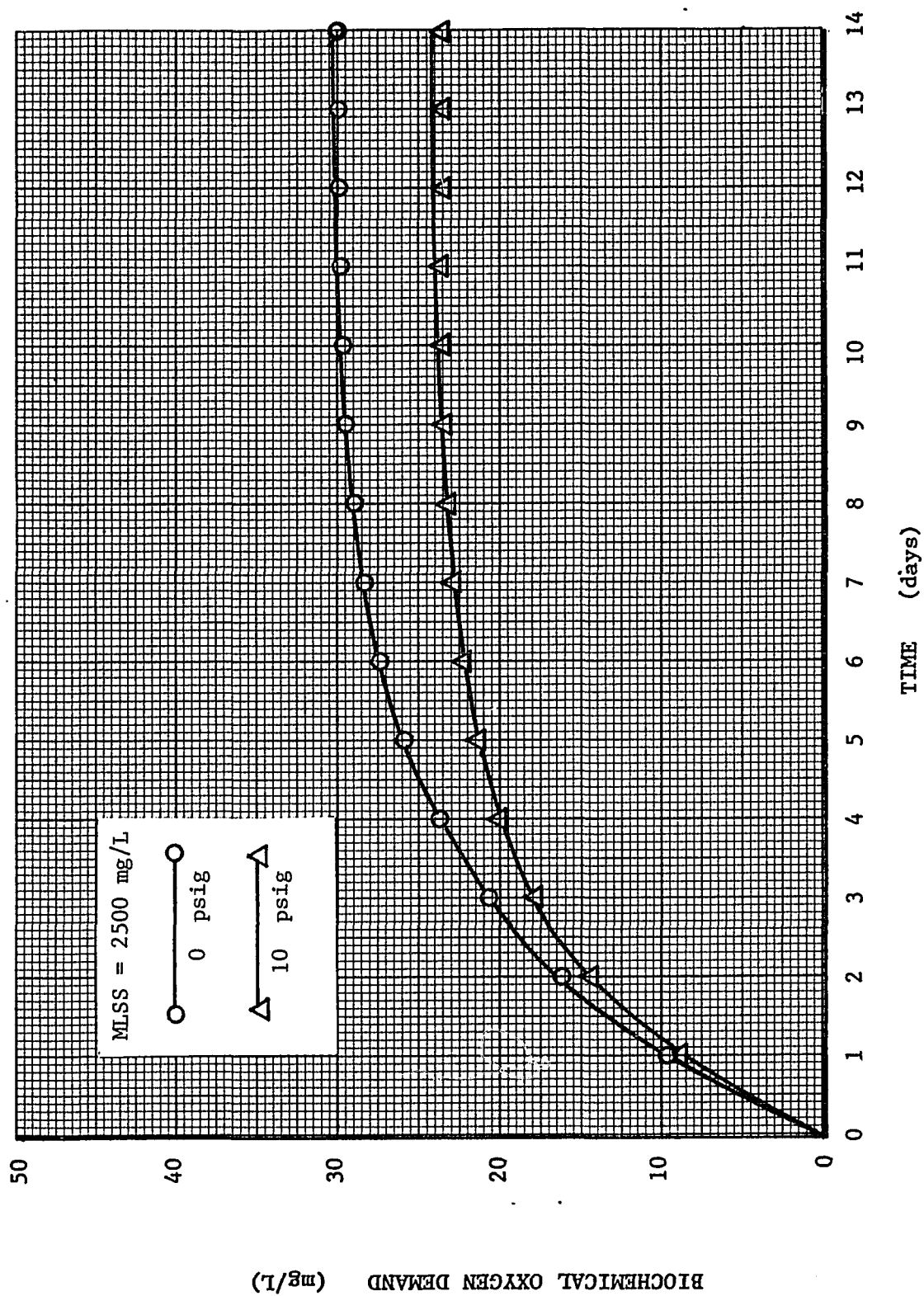
## BIOCHEMICAL OXYGEN DEMAND



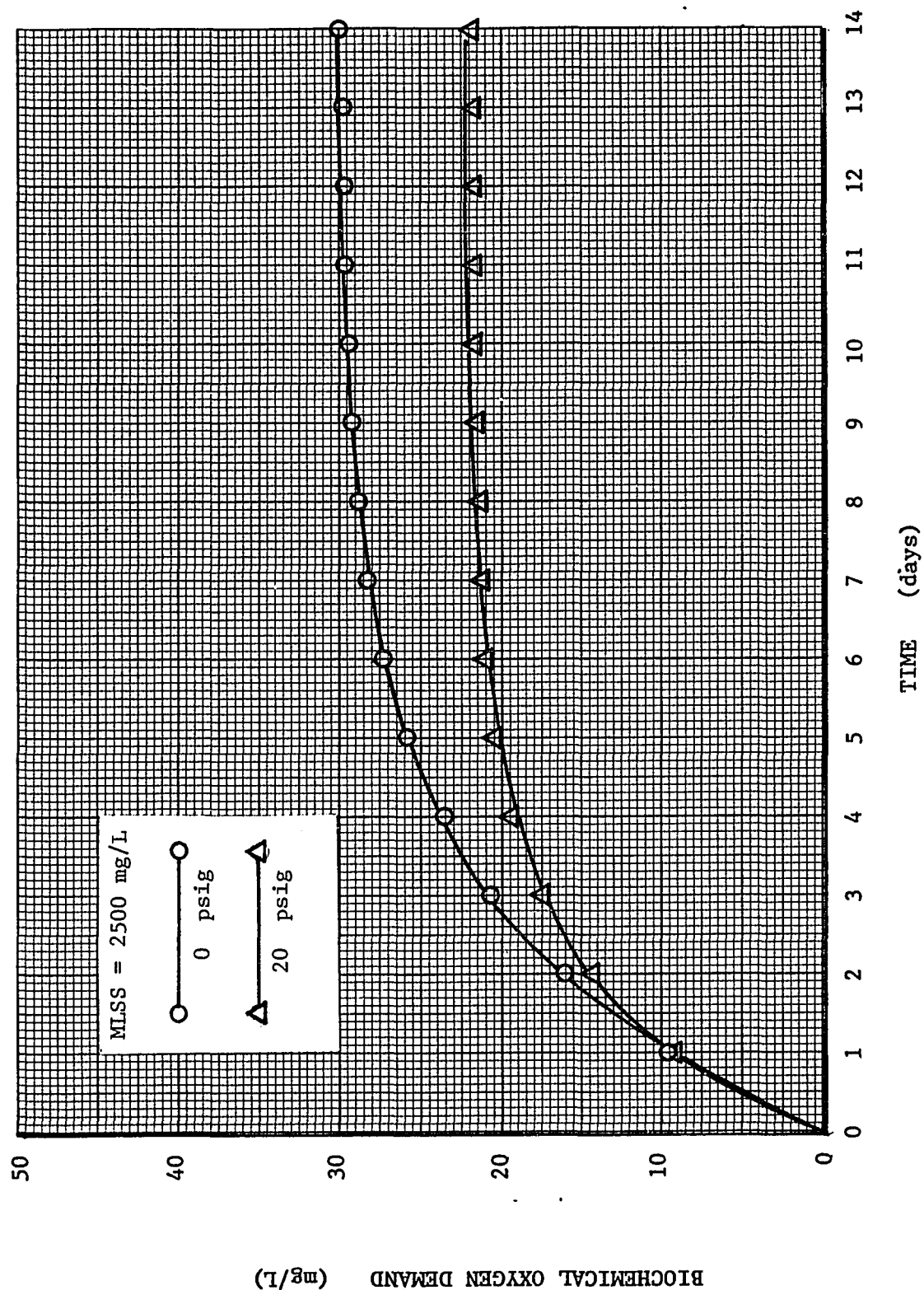
## BIOCHEMICAL OXYGEN DEMAND



## BIOCHEMICAL OXYGEN DEMAND

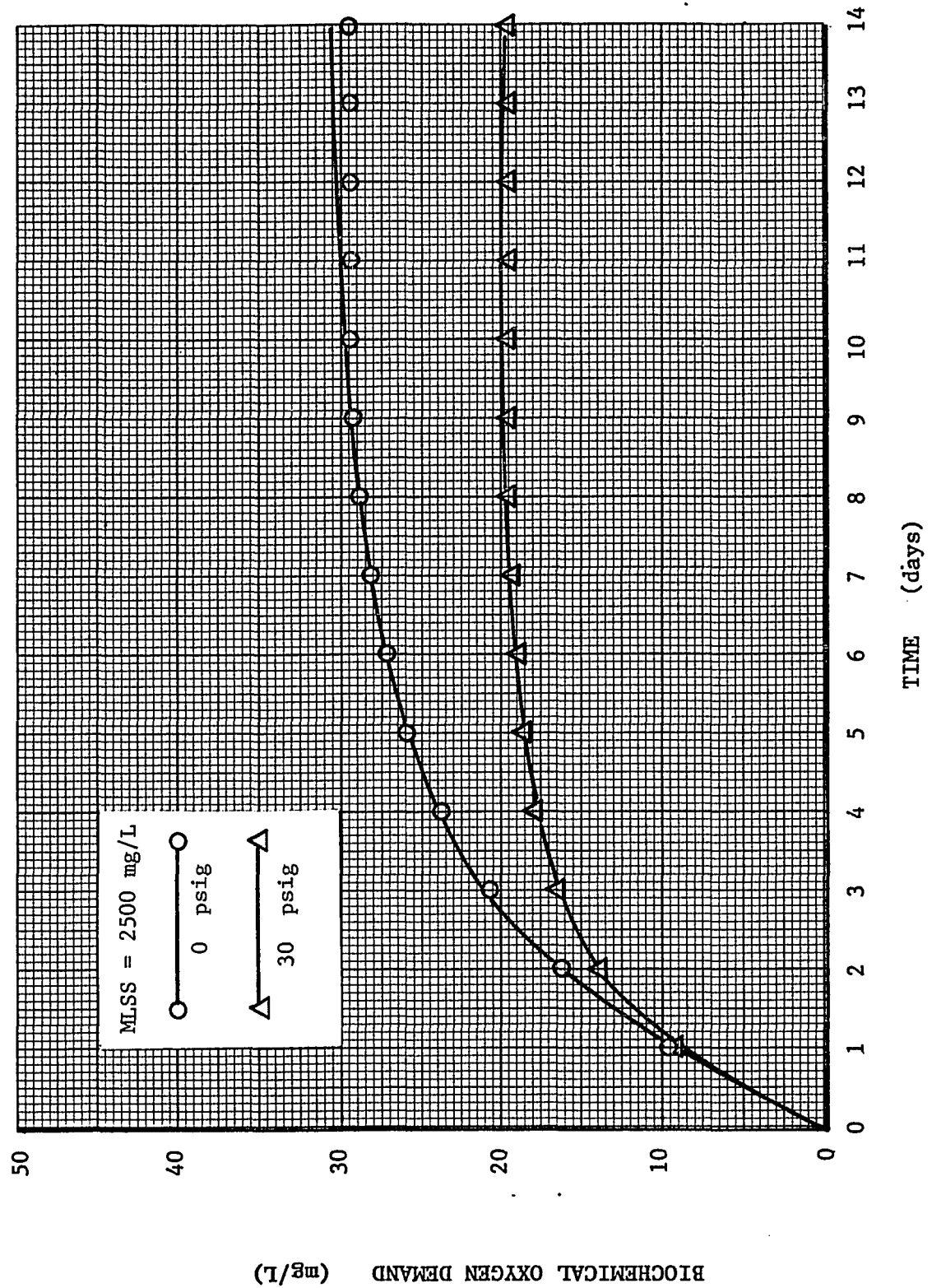


## BIOCHEMICAL OXYGEN DEMAND



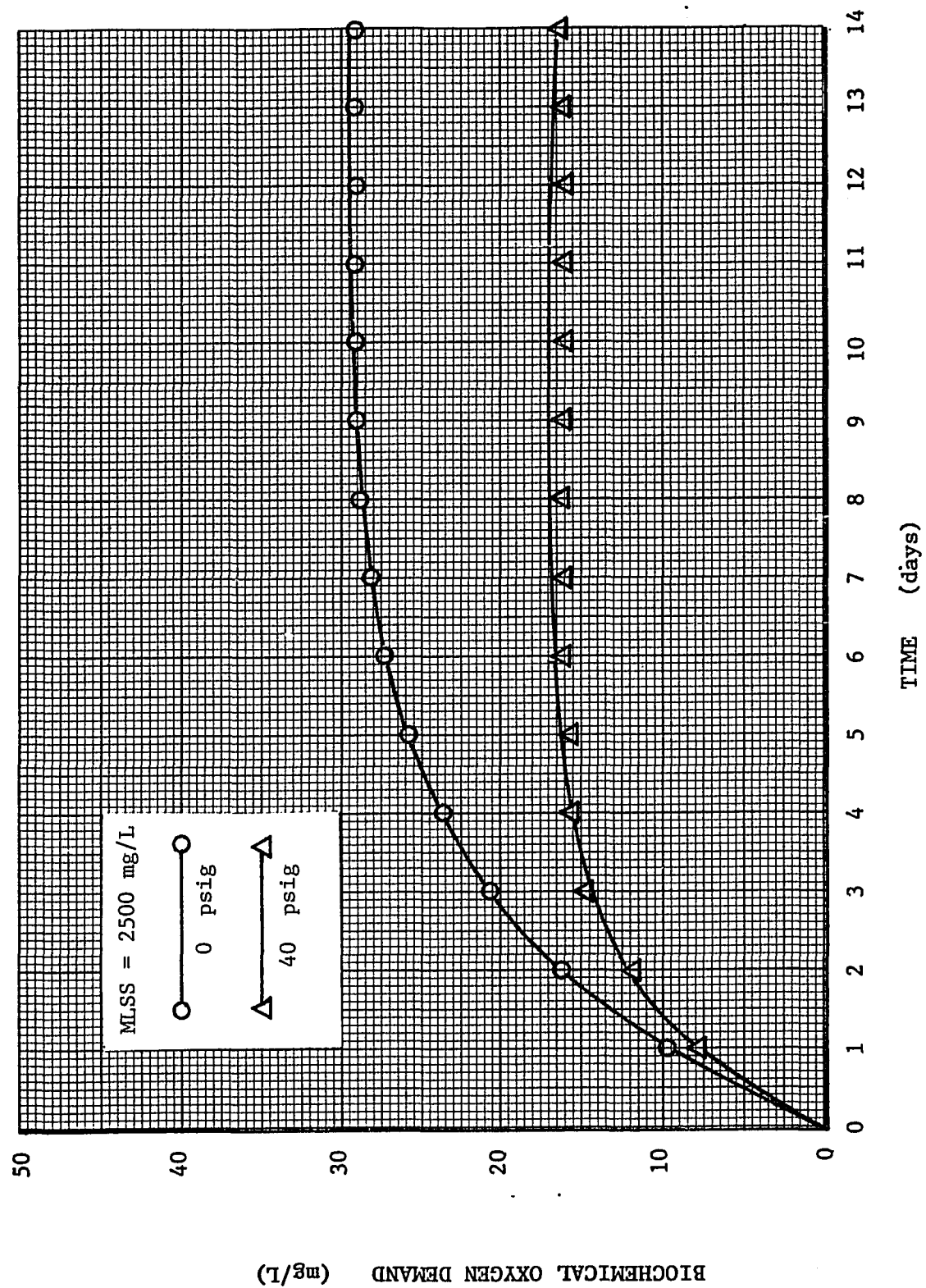


## BIOCHEMICAL OXYGEN DEMAND

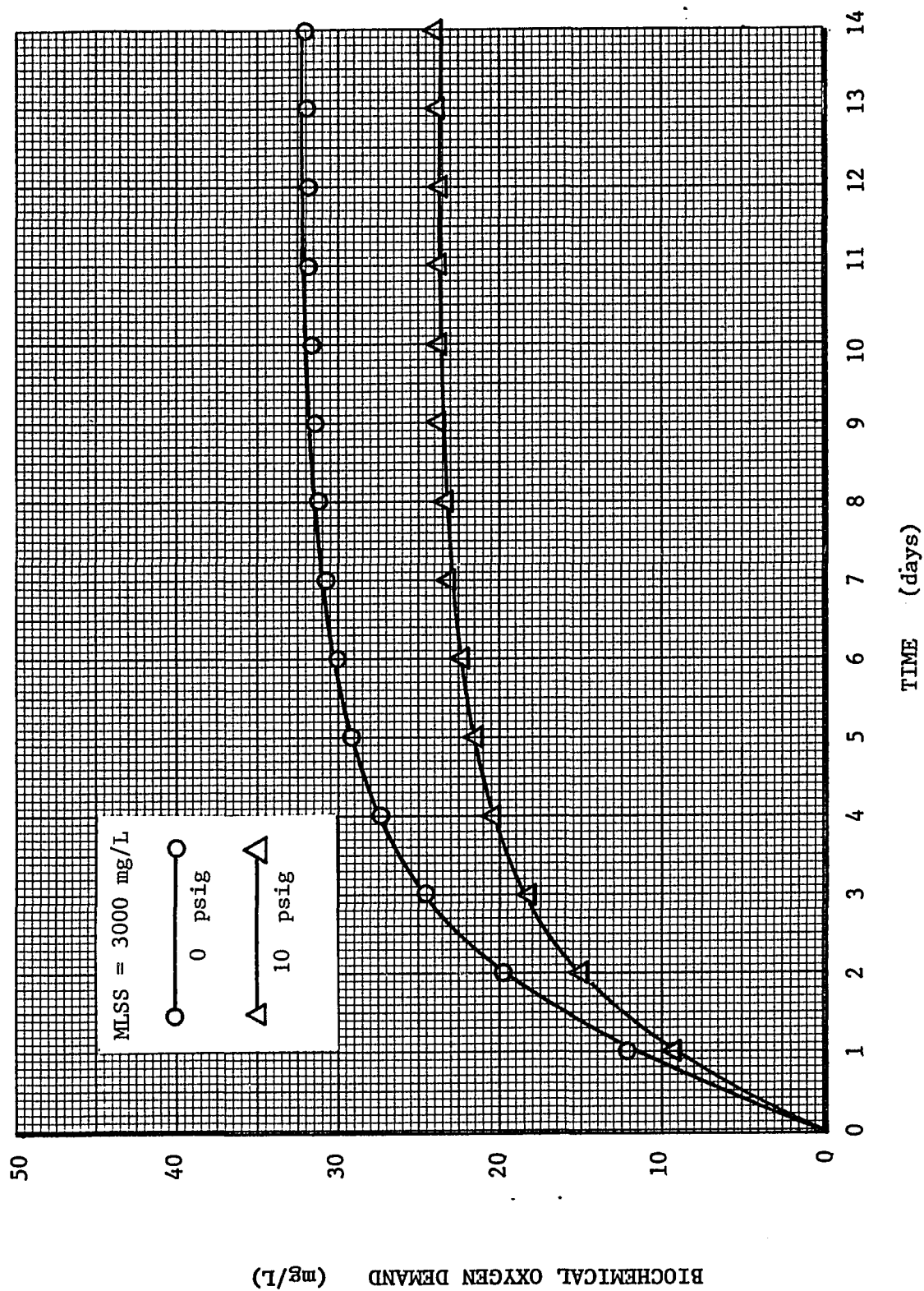




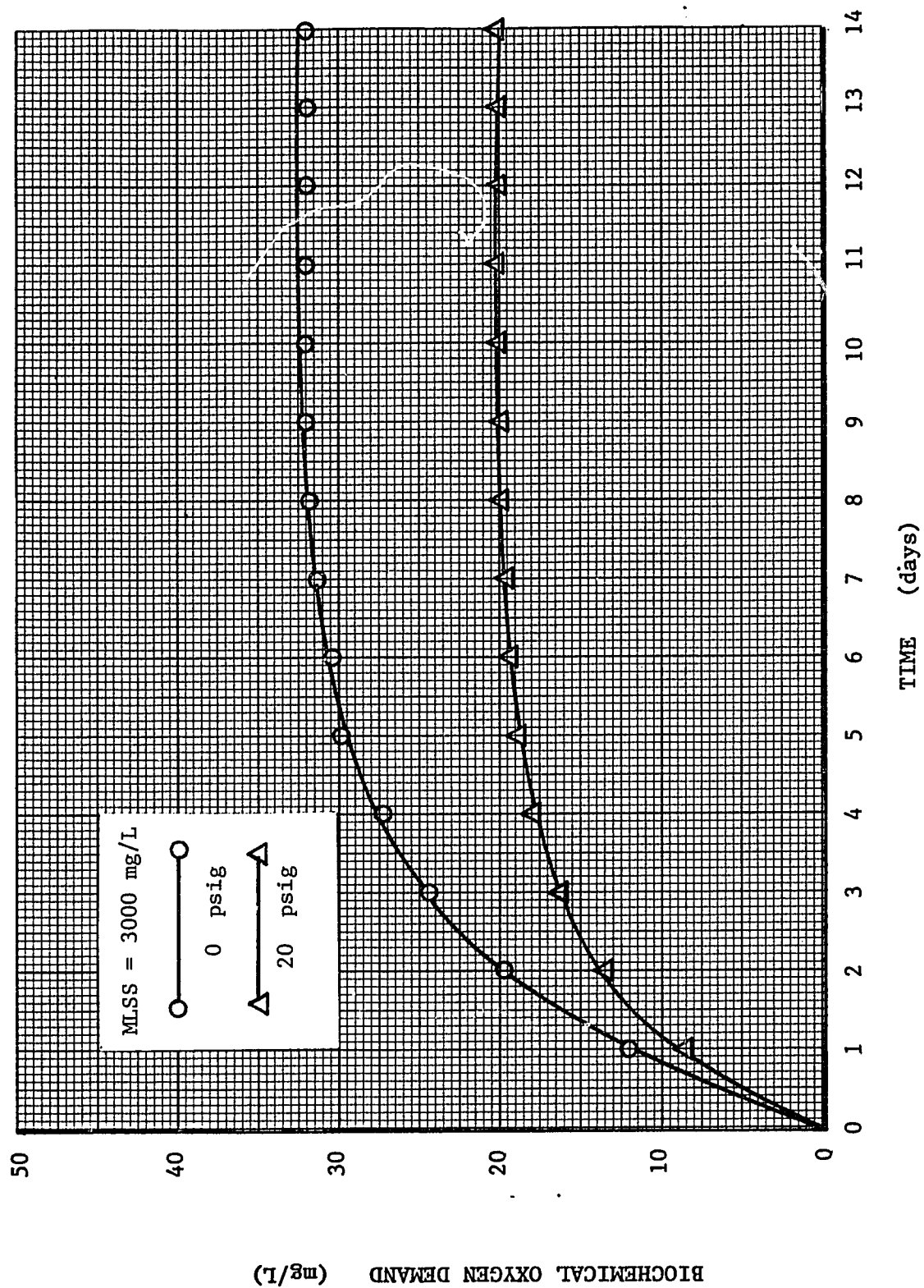
## BIOCHEMICAL OXYGEN DEMAND



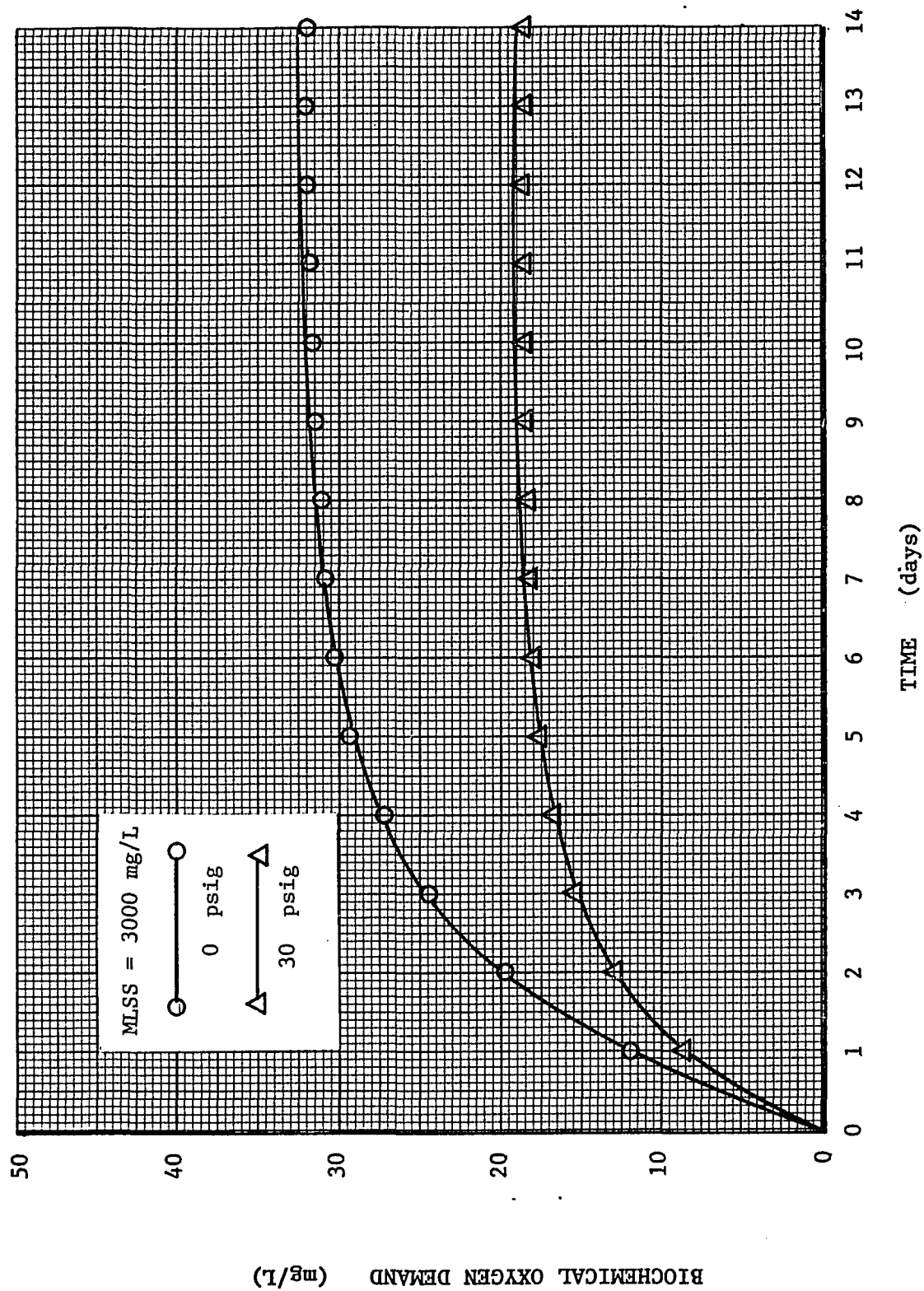
## BIOCHEMICAL OXYGEN DEMAND



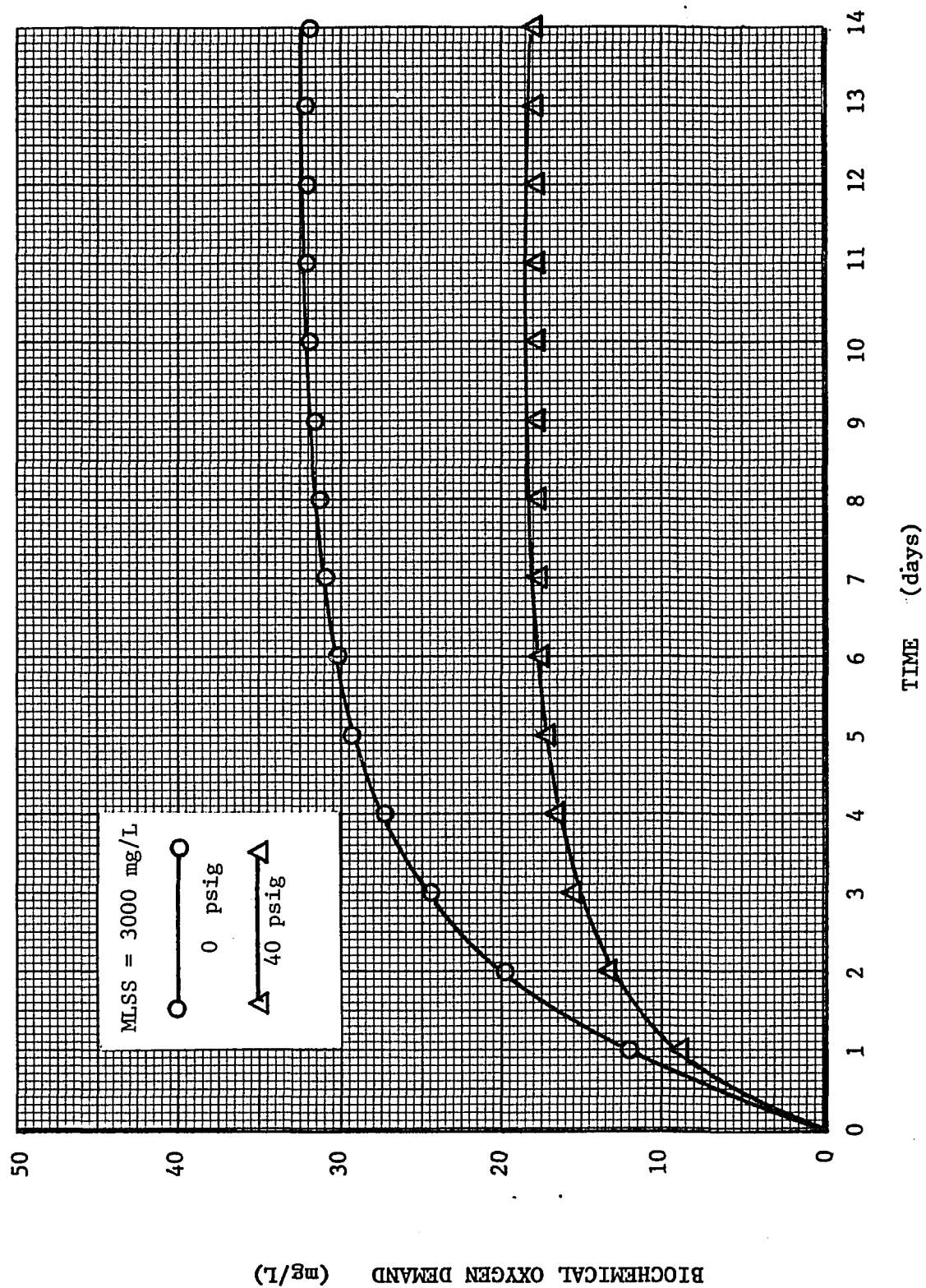
## BIOCHEMICAL OXYGEN DEMAND



## BIOCHEMICAL OXYGEN DEMAND



## BIOCHEMICAL OXYGEN DEMAND

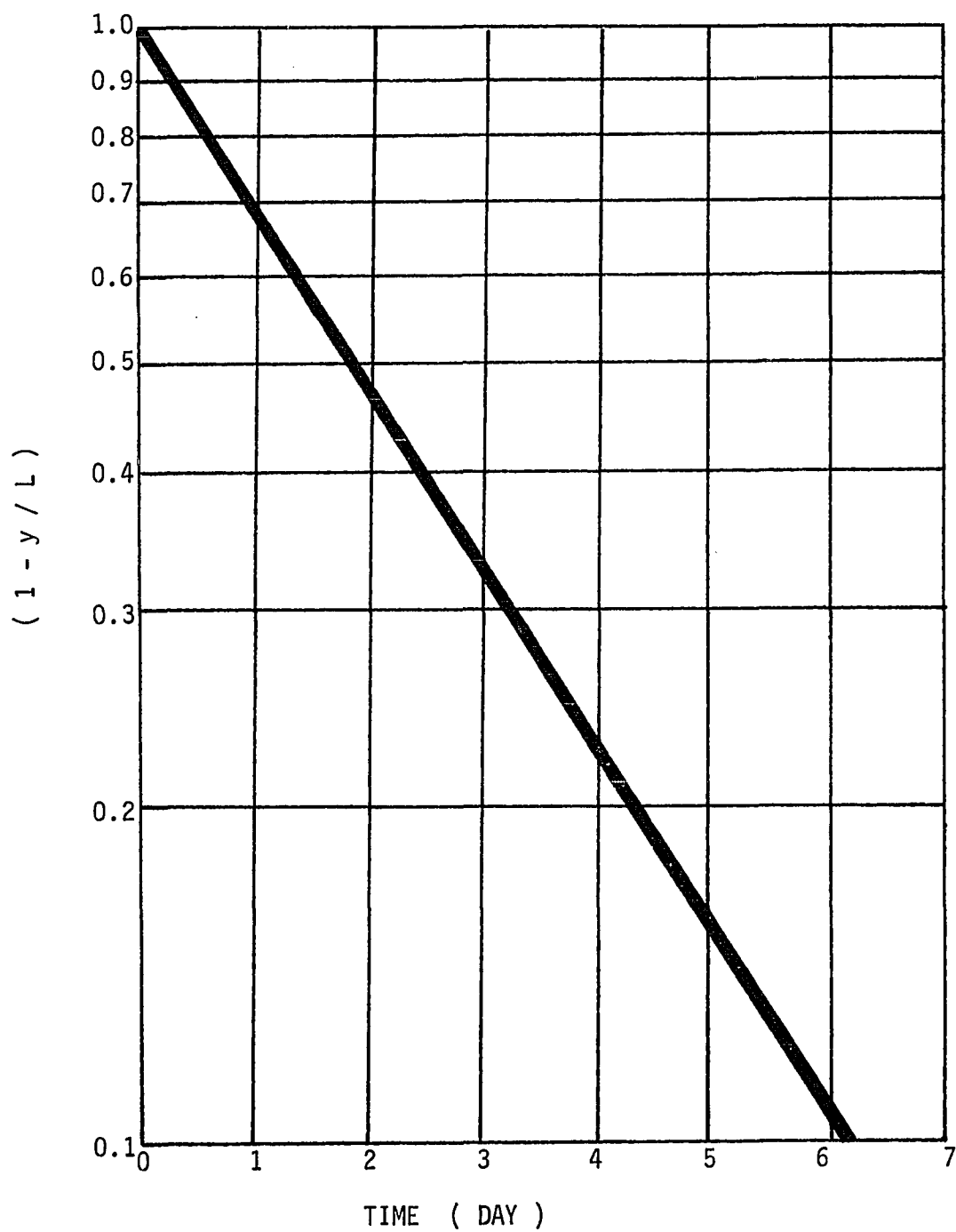


## APPENDIX II

THE FOLLOWING GRAPHS ILLUSTRATE THE PLOTS USED TO  
DETERMINE THE "FIRST-ORDER" REACTION RATE CONSTANT,  $k_1$ ,  
FOR THE EFFLUENT SYNTHETIC WASTEWATER

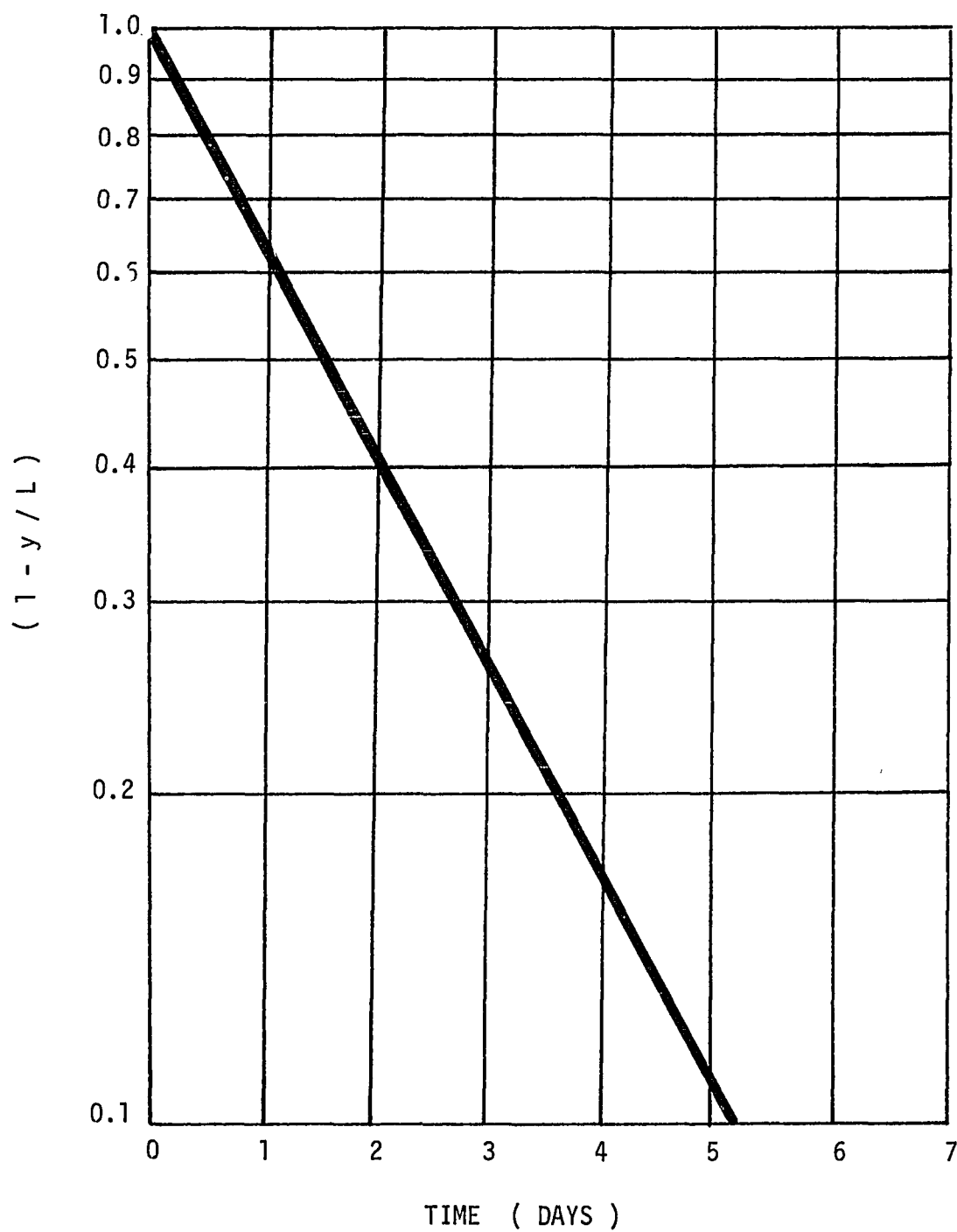
## FIRST ORDER REACTION RATE CONSTANT

PRESSURE = 0 psig  
MLSS = 1000 mg/L  
 $k_1$  = 0.170/day



## FIRST ORDER REACTION RATE CONSTANT

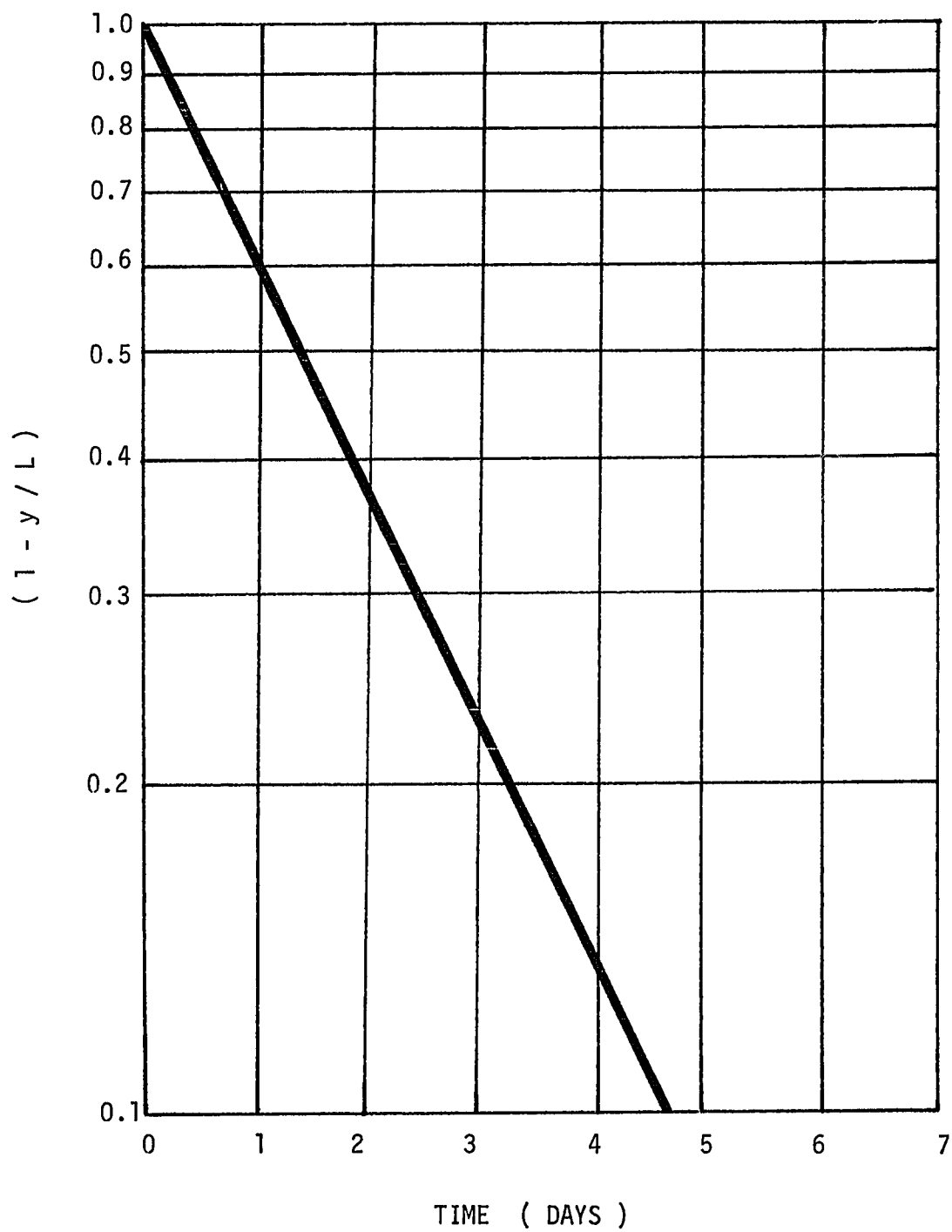
PRESSURE = 10 psig  
MLSS = 1000 mg/L  
 $k_1$  = 0.193/day





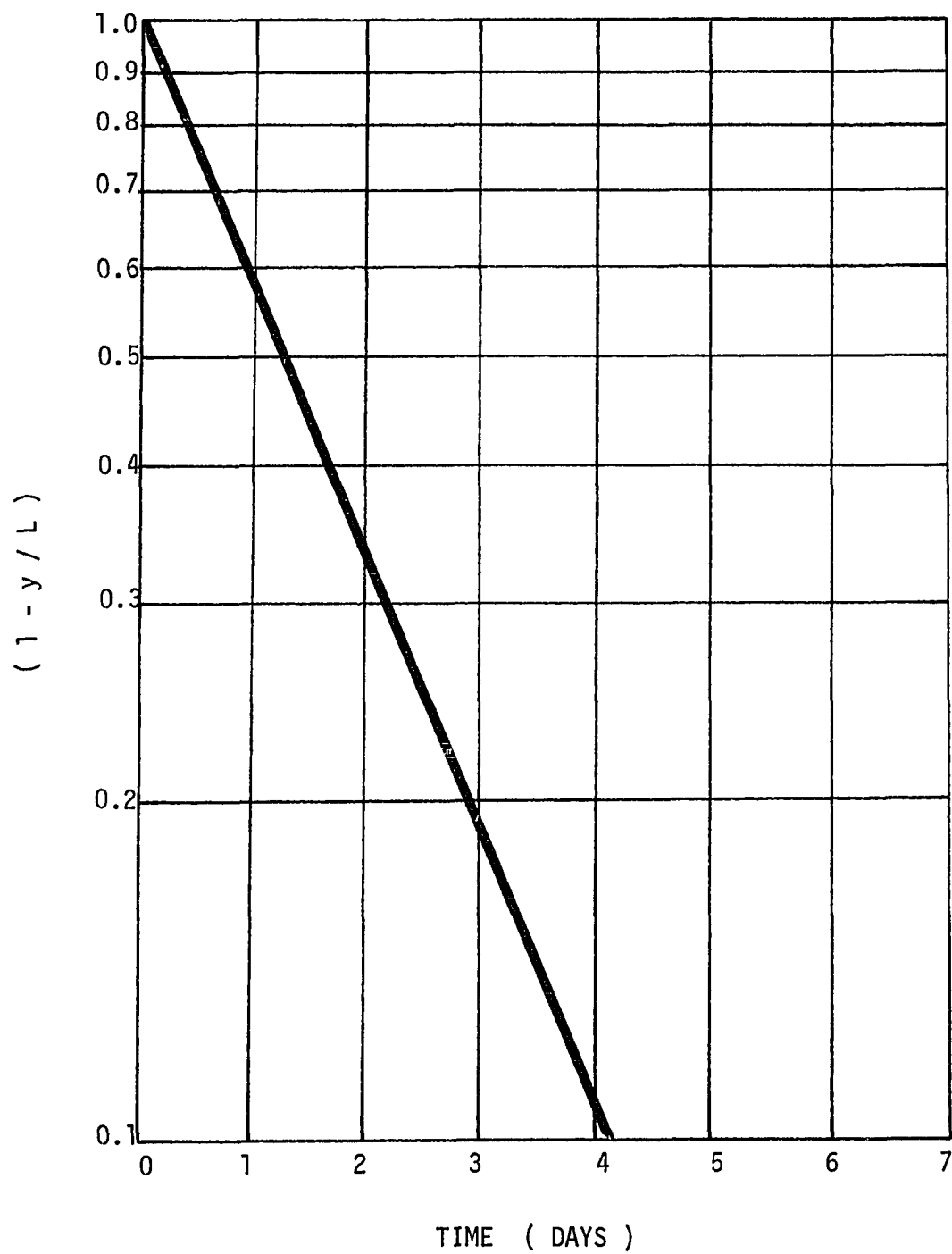
## FIRST ORDER REACTION RATE CONSTANT

PRESSURE = 20 psig  
MLSS = 1000 mg/L  
 $k_1$  = 0.214/day



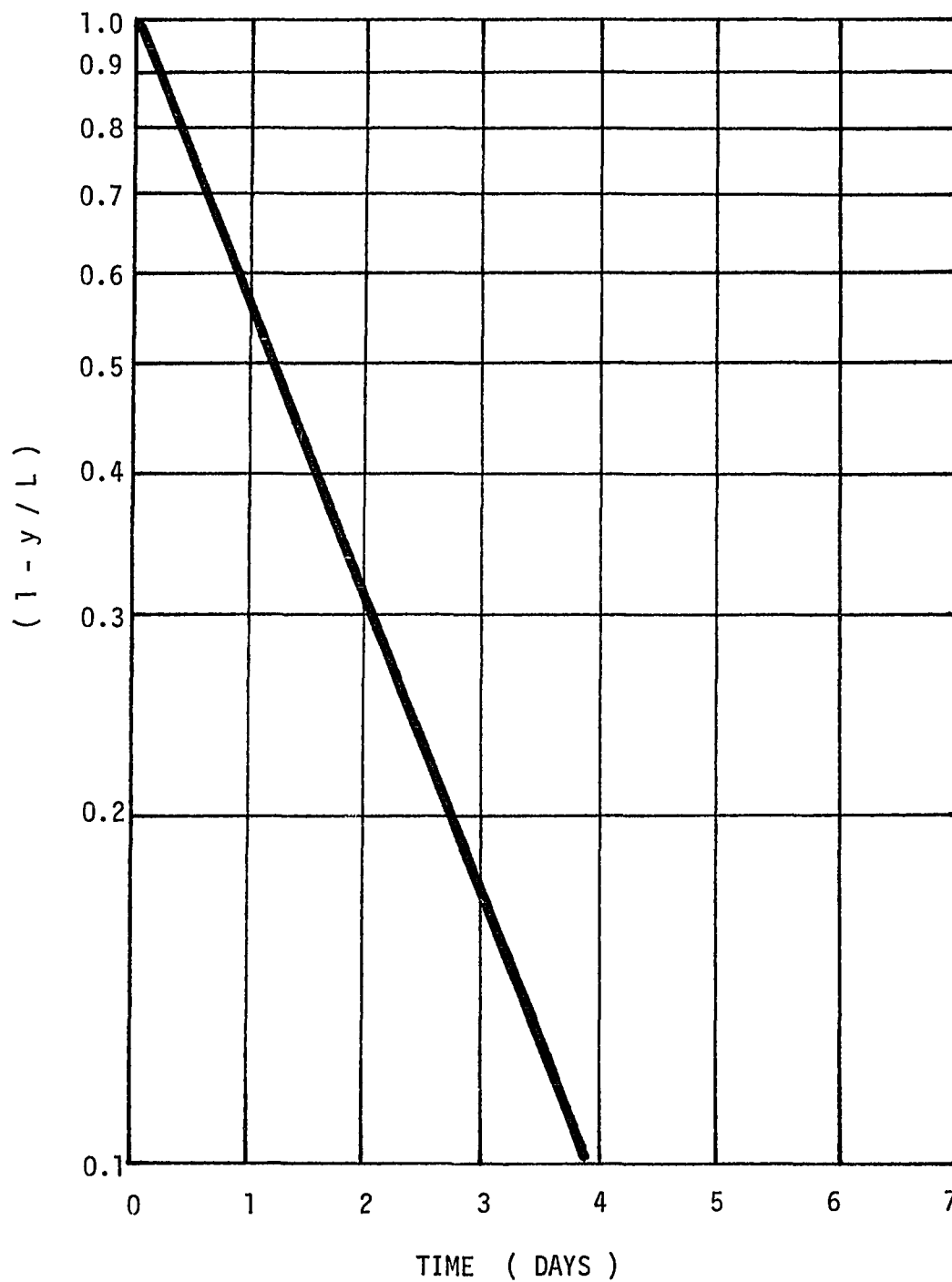
## FIRST ORDER REACTION RATE CONSTANT

PRESSURE = 30 psig  
MLSS = 1000 mg/L  
 $k_1$  = 0.233/day



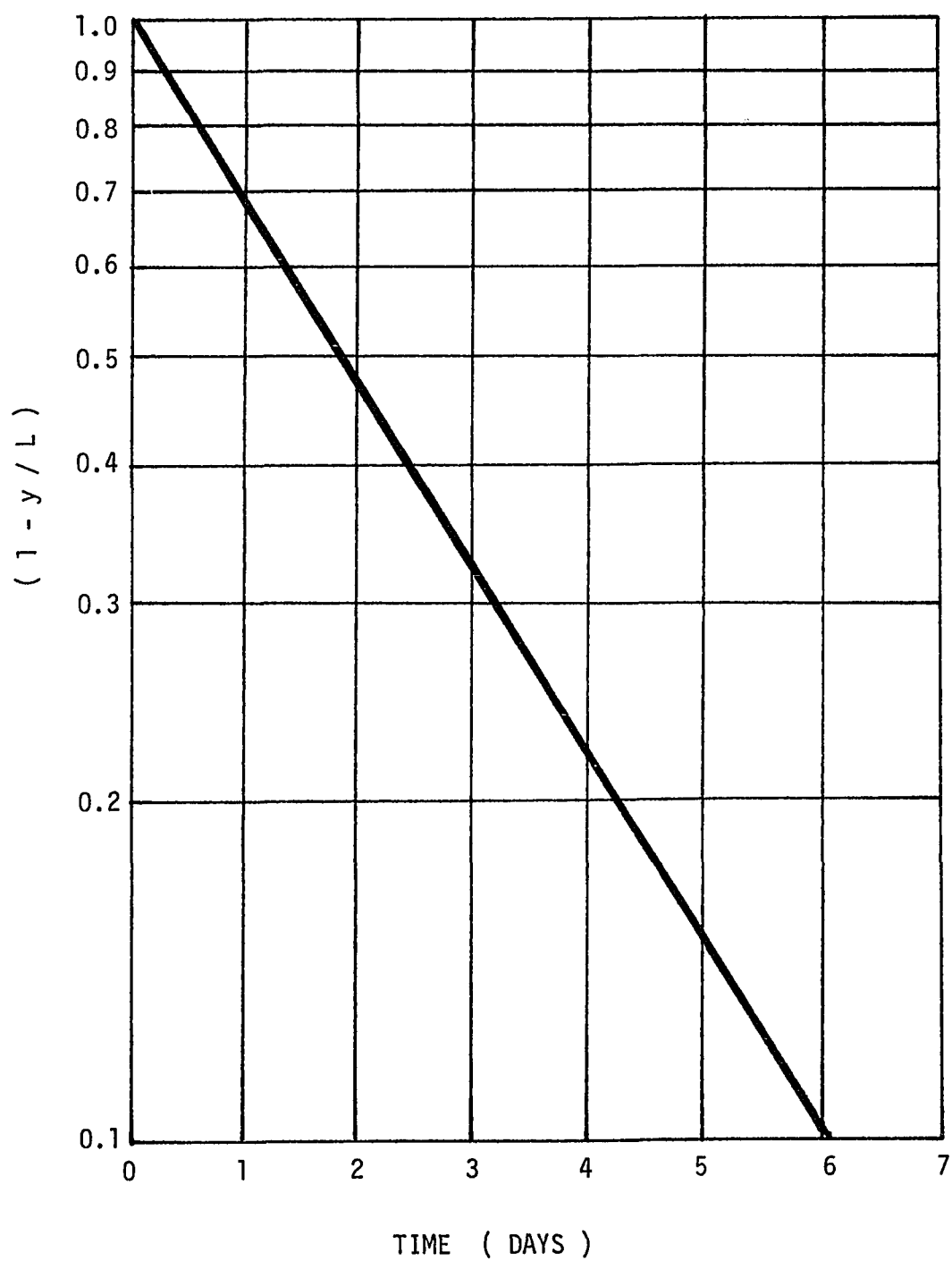
## FIRST ORDER REACTION RATE CONSTANT

PRESSURE = 40 psig  
MLSS = 1000 mg/L  
 $k_1$  = 0.256/day



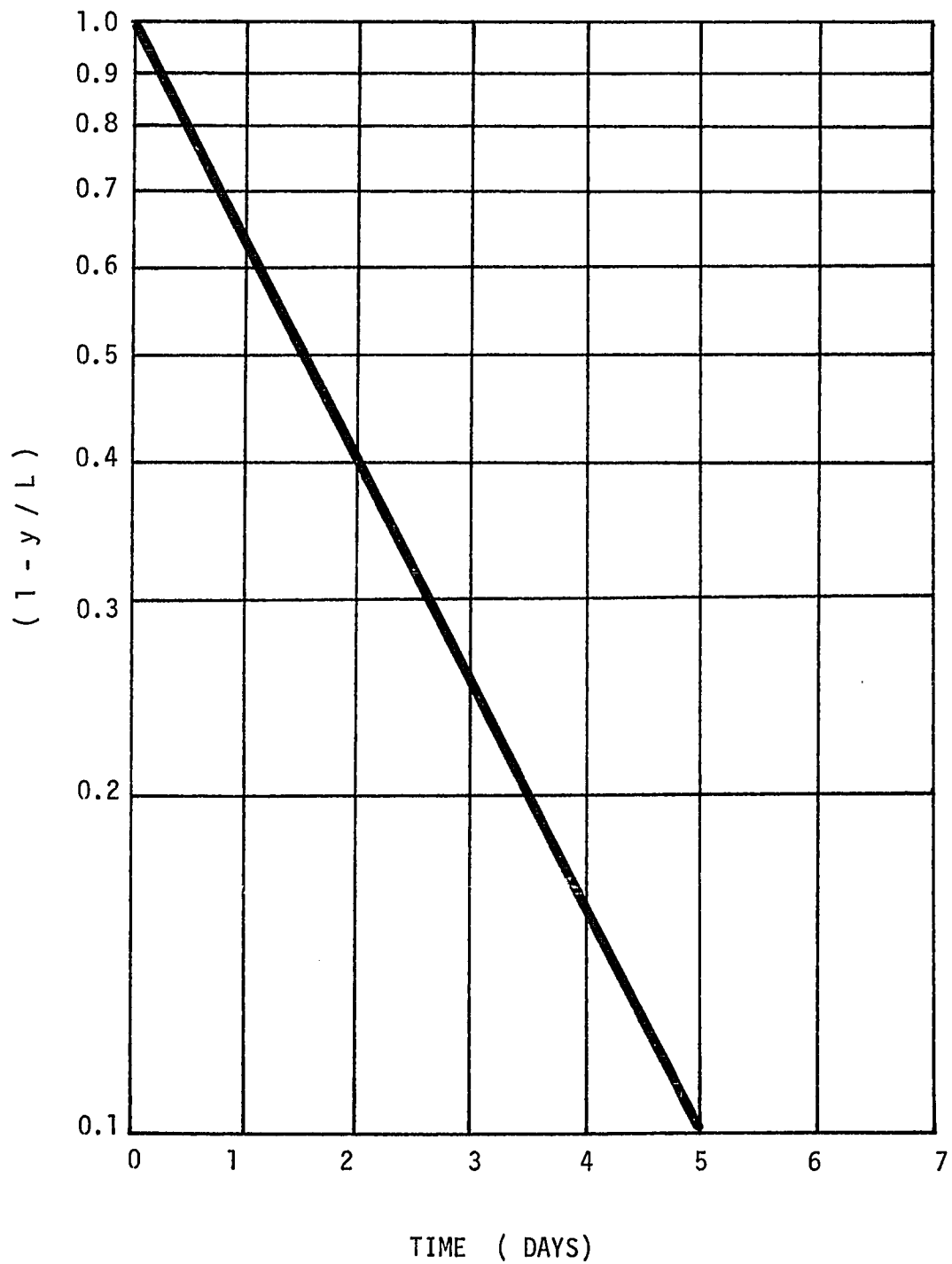
## FIRST ORDER REACTION RATE CONSTANT

PRESSURE = 0 psig  
MLSS = 1500 mg/L  
 $k_1$  = 0.170/day



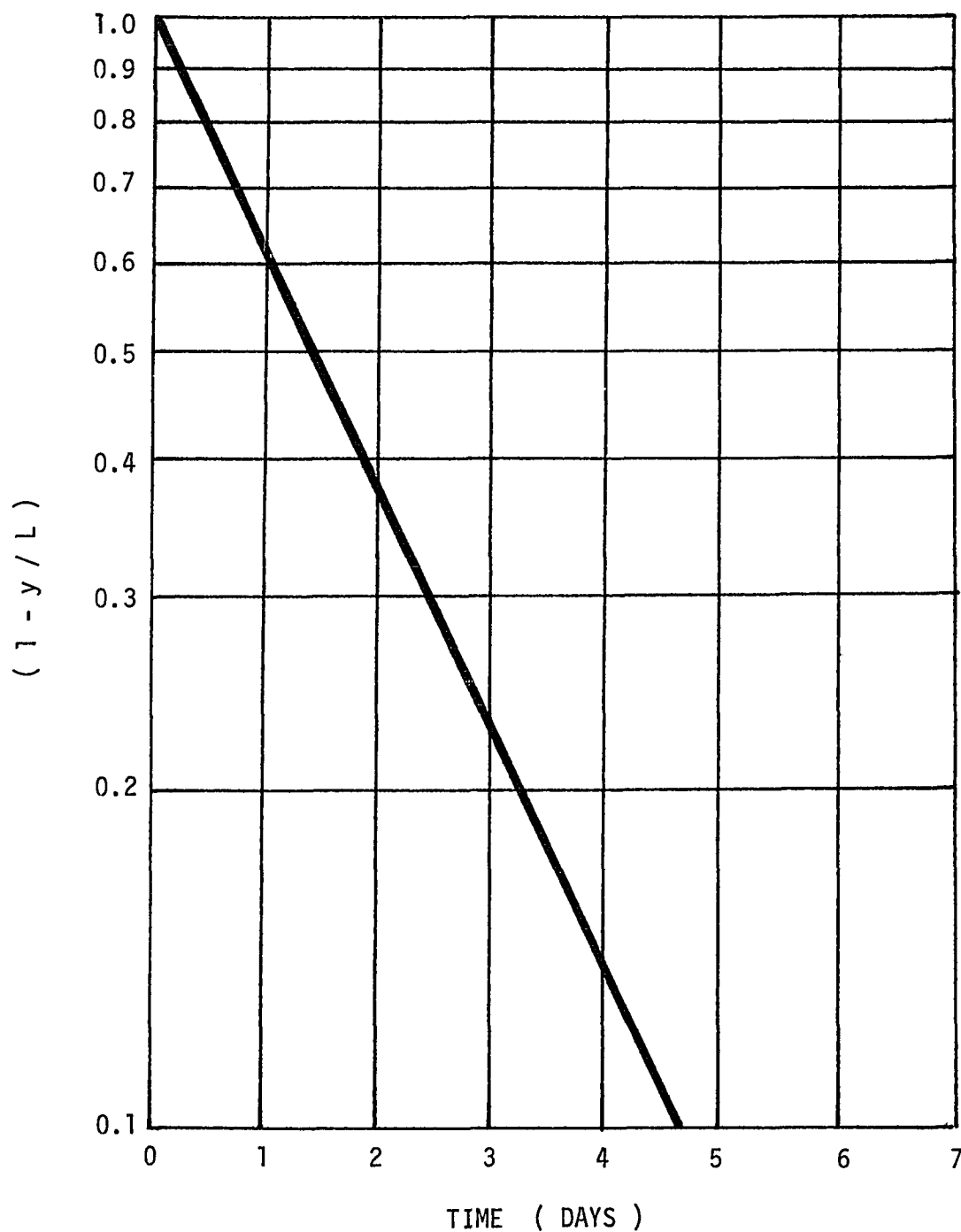
## FIRST ORDER REACTION RATE CONSTANT

PRESSURE = 10 psig  
MLSS = 1500 mg/L  
 $k_1$  = 0.198/day



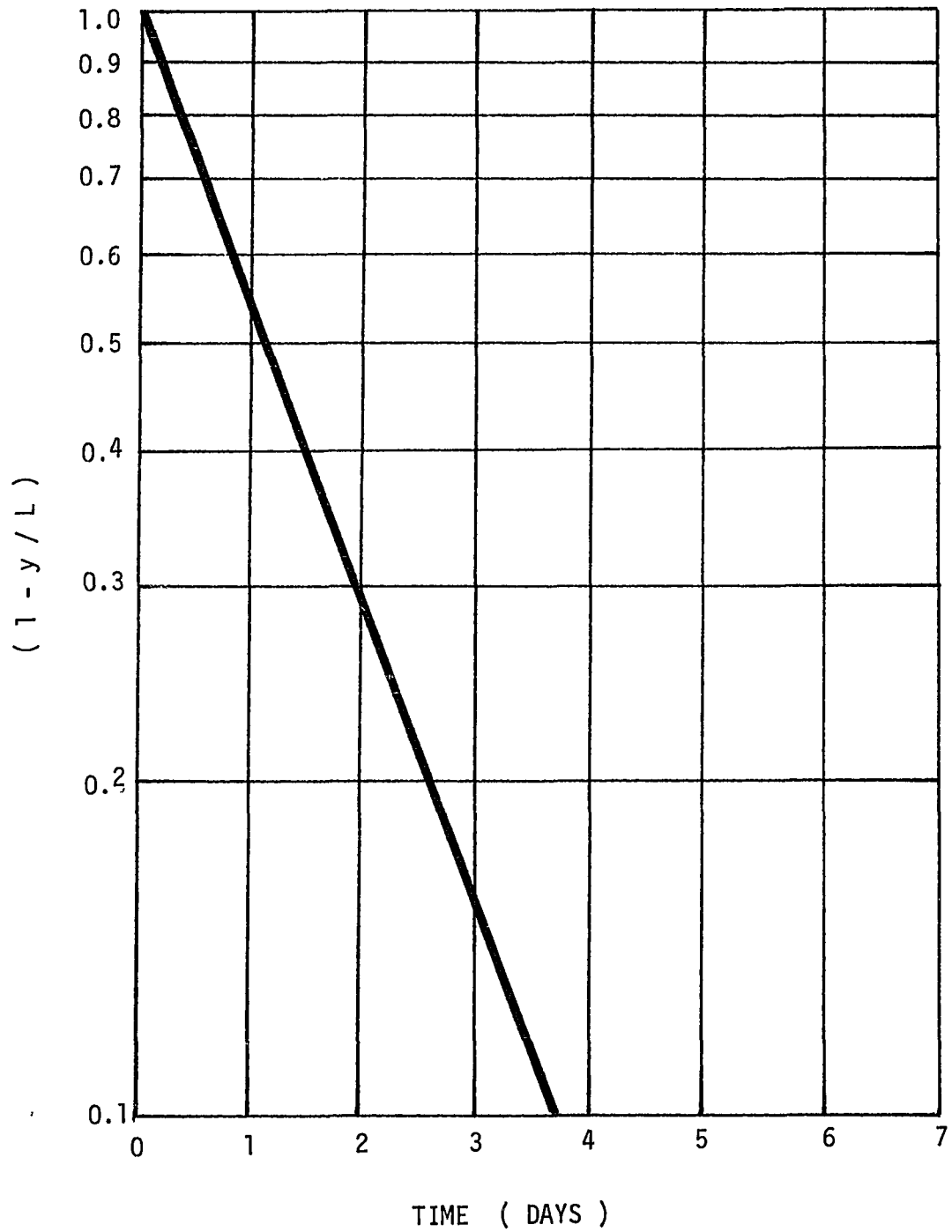
## FIRST ORDER REACTION RATE CONSTANT

PRESSURE = 20 psig  
MLSS = 1500 mg/L  
 $k_1$  = 0.214/day



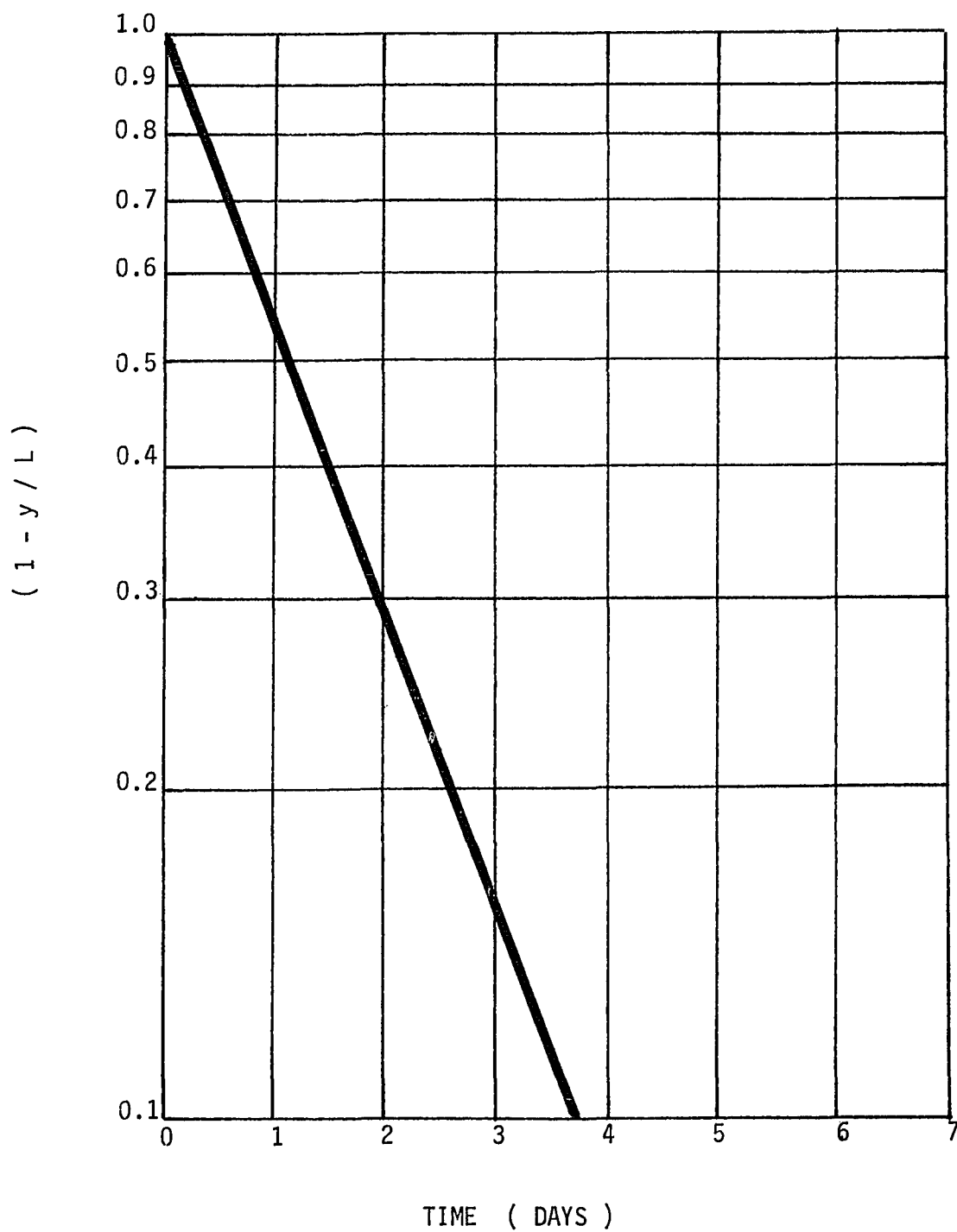
## FIRST ORDER REACTION RATE CONSTANT

PRESSURE = 30 psig  
MLSS = 1500 mg/L  
 $k_1$  = 0.278/day



## FIRST ORDER REACTION RATE CONSTANT

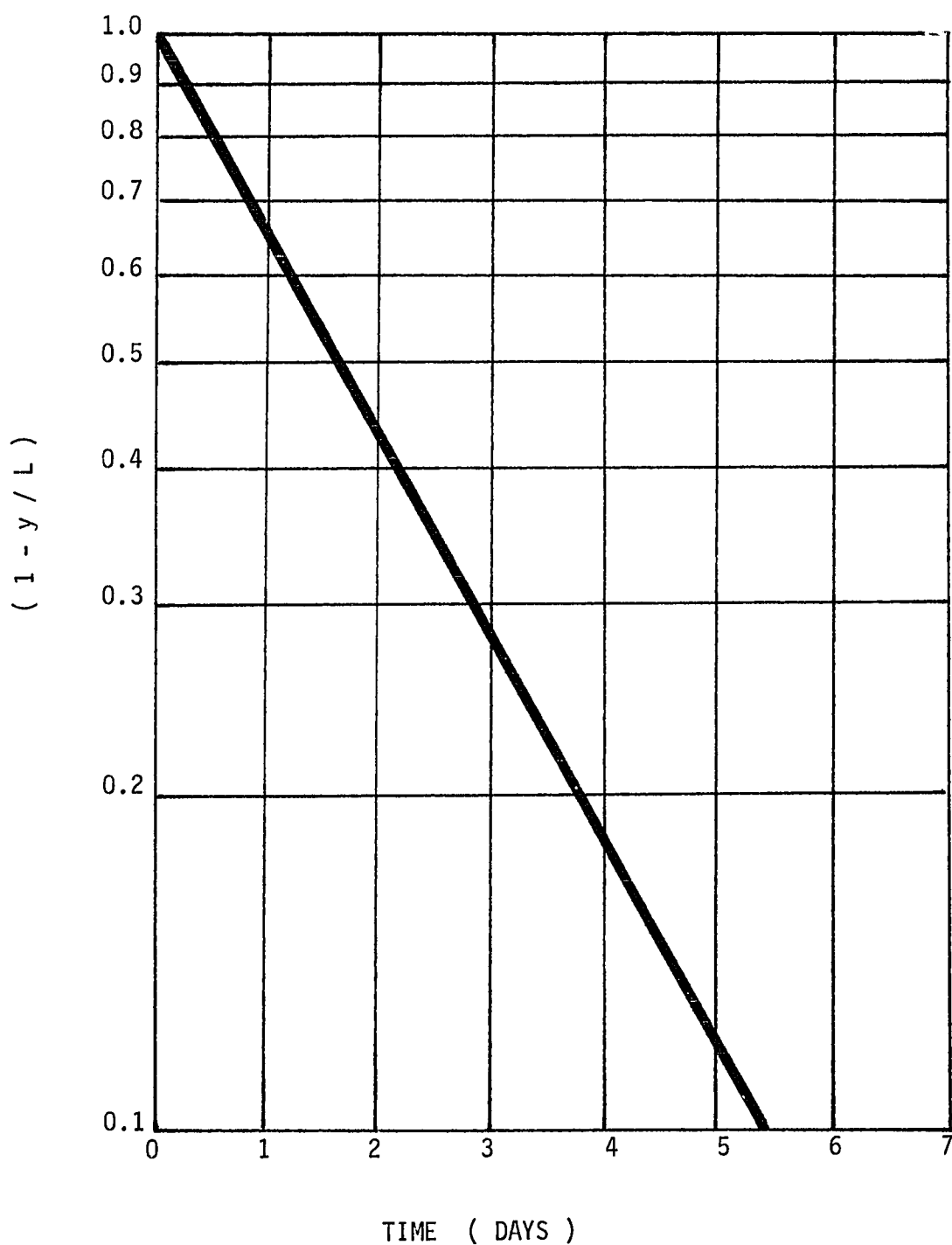
PRESSURE = 40 psig  
MLSS = 1500 mg/L  
 $k_1$  = 0.280/day





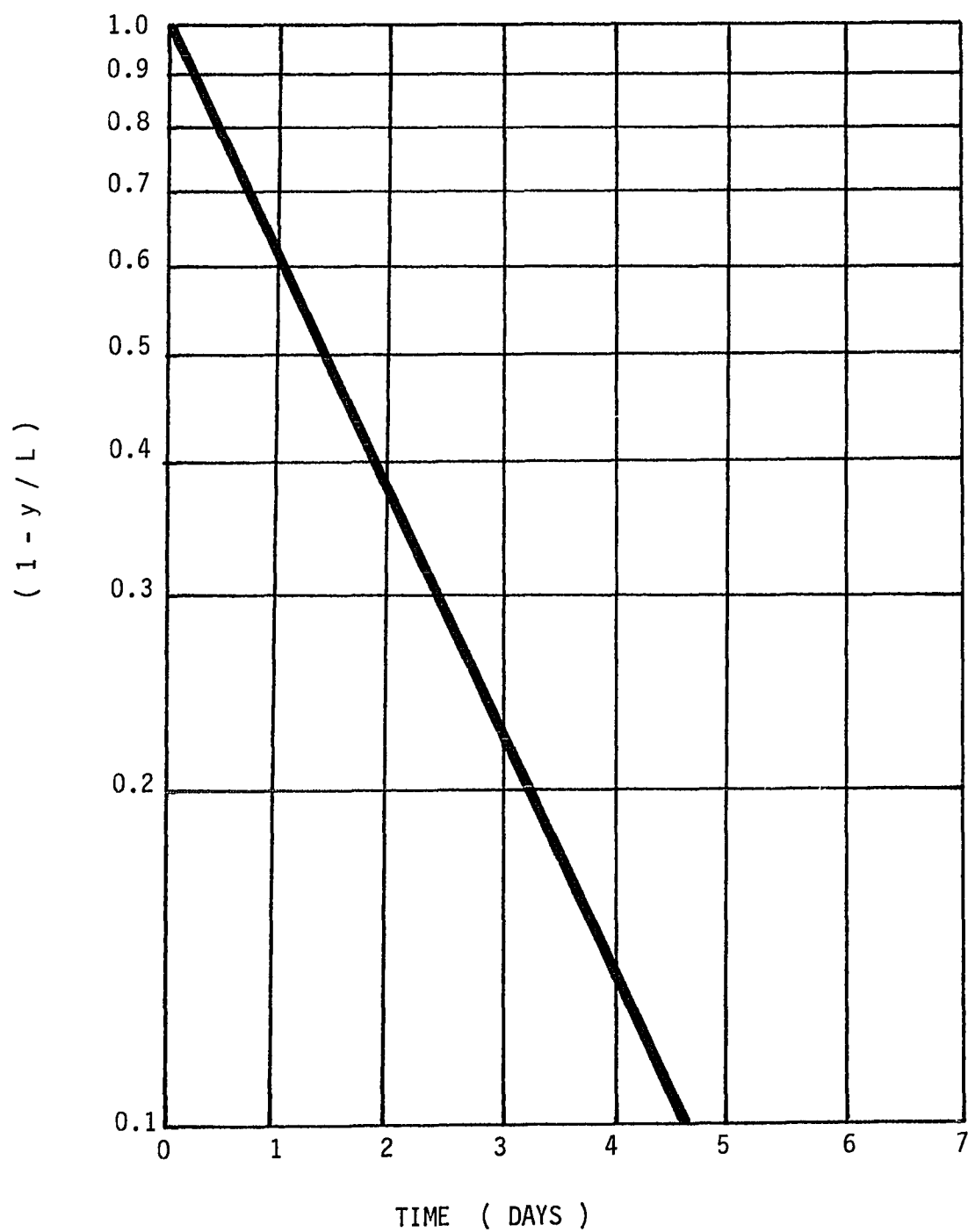
## FIRST ORDER REACTION RATE CONSTANT

PRESSURE = 0 psig  
MLSS = 2000 mg/L  
 $k_1$  = 0.190/day



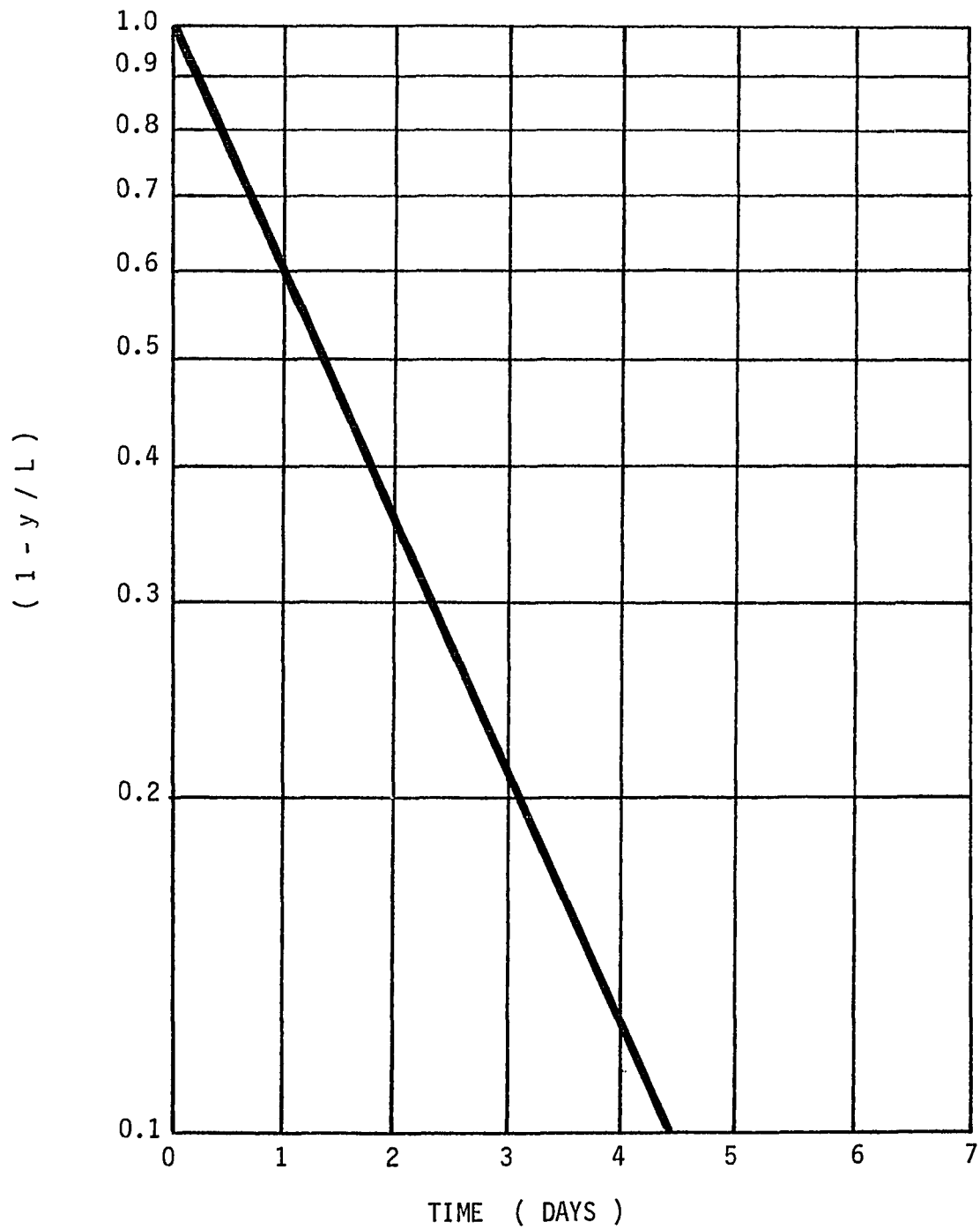
## FIRST ORDER REACTION RATE CONSTANT

PRESSURE = 10 psig  
MLSS = 2000 mg/L  
 $k_1$  = 0.208/day



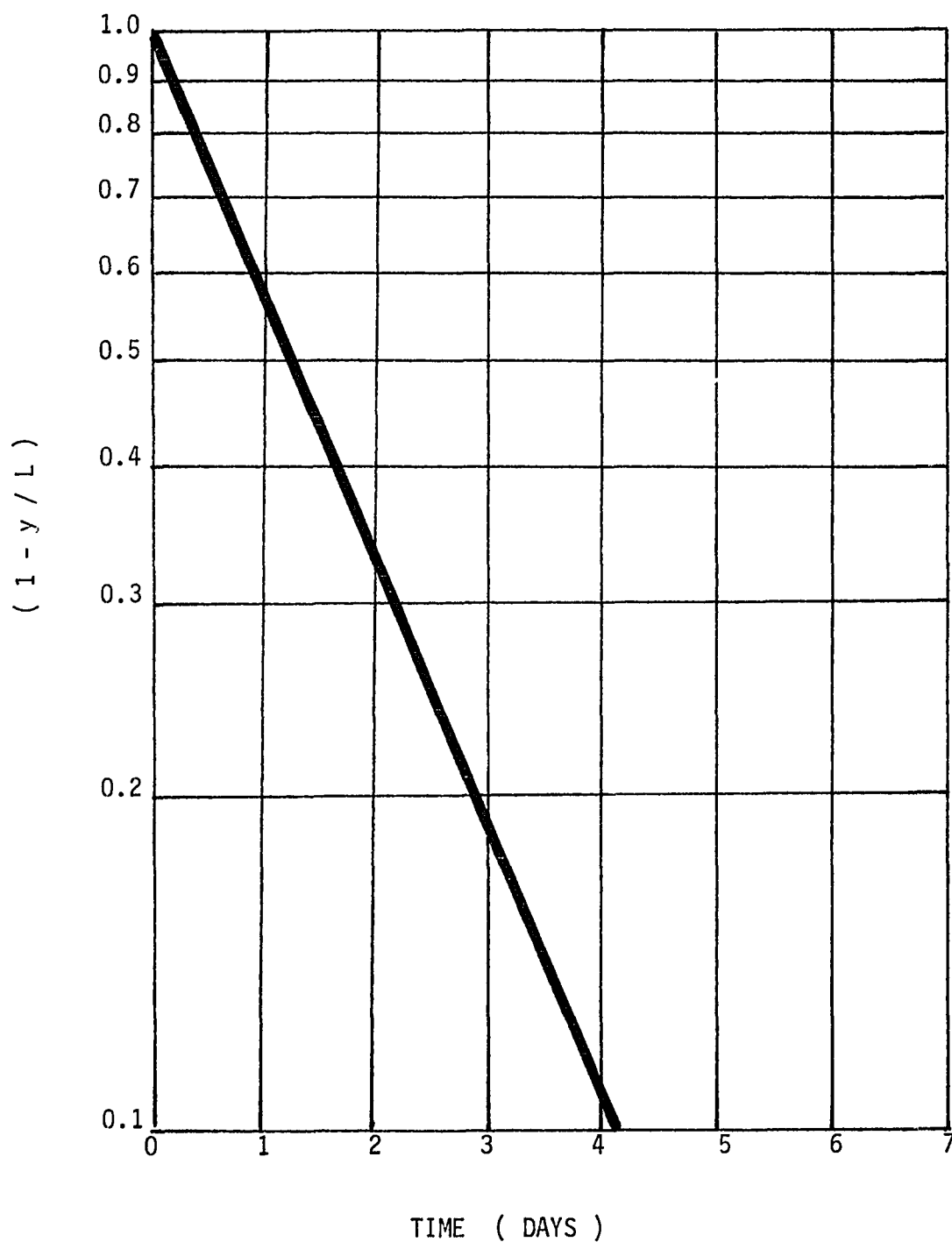
## FIRST ORDER REACTION RATE CONSTANT

PRESSURE = 20 psig  
MLSS = 2000 mg/L  
 $k_1$  = 0.225/day



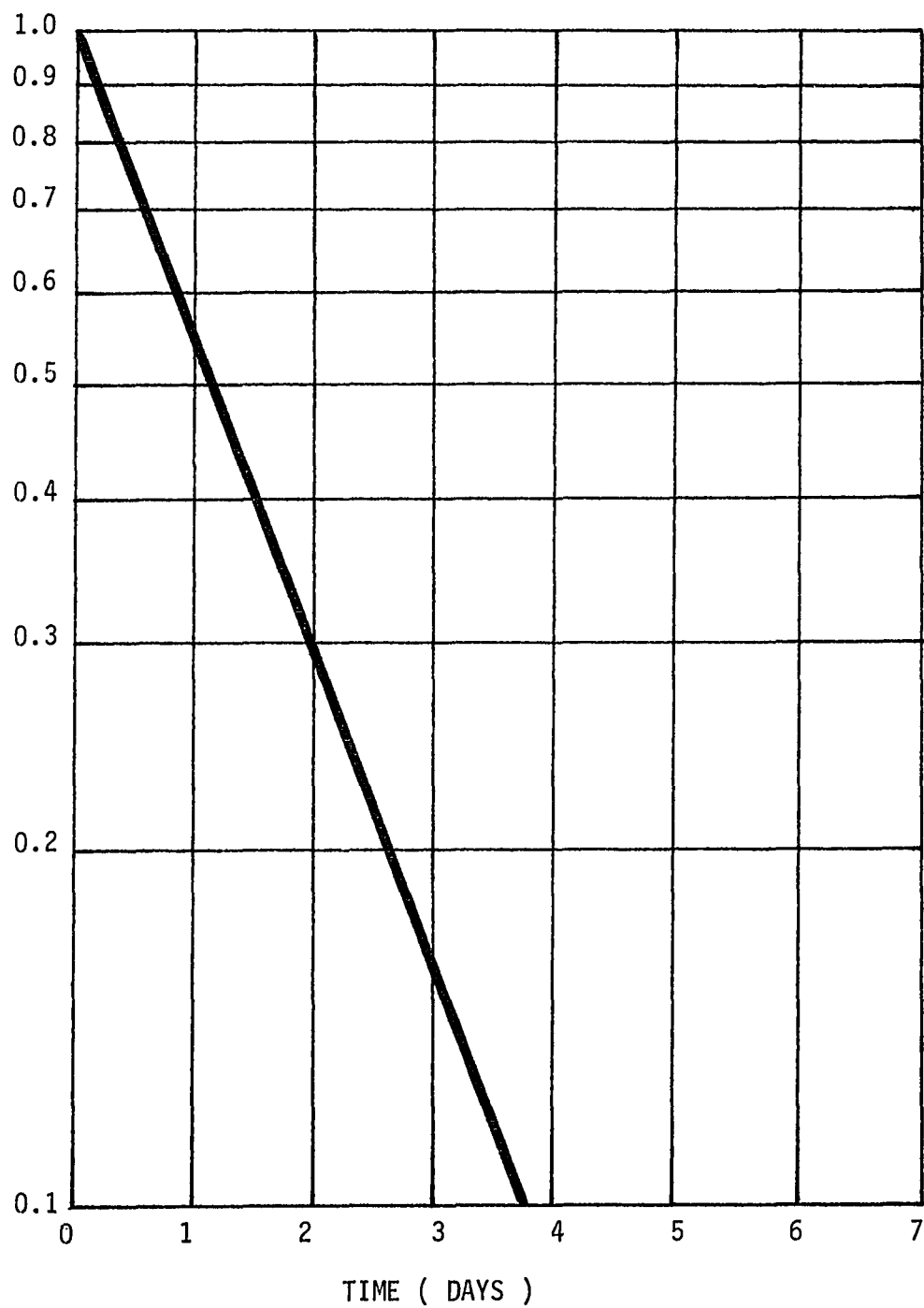
## FIRST ORDER REACTION RATE CONSTANT

PRESSURE = 30 psig  
MLSS = 2000 mg/L  
 $k_1$  = 0.249/day



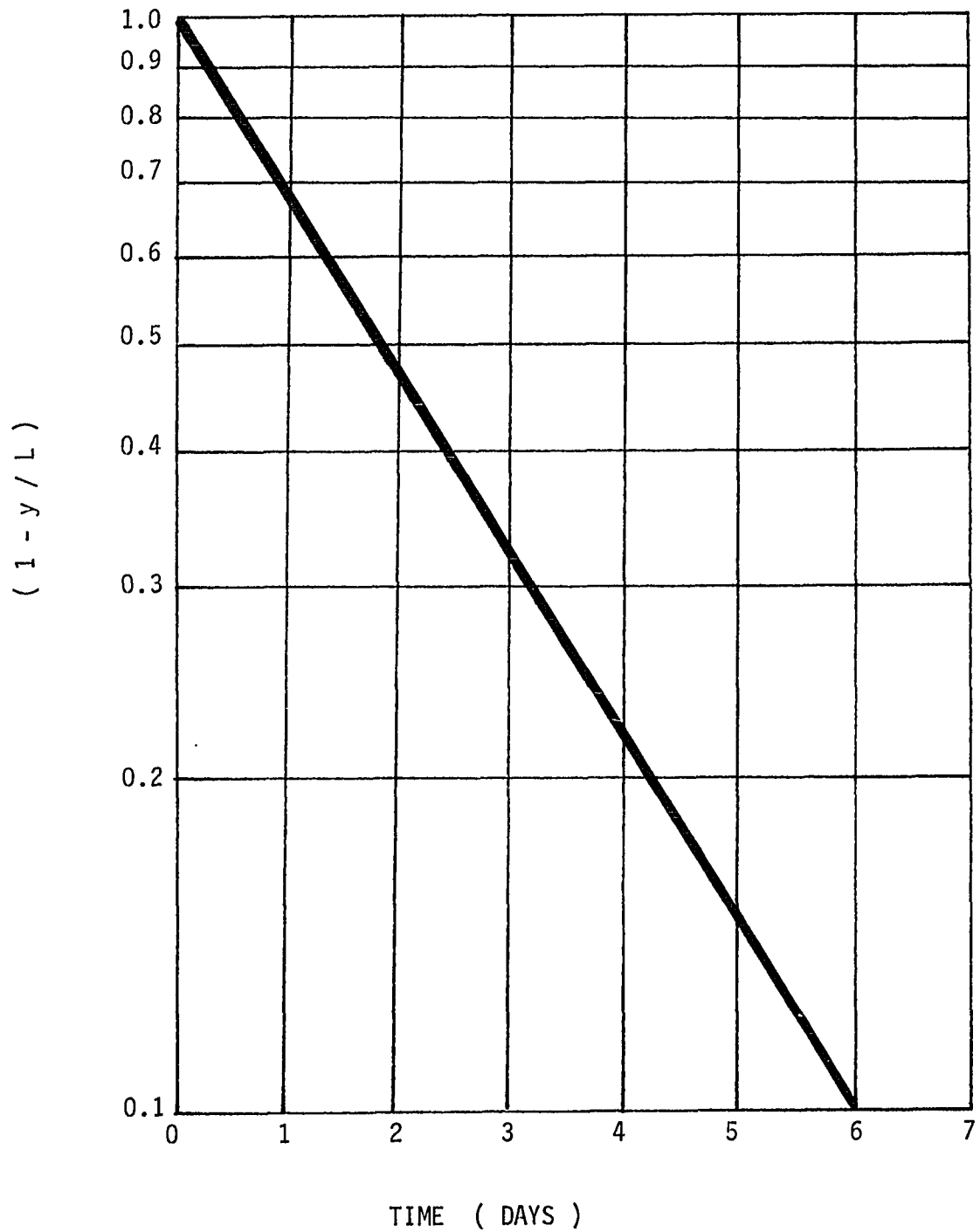
## FIRST ORDER REACTION RATE CONSTANT

PRESSURE = 40 psig  
MLSS = 2000 mg/L  
 $k_1$  = 0.285/day



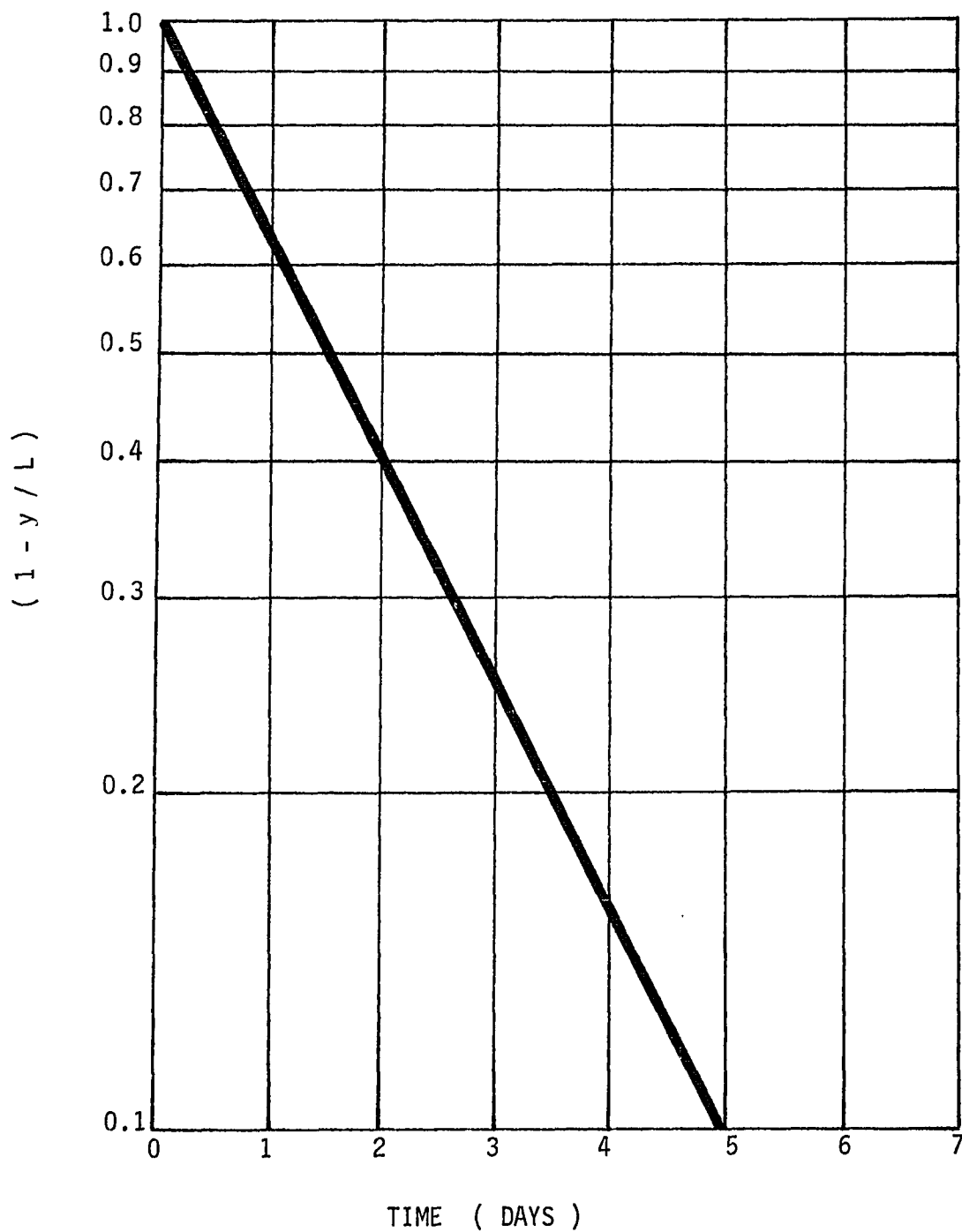
## FIRST ORDER REACTION RATE CONSTANT

PRESSURE = 0 psig  
MLSS = 2500 mg/L  
 $k_1$  = 0.170/day



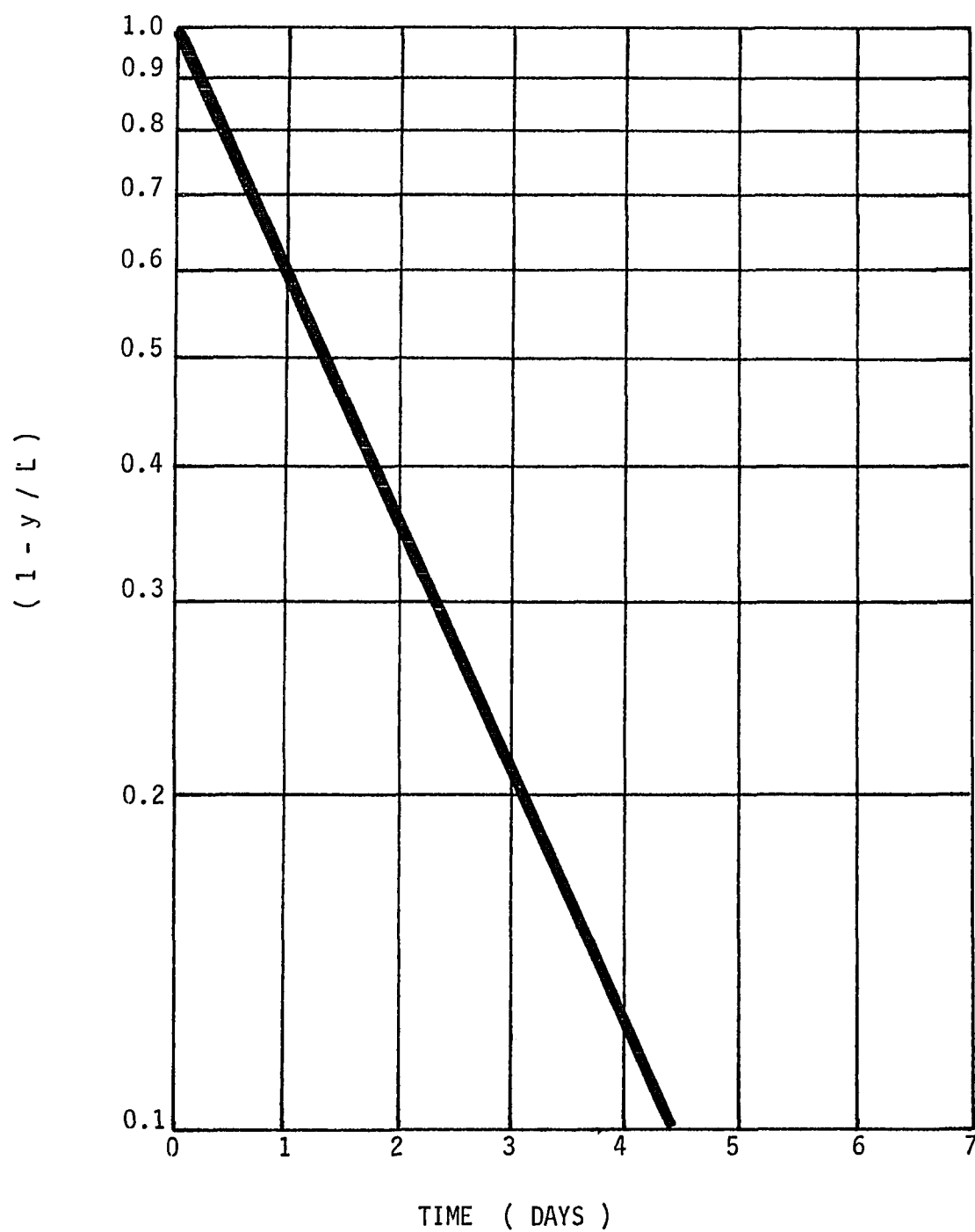
## FIRST ORDER REACTION RATE CONSTANT

PRESSURE = 10 psig  
MLSS = 2500 mg/L  
 $k_1$  = 0.198/day



## FIRST ORDER REACTION RATE CONSTANT

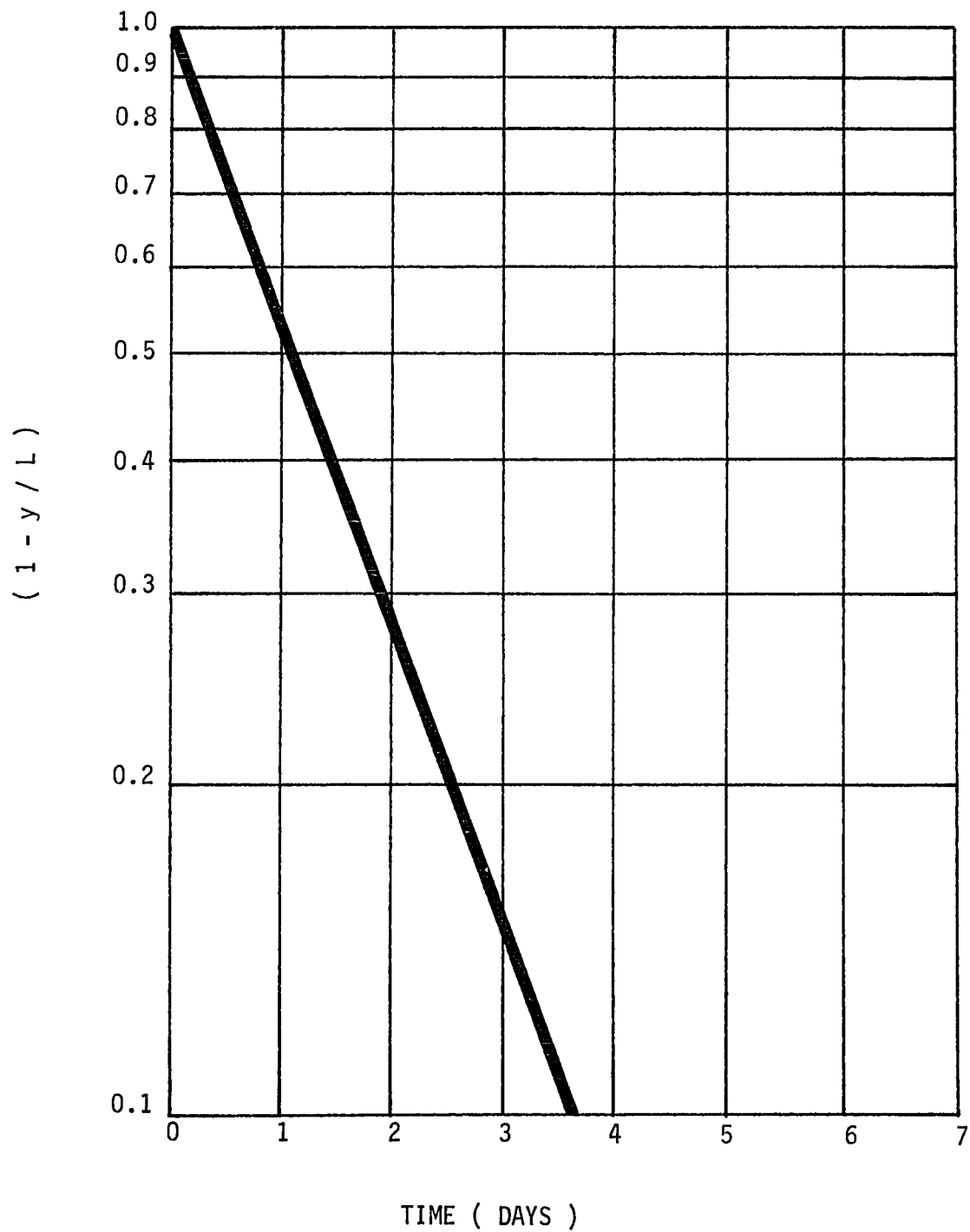
PRESSURE = 20 psig  
MLSS = 2500 mg/L  
 $k_1$  = 0.239/day





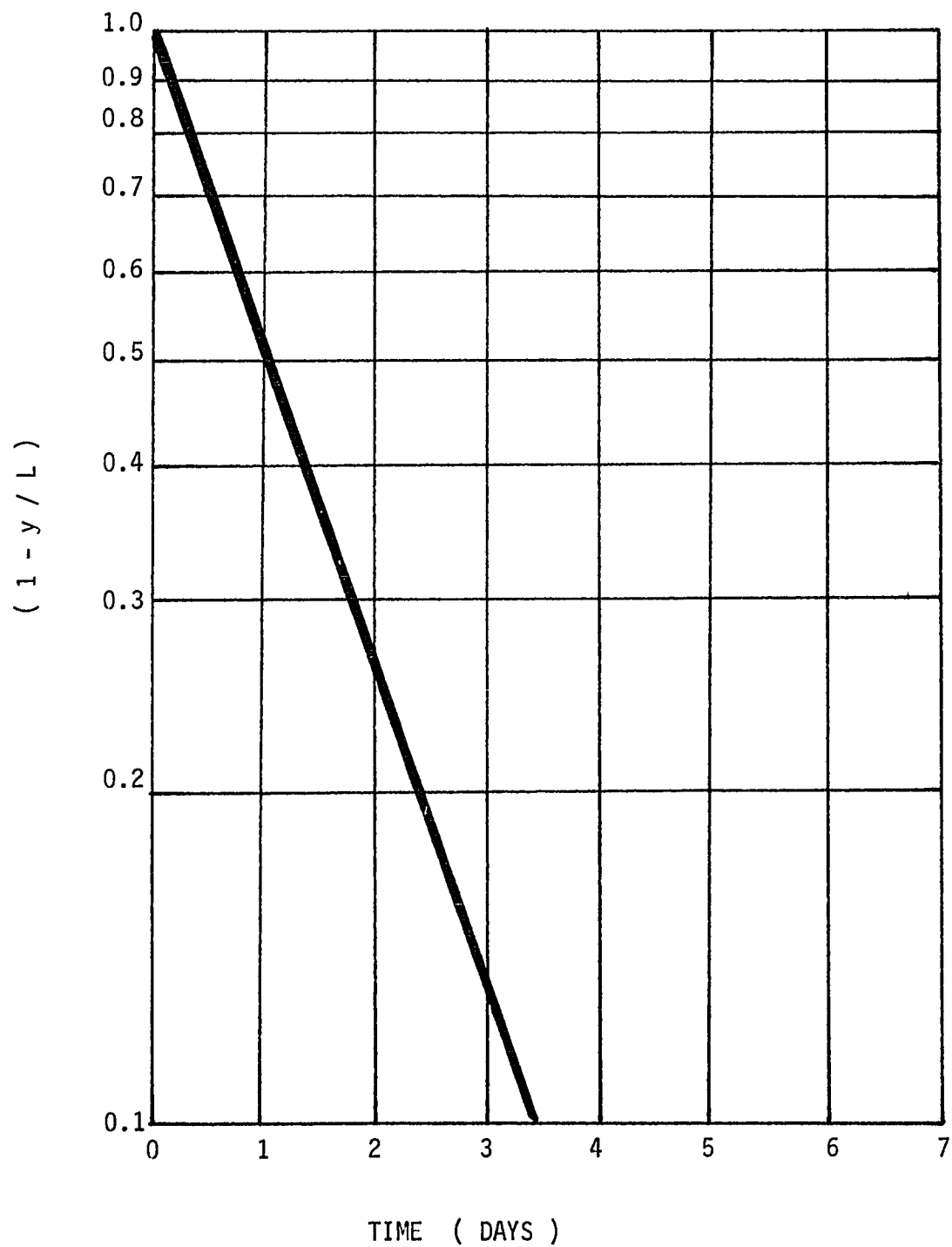
## FIRST ORDER REACTION RATE CONSTANT

PRESSURE = 30 psig  
MLSS = 2500 mg/L  
 $k_1$  = 0.278/day



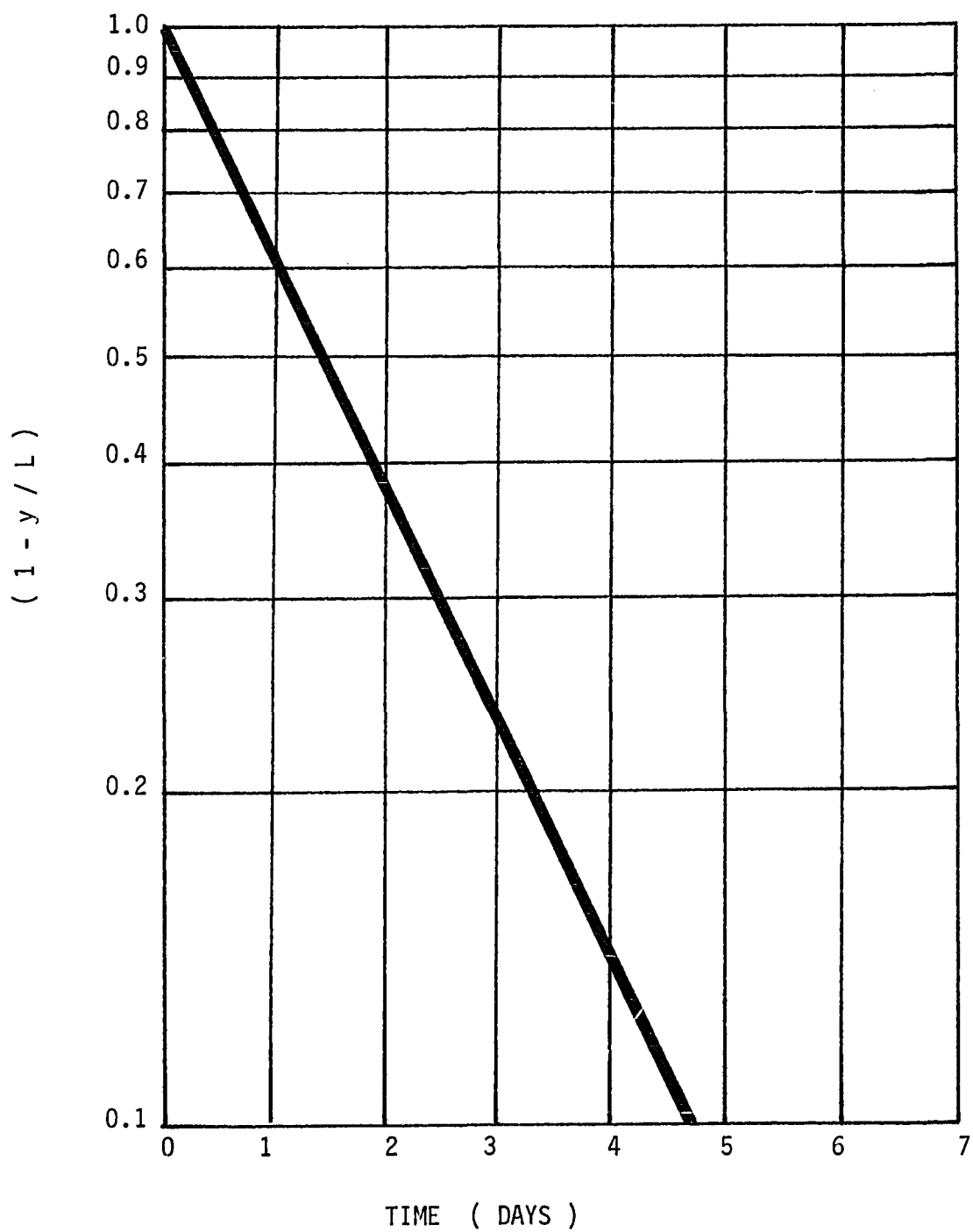
## FIRST ORDER REACTION RATE CONSTANT

PRESSURE = 40 psig  
MLSS = 2500 mg/L  
 $k_1$  = 0.288/day



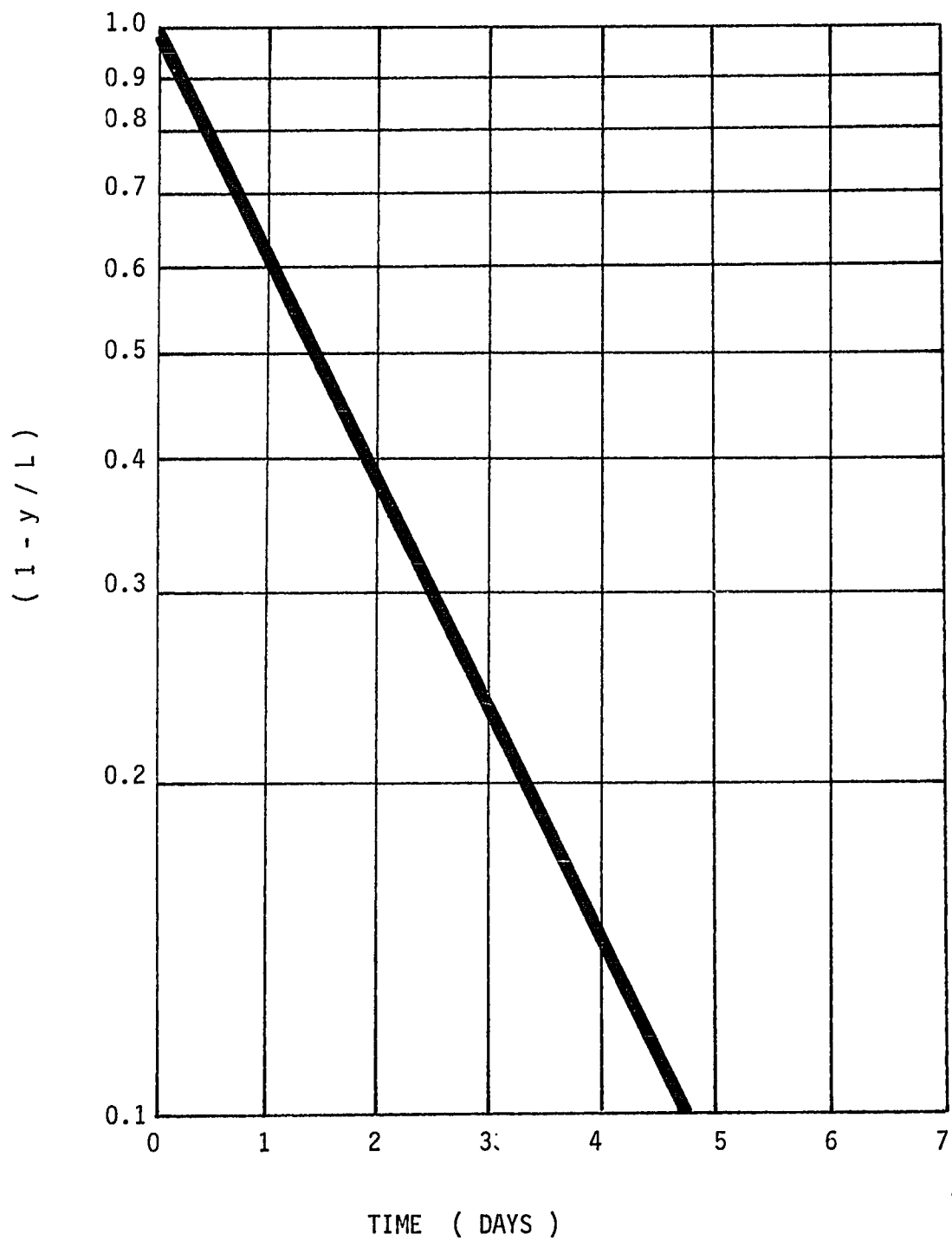
## FIRST ORDER REACTION RATE CONSTANT

PRESSURE = 0 psig  
MLSS = 3000 mg/L  
 $k_1$  = 0.209/day



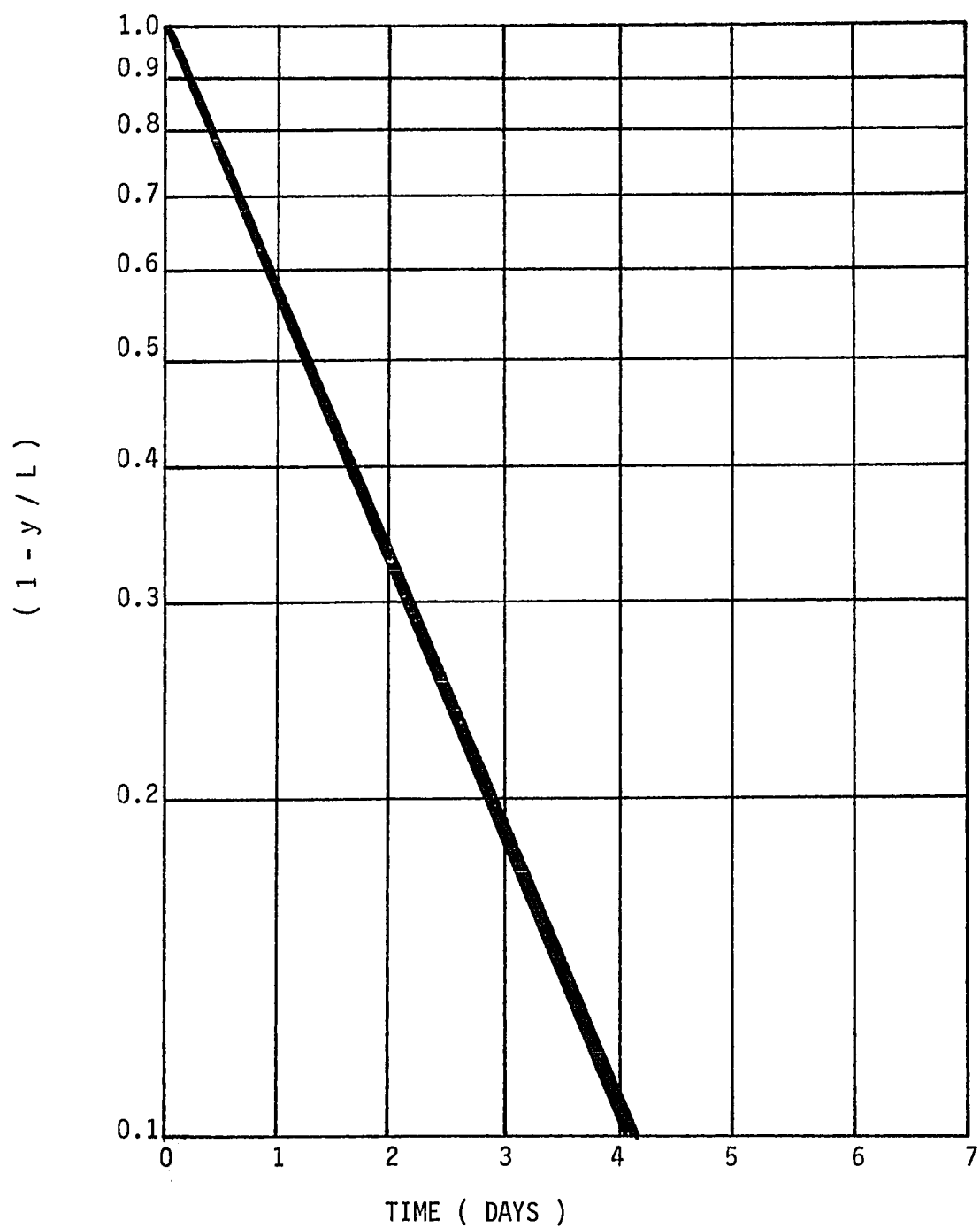
## FIRST ORDER REACTION RATE CONSTANT

PRESSURE = 10 psig  
MLSS = 3000 mg/L  
 $k_1$  = 0.218/day



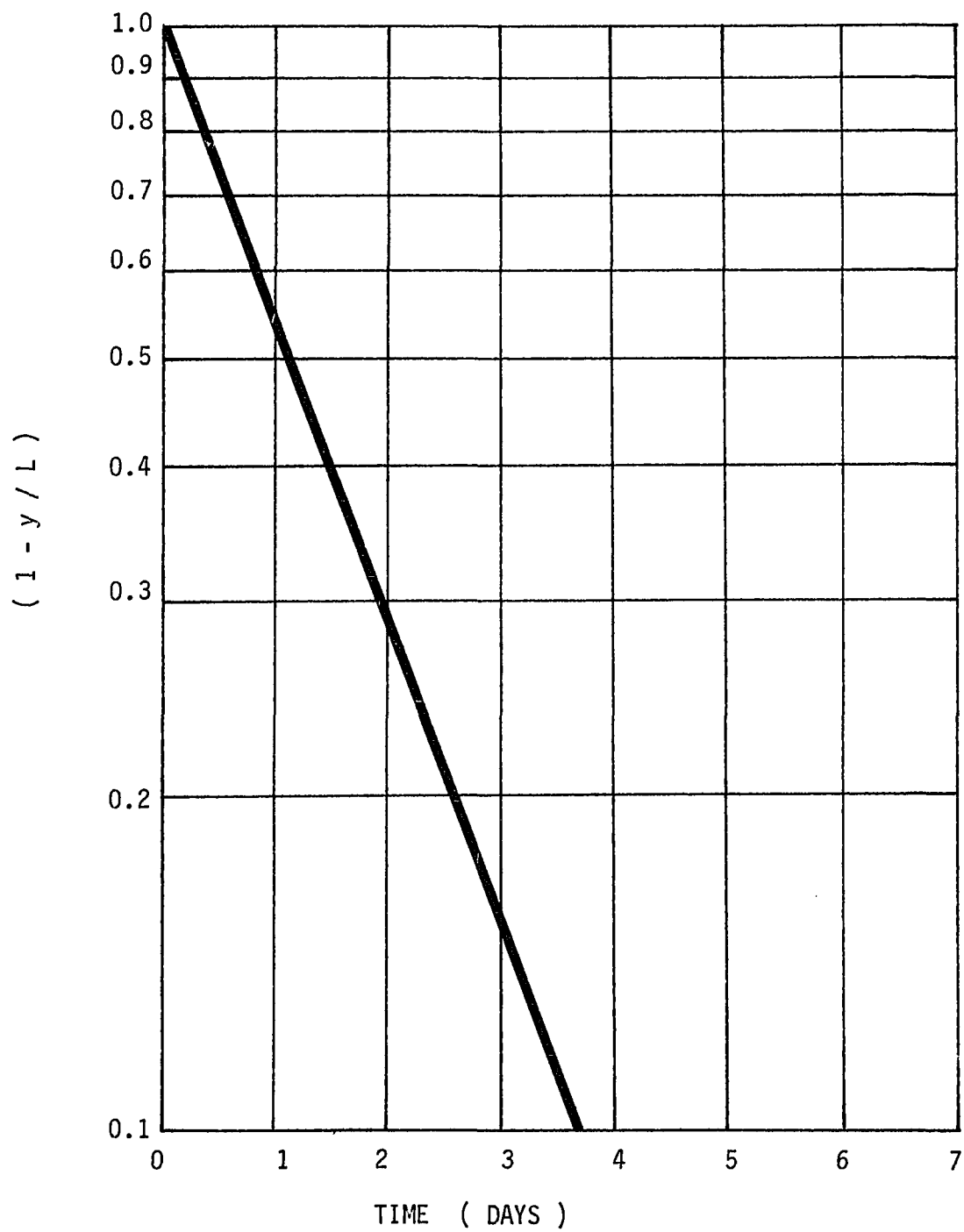
## FIRST ORDER REACTION RATE CONSTANT

PRESSURE = 20 psig  
MLSS = 3000 mg/L  
 $k_1$  = 0.247/day



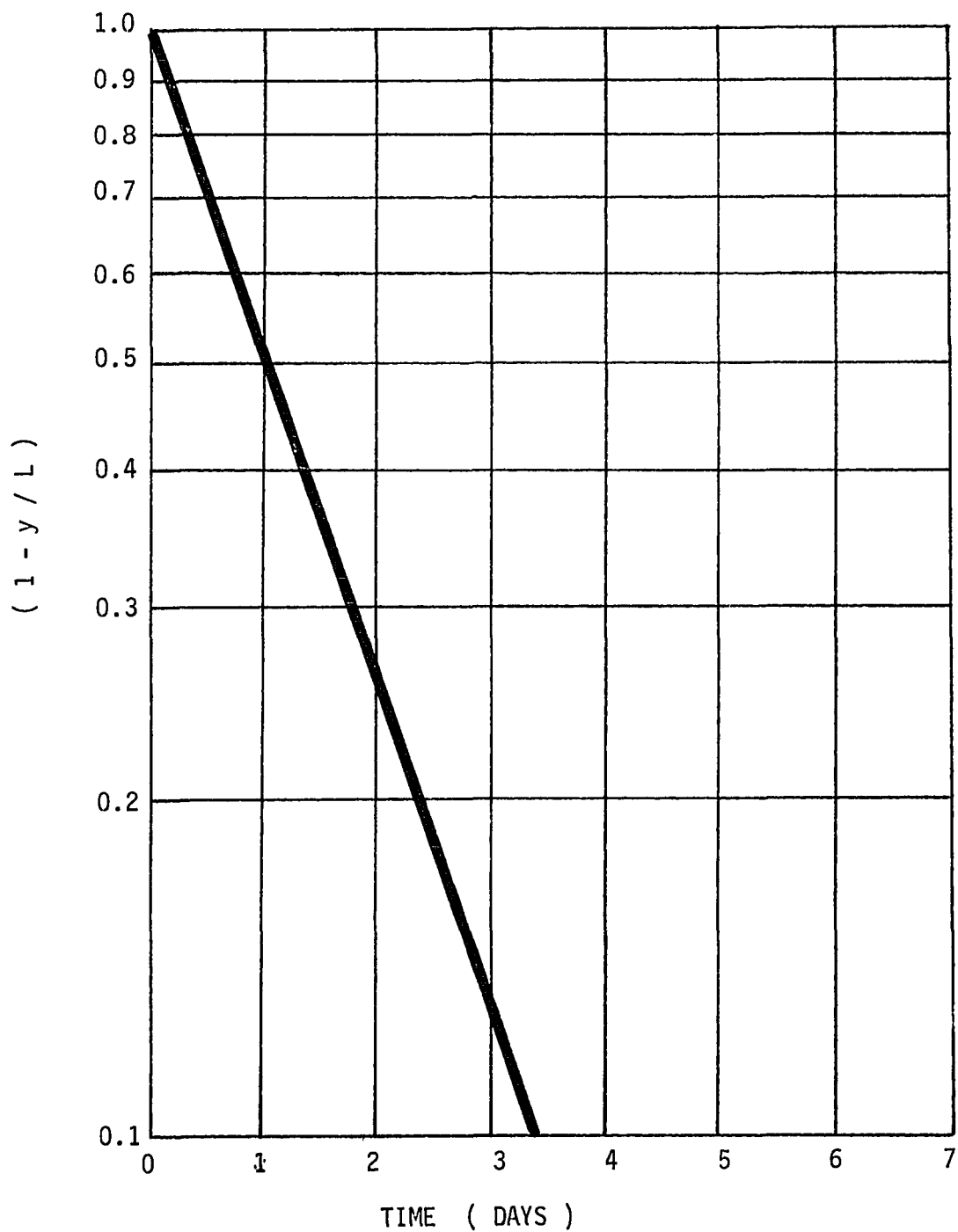
## FIRST ORDER REACTION RATE CONSTANT

PRESSURE = 30 psig  
MLSS = 3000 mg/L  
 $k_1$  = 0.267/day



## FIRST ORDER REACTION RATE CONSTANT

PRESSURE = 40 psig  
MLSS = 3000 mg/L  
 $k_1$  = 0.295/day



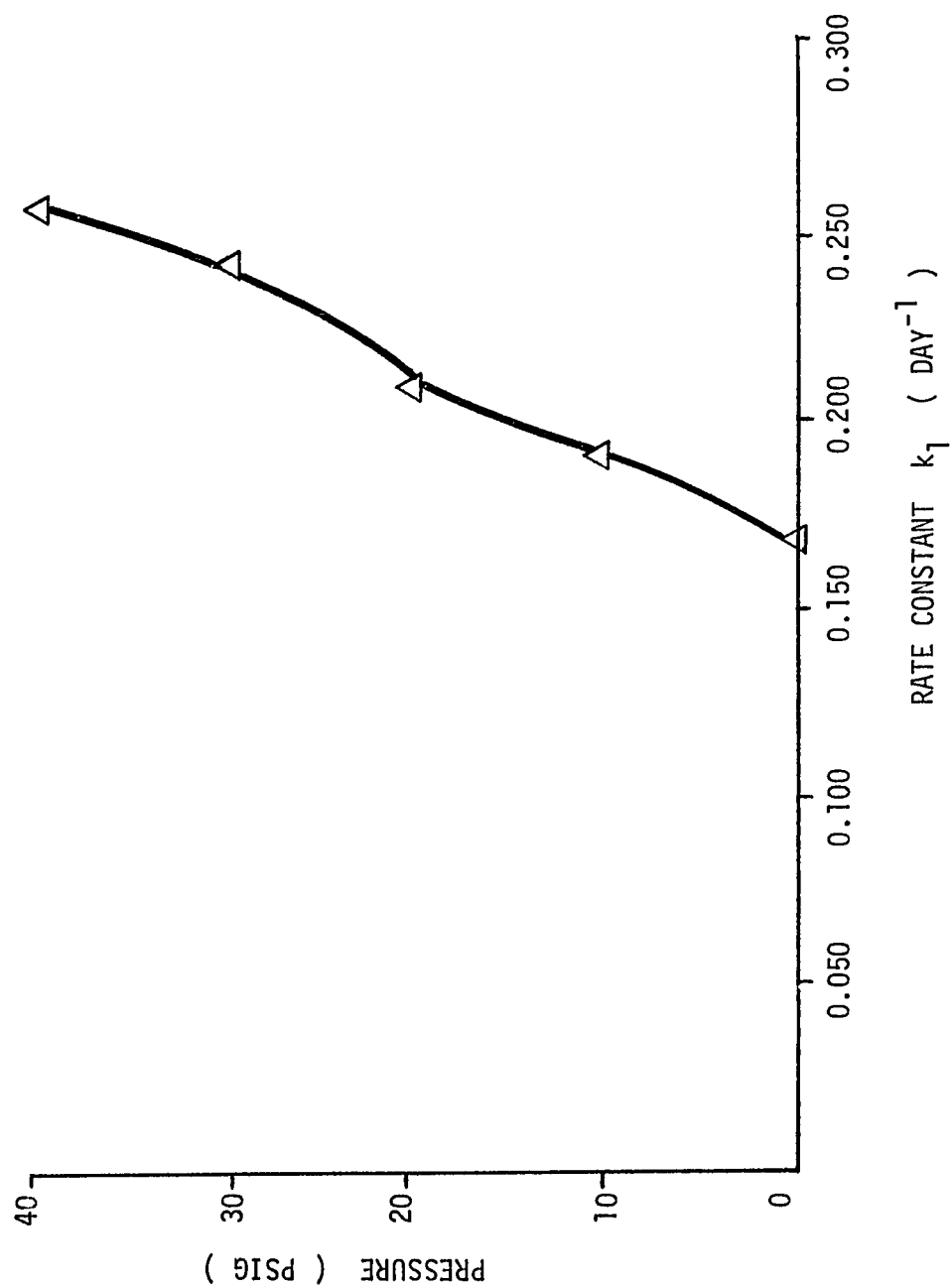
### APPENDIX III

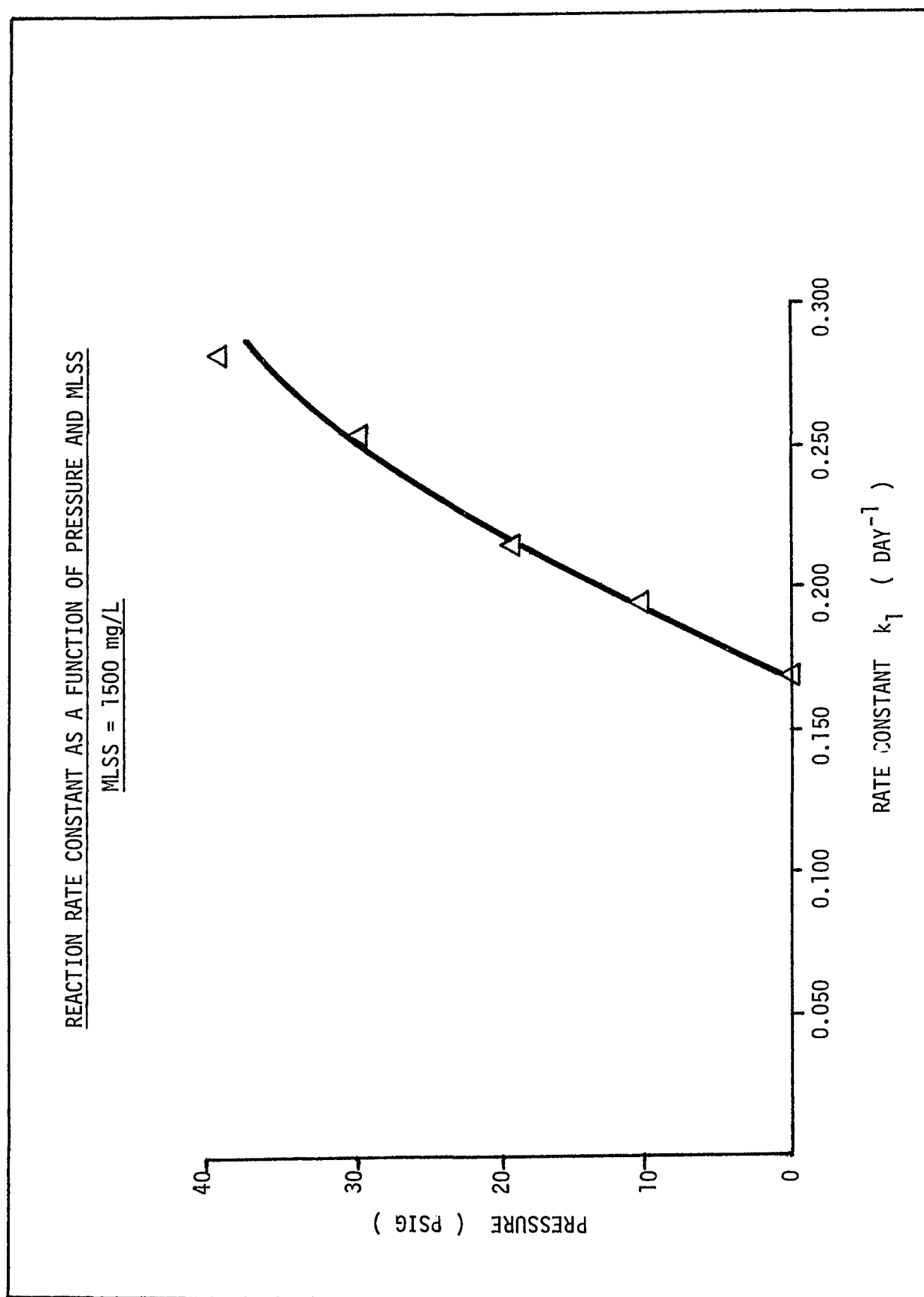
THE FOLLOWING GRAPHS ILLUSTRATE THE INDIVIDUAL CURVES  
SHOWN AS A COMPOSITE IN FIGURE 14 -  
CURVES INDICATE INCREASE IN REACTION RATE WITH AN INCREASE IN PRESSURE



REACTION RATE CONSTANT AS A FUNCTION OF PRESSURE AND MLSS

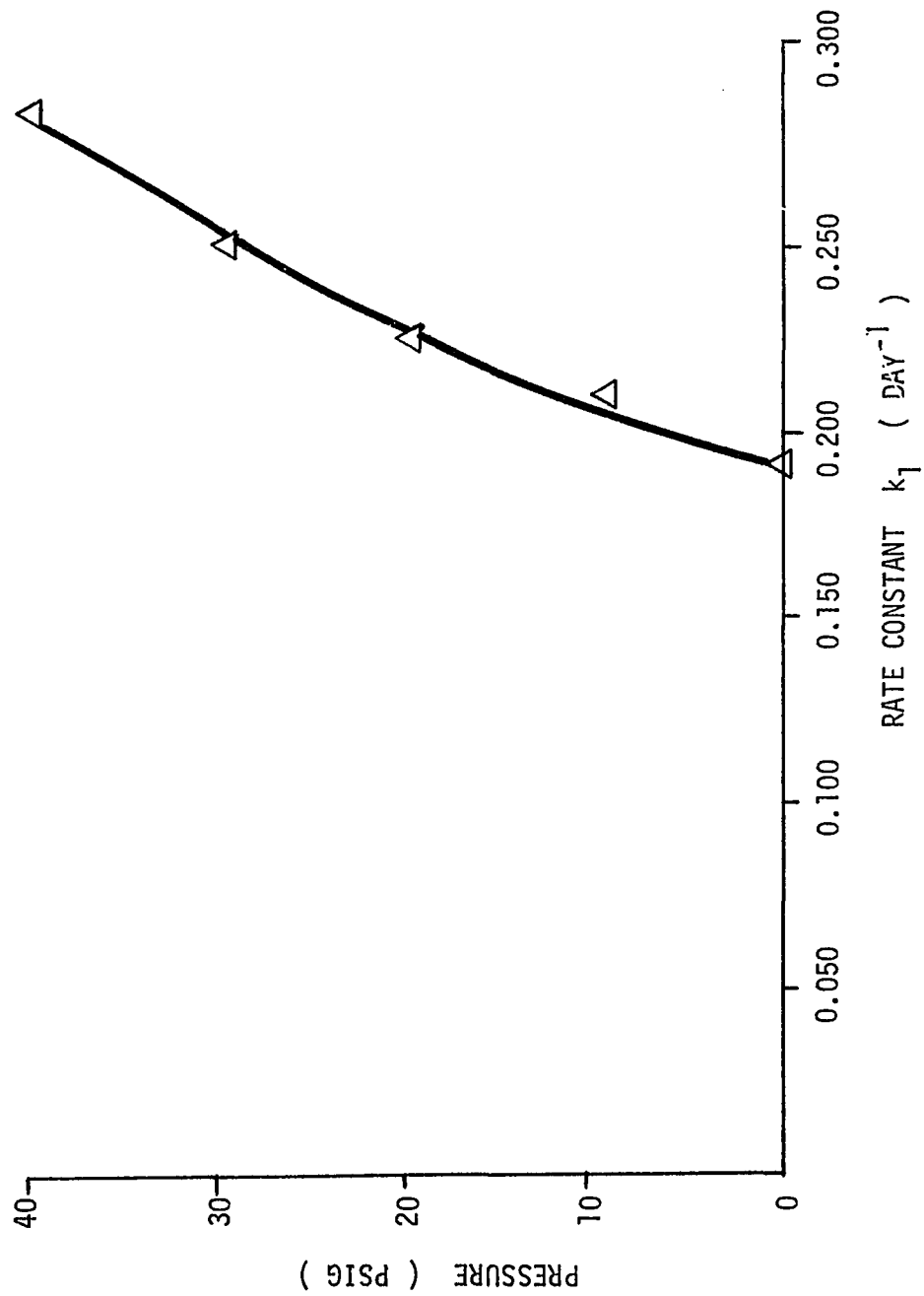
MLSS = 1000 mg/L





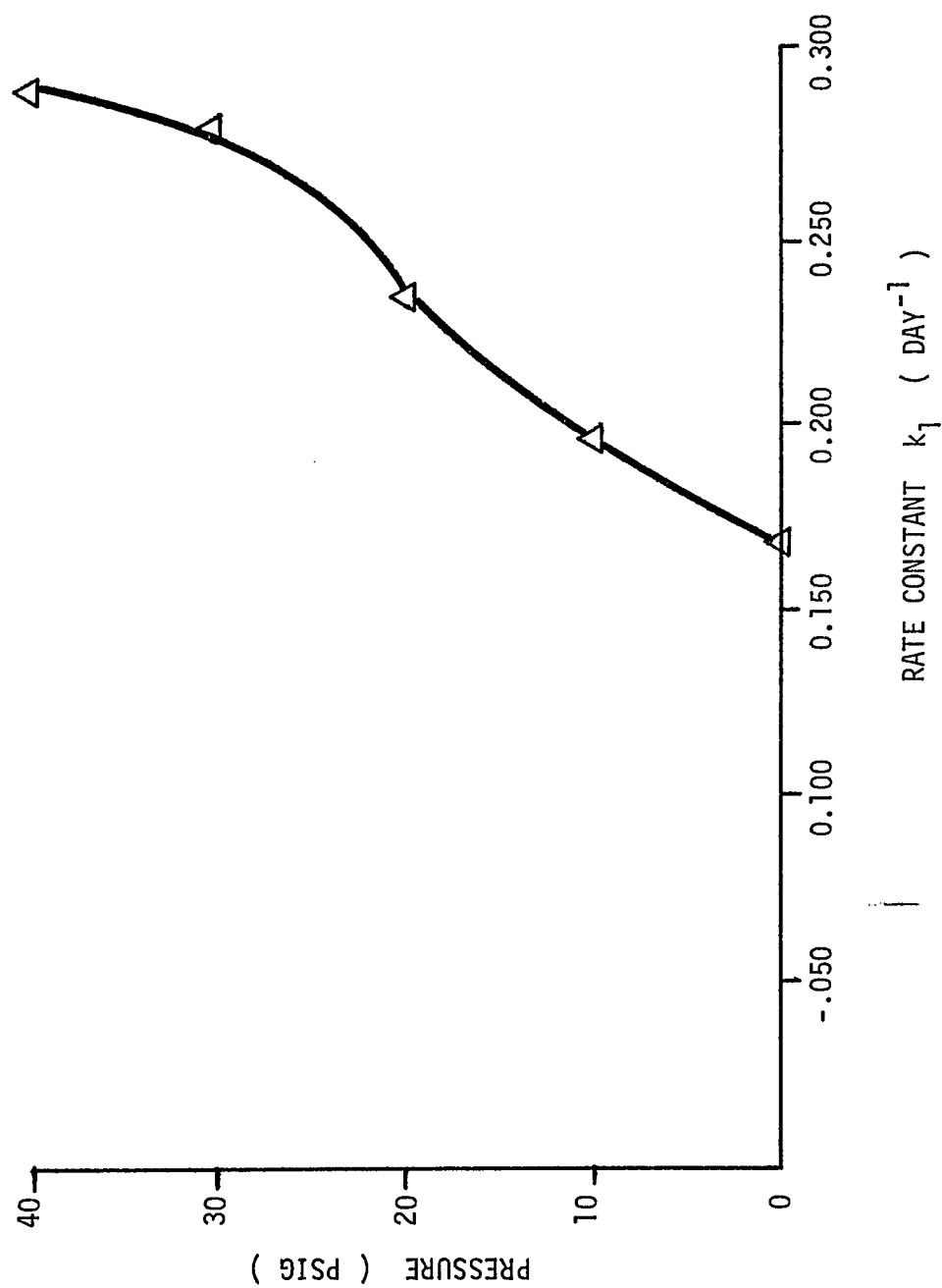
REACTION RATE CONSTANT AS A FUNCTION OF PRESSURE AND MLSS

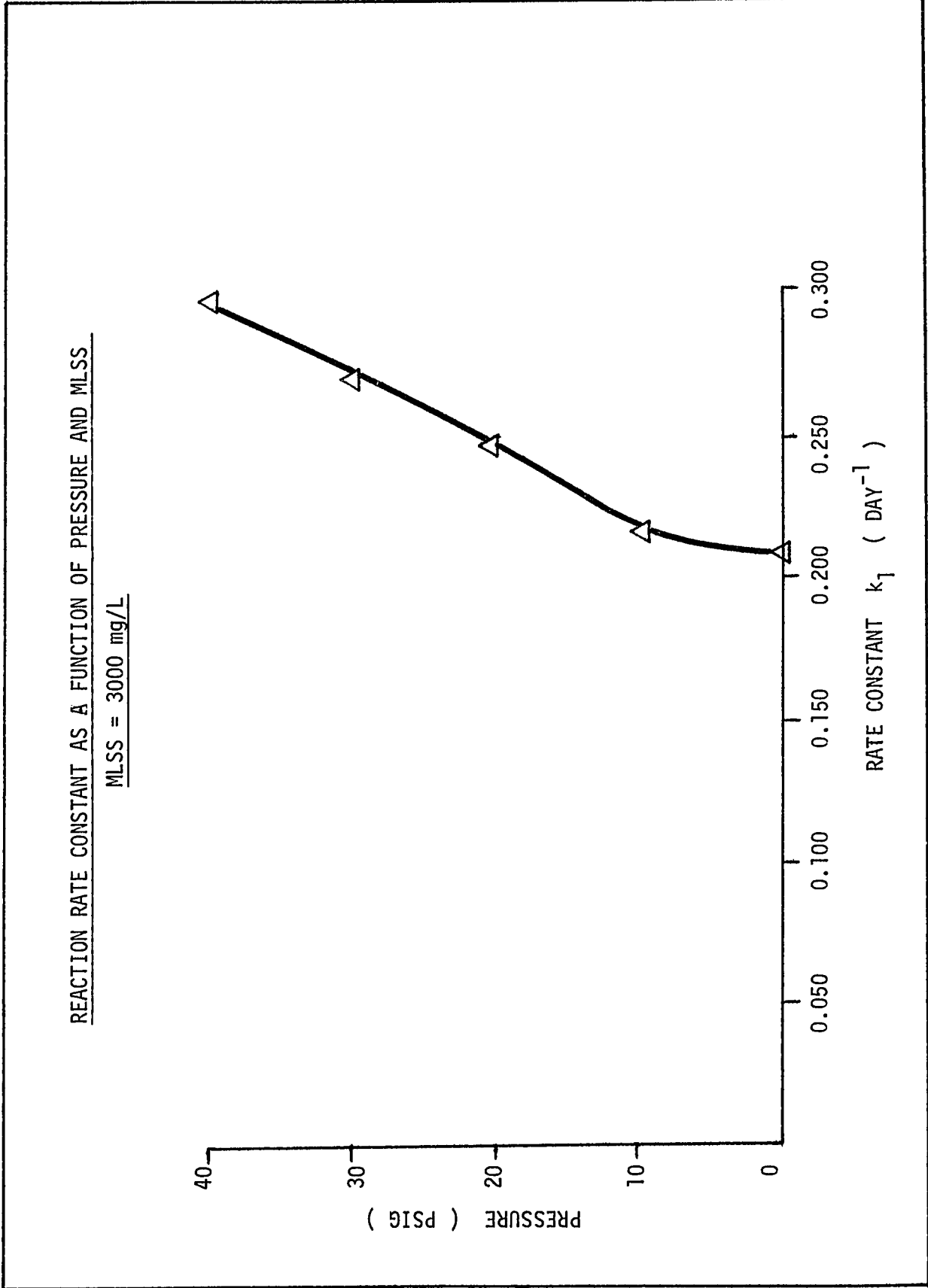
MLSS = 2000 mg/L



REACTION RATE CONSTANT AS A FUNCTION OF PRESSURE AND MLSS

MLSS = 2500 mg/L

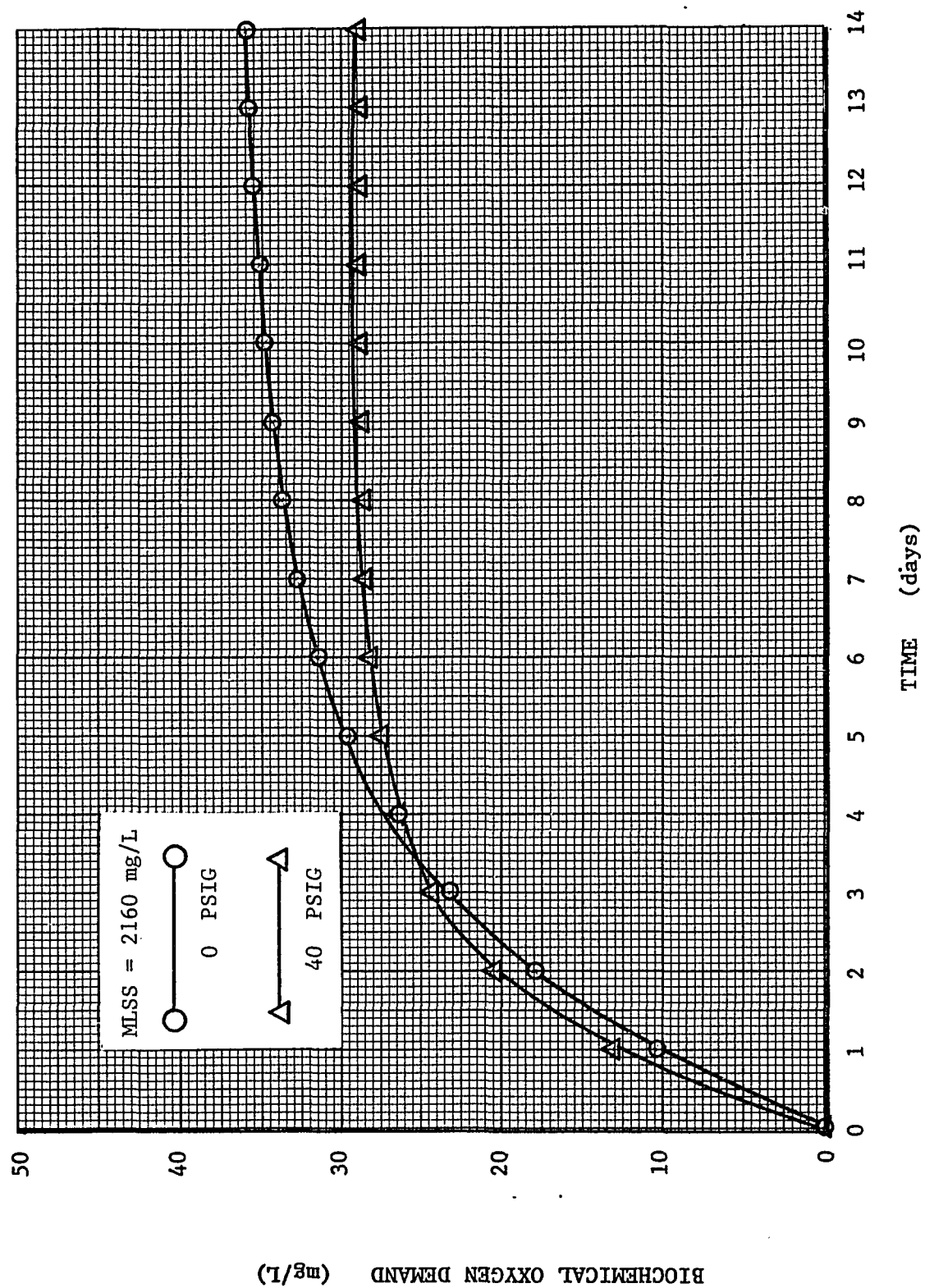




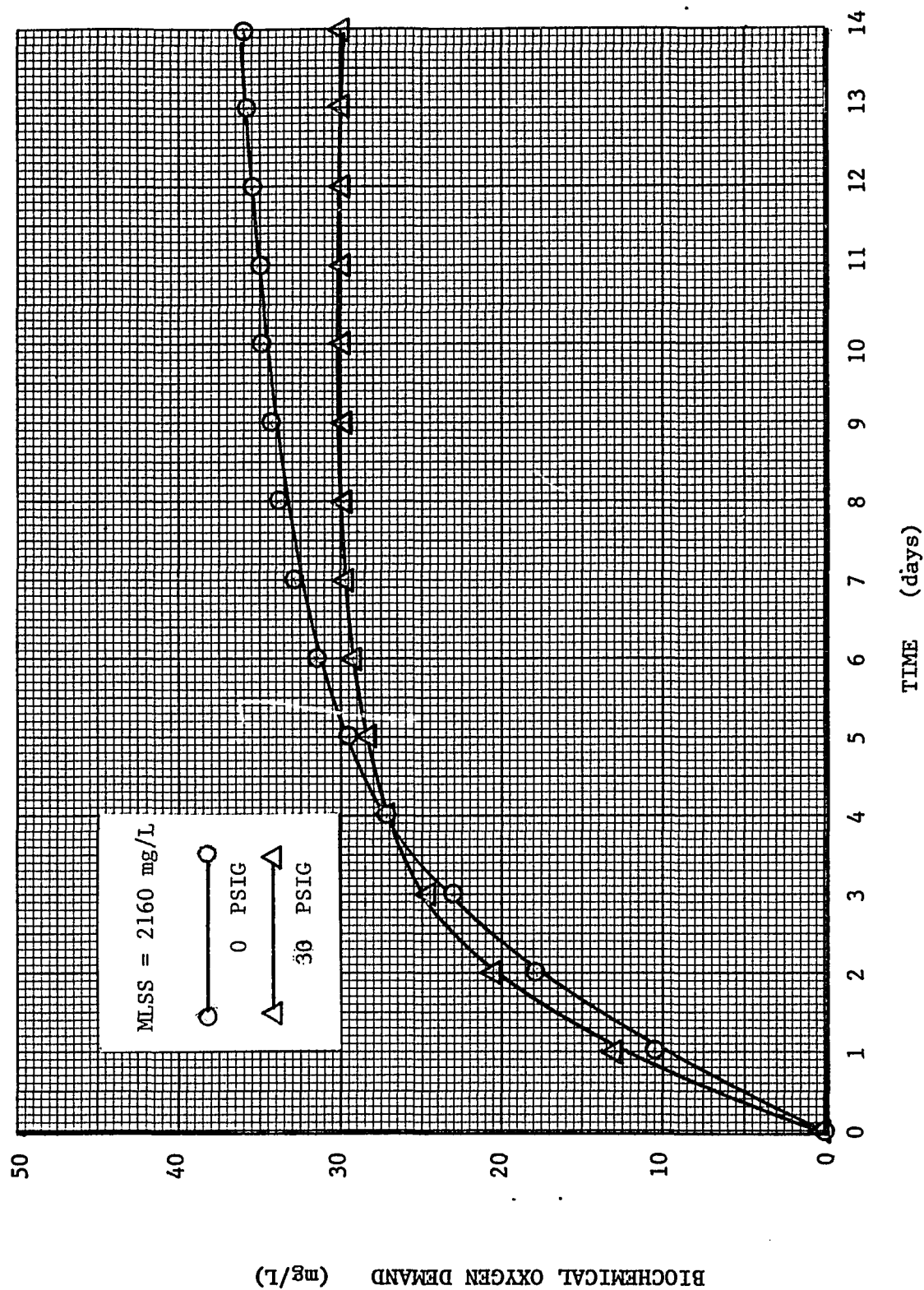
APPENDIX IV

THE FOLLOWING GRAPHS ILLUSTRATE THE DIFFERENCE IN  
EFFLUENT BOD FOR DOMESTIC WASTEWATER TREATED AT  
0 PSIG AND PRESSURES GREATER THAN 0 PSIG

## BIOCHEMICAL OXYGEN DEMAND

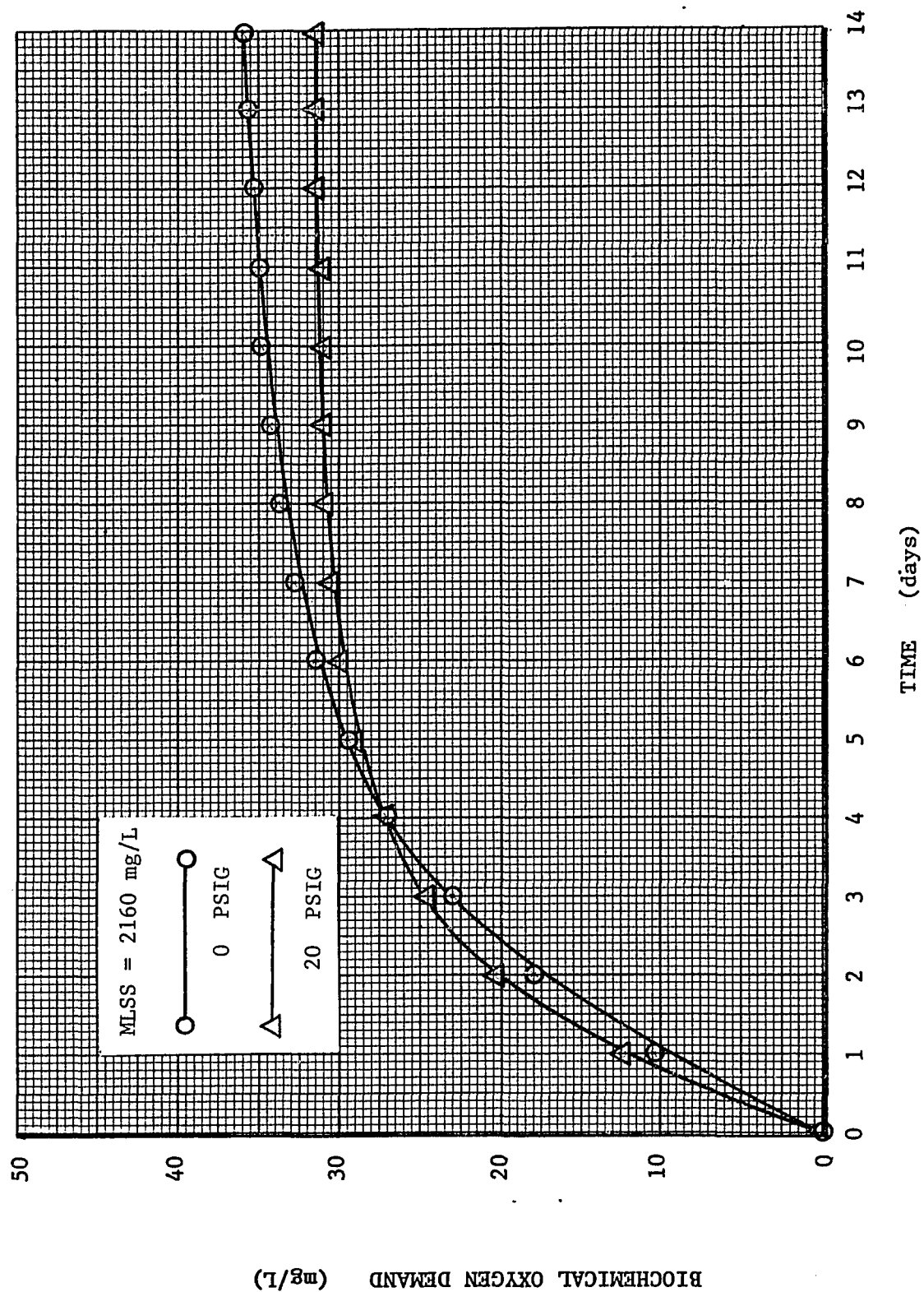


## BIOCHEMICAL OXYGEN DEMAND

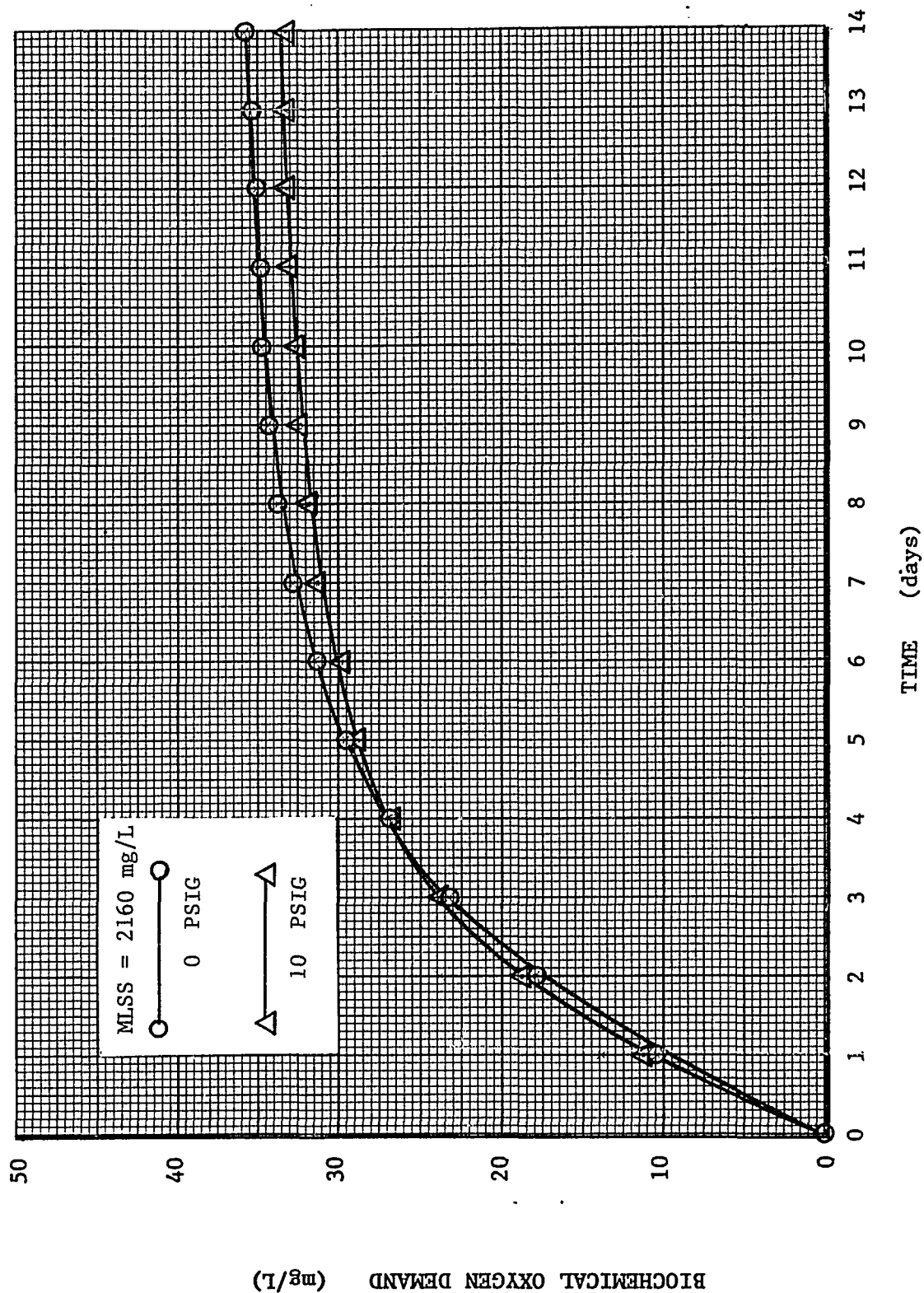




## BIOCHEMICAL OXYGEN DEMAND



BIOCHEMICAL OXYGEN DEMAND

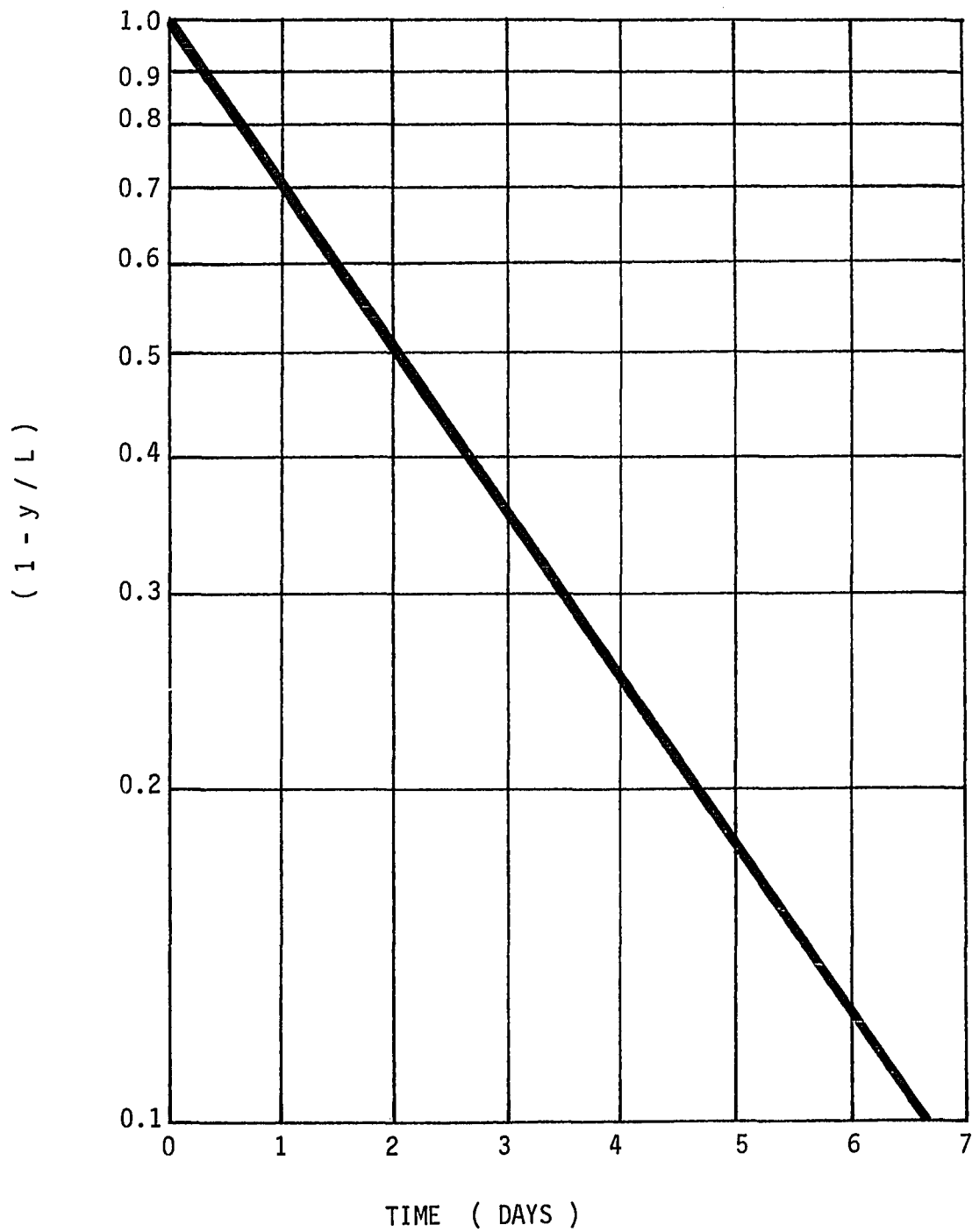


#### APPENDIX V

THE FOLLOWING GRAPHS ILLUSTRATE THE PLOTS USED  
TO DETERMINE THE "FIRST-ORDER" REACTION RATE CONSTANT,  $k_1$ ,  
FOR THE EFFLUENT DOMESTIC WASTEWATER

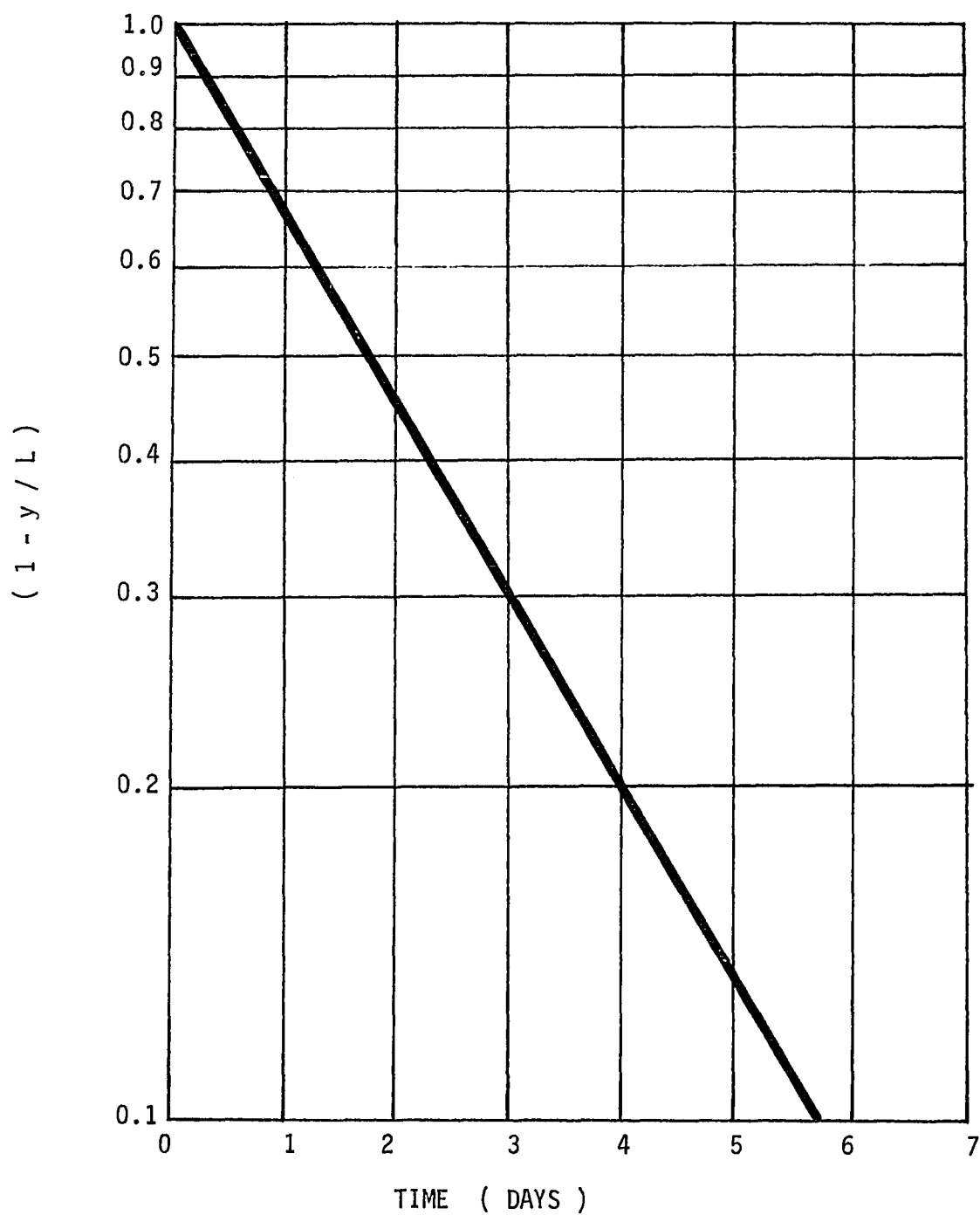
## FIRST ORDER REACTION RATE CONSTANT

PRESSURE = 0 psig  
MLSS = 2160 mg/L  
 $k_1$  = 0.150/day



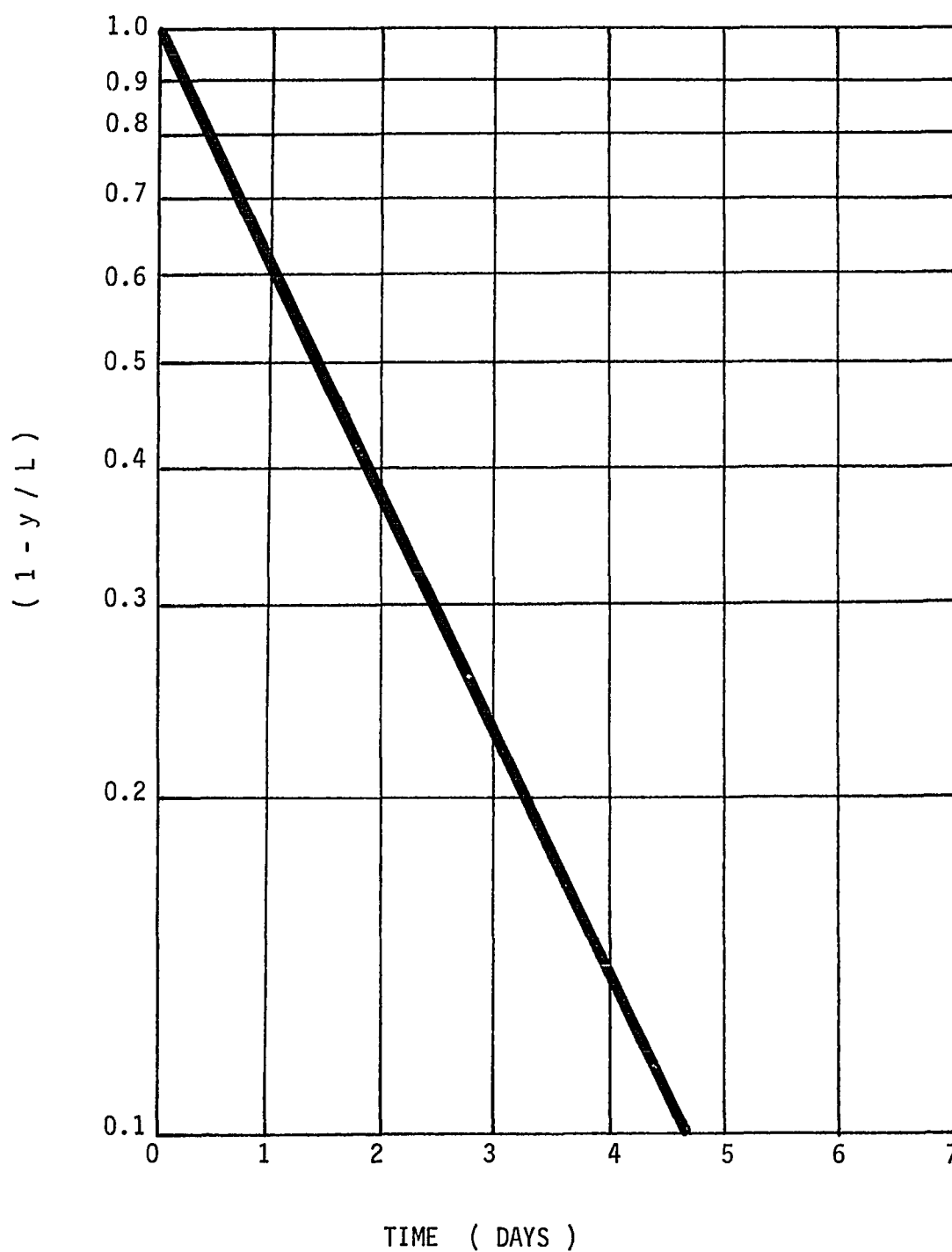
## FIRST ORDER REACTION RATE CONSTANT

PRESSURE = 10 psig  
MLSS = 2160 mg/L  
 $k_1$  = 0.180/day



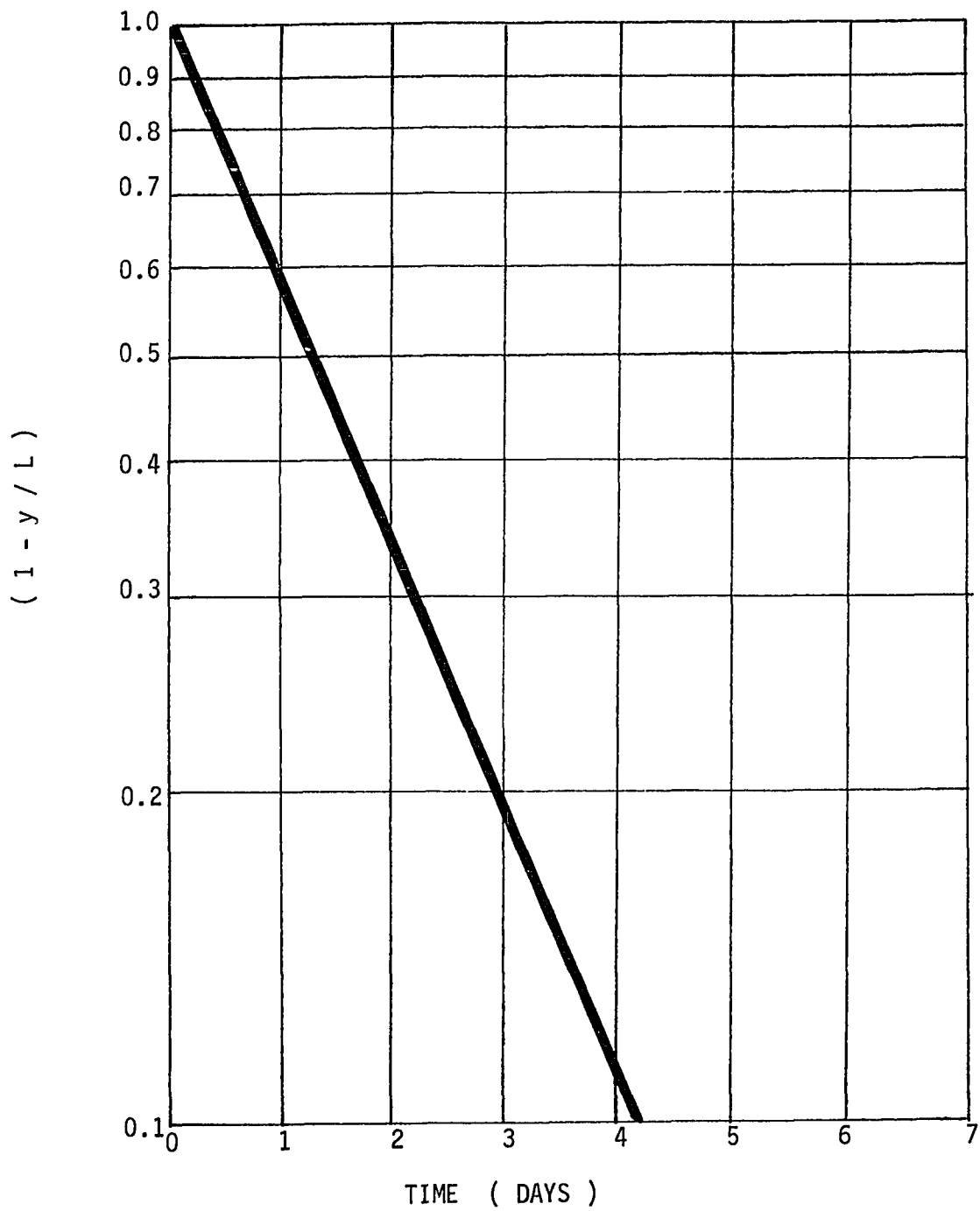
## FIRST ORDER REACTION RATE CONSTANT

PRESSURE = 20 psig  
MLSS = 2160 mg/L  
 $k_1$  = 0.220/day



## FIRST ORDER REACTION RATE CONSTANT

PRESSURE = 30 psig  
MLSS = 2160 mg/L  
 $k_1$  = 0.250/day



## FIRST ORDER REACTION RATE CONSTANT

PRESSURE = 40 psig  
MLSS = 2160 mg/L  
 $k_1$  = 0.270/day

