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COMBINED TREATMENT OF SEPTAGE WITH MUNICIPAL WASTEWATER BY COMPLETE MIXING ACTIVATED SLUDGE PROCESS

I. BATCH REACTORS

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PREFACE

This report is to present the results of a feasibility study on combined treatment of septage with municipal wastewater by complete-mixing activated sludge process. The experiments were performed by means of batch reactors. To confirm its applicability, and to determine the kinetic coefficients for design purposes, laboratory-scale continuous flow experiments will be conducted, the results of which will be published as the second installment of this report under the title "II. Continuous-Flow Reactors".

The laboratory work, reported herein, was done by Mr. Yu-liang Li, a graduate assistant in the Department of Civil Engineering at the University of Massachusetts.

The Division of Water Pollution Control, Massachusetts Water Resources Commission supported the work as a part of a research grant, Number 73-07(3). Mr. John R. Elwood, Supervising Sanitary Engineer of the Division, served as the Project Officer.

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Combined Treatment of Septage with

Municipal Wastewater By

Complete Mixing Activated Sludge Process

I. Batch Reactors

Summary and Conclusions

As a conclusion, although the experimental results which are based on batch reactors, indicate favorably the feasibility of treating septage combinedly with municipal wastewaters, laboratory-scale continuous-flow experiments, followed by pilot-plant studies must be conducted to confirm its applicability.

The findings are summarized as follows:

(1) The experimental results indicate that combined treatment of septage with municipal wastewater by activated sludge processes is feasible if the septage is discharged to the municipal wastewater treatment facilities in a steady manner, adequate mixing is provided in the aeration basin, and sufficient air is supplied to maintain aerobic conditions. It must be mentioned that the experiments were conducted in batch reactors which had a liquid volume of two liters.

(a) The removal of BOD_5 was above 95% after 24-hour aeration in batch reactors which were operated under steady-state conditions at sludge ages of four days and ten days, and at loading rate as high as 0.45 lb BOD_5/lb MLVSS-Day.

(b) The COD removal reached as high as above 90%. As the COD loading increased, the dissolved refractory organics increased and the percent removal of dissolved COD was decreased while the suspended and colloidal solids were effectively removed by enmeshment in the biological flocs, and thereby the over-all percent removal of COD was increased.

(c) The removal of ammonia nitrogen was as high as 90%, of which about 30% to 50% was converted to nitrate-nitrogen. The balance of the ammonia could be synthesized to cellular material or denitrified.

(d) The removal of PO_4-P in the treatment of municipal waste-waters by activated sludge processes has been reported in the range of 20 to 30%. Similar results were obtained in this study. However, as the PO_4-P concentration of the feed mixtures (influent to the reactors) increased, the percent removal reached as high as 90%. The removal at the sludge age of four days was significantly higher than the removal at the sludge age of ten days. Since more sludge was synthesized at higher BOD-loading (in this study, also at higher PO_4-P loading) and at shorter sludge age, it seems the removal of phosphate was essentially the result of phosphorus being tied up in cellular material.

(2) The SVI was between 20 and 80, which indicates that the mode of treatment employed in this study had produced sludges of good settling quality. The results also demonstrate that the higher the BOD loading, the longer the sludge age was needed to improve the sludge settleability.

(3) The steady MLSS concentration in the reactors varied from 160 mg/l to 9125 mg/l. The higher the BOD loading and the longer the sludge age, the higher the steady MLSS concentration was prevalent in the aeration reactors. When the MLSS reached 3000 mg/l or higher, anaerobic conditions developed. It was also found that the addition of septage in the feed-mixtures decreased the percentage of MLVSS in the MLSS.

(4) The sludge production rate was higher at the 4-day sludge age than the rate at the 10-day sludge age.

(5) The oxygen requirements were measured. When the feed-mixture BOD increased from 87 to 520 mg/l, the oxygen requirements were increased more than a four-fold.

(6) The dark-gray and odorous septage after being aerated with activated sludge for 24 hours, became light-yellow in color and free of the obnoxious odor.

Laboratory-scale continuous flow experiments will be performed as another phase of this study to not only demonstrate its applicability, but also to determine the kinetic coefficients which are needed for the design of activated sludge process facilities for the combined treatment of septage with municipal wastewater. The results will be reported as the second installment of this report under the title "II. Continuous-flow Reactors".

I. Introduction and Objectives

Septage is the pumpings removed from septic tanks, which is a mixture of the accumulated sludge in a septic tank, mixed with the supernatant liquor present in the tank during pumping. A brief description of septic-tank systems and the results of a survey on the characteristics of septages will be presented elsewhere in this report.

Septage is commonly disposed of by dumping on land, in streams, into convenient manholes leading to or to the inlet structure of a wastewater treatment plant. These disposal methods are expected to either generate adverse effects on the natural environment or reduce the performance efficiency of a treatment plant. Study programs are being conducted in the Department of Civil Engineering at the University of Massachusetts/Amherst: Phase (a) to survey the effects on the performance of wastewater treatment plants of the current practice of intermittently discharging septage into manholes or inlet structures of treatment works, Phase (b) to evaluate methods of treating septage so that the resulted liquid and solids would no longer cause unwanted environmental impact, and Phase (c) to devise facilities which can be incorporated with a municipal wastewater treatment plant to provide adequate treatment of septage in combination with the municipal wastewater.

The objectives of this study are related to Phase (c) of the study programs mentioned above. Specifically this study is designed to investigate the treatability of a equalized flow of septage in combination with municipal wastewater by complete-mixing activated sludge process.

II. Septage

Septic tank systems are used to provide waste treatment prior to the disposal of many individual sources of wastewater such as homes in rural and suburban areas, schools, motels, camps and trailer parks. A septic tank is horizontal, continuous-flow, one-story-tank to slow down the movement of sewage and allow the settlement of suspended solids while the effluent is usually disposed of to a subsurface leaching system. The settled solids are retained in the tank for a period of one to five years or longer, undergoing anaerobic decomposition. During the decomposition the solids are partially liquefied and gasified, thus reducing the volume of sludge to be finally disposed of. The sludge of a septic tank could be 25 to 40 percent less in weight, and 75 to 80 percent less in volume than the originally settled sludge. In many cases, however, septic tank systems do not function satisfactorily becuase of (a) inadequate retention time, (b) lack of proper maintenance, and (c) malfunction of leaching field. The liquid portion of septic tank contents is normally odorous and exerts a high immediate BOD. Besides, gas-lifted solids form a layer of scum at the surface which is often only partially decomposed. The pumpings from septic tanks (referred to hereafter as septages) should not be disposed of by dumping on open land without pretreatment because the "raw" septage could be a potential pollutant to both surface and ground waters, as well as create a nuisance for the surrounding areas.

Unlike municipal wastewater treatment plants where wastes from a variety of urban sectors are collected and treated combinedly, septic tank systems are designed for individual sources. As a result, the characteristics of septages are not as uniform as those of sludges of municipal wastewater treatment plants. In fact, their characteristics depend on such factors as: waste characteristics of individual sources; frequency of tank emptying; and design of tanks. Even family habits and size could have significanct effects on the characteristics of septages. There is only limited information available on the general nature of septages.

Kolega (1), associated with the University of Connecticut, conducted a comprehensive investigation in the summer of 1969 on the characteristics of septages in Hartford, Connecticut area. 180 samples were analyzed and the results (mean values) are as follows:

Septage:

BOD_5 = 4794 mg/l

COD = 26162 mg/l

Total solids = 22400 mg/l

Suspended Solids = 2350 mg/l

Volatile Suspended Solids = 531 mg/l

Org-N = 26 mg/l

NH_3-N = 72 mg/l

Septic Tank Supernatant:

BOD_5 = 1948 mg/l

COD = 6343 mg/l

III. Activated-Sludge Process Models Related to This Study

In the activated sludge processes, the removal of waste solids is accomplished through two steps: (a) conversion of soluble and biodegradable organic matter (substrate) to energy and bacterial cells and (b) coagulation and removal of colloidal and other non-settleable solids including bacterial cells. Therefore the treatment units must be designed to provide proper environmental conditions for bacterial growth, biological coagulation and final separation of solids from the liquid (treatment effluent). This study essentially deals with evaluation of the parameters involved in the design of such treatment units of activated sludge processes.

The following empirically developed relationship between biological growth and substrate utilization (2,3,5) is used as the basic model for this study:

$$\frac{dX}{dt} = Y\frac{dF}{dt} - k_d X \qquad (1)$$

The rate of substrate utilization of the above expression, that is dF/dt, can be approximated by the following equation (4,5).

$$\frac{dF}{dt} = \frac{kXS}{K_s + S} = \frac{dS}{dt} \qquad (2)$$

where $\frac{dX}{dt}$ = net growth rate of bacterial cells, mass/volume-time

Y = growth-yield coefficient, mass of cells/mass of substrate utilized.

$\frac{dF}{dt}$ = rate of substrate utilization by bacterial cells, mass/volume-time

k_d = bacterial decay coefficient, $time^{-1}$

X = concentration of bacterial cells, mass/volume

k = maximum rate of waste utilization per unit weight of bacterial cells, $time^{-1}$

K_s = waste concentrate at which rate of waste utilization is one-half the maximum rate, mass/volume

S = waste concentration surrounding the bacterial cells, mass/volume, which is the waste concentration in a complete-mixing continuous flow reactor.

Dividing both sides of Equation (1) by X, gives

$$\frac{dX/dt}{X} = Y \frac{dF/dt}{X} - k_d \tag{3}$$

On a finite mass and time basis, Equation (3) becomes

$$\frac{(\Delta X/dt)_M}{X_M} = Y \frac{(\Delta F/\Delta t)_M}{X_M} - k_d \tag{4}$$

where the subscript M represents a definite mass of bacterial cells. In Equation(4), the reciprocal of the term $(\Delta X/\Delta t)_M/X_M$ is often referred to as the "sludge age", and will be designated as θ_c.

$$\theta_c = \frac{X_M}{(\Delta X/\Delta t)_M} \tag{5}$$

The term $(\Delta F/\Delta t)_M/X_M$ is commonly known as the food-to-microorganism (F/M) ratio, and will be referred to as U,

$$U = \frac{(\Delta F/\Delta t)_M}{X_M} \tag{6}$$

Utilizing Equations (5) and (6), Equation(4) can be rewritten as

$$\frac{1}{\theta_c} = YU - k_d \tag{7}$$

and Equation (2) can be transformed to finite terms and rewritten as

$$U = \frac{kS}{K_s + S} \tag{8}$$

For this study, two types of reactors, batch reactors and complete-mixing continuous flow reactors, were used. By the principles of mass balance, it can be demonstrated mathematically that Equations (7) and (8) are satisfactory for modelling both batch reactors and complete-mixing continuous flow reactors under steady-state conditions.

Solving Equations (7) and (8) for S, gives

$$S = \frac{K_s(1 + k_d\,\theta_c)}{\theta_c(Yk-k_d)-1} \qquad (9)$$

and

$$S = \frac{U\,K_s}{k-U} \qquad (10)$$

Equations (9) and (10) give the relationship of S, the effluent substrate concentration to θ_c and U in an activated sludge process conducted in batch reactors or complete-mixing continuous flow reactors under steady-state conditions, the kinetic coefficients of which are Y, k_d, k and K_s. These kinetic coefficients can be determined by means of laboratory-scale batch reactors or complete-mixing continuous-flow reactors. The procedures are: (a) control sludge wasting and S_0, and measure S and X after a pre-set aeration time, from which θ_c and U can be calculated, (b) by utilizing Equation(8) plot U^{-1} versus S^{-1}, and determine k and K_s, and (c) by utilizing Equation (7) plot θ_c^{-1} versus U, and determine Y and k_d.

The efficiency of waste treatment by means of the types of reactors, mentioned above, can be defined as

$$E = 100 \frac{S_o - S}{S_o} \tag{11}$$

where E = efficiency of waste treatment, percent

S_o = substrate concentration of waste to be treated (influent to a reactor), mass/volume

S = substrate concentration of waste after treatment (effluent from a reactor), mass/volume.

The rate of substrate utilization, dF/dt, in the reactors can be expressed on a finite-time basis as follows:

$$\frac{\Delta F}{\Delta t} = \frac{Q}{V} (S_o - S) \tag{12}$$

where Q = flow rate, volume/time

V = volume of reactor, volume

By utilizing Equations (6) and (12), and setting $V/Q = \theta$, referred to as liquid retention time, the following equation can be obtained:

$$U = \frac{(S_o - S)}{\theta X} \tag{13}$$

Substituting U expressed by Equation(13) in Equation(7), and solving for X, gives

$$X = \frac{\theta_c}{\theta} \frac{Y(S_o - S)}{1 + k_d \theta_c} \tag{14}$$

which can be used to calculate the concentration of bacterial cells in the reactor.

The design of a complete-mixing activated sludge process to achieve a required treatment efficiency of a given waste can be proceeded as follows:

(a) By means of laboratory experiments the kinetic coefficients are determined.

(b) By Equation (11), the effluent substrate concentration is calculated to comply with the required efficiency.

(c) By Equation(9), the design sludge age (θ_c) is calculated.

(d) By Equation(14), the liquid retention time (θ) is calculated for a selected value of X, concentration of bacterial cells in the reactor. The selection of X is based upon the oxygen requirements and the method of aeration to be used.

(e) The reactor volume is then calculated on the basis of the calculated θ and the influent flow rate.

IV. General Procedures of Experimentation

As stated previously, the purpose of this phase of the septage-handling study is to evaluate the treatability of septage in combination with municipal wastewater by activated sludge process. As a preliminary step, batch-method was used for the evaluation. Each batch reactor was a 4-liter jar which contained a volume of 2 liters of activated-sludge mixed liquor. The initial activated-sludge mixed liquor was provided by the UM-Pilot Plant of wastewater treatment, which had a mixed-liquor suspended solids (MLSS) concentration varying from 1500 to 2500 mg/l. The experimental procedure can be described briefly as follows:

(a) Batch reactors are used to evaluate the treatability of mixtures of septage and municipal wastewater.

(b) The contents of a reactor are aerated with compressed air through a diffuser so that sufficient oxygen and adequate mixing are provided.

(c) A mixture of septage and municipal wastewater is prepared as follows: a septage sample is mixed with municipal wastewater in a ratio so that a predetermined BOD level of the mixture can be obtained. The mixture is allowed to settle for 30 minutes. The decanted supernatant (referred to as feed mixture) is used to feed the batch activated sludge reactors.

(d) The reactors are fed every 24 hours by the following steps:

Step 1. Sludge is wasted directly from the reactor by drawing off a pre-determined volume of mixed liquor before stopping the aeration. The amount wasted depends on the desired sludge age (θ_c). For example, since the reactor volume is 2 liters and if the desired θ_c is ten days, 200 ml of the mixed liquor is drawn off per 24 hours.

Step 2. Stop aeration and let the mixed liquor settle for 30 minutes then decant the supernatant (effluent of the treatment).

Step 3. Fill the reactor to 2 liter mark with a feed-mixture.

e. Maintain the operation until a steady-state condition is reached. This is obtained when the MLSS concentration and BOD_5 or COD of the effluent become steady. It would take one to two weeks to reach a steady-state condition.

f. After a steady state condition is reached, the feeding continues for three more days. The mixed liquor suspended solids (MLSS) concentrations, BOD_5, COD and other characteristics of the feed-mixtures and effluent are analyzed for the last three runs (under steady-state condition), which are the data gathered for the evaluation of the process.

V. Experimental Results and Discussion

The experimental results and discussion are presented in two parts: (A) "Try-Out" Study, and (B) Treatability Study by Batch Method.

Part A. "Try-Out" Study

The "try-out" study as presented here-in-below, was to find the effects of sludge age on mixed liquor suspended solids (MLSS) concentration and settleability, and levels of BOD and COD removals in the treatment of a series of mixtures of septage and municipal wastewater by batch reactors of activated sludge process.

The general procedures of experimentation, described in Section IV were followed. A sample of household septage was collected in Amherst, Massachusetts area. The municipal wastewater was a sample of raw sewage collected at the Amherst, Massachusetts Wastewater Treatment Plant. A set of five batch reactors was used for each mixture of the septage and the Amherst raw sewage. Four mixtures, the septage-portions of which were 0% (sewage only), 3%, 6% and 9% respectively, were studied. The 2-liter reactors were fed daily for about two weeks when a steady-state condition was reached. After a steady-state condition was reached, the feeding continued for three more days. The mixed liquor suspended solids (MLSS) concentrations, BOD_5 and COD of the feed-mixtures and effluents were analyzed for the last three runs (under steady-state conditions). The data were averaged and presented in Table I.

The results show that a source of household septage can be treated in combination of a source of municipal wastewater similar to the sewage

Table . Results of Batch Treatment of Septage-Sewage Mixtures by Activated Sludge Process*

Sample	Sludge Age Days	MLSS mg/l	Feed-Mixture mg/l		Filtered Effluent** mg/l	
			BOD_5	COD	BOD_5	COD
Municipal	20	2184	120	240	<2	38.6
Wastewater	10	1410			<2	32.7
	6.67	1092			<2	39.2
	4	628			<2	21.5
	2	329			<2	44.6
3% Septage	20	2180	260	652	<2	59.5
Added	10	1868			<2	53.3
	6.67	1763			<2	53.3
	4	1476			2.3	63.5
	2	643			2.6	75.9
6% Septage	20	4468	528	1100	<2	49.5
Added	6.67	2402			2.1	64.7
	4	1509			2.6	76.1
	2	1540			9.2	125.5
	1.33	1188			14.4	148.4
9% Septage	20	3248	735	1891	2.5	79.9
Added	6.67	2494			2.6	72.3
	4	1358			2.3	97.0
	2	661			12.8	188.3
	1.33	524			19.2	209.2

*Liquid retention time (θ) = 24 hrs.

**All the samples of supernatant after 30-minute settling (effluent of the treatment) were filtered through Gelman Glass Fiber Filter Type A before the analysis of BOD and COD.

of Amherst, Massachusetts, with high degree of BOD and COD removal after 24-hour aeration in batch reactors of activated sludge process. The BOD_5 of the feed-mixture was as high as 735 mg/l, and the BOD_5 of the corresponding filtered effluents varied from 2.5 to 19.2 mg/l, depending upon the sludge age. It should be noted that such efficiency of treatment was obtained under the following operational and environmental conditions:

(a) well-mixed and aerated batches of acclimated activated sludge were used.

(b) reactors were fed once every 24 hours.

(c) temperature was in the range of 20-24^{o}C.

(d) pH was in the range of 6.8-7.5.

Also it must be mentioned that the mixed liquor suspended solids (MLSS) were dispersed and did not settle when the controlling sludge age was less than 6.67 days. The MLSS settled the best when the sludge age was 6.67 days for 6% and 9% mixtures, and 10 days for 0% and 3% mixtures.

Part B. Treatability Study by Batch Method

(1) Sample Preparation and Procedural Specifics

For this part of the study, the municipal wastewater used was a sample of raw sewage collected at the Amherst, Massachusetts Wastewater Treatment Plant. Two samples of septage were collected for use: a one-year-old household septage from Pelham, Massachusetts (referred to as Septage Sample A) and a six-year-old household septage from Pelham, Massachusetts (referred to as Septage Sample B)

The feed mixtures (influents to the reactors) were prepared according to the general procedures described in Section IV. The feed-mixtures were analyzed, and the analytical results are presented in Table II.

Unfortunately the analysis of the septage samples, as they were sampled, was neglected. However by utilizing the data shown in Table II, the following estimation, based upon the percent of septage in the feed mixtures may reflect the characteristics of the supernatant of the septage samples after 30 minute settling.

Septage Sample	Characteristics, mg/l				
	BOD_5	COD	NH_3-N	NO_3-N	Ortho-P
A	1250	4900	200	4	42
B	11000	24000	300	11	60

Table II. Analytical Results of Feed-Mixtures

Characteristics mg/l	Feed Mixture - Septage Sample A					Feed Mixture - Septage Sample B				
	% of Septage					% of Septage				
	0	7	20	30	40	0	5	10	15	20
BOD_5	87	175	330	430	520	51	720	1470	1830	2250
COD	217	560	1130	1680	1974	104	2272	3306	4564	4960
NH_3-N	33.8	45.0	60.0	80.0	82.5	23.8	32.5	42.5	55.0	60.0
NO_3-N	2.8	1.8	1.4	1.5	1.6	2.0	2.2	2.2	2.1	2.1
Ortho-P	4.0	6.0	11.0	17.0	21	2.4	4.5	6.3	8.0	12.0

From the above estimation it can be seen that septages vary widely in their characteristics.

The general experimental procedures, as described in Section IV were followed. For each septage sample, two sets of 5 batch reactors were used: one set for $\theta_c = 4$ and the other for $\theta_c = 10$. The feed-mixtures prepared for the study were analyzed and the results were shown in Table II. The reactors were fed once every 24 hours. After a steady-state condition was reached, the feeding continued for three more days. For the last three runs under steady state condition, the mixed liquor suspended solids concentrations, BOD_5 (both filtered through Glass Fiber Filter* and unfiltered), COD (both filtered through Glass Fiber Filter* and unfiltered), NH_3-N, NO_3-N, orthophosphate-P of the feed mixtures and effluents were analyzed. Sludge volume indexes (SVI) were measured. Microscopic examinations of the mixed liquor were made. Color and odor of effluent were examined. Oxygen requirements were calculated by (1) measuring the oxygen uptake rates after pre-set times of aeration and (2) on the basis of the measurements estimating the amount of oxygen required by a reactor in the total period of aeration.

(2) Analysis of Experimental Data and Discussion

(a) BOD_5. All the influent and effluent samples were analyzed for BOD_5 before and after being filtered through Glass Fiber Filter*. All the filtered effluents in the treatment experiments of both septage samples had BOD_5 less than 2 mg/l.

*Gelman Type A

Because of the carry-over of suspended solids in the effluent after 30-minute settling, the unfiltered effluent samples had higher BOD_5 as shown in Figures 1 and 2. The results for Septage Sample A are shown in Figure 1, and for Septage Sample B in Figure 2. As shown the removal was slightly higher with θ_c equal 10 days than with θ_c equal to 4 days. The BOD_5 removal for Septage Sample A was better with the increase of influent BOD concentration in terms of both percentage and effluent concentration. In case of Septage Sample B, at influent concentrations exceeding 1500 mg/l anaerobic conditions developed due to insufficient supply of oxygen. The removal decreased and the effluent BOD_5 concentration reached as high as 150 mg/l. However, it may be surmised that the biodegradable organics in domestic septage can be readily oxidized in an activated sludge process.

In laboratory-scale batch process high BOD removals can be accomplished, using 24-hour extended aeration, at influent concentration as high as 1500 mg/l. If aerobic conditions could have been maintained, high BOD removal could still be obtainable at even higher influent concentrations.

(b) COD. The experimental data on COD removal are presented in the following figures:

Figure 3. For Septage Sample A, both Influent and Effluent Filtered

Figure 4. For Septage Sample A, both Influent and Effluent Unfiltered

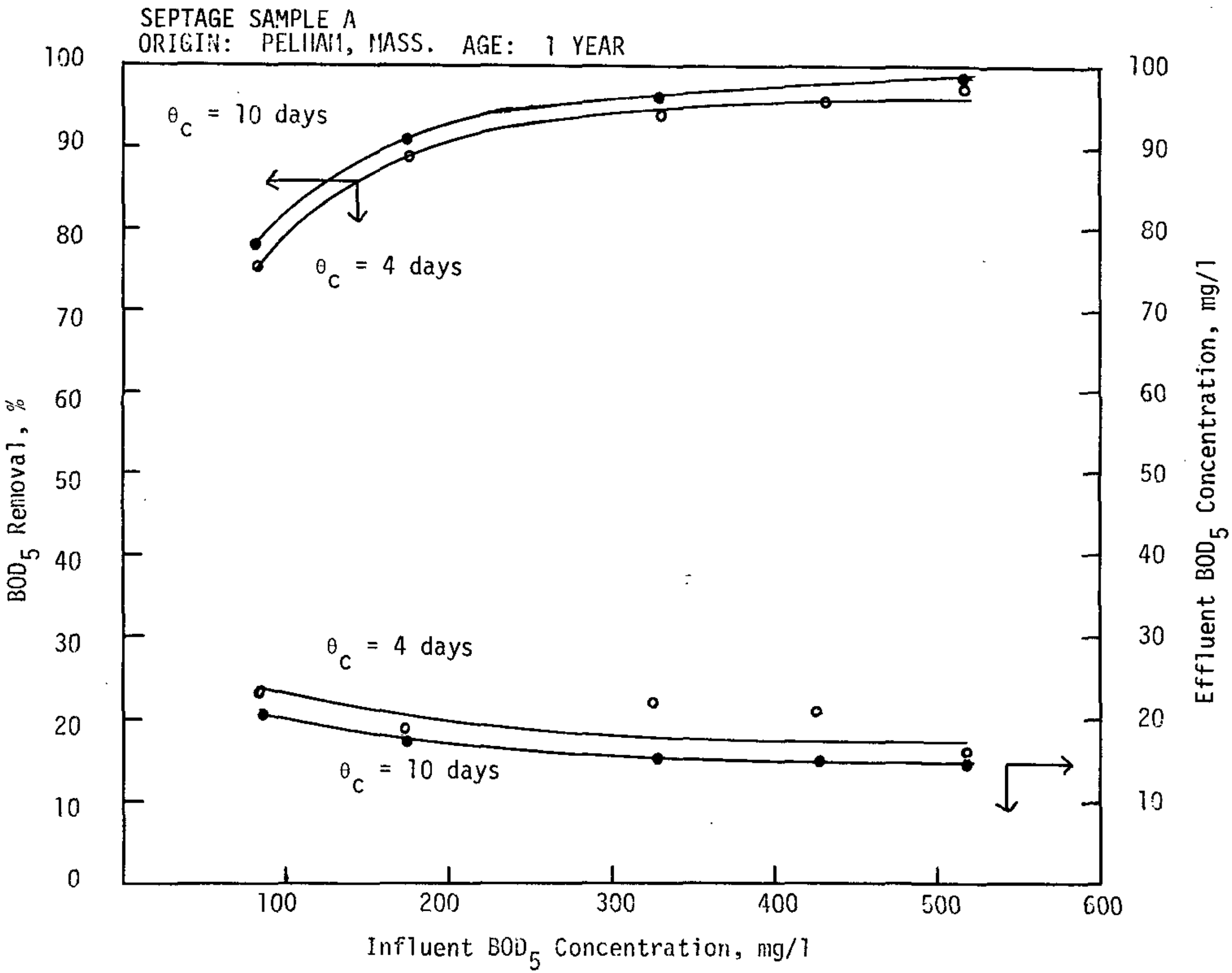

Figure 1. Removal of BOD_5 (both influent and effluent not filtered).

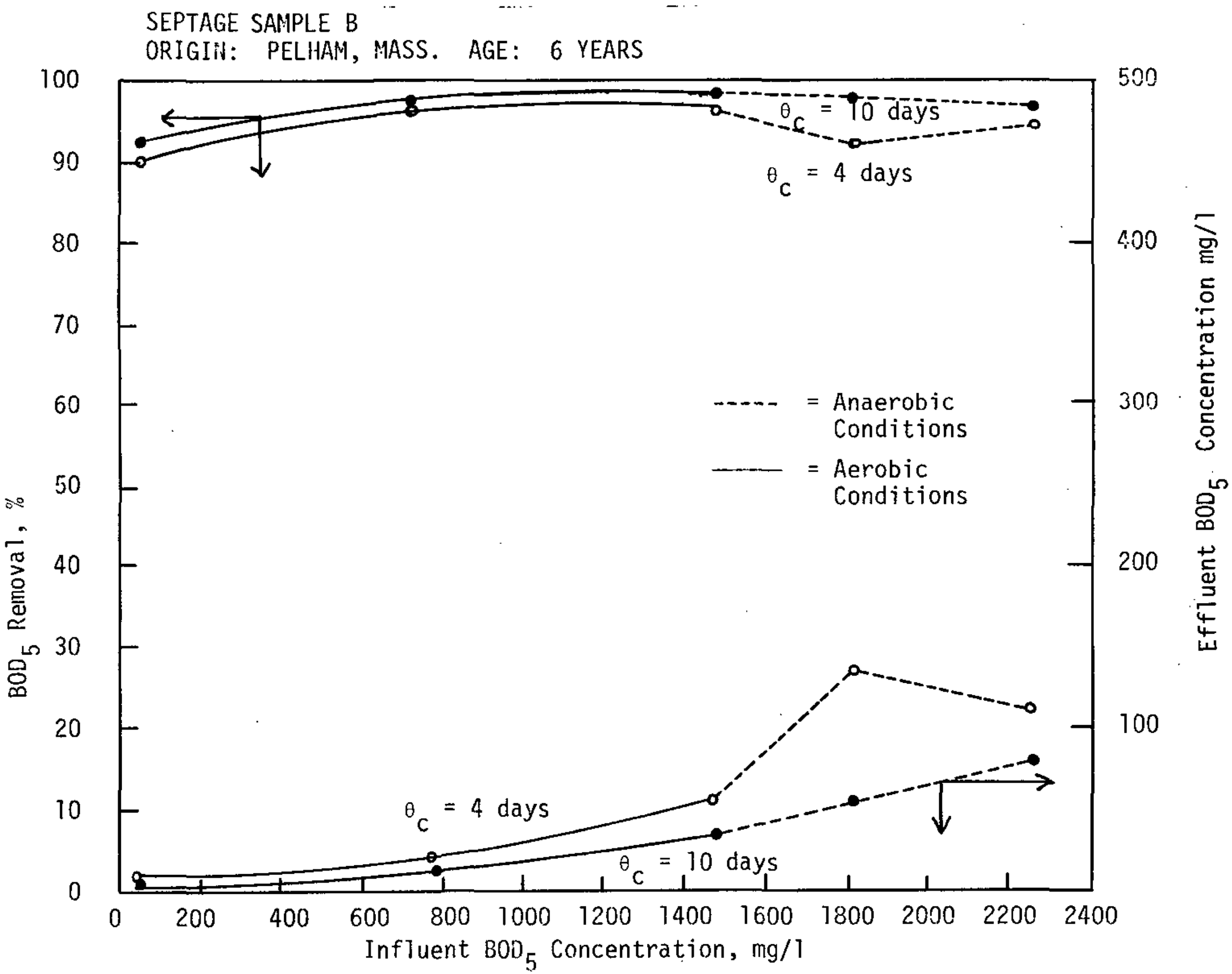

Figure 2. Removal of BOD_5 (both influent and effluent not filtered).

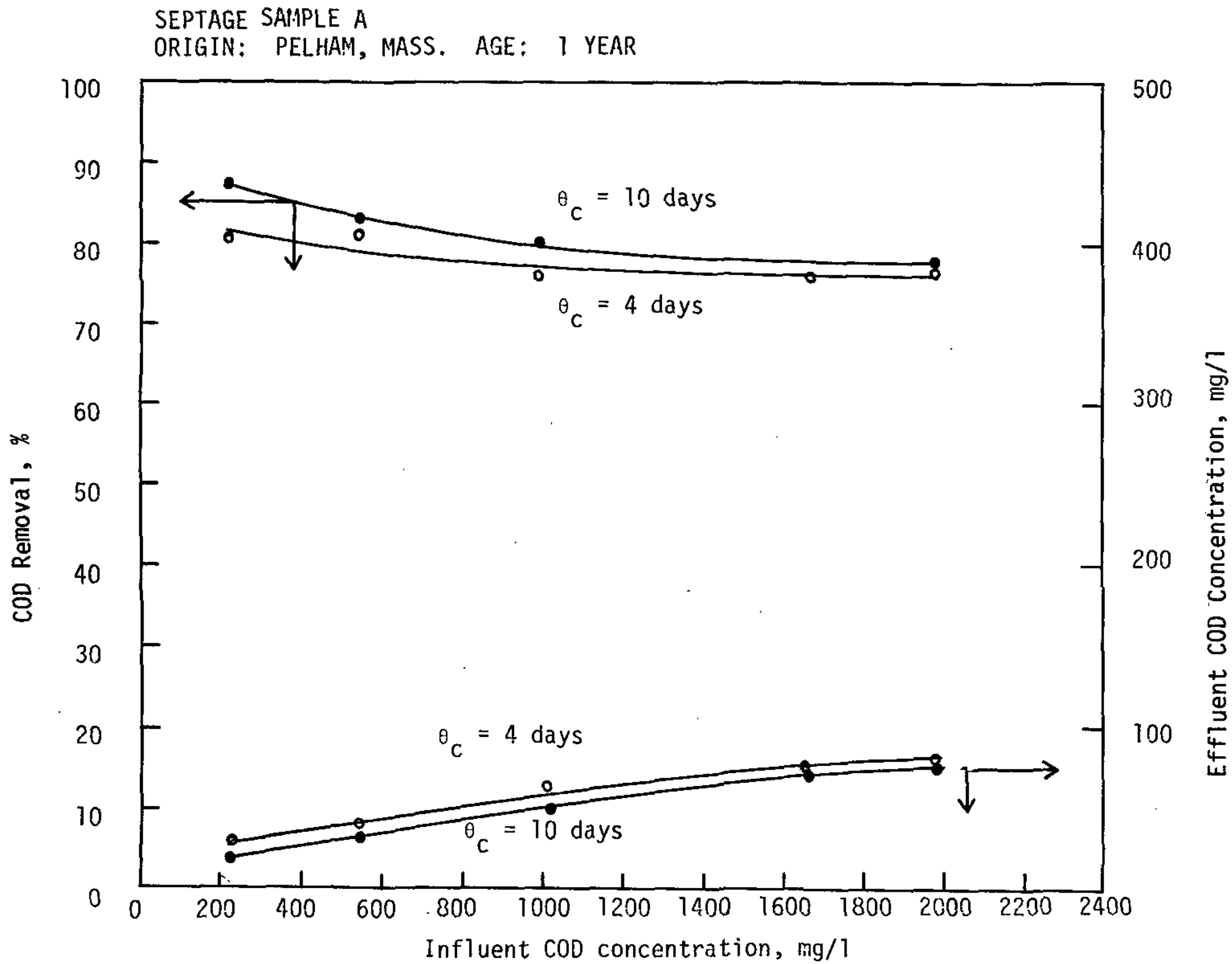

Figure 3. Removal of COD (both influent and effluent filtered).

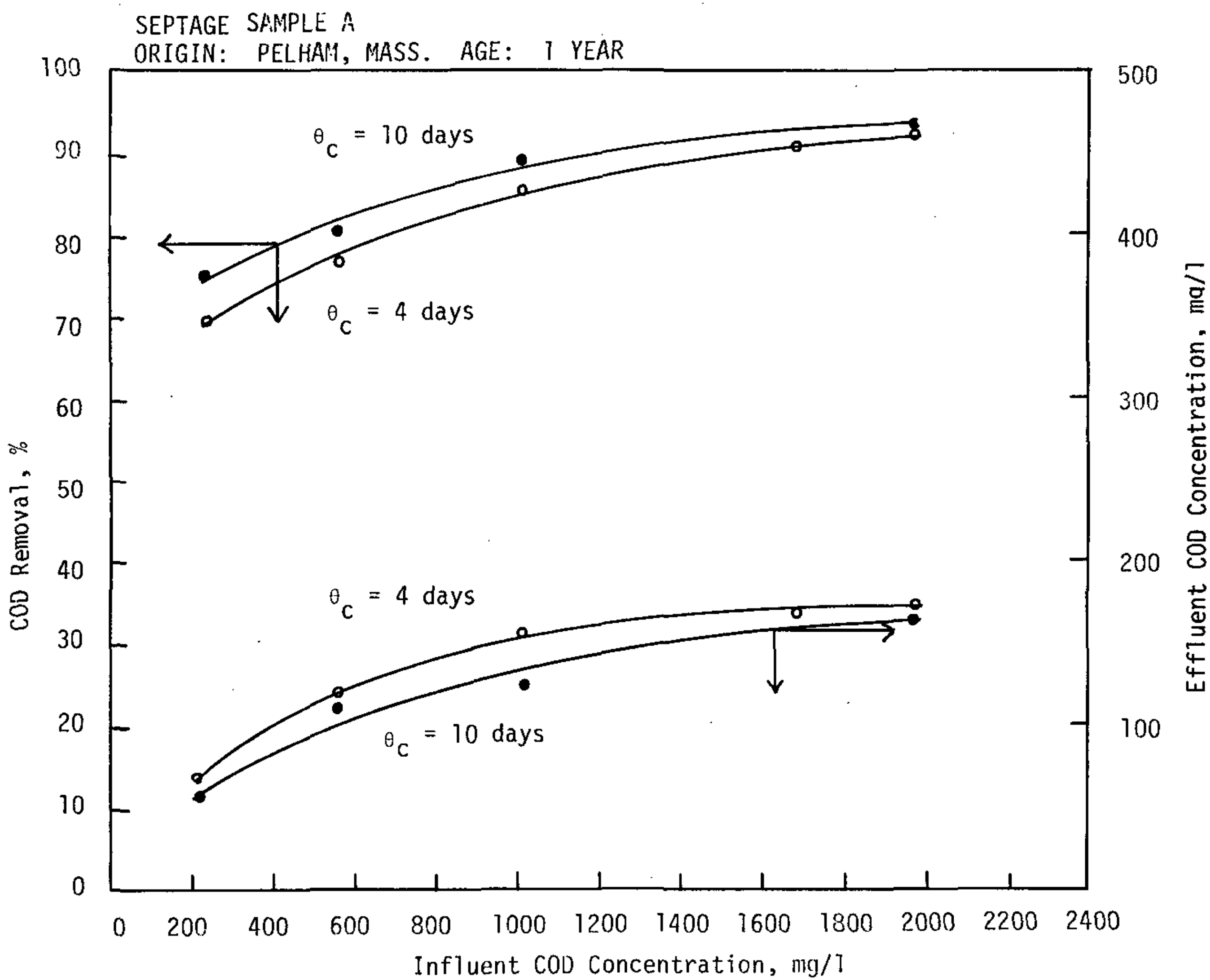

Figure 4. Removal of COD (both Influent and Effluent not Filtered).

Figure 5. For Septage Sample B, both Influent and Effluent Filtered.

Figure 6. For Septage Sample B, both Influent and Effluent Unfiltered.

It is shown in Figures 3 and 4 that the COD in filtrate of Septage Sample A was removed at a lower percentage as the influent COD concentration increased, but the suspended portion (not passing the filter) of COD was removed at a higher percentage as the influent COD concentration increased. The results may reflect the effective enmeshment of COD-causing suspended and colloidal matter in the activated sludge.

In the case of Septage Sample B, similar trends were indicated in Figures 5 and 6. But at the high influent concentrations, anaerobic conditions developed. Therefore the results may not be representative.

(c) Nitrogens

Ammonia and nitrate concentrations in the samples after the treatment were related because ammonia was converted to nitrite, and then to nitrate by nitrifying bacteria. For Septage Sample A, the data are presented in Figures 7 and 8. As shown, while above 90 percent of the ammonia was removed, only about 30 to 50 percent was converted to nitrate. The balance of the ammonia could be synthesized to cellular material, or denitrified. As shown

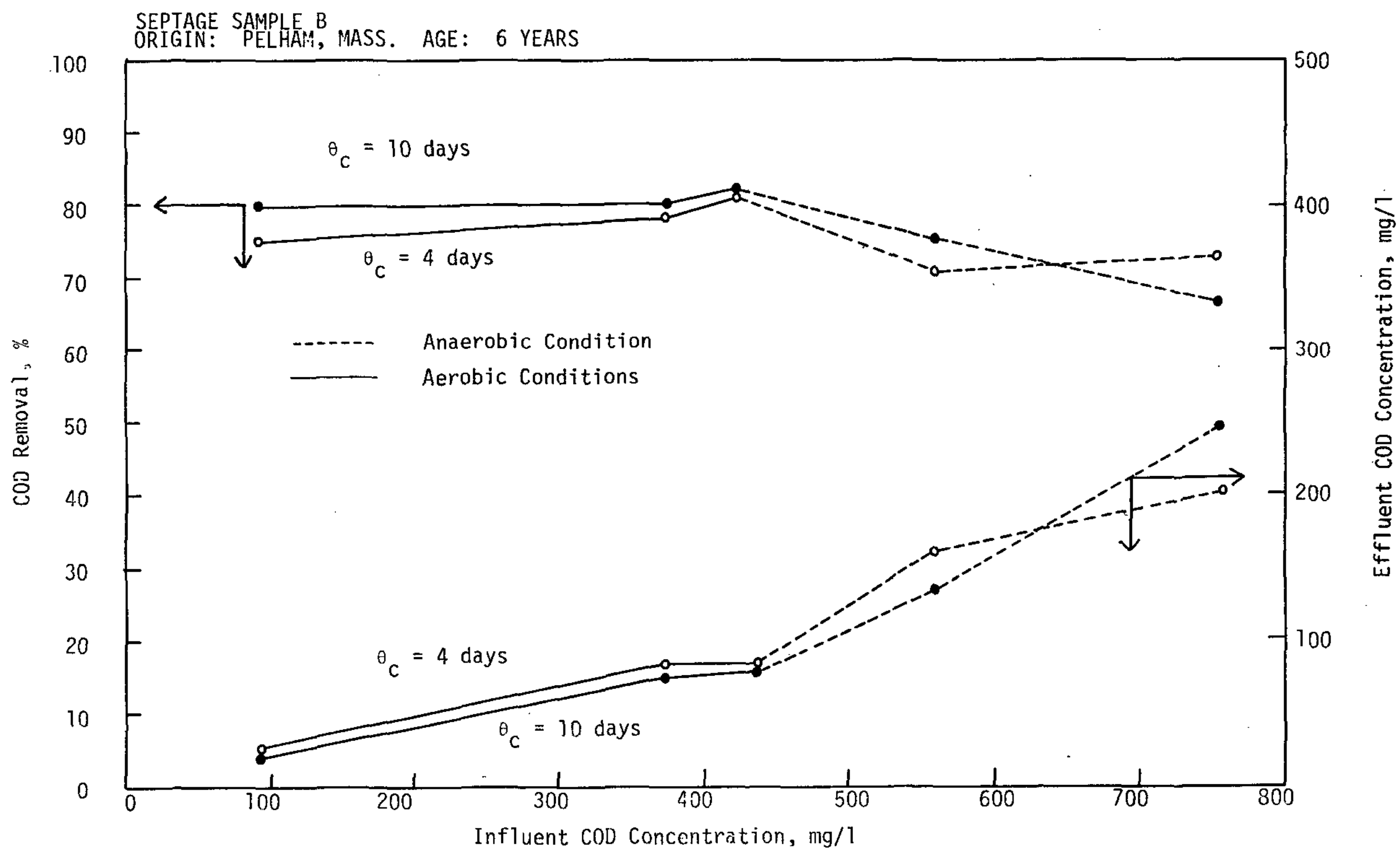

Figure 5. Removal of COD (both influent and effluent filtered).

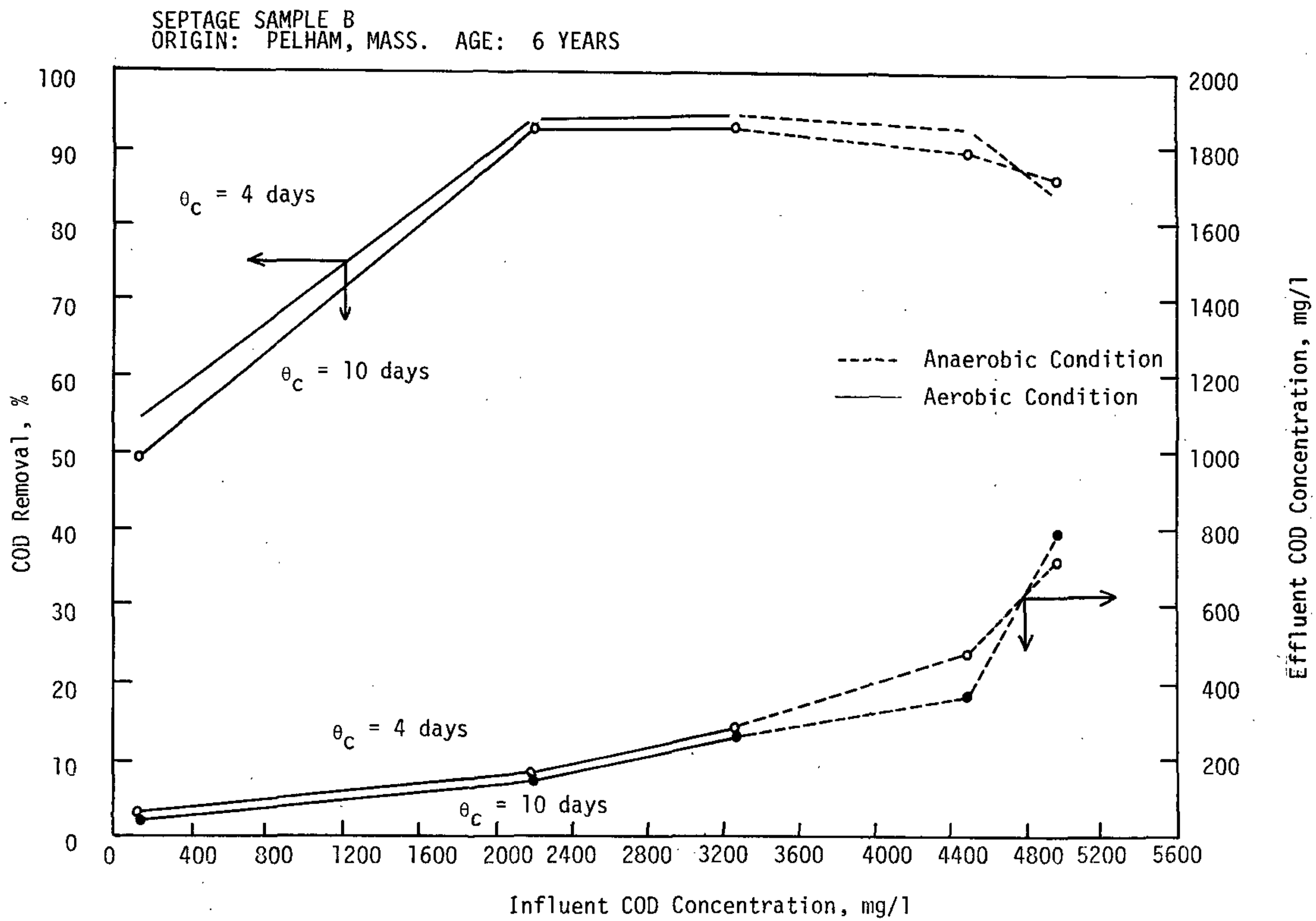

Figure 6. Removal of COD (both influent and effluent not filtered).

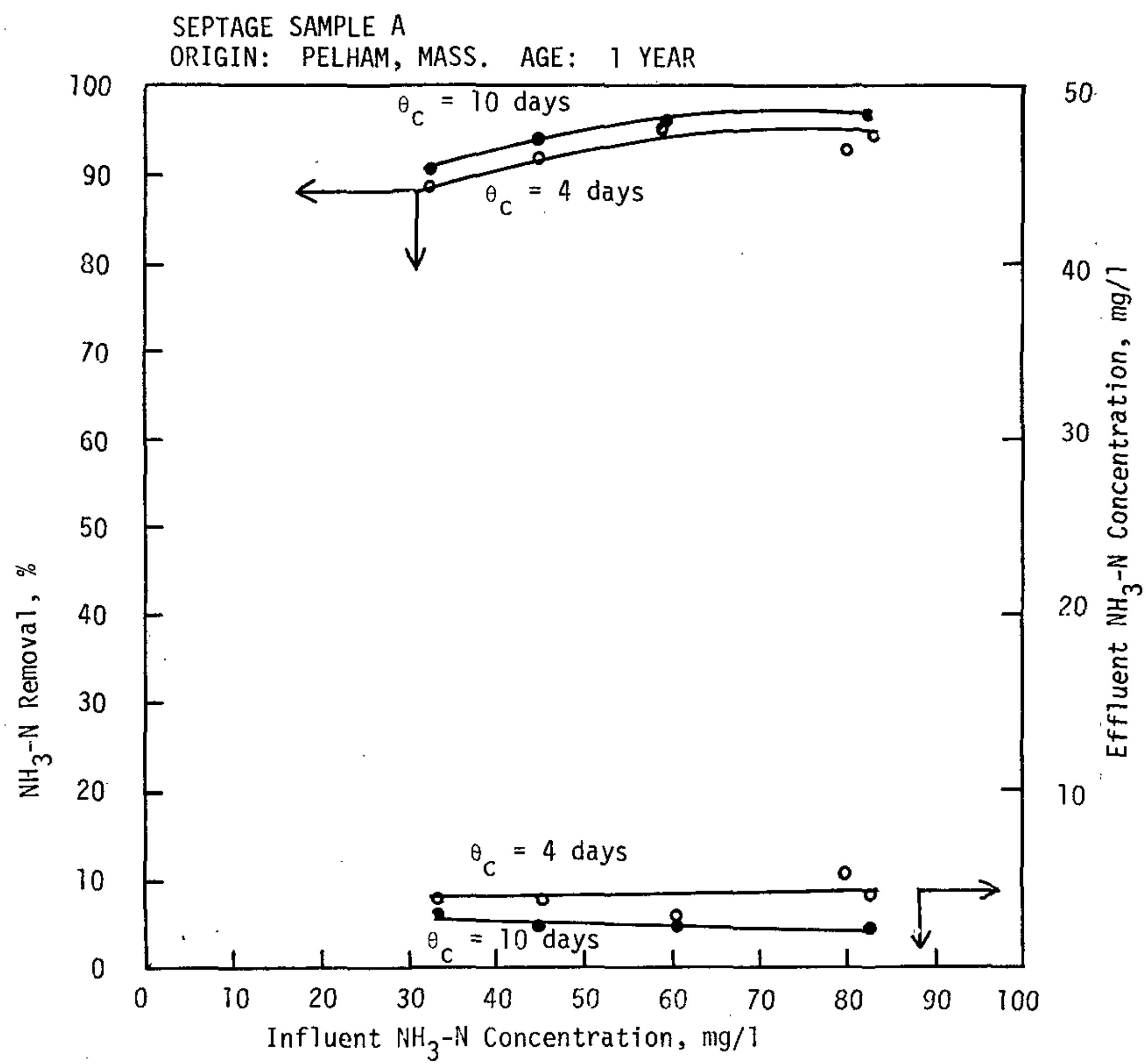

Figure 7. Removal of NH_3-N.

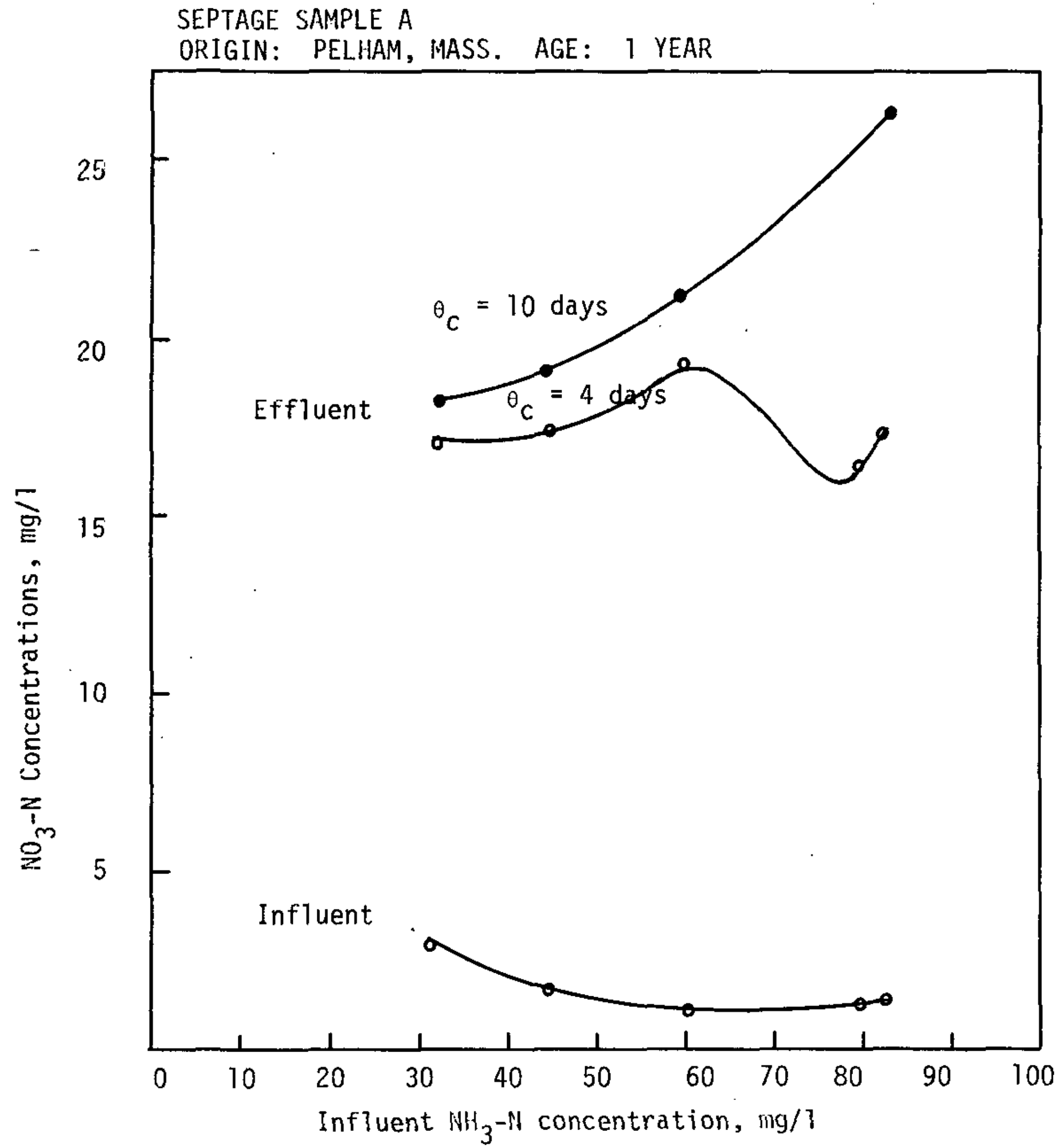

Figure 8. Nitrogen Conversion

in Figure 8, a smaller percentage of the ammonia was converted to nitrate as the influent concentration of ammonia (also BOD_5) increased, in which case it was more susceptible to the development of anaerobic conditions, and therefore to the denitrification. The nitrification was higher at θ_c of 10 days than at θ_c of 4 days.

For Septage Sample B, the data are presented in Figures 9 and 10. As the influent increased in strength, anaerobic conditions gradually developed. When feed mixture was municipal wastewater only, nitrification was highly accomplished. When 5 percent septage was added, nitrification occurred, but a large portion of the formed nitrate was immediately denitrified. As the septage-addition further increased, it seemed that nitrification was hindered.

(d) Orthophosphate

The data for Septage Sample A are shown in Figure 11, and for Septage Sample B in Figure 12. As shown in both figures, the removal of orthophosphate in the treatment of municipal wastewater by activated sludge process was about 20 to 30 percent, which agrees with previous findings by other researchers. In the case of Septage Sample A, as the feed mixture increased in PO_4-P with the addition of septage, the percent removal was as high as 60 percent, but the effluent PO_4-P concentration kept increased from about

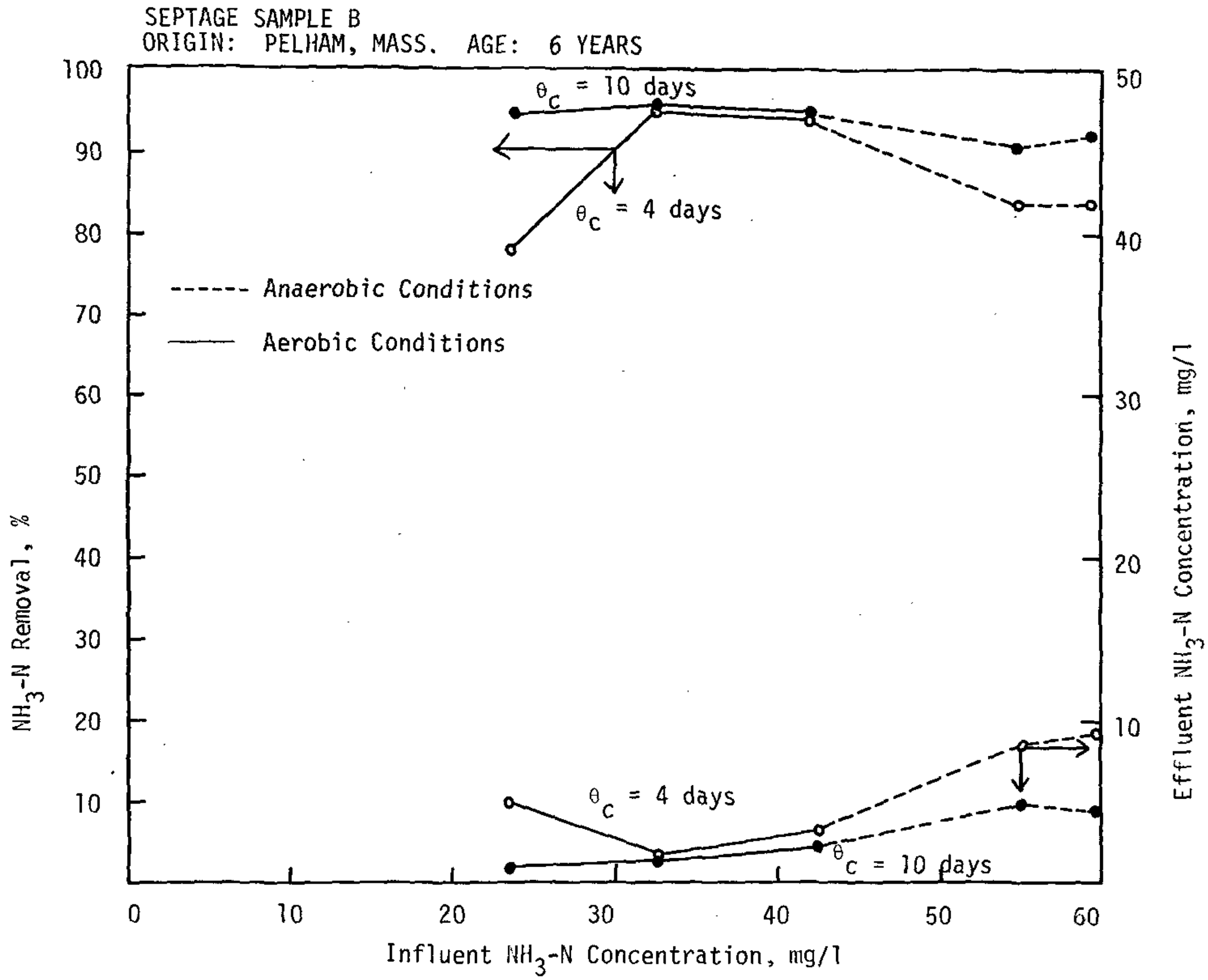

Figure 9. Removal of NH_3-N.

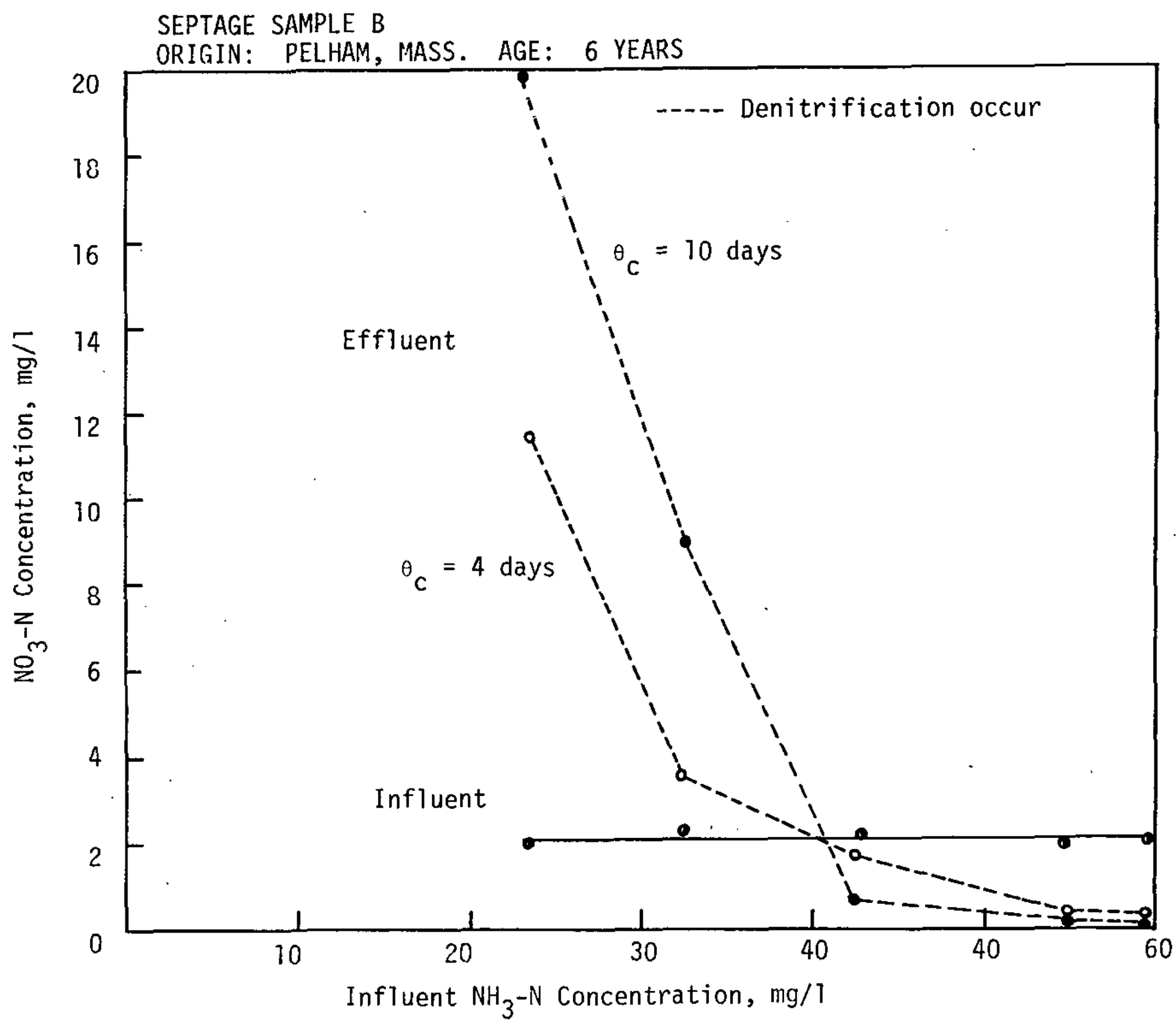

Figure 10. Nitrogen Conversion

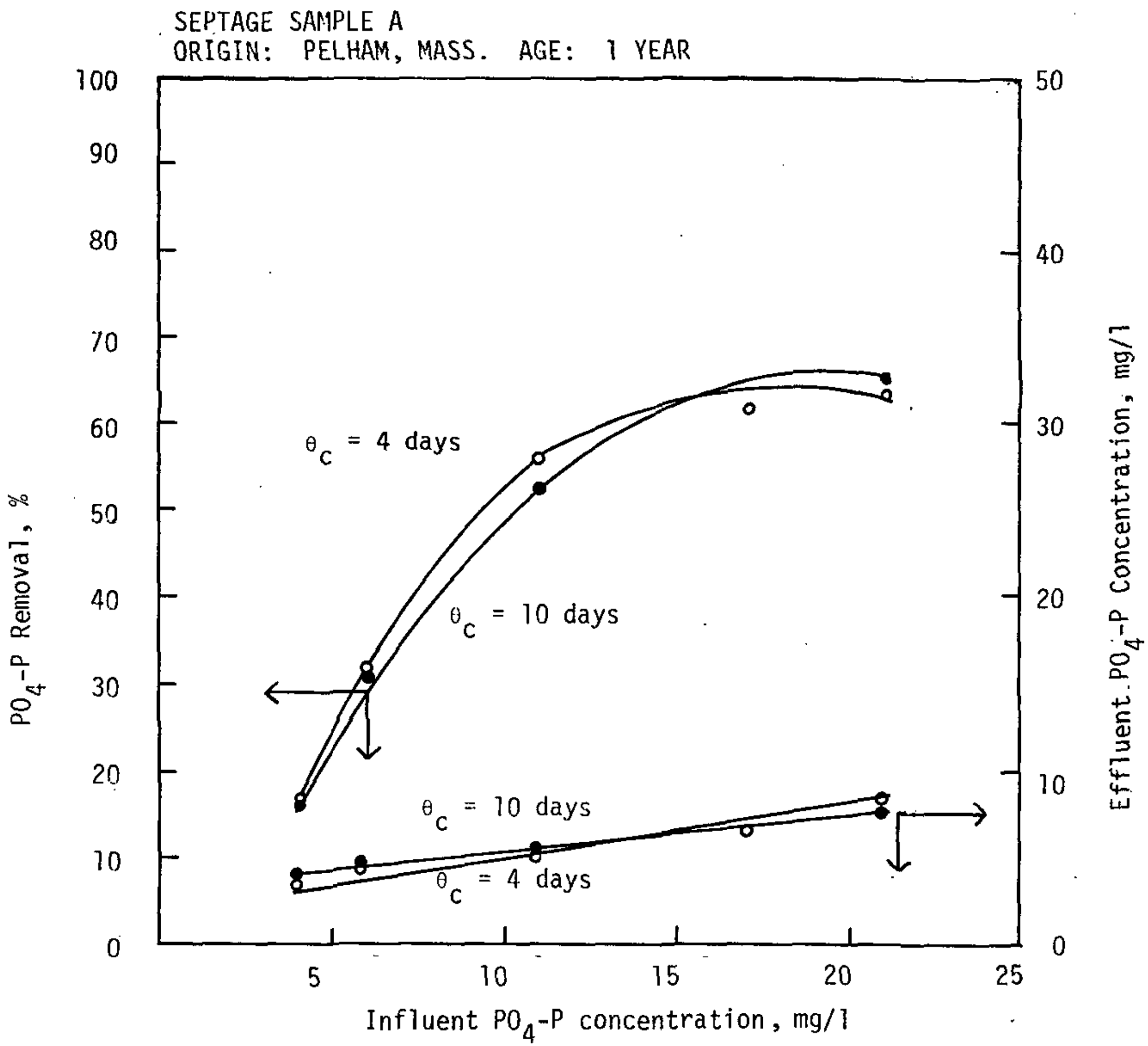

Figure 11. Removal of Orthophosphate.

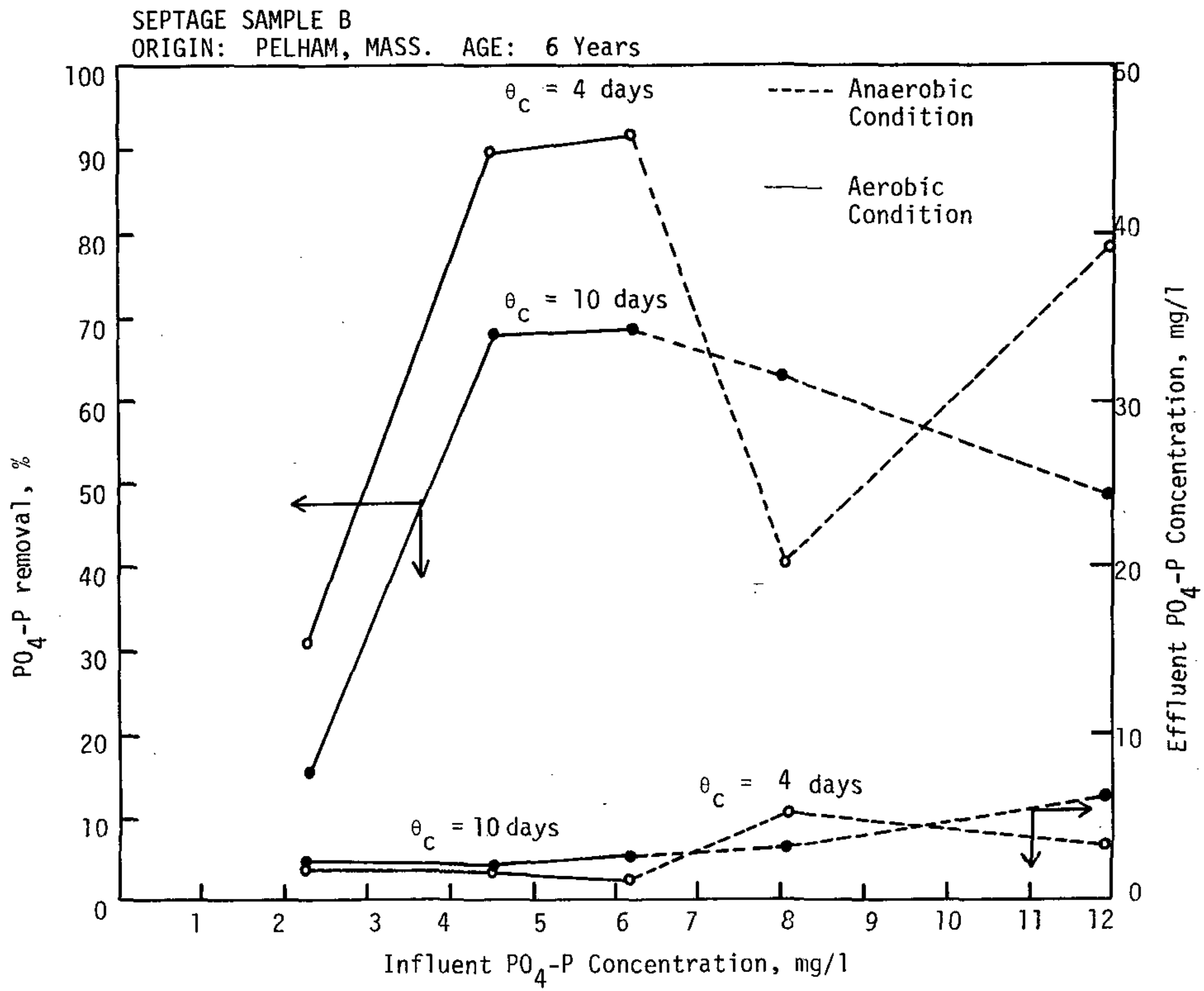

Figure 12. Removal of Orthophosphate.

3 mg/l to 8 mg/l. The effect of sludge age was not significant.

As for Septage Sample B, the percent removal reached as high as 90 percent, as the feed mixture was added septage and increased greatly in BOD_5. However, the removal was reduced when more septage was added and anaerobic conditions developed. Another noteworthy indication is that at θ_c equal to 4 days, the removal was significantly higher than the removal at θ_c equal to 10 days. Since more sludge was synthesized at θ_c equal to 4 days, it seems that the removal of phosphate was essentially the result of phosphorus being tied up in cellular material.

(e) Sludge Volume Index

Sludge Volume Index (SVI) is the volume in ml occupied by one gram of suspended solids after 30 minutes settling. It is computed as follows:

$$SVI = \frac{\text{Sludge Volume after Settling (ml/l)} \times 1000}{\text{MLSS (mg/l)}}$$

The SVI is a measure of activated sludge settleability, a value of which in the range of 50-150 indicates a good settling sludge. As shown in Figure 13 for Septage Sample A the SVI of a batch at $\theta_c = 4$ days indicated better settling sludge than its counterpart at $\theta_c = 10$ days. But, as shown in Figure 14, the reverse held true for Septage Sample B. It is reasonable to assume that the higher the BOD loading, the longer the sludge age was desired to improve the sludge settleability. By commonly used criteria stated above, all the batches of various loading rates for both septage samples had good settling sludge.

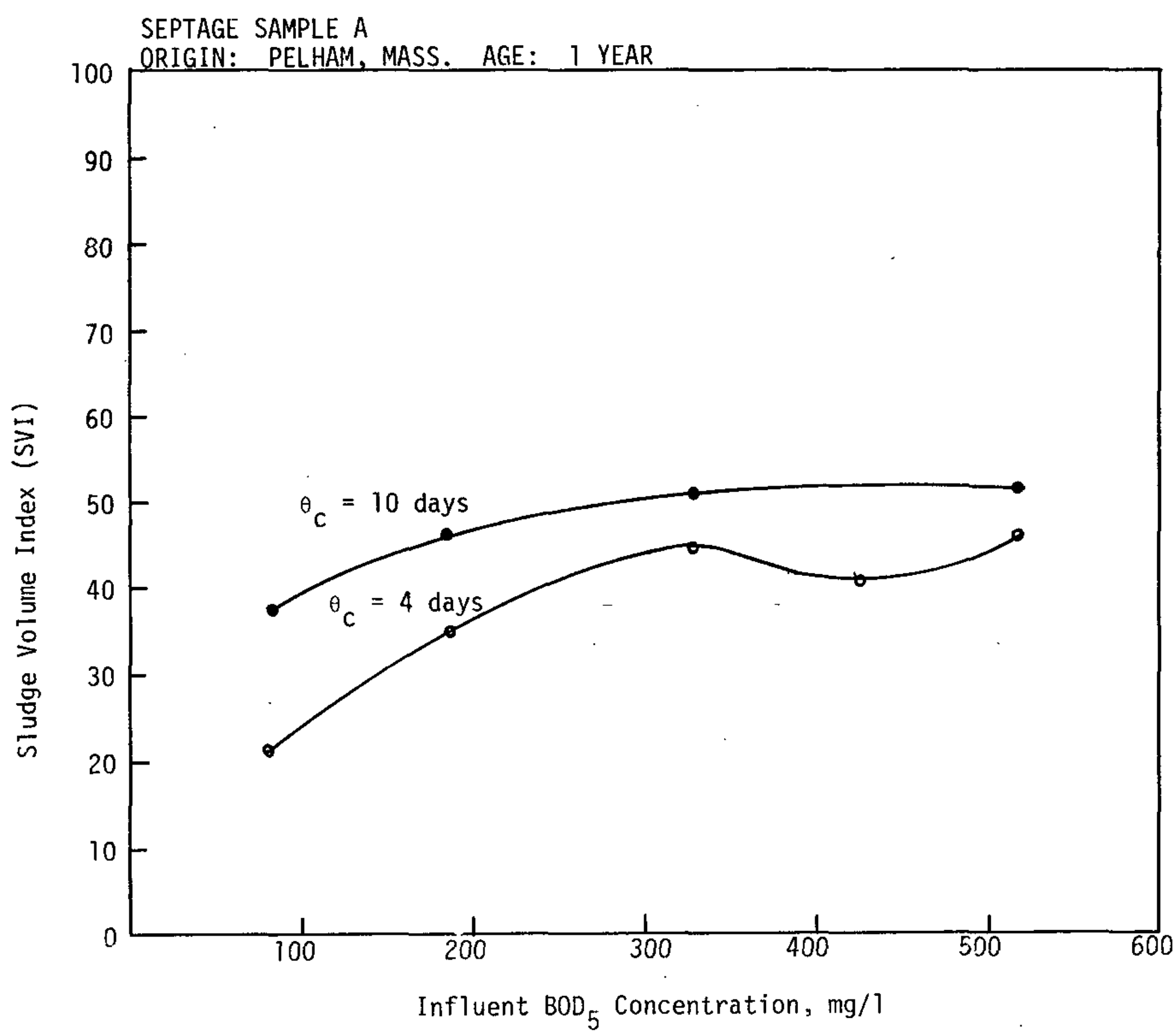

Figure 13. Sludge Voluem Index.

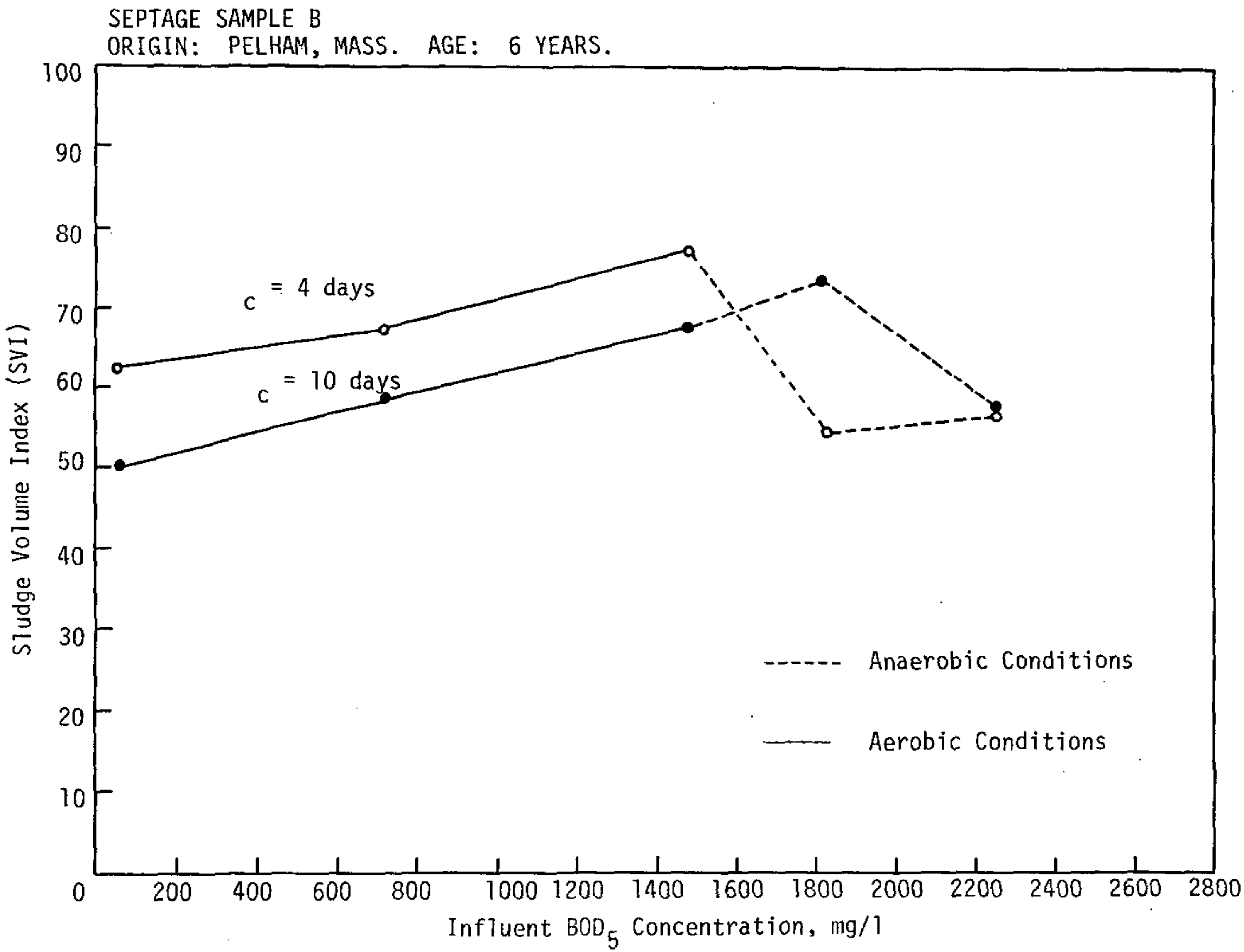

Figure 14. Sludge Volume Index

(f) Mixed Liquor Suspended Solids (MLSS)

Mixed liquor suspended solids (MLSS) and mixed liquor volatile suspended solids (MLVSS) in all the batch reactors were maintained at steady concentrations. The analytical results of MLSS and MLVSS are presented in Table 3 for Septage Sample A and in Table 4 for Septage Sample B against their respective sludge ages, feed mixture BOD's and feed mixture COD's. As shown in the Tables, at a given sludge age, higher steady concentrations of MLSS and MLVSS could be maintained at higher BOD loadings. It is also indicated that at the sludge age of 10 days, the steady concentrations of MLSS and MLVSS were higher than their respective concentrations at the sludge age of 4 days. A noteworthy information, as shown, is that the addition of septage in the feed mixtures decreased the percentage of MLVSS in the MLSS.

(g) Sludge Production

The sludge production* is the amount of sludge wasted per unit time, commonly the daily waste of sludge. If an activated sludge process is controlled by "sludge age (θ_c)" the daily production of sludge (or the daily waste of sludge) can be calculated by Equation (5), which can be expressed as follows:

$$\left(\frac{\Delta X}{\Delta t}\right)_M = \frac{X_M}{\theta_c}$$

where X_M = concentration of MLSS in the aeration basin in mg/l

θ_c = sludge age in days

$\left(\frac{\Delta X}{\Delta t}\right)_M$ = sludge produced in mg/liter-day.

*under steady-state conditions.

Table 3. Concentrations of MLSS and MLVSS Maintained in the Batch Reactors - Septage Sample A.

Septage Sample A - Age: 1 Year

Sludge Age θ_c (days)	Feed Mixture BOD_5 mg/l	Feed Mixture COD mg/l	MLSS mg/l	MLVSS % of MLSS
4	87	217	232	93
	175	560	746	78
	330	1130	1452	
	430	1680	2045	
	520	1974	2391	
10	87	217	662	88
	175	560	1522	78
	330	1130	2455	
	430	1680	-	
	520	1974	3010	

Table 4. Concentrations of MLSS and MLVSS Maintained in the Batch Reactors - Septage Sample B.

Septage Sample B - Age: 6 Years

Sludge Age θ_c (days)	Feed Mixture BOD_5 mg/l	Feed Mixture COD mg/l	MLSS mg/l	MLVSS % of MLSS
4	51	104	160	98
	720	2272	2540	
	1470	3306	3900*	82
	1830	4564	5468*	
	2250	4960	6156*	
10	51	104	400	90
	720	2272	4184	
	1470	3306	6936*	
	1830	4564	8638*	82
	2250	4960	9125*	

*Anaerobic Conditions occurred

The daily production of sludge in terms of volume can be calculated by the following expression:

$$v = \frac{1}{\theta_c}$$

where v = daily production of sludge in liters per liter.

θ_c = sludge age in days.

The data on sludge production in terms of milligrams per liter per day are presented in Figure 15 for Septage Sample A and in Figure 16 for Septage Sample B. As shown in the Figures sludge production rate increased with the increase of BOD-loading. For a same BOD loading the sludge production at 4-day sludge age was higher than at 10-day sludge age.

(h) Oxygen Requirements

For diffused-air aeration, the amount of air required for an activated sludge system has commonly ranged from 0.5 to 2.0 cu ft/gal at different installations, with 1.0 cu ft/gal as an average. Under the assumption that 150 mg/l of BOD are removed, 1.0 cu ft/gal is equivalent to 830 cu ft of air/lb of BOD removed.

The air supply must be adequate to satisfy the BOD of the waste, to satisfy the endogenous respiration of the sludge organisms and to provide adequate mixing. There are about 14.0 lb of oxygen in the 830 cu ft of air provided for each lb of BOD removed. Therefore only less than 10 percent of the oxygen is used for satisfying BOD. The amount of oxygen available for biochemical oxidation is limited

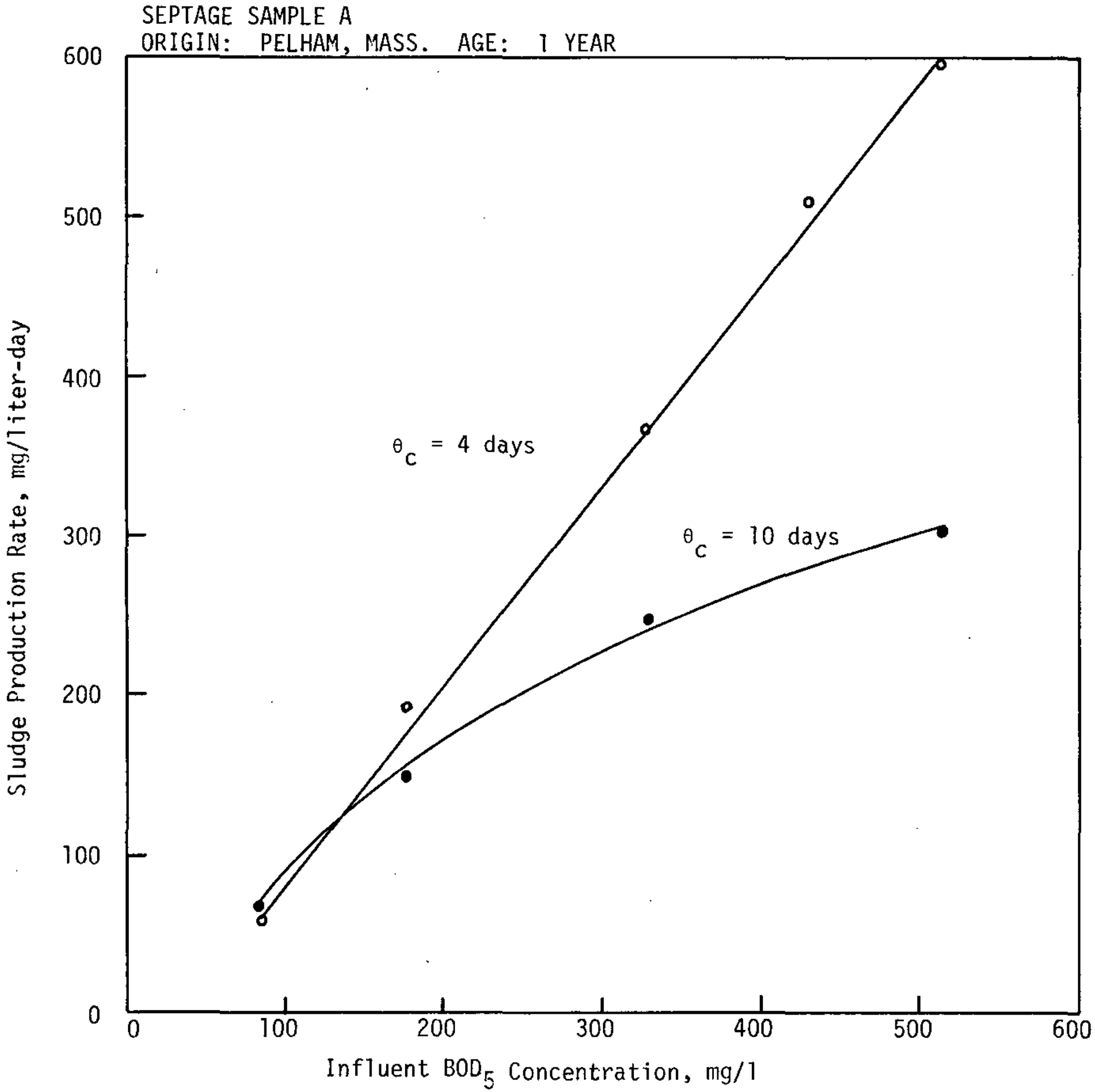

Figure 15. Sludge Production

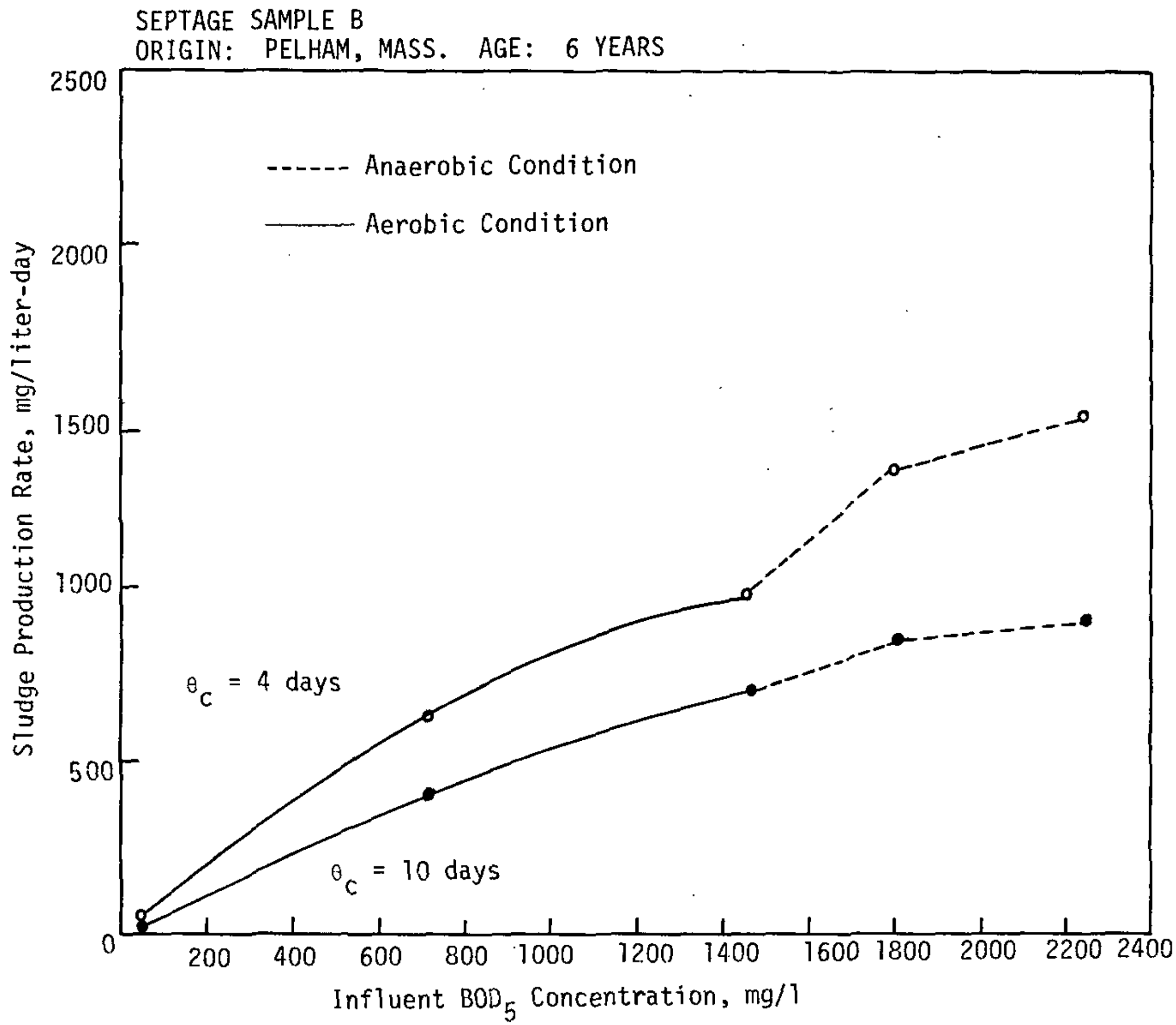

Figure 16. Sludge Production.

by the efficiency of oxygen transfer, which depends upon the type and porosity of the diffuser, the size of bubbles produced, the depth of submersion and other factors. In general, the efficiency varies from 5 to 15 percent.

By the above reasoning, the oxygen requirements for satisfying BOD must therefore be taken into consideration in design and cost evaluation.

For this study, only the batch reactors for studying Septage Sample A operated at θ_c equal to 10 days were analyzed for their oxygen requirements. The procedures were as follows:

1. During the 24-hour aeration period every 30 minutes to 10 hours sufficient volume of mixed liquor was taken from an aeration reactor to fill a 300 ml BOD bottle. The BOD bottle was fit air tightly with a DO-probe and used to measure the oxygen uptake rate. The results were plotted as shown in Figure 17, the slope of which represents the oxygen uptake rate.
2. The values of oxygen uptake rate measured for each aeration reactor were plotted against the time of aeration at which the sample was taken for the measurement, as shown in Figure 18. The rate of oxygen requirements was the highest at the onset of aeration and reduced to a minimum rate after 2 to 3 hours, after which the rate slowly climbed to a moderate peak and then declined again. The rise and decline of the moderate peak could be attributed to the results of nitrification.

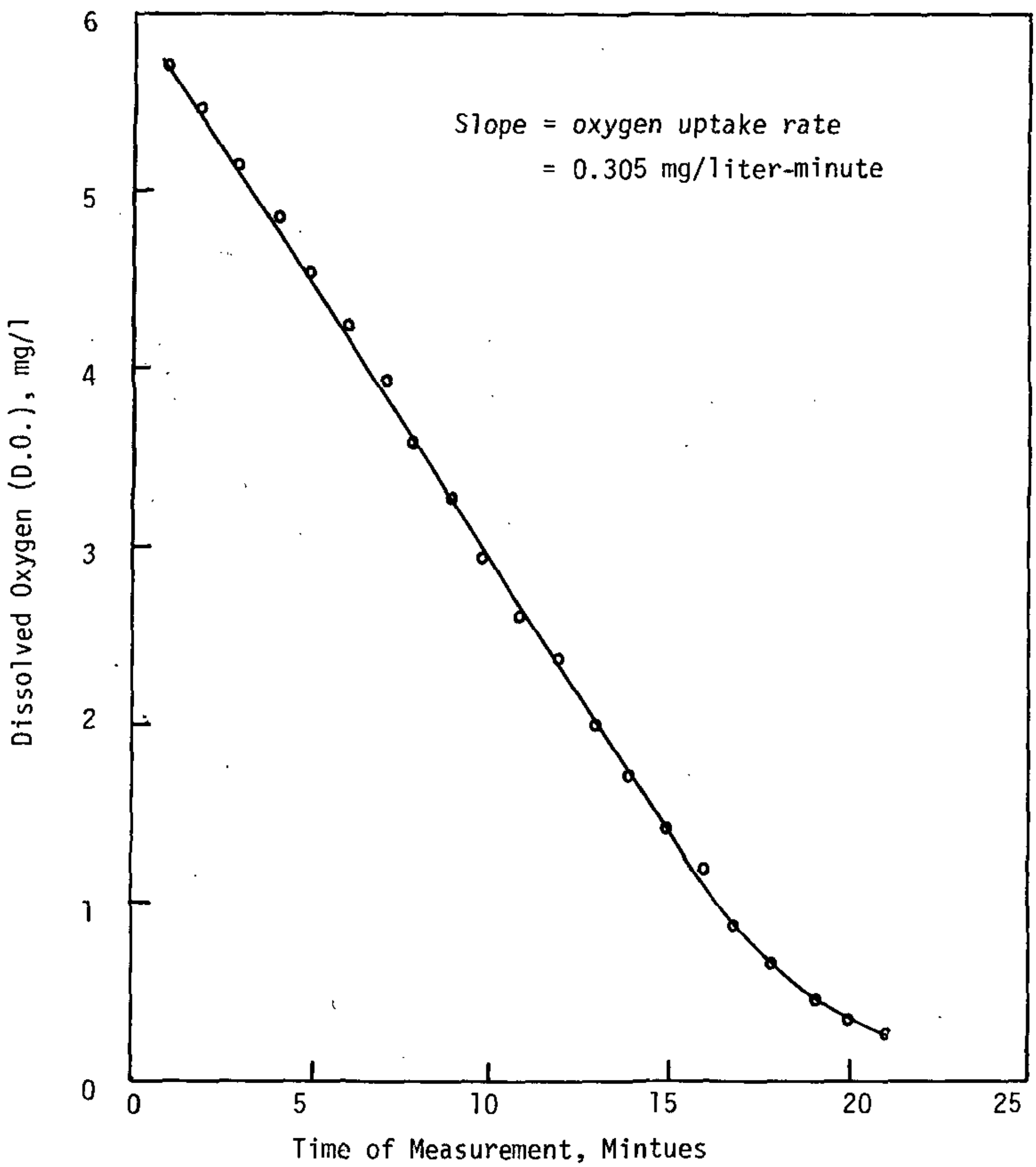

Figure 17. Measurement of Oxygen Uptake Rate - A Typical Curve.

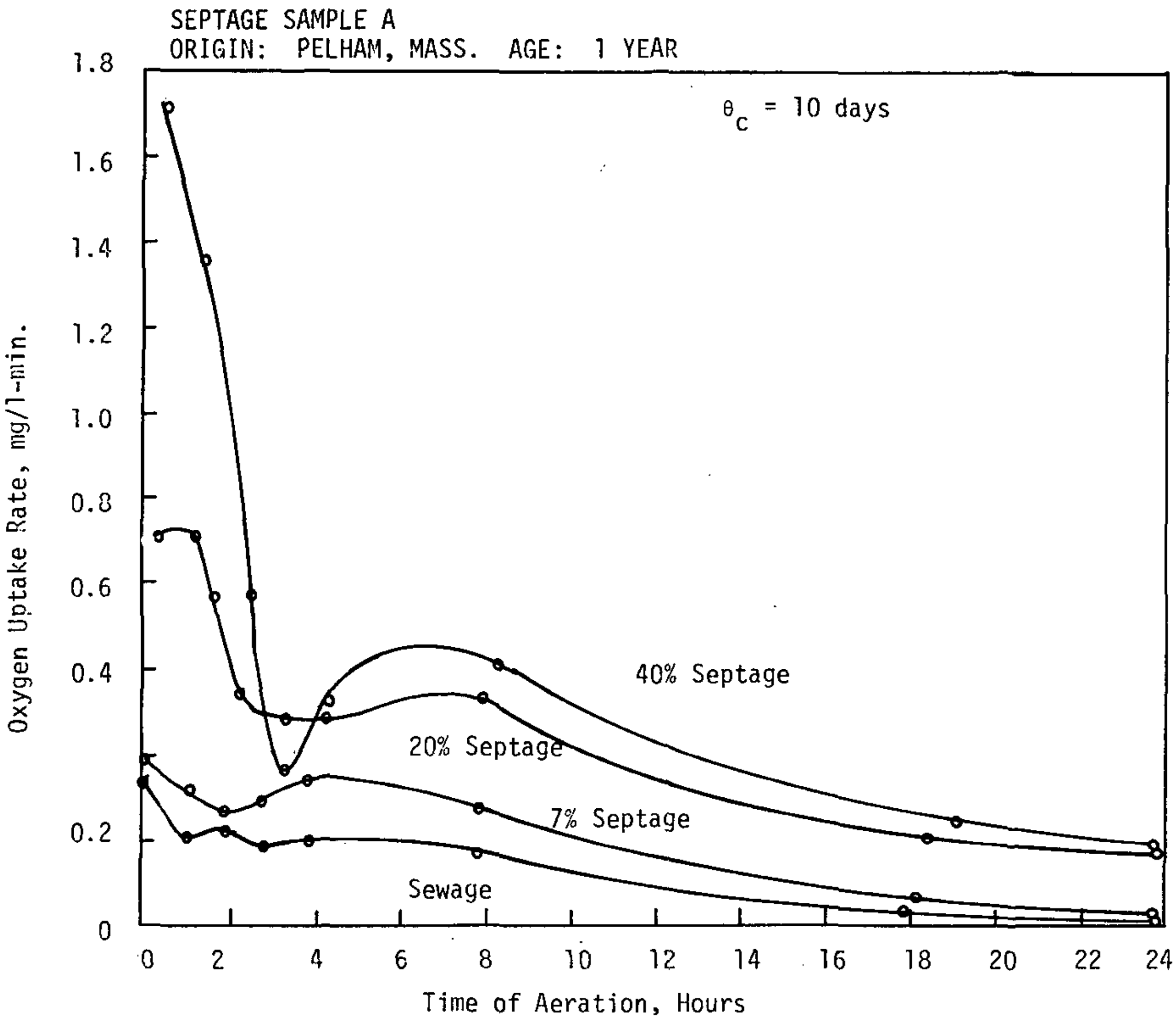

Figure 18. Oxygen Requirements During Aeration

3. The total oxygen requirements of an aeration reactor during the 24-hour aeration can be calculated by measuring the area surrounded by the coordinate axes and its oxygen-requirement curve, as shown in Figure 18.

4. In order to illustrate the variation of oxygen requirements under various BOD-loadings, the total oxygen requirements were calculated as follows:

Septage Sample A, θ_c = 10 days

% Septage	0%	7%	20%	40%
Total O_2 requirements lb/liter/day	0.00035	0.00056	0.0011	0.0015

Then the relative oxygen requirements were calculated by dividing the O_2-requirement values in the above table by 0.00035 as follows:

% Septage	0%	7%	20%	40%
Relative O_2 requirements, units	1	1.6	3.1	4.3

The relative oxygen requirements were plotted against influent (feed mixture) BOD_5, as shown in Figure 19. With the increase of BOD in feed mixture by adding 40% of Septage Sample A, the total oxygen requirements could be four times the requirements for treating municipal wastewater only.

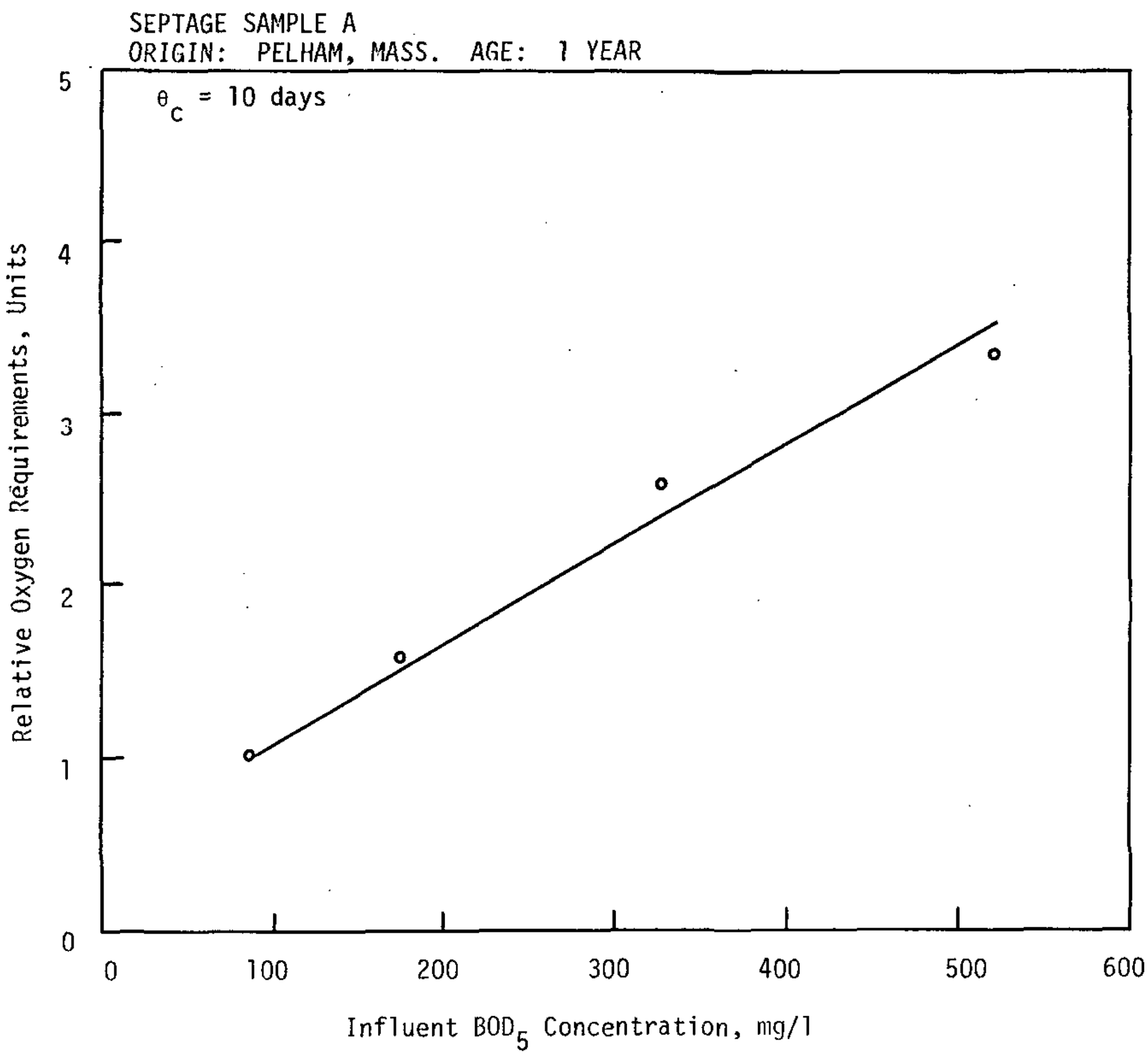

Figure 19. Comparison of Oxygen Requirements.

2) Aesthetic Qualities

Septage samples had a dark gray color with an obnoxious odor. The dark gray color was mainly caused by suspended solids and colloids. All the feed-mixtures, even the ones with low percent of septage, still retained the color and odor. After the 24-hour aeration with activated sludge, the effluent became light yellow in color and was free of the obnoxious odor.

Appendix I. References

1. Kolega, J. J., "Design Curves for Septages." Water & Sew. Works, 118, 5, 132 (1971).

2. Heukelekian, H., Oxford, H. E., and Manganelli, R., "Factors Affecting the Quantity of Sludge Production in the Activated Sludge Process." Sew. and Ind. Wastes, 23, 8 (1951).

3. Jenkins, D., and Garrison, W. E., "Control of Activated Sludge by Mean Cell Residence Time." Jour. Water Poll. Control Fed., 40, 11, Part 1 (1968).

4. McCarty, P. L., "Kinetics of Waste Assimilation in Anaerobic Treatment." Developments in Industrial Microbiology, Vol. 7, American Institute of Biological Sciences, Washington, D.C. (1966).

5. Metcalf & Eddy, Wastewater Engineering: Collection Treatment and Disposal. pp. 391-406. McGraw Hill, New York, New York (1972).