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THE STABILIZATION OF SEPTAGE BY HIGH DOSAGES OF CHLORINE

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Environmental Engineering Program

Department of Civil Engineering

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PREFACE

This report is the first phase of a study on the application of high dosages of chlorine to the stabilization of sludges of domestic origin, known as the BIF Purifax Process. Special attention was focused upon the stabilization of septage.

This phase of the study is reported in two parts: Part A - Investigation of the Effects of Chlorine Dosage and Mixing Time on the Performance of the Purifax Process, and Part B - Investigation of Variation in Characteristics of Different Sources of Household Septages and Their Treatability by the Purifax Process. The findings are summarized and presented as "Summary" at the end of each Part.

The experiments were performed by Mr. Wen-Kang Shieh to fulfill a requirement for the degree in Master of Science in the Department of Civil Engineering at the University of Massachusetts. Mr. Shieh is currently a doctoral candidate at the University of Massachusetts.

The second phase of the study is planned to essentially devote to the disposal of the Purifaxed sludges.

The work was supported by the Division of Water Pollution Control, Massachusetts Water Resources Commission in the form 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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ABSTRACT

The objective of this study is to investigate the stabilization of various sources of household septages and primary and digested sludges from a municipal wastewater treatment plant by a high-dosage chlorination known as the BIF Purifax Process. The experimental results and discussion are presented in two parts as follows:

Part I.- Investigation of the effects of chlorine dosage and mixing time on the performance of the Purifax Process.

Part II.- Investigation of variation in characteristics of different sources of household septages and their treatability by the Purifax Process.

In Part I a source of primary sludge and one sample of household septage were used for the investigation. Chlorine dosage used varied from 500 to 2500 mg/l, and mixing time ranged from 5 to 11 minutes. The results showed that higher chlorine dosage and longer mixing time improved BOD-removal more than COD- and NH_3-removal. The process could hardly remove any of the phosphates, even with the combination of 2500 mg/l of chlorine and 11 minutes of mixing. The resultant chlorine residuals increased with chlorine dosage for a given mixing time, and decreased with mixing time at a given dosage.

In Part II, four different samples of household septage, one sample each of primary sludge and anaerobically digested sludge from a municipal wastewater treatment plant were studied. Two chlorine dosages, 1900 and 2500 mg/l were used, and four mixing periods, 5, 7, 10 and 13 minutes were applied. It was found that the characteristics of household septage samples varied widely. The measured characteristics were pH, total solids, total suspended solids, volatile suspended solids, NH_3-N, BOD_5, TOC and specific resistance. In general, as the result of treatment practically there were no change of solids concentration, BOD_5 were removed from 50 to 80 percent, dewatering quality were greatly improved, sludge solids were bleached to light yellow color and the odor was completely removed.

I. INTRODUCTION AND OBJECTIVES

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 a 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.[1,2,3] 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.[3] In many cases, however, septic tank systems do not function satisfactorily because of (1) inadequate retention time, (2) lack of proper maintenance, and (3) 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.

A. Characteristics of Septages

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 significant effect on the characteristics of septages. There is only limited imformation available on the general nature of septages.[4]

Kolega,[4] 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

Hickey and Duncan[5] found that septic tank effluents from Anchorage and Fairbanks, Alaska possessed the following characteristics (mean value):

pH = 7.26

BOD_5 = 77.6 mg/l

Alkalinity (as $CaCO_3$) = 318 mg/l

Org-N = 3.4 mg/l

NH_3-N = 37 mg/l

Acetic Acid = 36.4 mg/l

Propionic Acid = 3.8 mg/l

Butyric Acid = 0.8 mg/l

Total Solids = 450 mg/l

Suspended Solids = 27.7 mg/l

The septic tank gas had the following compositions:

CO_2 = 2.2 percent

O_2 = 4.9 percent

N_2 = 90.7 percent

CH_4 = 2.1 percent

According to Babbitt,[3] septages possessed the following characteristics:

Moisture = 93 percent

Specific Gravity = 1.03 percent

Volatile Solids = 45 percent of total solids

Total Nitrogens = 1.5 percent of total solids

Phosphate (P_2O_5) = 1.0 percent of total solids

Fat (ether soluble) = 9.0 percent of total solids

The results obtained in this study showed that the characteristics of septages varied not only from source to source but also with the age of sludge from a same source (see Table VII to Table X).

In summary, the characteristics of septages are highly variable and affected by many factors. Extensive investigations are needed to identify the variation of septage characteristics under different conditions.

B. Biochemistry of Septic Tank Systems

Basically, the biochemical environment of septic tank systems is similar to that of anaerobic sludge digesters except that the sludge digesters are usually controlled at a desired temperature and provided with a certain degree of mixing.

In the process of anaerobic sludge digestion there is an orderly and controlled decomposition of the substrates without molecular oxygen acting as hydrogen acceptor. The microbial population consists of both facultative and anaerobic bacteria which are able to utilize bound oxygen such as NO_3^-, CO_2, $SO_4^=$ and organic compounds as hydrogen acceptor.[6,7,8]

The overall digestion process is composed of two stages, liquefaction and gasification. In the liquefaction stage, such organic compounds as polysaccharides, carbohydrates, fats and proteins are hydrolyzed by means of extracellular enzymes from microbial population called acid-formers and converted to smaller molecules which diffuse into the microbial cells. Then proteins are biodegraded to amino acids, iminoacids and ketoacids and polysaccharides to glucose and eventually to alcohols and organic acids (volatile acids).

In the second stage the organic acids and alcohols formed in the first stage are used by microbes generally referred to as methane-bacteria. The end products are CH_4, CO_2, H_2S and others.

An efficient digestion process depends on the set-up of so-called dynamic equilibrium between the two stages described above. The reaction rate of the second stage is usually slower than that of the first stage. Besides, methane-bacteria are strictly anaerobic and sensitive to variations of the environment such as temperature, pH and organic acid concentration. Consequently, this stage becomes the rate-limiting step of the whole process. Septic tanks are exposed to natural conditions in most cases and dynamic equilibrium between the two stages may be shifted as time elapses. Analytical data on septages in the area of Anchorage and Fairbanks, Alaska[5] showed that molecular oxygen existed in the gaseous products and CH_4 content was very low. If the activities of methane-bacteria are suppressed by low pH or other environmental factors, organic acids will accumulate in the septage and further suppress the production of CH_4.

C. Application of the Purifax Process to Septage Treatment

Septages from Amherst and nearby areas are disposed of by dumping into the primary sedimentation tanks of the 3-MGD primary wastewater treatment plant of Amherst, Massachusetts. There are two or three 1600 gallon dumpings daily during the week days. The wastewater treatment plant operators of Amherst and other towns and cities of Massachusetts have reported that such practice of septage disposal would induce short-circuiting in a primary sedimentation tank and thus adversely affect its normal performance and consequently deteriorate the quality of primary effluents. The Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) require that all municipal wastewater treatment plants be provided with secondary treatment or its equivalent by 1977. The dumping of septage into a municipal wastewater treatment plant may have far worse effects on the treatment processes beyond the primary treatment. One possible way to overcome such disruption of designed performance of a municipal wastewater treatment plant is to provide separate treatment to stabilize and disinfect the septages so that they can be disposed of without creating contamination and nuisance. The Purifax Process, developed by BIF Purifax, Incorporated (referred to hereafter as BIF) uses chlorine to oxidize, stabilize and disinfect wastewater treatment plant sludges. Its simple operation, reported low cost and complete stabilization and disinfection of sludges should justify an evaluation as to whether the Purifax Process is effective and therefore applicable to septage treatment. To make such an evaluation was the purpose of this study. BOD_5 removal, NH_3-N removal, COD removal, TOC removal, PO_4 removal, chlorine residuals and improvement in dewatering quality were among the parameters used for the evaluation.

II. CHEMISTRY OF CHLORINATION

As a strong oxidizing agent, chlorine reacts with many chemical compounds contained in wastewaters and sludges. The following compounds are of significance in their reactions with chlorine:[9] (1) ammonia, (2) amino acids, (3) proteins, (4) carbonaceous material, (5) nitrates, (6) hydrogen sulfide, (7) cyanides, (8) iron, and (9) maganese.

The inorganic substances generally react rapidly and stoichiometrically and the response of organic material is generally slow. In the case of septages of domestic origin, only compounds (1) to (6) mentioned above are significant in chlorination and briefly discussed as follows.

The solubility of chlorine gas in water is about 7300 mg/l at 20°C and 1 atm. It combines with water to form hypochlorous and hydrochloric acids:

$$Cl_2 + H_2O \rightleftarrows HOCl + HCl \qquad (2\text{-}1)$$

The hypochlorous acid formed undergoes partial dissociation which is a function of pH and temperature:

$$HOCl \rightleftarrows H^+ + OCl^- \qquad (2\text{-}2)$$

Both HOCl and OCl^- are called free available chlorine. OCl^- is more than 90 percent at pH above 9. HOCl becomes predominant at pH below 6. Molecular chlorine starts to appear at pH below 4.

A. Nitrogeneous Compounds

The most important reaction of chlorine with nitrogeneous compounds is that between chlorine and ammonia which forms different types of chloramines:

$$HOCl + NH_3 \rightarrow NH_2Cl + H_2O \qquad (2\text{-}3)$$

$$HOCl + NH_2Cl \rightarrow NHCl_2 + H_2O \qquad (2\text{-}4)$$

$$HOCl + NHCl_2 \rightarrow NCl_3 + H_2O \qquad (2\text{-}5)$$

The predominance of each type of chloramine depends on temperature, contact time, pH and initial molar ratio of chlorine to ammonia. The chloramines formed are called combined available chlorine.

Reaction rates of both (2-3) and (2-4) are pH-dependent and the former is much faster than the latter. When an excess of chlorine is present, some NCl_3 will be formed. NCl_3 readily envolves as gas because of its low solubility in water.[9] Therefore its formation is very difficult to detect especially under a condition of vigorous mixing.

Nitrites react readily with free chlorine and are oxidized to nitrates as follows:

$$NO_2^- + HOCl \rightarrow NO_3^- + H^+ + Cl^- \qquad (2\text{-}6)$$

Besides, nitrites will react with chloramines at favorable pH values and thus complicate the relative distribution of chlorine residuals.

The presence of organic nitrogeneous compounds in sludges further complicates the process of chlorination. The proteins are the most difficult to deal with in chlorination because they are highly complex in structure and large in molecular weight (20,000 to 20 million). Furthermore, a particular protein will exhibit specific reactions with chlorine depending on the number of amino groups available for such reactions. The availability of amino groups, in turn, depends upon the degree of hydrolysis of the organic nitrogen.

Another important organic nitrogeneous compound, as far as chlorination is concerned, is urea. Urea hydrolyzes with ammonia as one of the end products.

$$CO(NH_2)_2 \xrightarrow{+H_2O} 2NH_3 + CO_2 \qquad (2\text{-}7)$$

Urea functions as a reservoir for supplying ammonia which keeps comsuming free available chlorine.

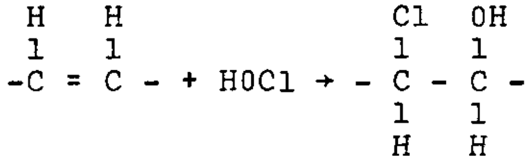
The presence of organic nitrogens in sludge causes the formation of unstable chlorine residuals unless long contact periods (several hours) are provided, under which conditions stable chlorine residuals may be produced. The relative stability of chlorine residuals is dependent on the complexity and the characteristics of the nitrogeneous compounds.[9]

B. Carbonaceous Compounds

All organic compounds found in wastes are carbonaceous. Proteins, urea, sugars, starches, cellulose, wood fiber, butter, lard, margarine, vegetable fats and oils, detergents and others are the most significant carbon-containing compounds in sludges. Carbon will react with chlorine as follows:

$$C + 2Cl_2 + 2H_2O \rightarrow 4HCl + CO_2 \qquad (2-8)$$

Organic compounds that possess unsaturated linkages will also react with hypochlorous acid and thus increase chlorine demand



$$-\overset{\text{H}}{\overset{|}{\text{C}}}=\overset{\text{H}}{\overset{|}{\text{C}}}- + \text{HOCl} \rightarrow -\overset{\text{Cl}}{\overset{|}{\underset{\text{H}}{\underset{|}{\text{C}}}}}-\overset{\text{OH}}{\overset{|}{\underset{\text{H}}{\underset{|}{\text{C}}}}}-$$

(2-9)

The fact that a large variety of carbonaceous compounds exists in sludges makes the determination of chlorine demand of this category of compounds impossible. However, the removal of BOD_5 can be explained as a portion of biodegradable organic carbonaceous compounds having been oxidized by chlorination. The removal of TOC can be explained as a portion of both biodegradable and nonbiodegradable organic carbonaceous compounds having been oxidized by chlorination. However, it is important to note that no correlation can be established as yet between BOD_5 (or TOC) removal and chlorine demand of carbonaceous compounds, because only limited data in this respect are now available.

C. Hydrogen Sulfide

Hydrogen sulfide is usually formed during the anaerobic digestion process. It reacts instantaneously with chlorine either to precipitate element sulfur or to form sulfuric acid, depending on pH.

$$H_2S + 4Cl_2 + 4H_2O \rightarrow H_2SO_4 + 8HCl \qquad (2\text{-}10)$$

$$H_2S + Cl_2 \rightarrow S\downarrow + 2HCl \qquad (2\text{-}11)$$

There are some side reactions which occur concurrently with (2-10) and (2-11) and thus interfere with the estimation of chlorine demand of hydrogen sulfide in sludges.

D. Methane

It is possible[9] for methane gas, a main end product of anaerobic digestion, to react with chlorine gas to form CCl_4 at temperature of 300°C and higher as follows

$$CH_4 + 4Cl_2 \rightarrow CCl_4 + 4HCl \tag{2-12}$$

However, there is no reaction between methane and hypochlorous acid. Therefore there should not be chlorine demand due to methane dissolved in waters.

III. EXPERIMENTAL APPARATUS AND METHODS

A. Experimental Apparatus

The laboratory apparatus, referred to hereafter as Purifax Unit, used in this study is a miniaturized complete-mixing batch type system designed by BIF. The Purifax Unit consists of the following basic components (Figure 1):

Reactor
Graduated sludge reservoir
Chlorine supply and chlorine inlet valve
Vacuum valve
Reactor inlet and outlet valves
Pressure gauge
Vacuum pump
Recirculation pump
Selector and discharge valves

The recirculation pump is a 1/4 HP, rotary type pump. Its suction side is connected to the reactor outlet valve and graduated sludge reservoir through a selector valve.

The graduated sludge reservoir is used for holding the sludge to be treated. It has a holding capacity of 2500 ml and is graduated from 0 ml to 2500 ml with 100-ml divisions.

The reactor where chlorine gas is mixed with the sludge being treated is a plastic, corrosion-resistant cylinder. A special nozzle is located in the inlet port, which induces a high speed tangential jet to promote proper agitation in the reactor. The outlet port is located at the bottom. Chlorine inlet valve, vacuum valve and a pressure gauge are connected to the reactor through its top cover. The pressure gauge is used as a gauge to monitor the flow rate of chlorine.

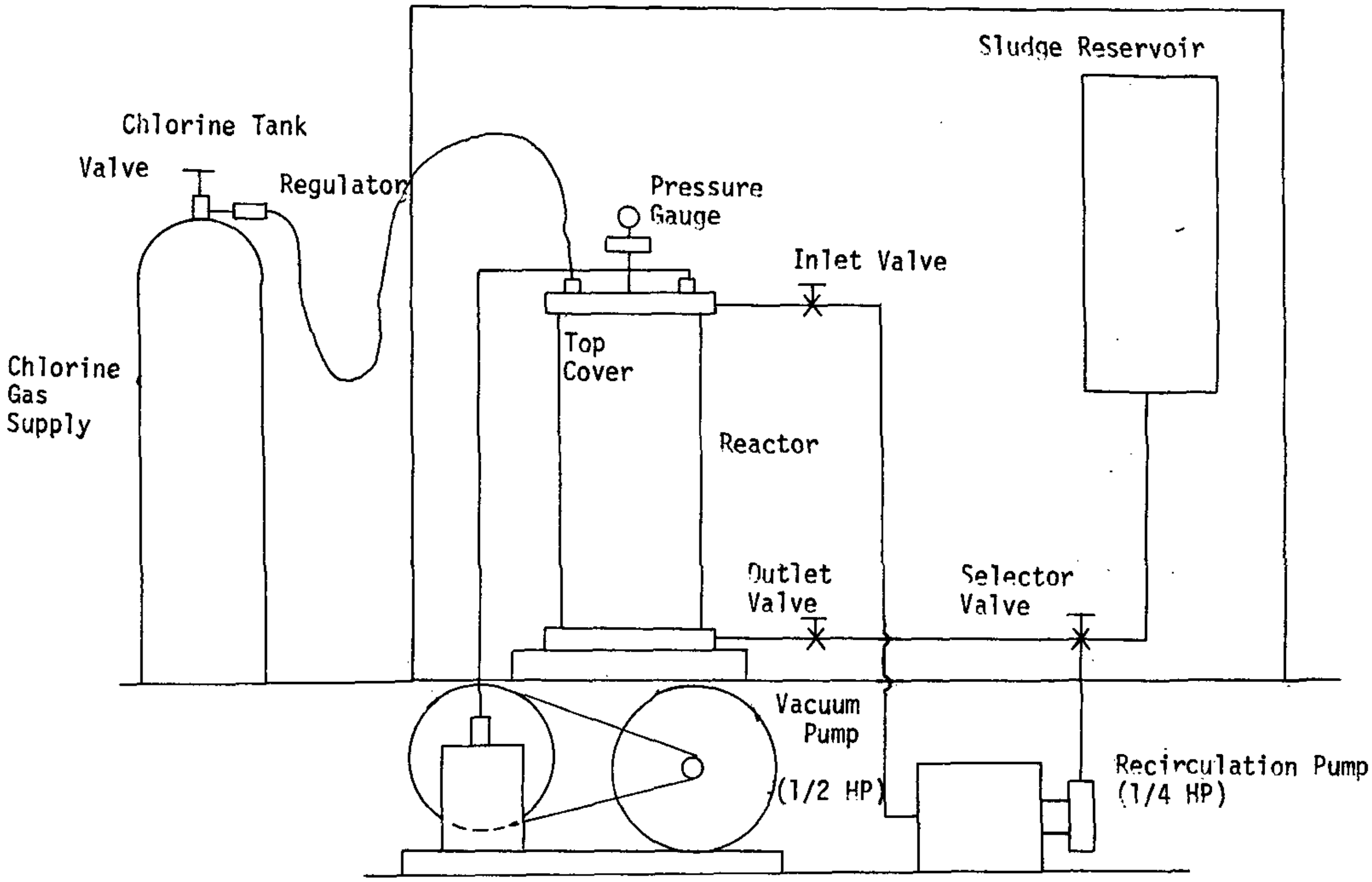


Figure 1.
The Purifax Unit

B. Determination of Chlorine Dosage

Calibration curves are provided by BIF for the Purifax Unit, which relates chlorine dosage to initial system loading of sludge in a linear form as shown in Figure 2. To apply the curve, a desired chlorine dosage is chosen on the "dosage" scale. Then read across to the appropriate chlorine pressure curve and drop straight down to the "initial system loading" scale. This gives the volume of sludge in ml that must be pumped into the Purifax Unit before the unit is charged with chlorine to a pressure of 5 psi or 10 psi, depending on which pressure curve is used to yield the desired dosage. For example, if the chlorine dosage is 1500 mg/l the corresponding initial system loading should be of 1400 ml of sludge.

C. Preparation of Sludges

Samples of household septage different in age were collected for the study from nearby areas of Amherst, Massachusetts. Primary and anaerobically digested sludge samples from Amherst Wastewater Treatment Plant were also included in the investigation. These types of sludge are usually consistent in characteristics and their inclusion in the experiments could be served as control for comparison with the experimental results of highly variable septages.

Since the Purifax Unit is a miniaturized laboratory apparatus, all the large particles in a sludge sample must be reduced in size by means of a blender in order to be pumped into the reactor through the small openings and conduits of the unit without clogging. The average blending time used was about 3 minutes.

In order to further prevent clogging the suspended solids concentration of the sludge to be pumped through the Purifax Unit must be less than 2% and is preferred to be around 1%. Therefore all the original samples were diluted with distilled and deionized water. The dilution ratio used was 1 volume of original sample to 2 volumes of dilution water, because the septage and sludge samples had more or less suspended solids concentrations ranging from 2 to 6%.

D. Operation Steps

The operation of the Purifax Unit can be described in the following steps.

(1) Turn on the vacuum pump until the reading of the pressure gauge reaches 26 inches of mercury.

(2) Shut off the vacuum pump.

(3) Turn on the recirculation pump and pump the desired initial system loading of sludge into the reactor by switching the selector valve open to the sludge reservoir. Then shut off the recirculation pump and then re-evacuate the system to 26 inches of mercury

(4) Open the chlorine tank valve slowly and then adjust the chlorine gas flow by turning the regulator.

(5) Open the chlorine inlet valve of the reactor slowly and admit chlorine gas into the reactor until the reading of the pressure gauge reaches 5 psi. Then close the valve and back off the regulator as soon as possible. Shut off the chlorine tank valve.

(6) Turn on the recirculation pump and immediately switch the selector valve open to the sludge reservoir. At the same time start to count time by on an electric timer.

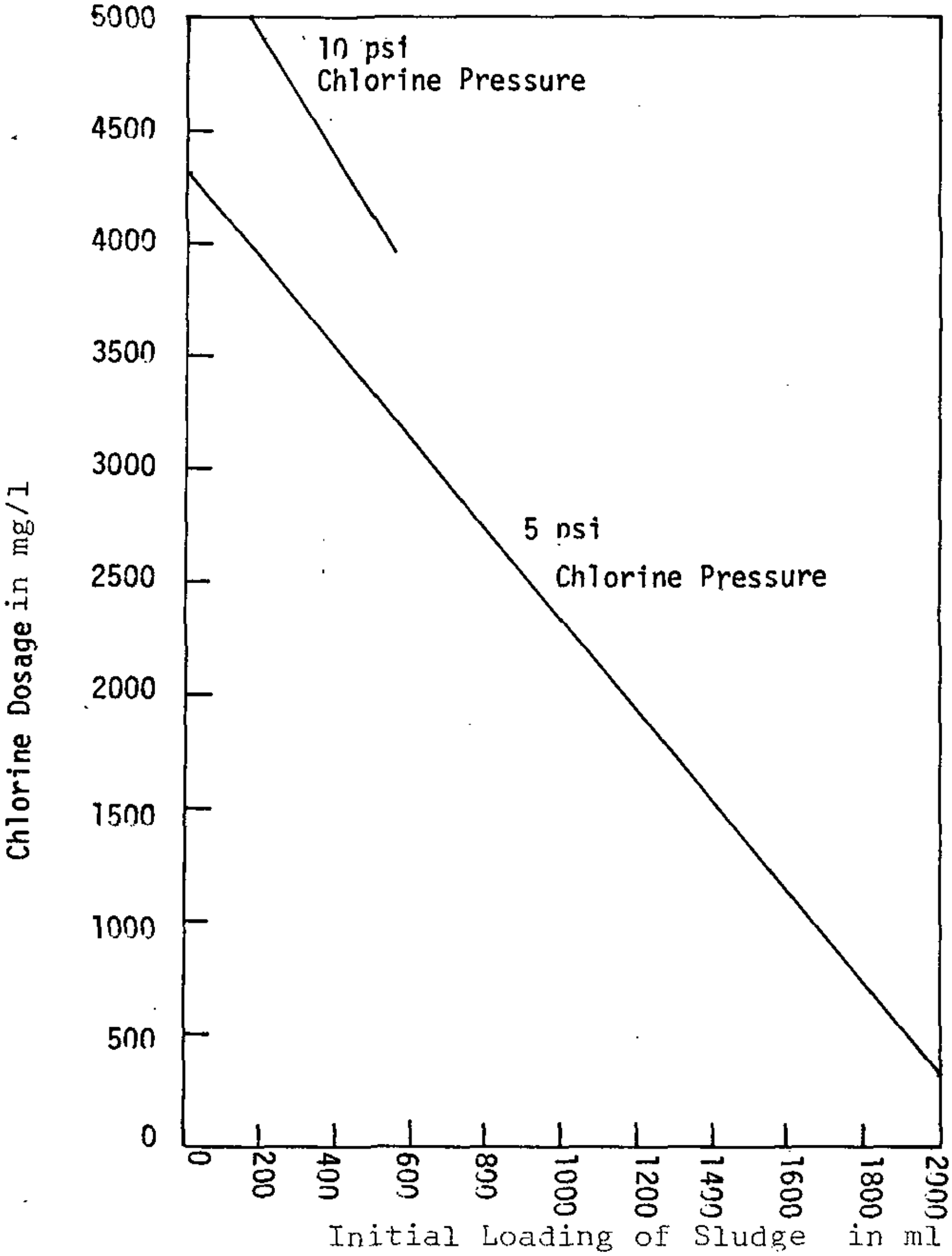


Figure 2.

Calibration Curve for Chlorine Dosage

(7) Continue step (6) until all 2500 ml of sludge is drawn into the reactor. Then switch the selector valve open to the reactor outlet and thus mix the contents in the reactor for a specified time.

(8) The "Purifax" treatment is completed when a specified mixing time is reached and by then open the discharge valve (not shown in Figure 1) and collect the treated sample for analysis.

(9) By pumping tap water into the reactor instead of sludge from the reservoir. This step should be repeated three or four times.

E. Analysis of Sludge Characteristics

Both untreated and treated (purifaxed) sludge and septage samples were subjected to the following preconditioning before being analyzed.

(a) No preconditioning, referred to hereafter as "whole sample".

(b) Samples centrifuged at 2550 rpm for 5 minutes in a Model CL International Clinical Centrifuge (at about 730 G); the supernatant of the centrifuged samples collected for analysis, referred to hereafter as "centrate".

(c) Samples filtered through Whatmann No. 40 filter paper; the filtrate collected for analysis, referred to hereafter as "filtrate".

The following characteristics of both untreated and treated sludge samples were analyzed and used as parameters for a measurement of the efficacy of the Purifax Process.

pH

Total Solids

Suspended Solids

Volatile Suspended Solids

Ammonia Nitrogen

TOC

COD

BOD_5

Chlorine Residuals

Total Phosphate and Orthophosphate

Specific Resistance

A Beckman Model 915 Total Organic Carbon Analyzer was used for the determination of TOC. Calibration curves of total carbon and inorganic carbon were prepared by following the instruction manual of the TOC Analyzer (see Appendix). TOC value is the difference of total carbon and inorganic carbon values. Samples were diluted by distilled, deionized water before being subjected to the TOC test.

A Bausch & Lomb Spectronic-20 spectrophotometer was used for the determination of both ammonia nitrogen and chlorine residuals (OTA method). Respective calibration curves were prepared by following the instruction of the "Standard Methods"[10] (see Appendix). Samples were diluted when needed.

All the analyses were made in accordance with the "Standard Method" except the determination of specific resistance for which a procedure proposed by Coackley and Eckenfelder[11,12] were followed. The experimental apparatus consisted of a Buchner funnel, a graduated buret, a vacuum pump and a manometer (U tube) as shown in Figure 3. The apparatus was assembled so that measurements can be made of the volumes of filtrate collected at various intervals of time during filtration.

Because the Purifax Process had disinfected the sludges and may have formed toxic chlorocompounds remaining with the sludges, special caution was taken in BOD determination to minimize such post-chlorination effects. The chlorinated sludges were stored at room temperature until no chlorine residuals can be detected and then diluted with seeded BOD-dilution water as needed for the BOD determination.

Chlorine residuals were measured by the OTA method (Orthotolidine Arsenite) in accordance with the "Standard Methods".[10] But due to the apparent release of fast-reacting (to orthotolidine) chlorine residuals from some of the formed chlorocompounds during the analysis, the arsenite must be added within 5 seconds after orthotolidine was added in measuring free chlorine residuals. The difference between chlorine added and chlorine residuals is known as chlorine demand.

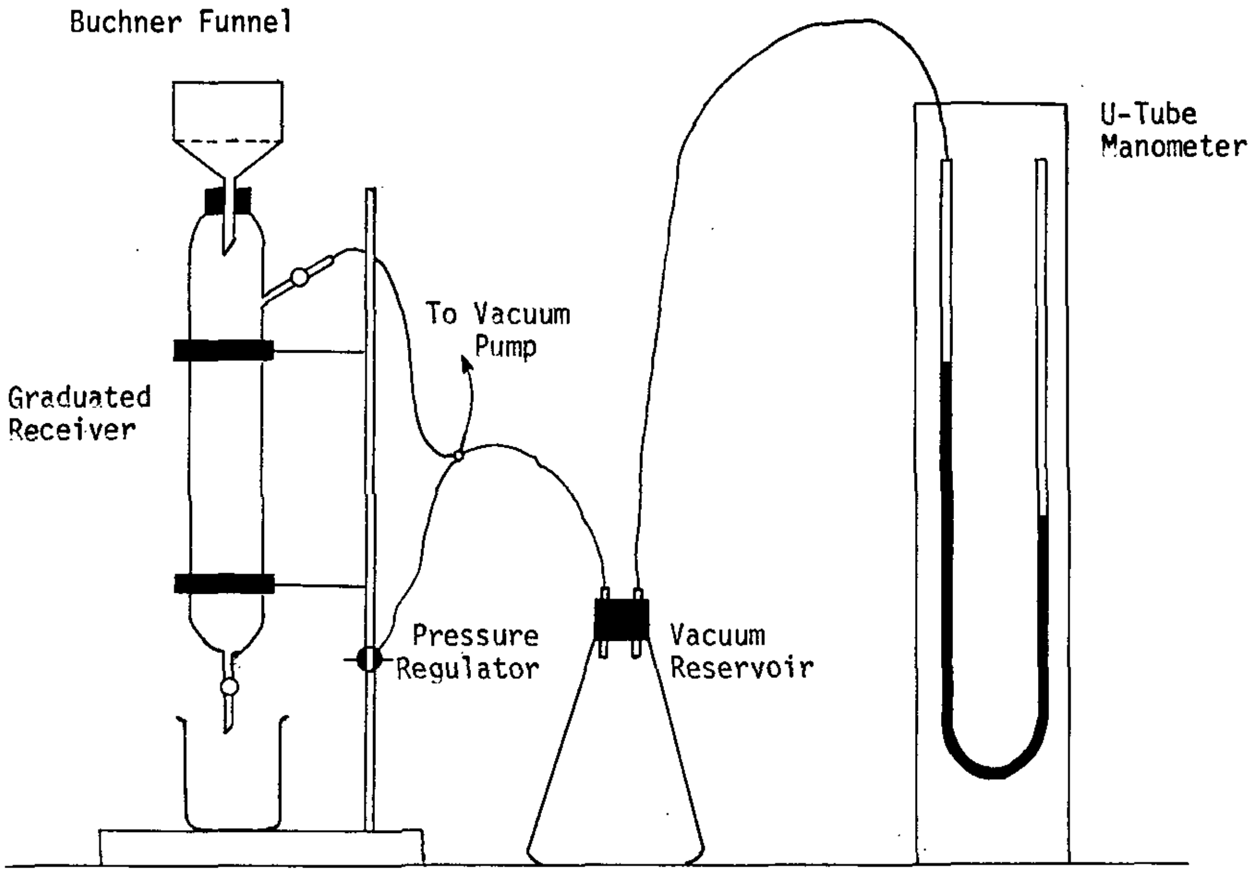


Figure 3.

Apparatus for Vacuum Filtration

IV. EXPERIMENTAL RESULTS AND DISCUSSION

The experimental results and discussion are presented in two parts as follows:

Part A - Investigation of the effects of chlorine dosage and mixing time on the performance of the Purifax Process.

Part B - Investigation of variation in characteristics of different sources of household septages and their treatability by the Purifax Process.

Part A.

Investigation of the effects of chlorine dosage and mixing time on the performance of the Purifax Process.

I. General Description and Summary of Data

This part of the study is preliminary in nature. It was decided to investigate the degree of purifaxing which can be achieved with various dosages and for different mixing (reacting) time intervals. The dosages of chlorine used ranged from 500 mg/l to 2500 mg/l with increments of 500 mg/l. The three different time intervals used were 5 minutes, 8 minutes and 11 minutes (manufacturer's typical mixing time is 5 to 12 minutes). The sludge samples used were:

(1) primary sludge from Amherst, Massachusetts Wastewater Treatment Plant which would serve as a control for comparison with the septage, and

(2) one sample of domestic septage from Amherst, Massachusetts area with an age of 3 years.

The following characteristics of both untreated and treated samples were analyzed and used as parameters for this preliminary investigation:

pH

BOD_5 (whole sample, centrate and filtrate)

COD (whole sample, centrate and filtrate)

Total Phosphate (centrate and filtrate)

Ortho Phosphate (centrate and filtrate)

NH_3-N (whole sample, centrate and filtrate)

Chlorine Residuals (centrate and filtrate)

All the analysis were made in accordance with the "Standard Method".[10]

The results are presented in Tables I to VI which summarize all the experimental data. Tables I to III are the data on septage and Tables IV to VI on primary sludge. The data are further prepared in form of graphs as shown in the following figures :

Figures 4 to 6	Removal of NH_3-N of Septage
Figures 7 to 9	Removal of NH_3-N of Primary Sludge
Figures 10 to 12	Removal of BOD_5 of Septage
Figures 13 to 15	Removal of BOD_5 of Primary Sludge

Figures 16 to 18	Removal of COD of Septage.
Figures 19 to 21	Removal of COD of Primary Sludge.

2. Discussion of Experimental Results

The discussion is presented in the following aspects:

(a) pH

(b) Chlorine Residuals

(c) NH_3-N

(d) BOD_5

(e) COD

(f) Phosphates

(a) pH:

The pH values of the treated samples were about 2 or less. As chlorine dosage and mixing time increased, pH values became lower despite the characteristic differences of the samples. The formation of HCl could be the main cause which depressed the pH.

(b) Chlorine Residuals:

Both free and total chlorine residuals of the treated samples were determined by using OTA method. Tables I to VI show the results obtained. For the septage, the chlorine residuals were very low at low dosages (500 mg/l and 1000 mg/l), especially the free chlorine residuals. As chlorine dosage increased beyond 1500 mg/l, the value of chlorine residuals greatly increased. This apparently demonstrates that most of the chlorine demand of the septage could have been met with chlorine dosages less than 1500 mg/l. The mixing time had little effect on the residuals at low chlorine dosages. As dosage increased, longer mixing time lowered the chlorine residuals. It is also interesting to note that the chlorine residuals of the centrate were higher than those of the filtrate. Similar and compatible results were obtained for primary sludge.

TABLE I.

Septage
Reaction Time: 5 Minutes

Measured Characteristics	Untreated Sample	Chlorine Dosage (mg/l)				
		500	1000	1500	2000	2500
pH(Units)	5.6	2.4	2.2	2.3	2.1	1.85
NH$_3$-N(mg/l)						
Whole Sample	42	27	14	13.5	13	12.5
Centrate	30	16	11	11	9.5	7.5
Filtrate	23	14.5	6.7	2	2	2
COD(mg/l)						
Whole Sample	14700	12402	11524	10000	9280	8528
Centrate	3293	1882	1278	978	900	800
Filtrate	2000	902	752	720	677	640
BOD$_5$(mg/l)						
Whole Sample	3630	3217	3160	2910	2810	2790
Centrate	788	475	450	345	335	330
Filtrate	657	450	393	322	262	247
Total P(mg/l)						
Centrate	25	25	25	25	25	25
Filtrate	25	25	25	25	25	25
Ortho P(mg/l)						
Centrate	25	25	25	25	25	25
Filtrate	25	25	25	25	25	25
Total Chlorine Residual(mg/l)						
Centrate		14.8	34	160	248	365
Filtrate		11.2	16	37.5	50	58
Free Chlorine Residual (mg/l)						
Centrate		0.6	10	80	170	337.5
Filtrate		0	2.8	22.5	33	38

TABLE II.

Septage
Reaction Time: 8 Minutes

Measured Characteristics	Untreated Sample	Chlorine Dosage (mg/l)				
		500	1000	1500	2000	2500
pH(Units)	5.6	2.4	2.1	2.2	2.0	1.9
NH_3-N(mg/l)						
Whole Sample	42	22	16	15	13.5	11.5
Centrate	30	16.5	10	7.5	7.5	7.5
Filtrate	23	16	5.5	2.5	2.5	2.0
COD(mg/l)						
Whole Sample	14700	12112	11348	9900	8810	8200
Centrate	3293	1360	1058	960	880	790
Filtrate	2000	800	752	720	720	602
BOD_5(mg/l)						
Whole Sample	3630	2516	2460	2216	2216	2164
Centrate	788	275	275	275	250	250
Filtrate	657	247	225	218	210	195
Total P(mg/l)						
Centrate	25	20	20	20	20	20
Filtrate	25	20	20	20	20	20
Ortho P(mg/l)						
Centrate	25	20	20	20	20	20
Filtrate	25	20	20	20	20	20
Total Chlorine Residual(mg/l)						
Centrate		10	24.5	72	158	200
Filtrate		8.5	13.6	21.5	40	44
Free Chlorine Residual (mg/l)						
Centrate		0.4	0.6	44	148	200
Filtrate		0	0	14.5	22	25

TABLE III.

Septage
Reaction Time: 11 Minutes

Measured Characteristics	Untreated Sample	Chlorine Dosage (mg/l)				
		500	1000	1500	2000	2500
pH(Units)	5.6	1.8	1.7	1.7	1.6	1.4
NH_3-N(mg/l)						
Whole Sample	42	22	13.5	11	11.5	6.5
Centrate	30	12.5	9	6.5	6.5	6.5
Filtrate	23	16	5	2	2	2
COD(mg/l)						
Whole Sample	14700	12014	11200	9562	8600	6961
Centrate	3293	1200	1040	880	840	752
Filtrate	2000	720	720	627	600	480
BOD_5(mg/l)						
Whole Sample	3630	1785	1612	1585	1585	1585
Centrate	788	275	210	195	195	195
Filtrate	657	150	135	135	135	135
Total P(mg/l)						
Centrate	25	20	20	20	20	20
Filtrate	25	20	20	20	20	20
Ortho P(mg/l)						
Centrate	25	20	20	20	20	20
Filtrate	25	20	20	20	20	20
Total Chlorine Residual(mg/l)						
Centrate		7.8	19	58	96	150
Filtrate		7.3	11.2	11	27.5	34
Free Chlorine Residual (mg/l)						
Centrate		0.3	0.6	1.0	104	110
Filtrate		0	0	0	20	20

TABLE IV.

Primary Sludge
Reaction Time: 5 Minutes

Measured Characteristics	Untreated Sample	Chlorine Dosage (mg/l)				
		500	1000	1500	2000	2500
pH(Units)	5.6	2.0	1.7	1.8	1.6	1.5
NH_3-N(mg/l)						
Whole Sample	45	23	19	18	16	16
Centrate	31	15	7	7	7	6
Filtrate	23	15	8	7	7	6
COD(mg/l)						
Whole Sample	6050	4348	4326	3670	3090	2920
Centrate	2286	1694	1568	1502	1369	1269
Filtrate	1513	1167	1089	1018	917	800
BOD_5(mg/l)						
Whole Sample	2800	1600	1462	1032	956	910
Centrate	1478	846	766	728	728	716
Filtrate	1240	662	621	600	600	600
Total P(mg/l)						
Centrate	52	50.5	50.5	50.5	50	50
Filtrate	50	50	50	47.5	47.5	47.5
Ortho P(mg/l)						
Centrate	49	46	46	46	46	46
Filtrate	49	46	46	46	46	46
Total Chlorine Residual(mg/l)						
Centrate		17	50	124	149	315
Filtrate		15	13	55	57	128.5
Free Chlorine Residual (mg/l)						
Centrate		2.5	22.5	63	125	280
Filtrate		1.6	5.8	24	42	49

TABLE V.

Primary Sludge
Reaction Time: 8 Minutes

Measured Characteristics	Untreated Sample	Chlorine Dosage (mg/l)				
		500	1000	1500	2000	2500
pH(Units)	5.6	2.2	1.8	1.8	1.8	1.7
NH_3-N(mg/l)						
Whole Sample	45	22	19	17	15	14
Centrate	31	14	13	7	7	5
Filtrate	23	14	5	5	4	4
COD(mg/l)						
Whole Sample	6050	4105	3374	3237	3005	2687
Centrate	2286	1635	1502	1394	1253	1169
Filtrate	1513	1090	1042	1000	906	698
BOD_5(mg/l)						
Whole Sample	2800	1410	1142	1010	921	816
Centrate	1478	720	661	660	600	600
Filtrate	1240	652	636	600	540	510
Total P(mg/l)						
Centrate	52	49	49	49	46	46
Filtrate	50	49	49	49	46	46
Ortho P(mg/l)						
Centrate	49	45	45	44	44	44
Filtrate	49	45	45	44	44	44
Total Chlorine Residual(mg/l)						
Centrate		15	39.5	112	147	257.5
Filtrate		7.5	13.2	29	51	66.5
Free Chlorine Residual (mg/l)						
Centrate		1.0	3.2	16	40	38
Filtrate						

TABLE VI.

Primary Sludge
Reaction Time: 11 Minutes

Measured Characteristics	Untreated Sample	Chlorine Dosage (mg/l)				
		500	1000	1500	2000	2500
pH(Units)	5.6	2.1	1.9	1.8	1.8	1.4
NH_3-N(mg/l)						
Whole Sample	45	18	16.5	13	12	11
Centrate	31	13	3	2.5	2.5	2.5
Filtrate	23	12	1.2	1.2	1.2	1.2
COD(mg/l)						
Whole Sample	6050	3623	3204	3004	2800	2672
Centrate	2286	1527	1394	1302	1194	1069
Filtrate	1513	993	940	900	797	652
BOD_5(mg/l)						
Whole Sample	2800	1080	930	780	780	660
Centrate	1478	630	545	540	520	480
Filtrate	1240	510	485	480	467	445
Total P(mg/l)						
Centrate	52	49	48	49	46	46
Filtrate	50	49	48	49	46	46
Ortho P(mg/l)						
Centrate	49	45	45	44	44	44
Filtrate	49	45	45	44	44	44
Total Chlorine Residual(mg/l)						
Centrate		13	25.5	87	135	172.5
Filtrate		7.5	12.4	13	37.5	40
Free Chlorine Residual (mg/l)						
Centrate		1.7	5	52	102	127.5
Filtrate		0.8	0.8	3	19	29

(c) NH_3-N:

The ammonia concentration of the septage was about 42 mg/l of which 54% was in dissolved state. The amount of ammonia in the primary sludge was around 45 mg/l of which 50% was soluble.

The percentage removal of ammonia as related to chlorine dosage and mixing time is shown in Figures 4 to 9.

In the case of septage as shown in Figures 4 to 6, it can be observed that: (a) The removal of NH_3-N by chlorination increased with increased chlorine dosage and mixing time. However, as chlorine dosage increased beyond 1500 mg/l, little improvement in removal was obtained. The effect of mixing time beyond 5 minutes on NH_3-N removal was not significant. (b) Chlorination was more effective in removing soluble NH_3-N than that portion in combination with suspended solids. Removal of NH_3-N could not be improved with chlorine dosages greater than 1500 mg/l and mixing time beyond 8 minutes.

For primary sludge the removal of NH_3-N as related to chlorine dosage and mixing time is shown in Figures 7 to 9. Although the results were generally similar to those for the septage, sufficient differences were demonstrated in their characteristics as far as chlorination was concerned.

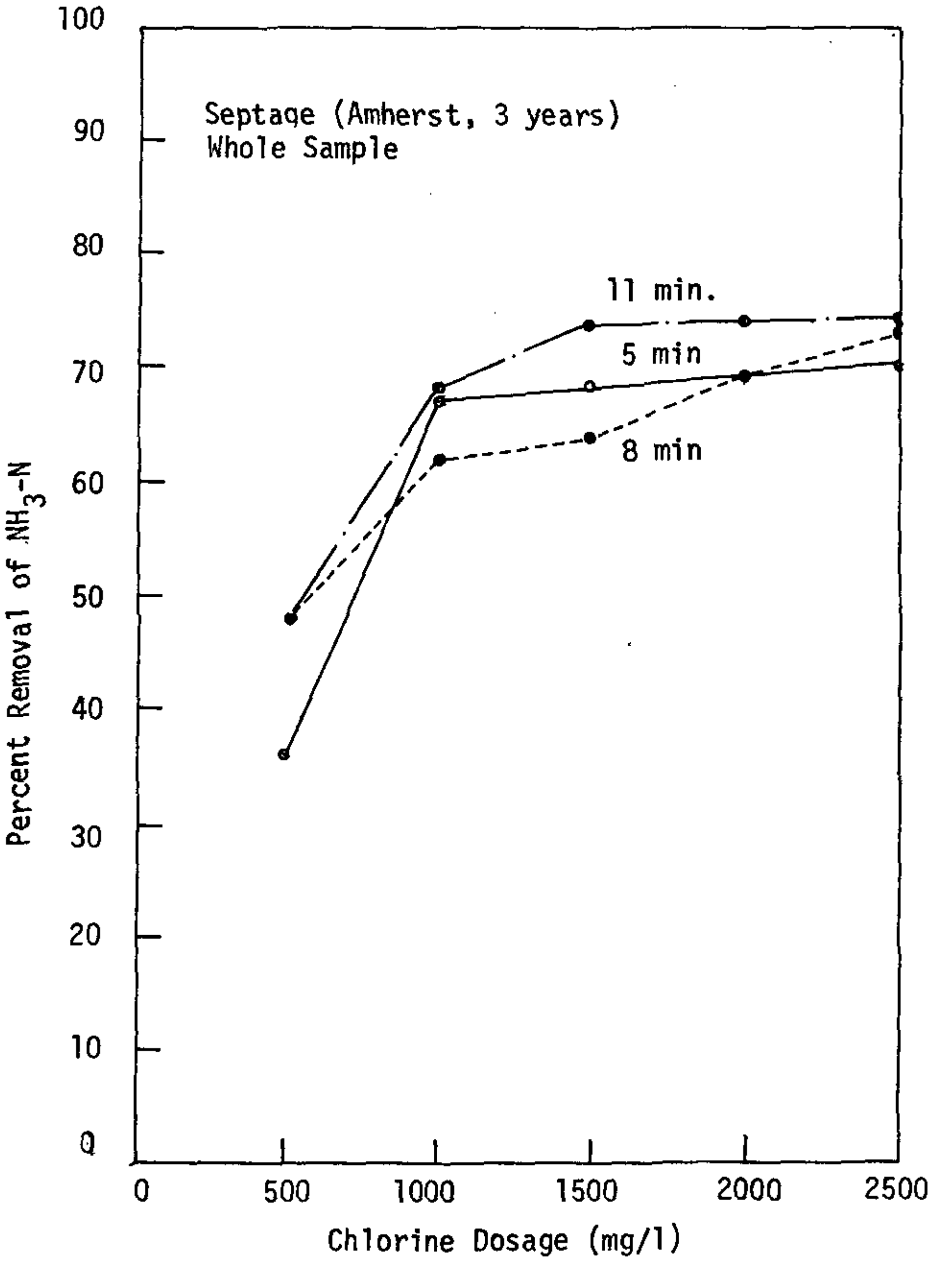


Figure 4.

Percent Removal of NH_3-N in Whole Sample of Septage.

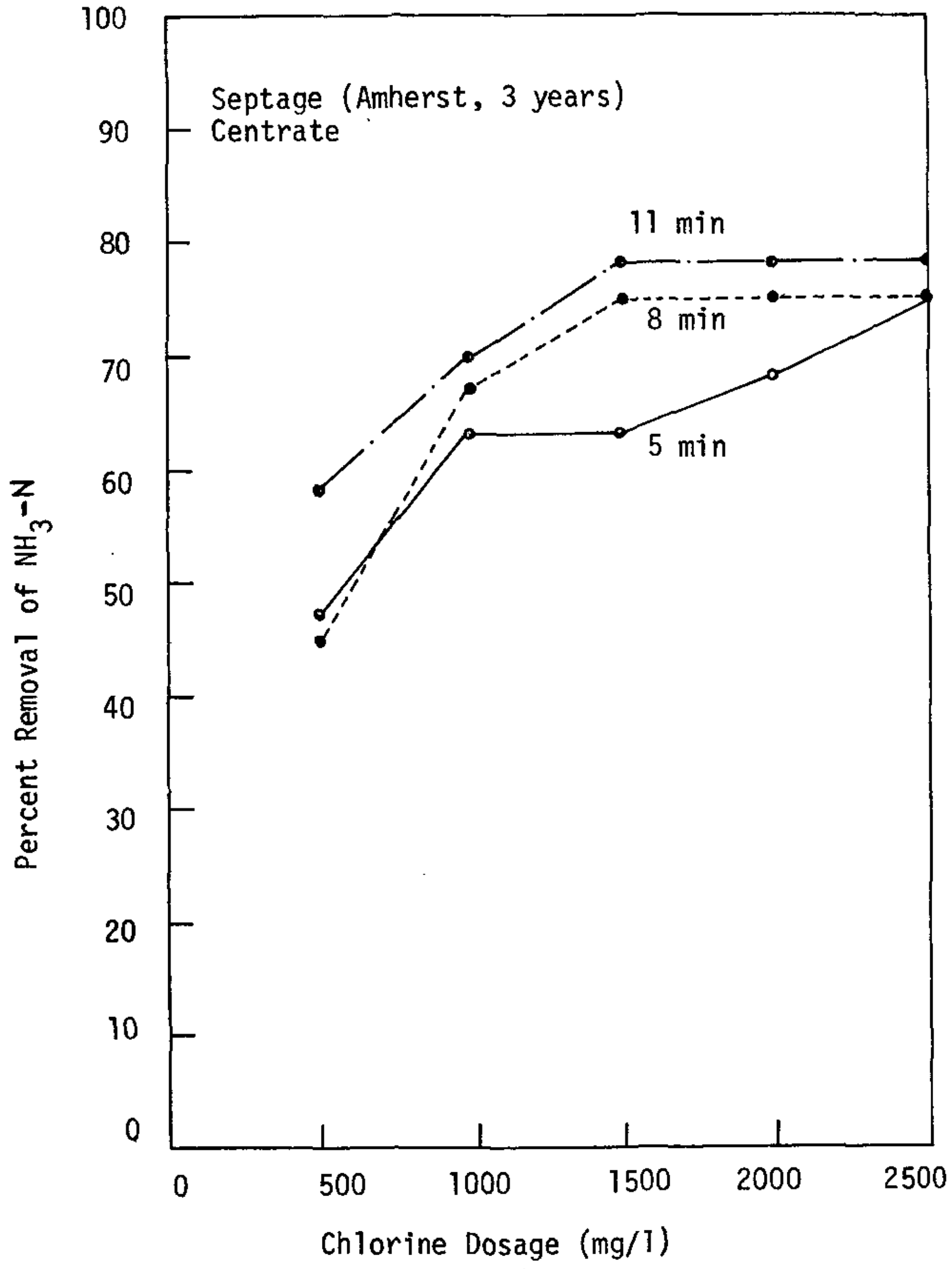


Figure 5.

Percent Removal of NH_3-N in Centrate of Septage.

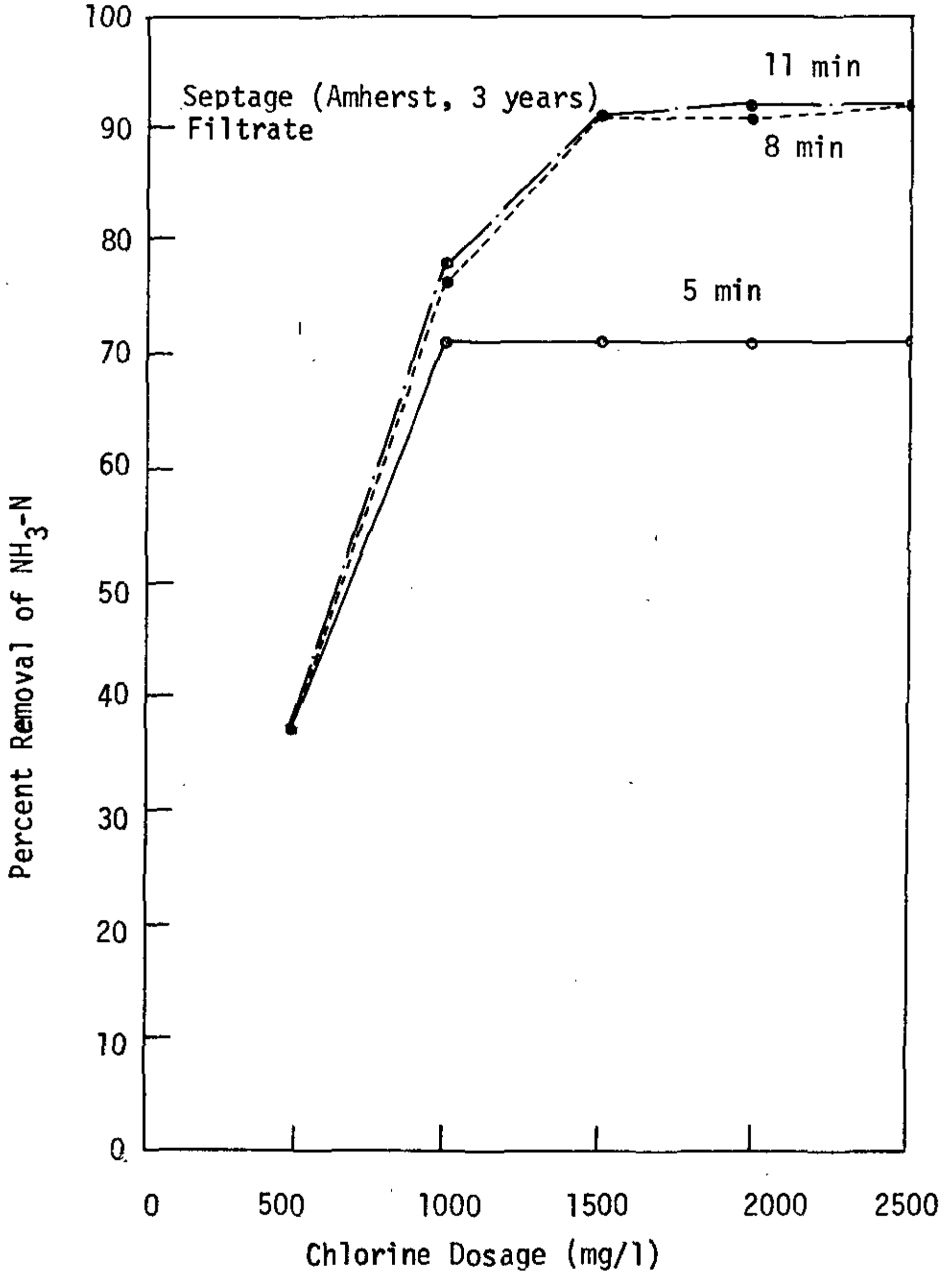


Figure 6.

Percent Removal of NH_3-N in Filtrate of Septage.

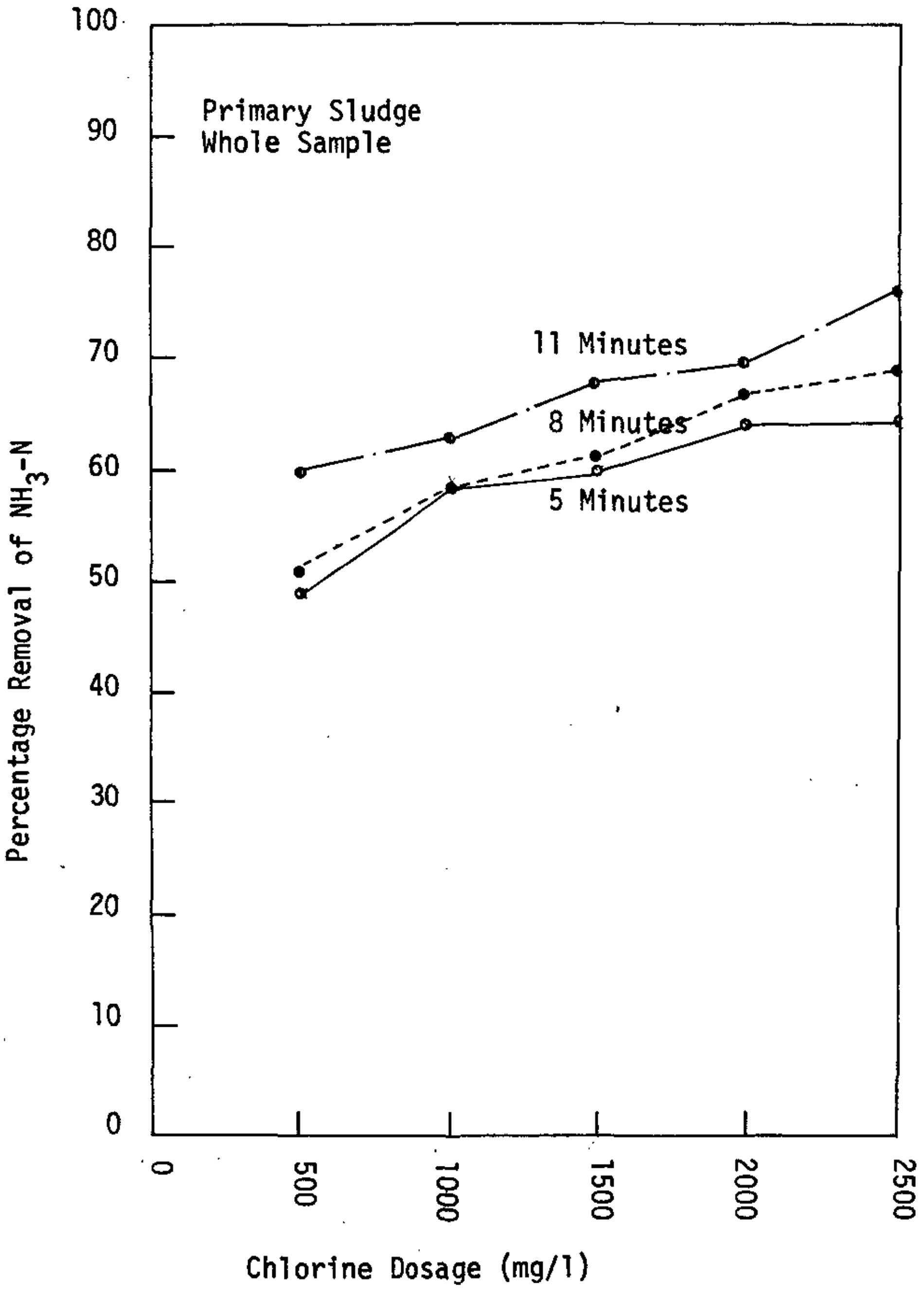


Figure 7.

Percent removal of NH_3-N in Whole Samples of Primary Sludge.

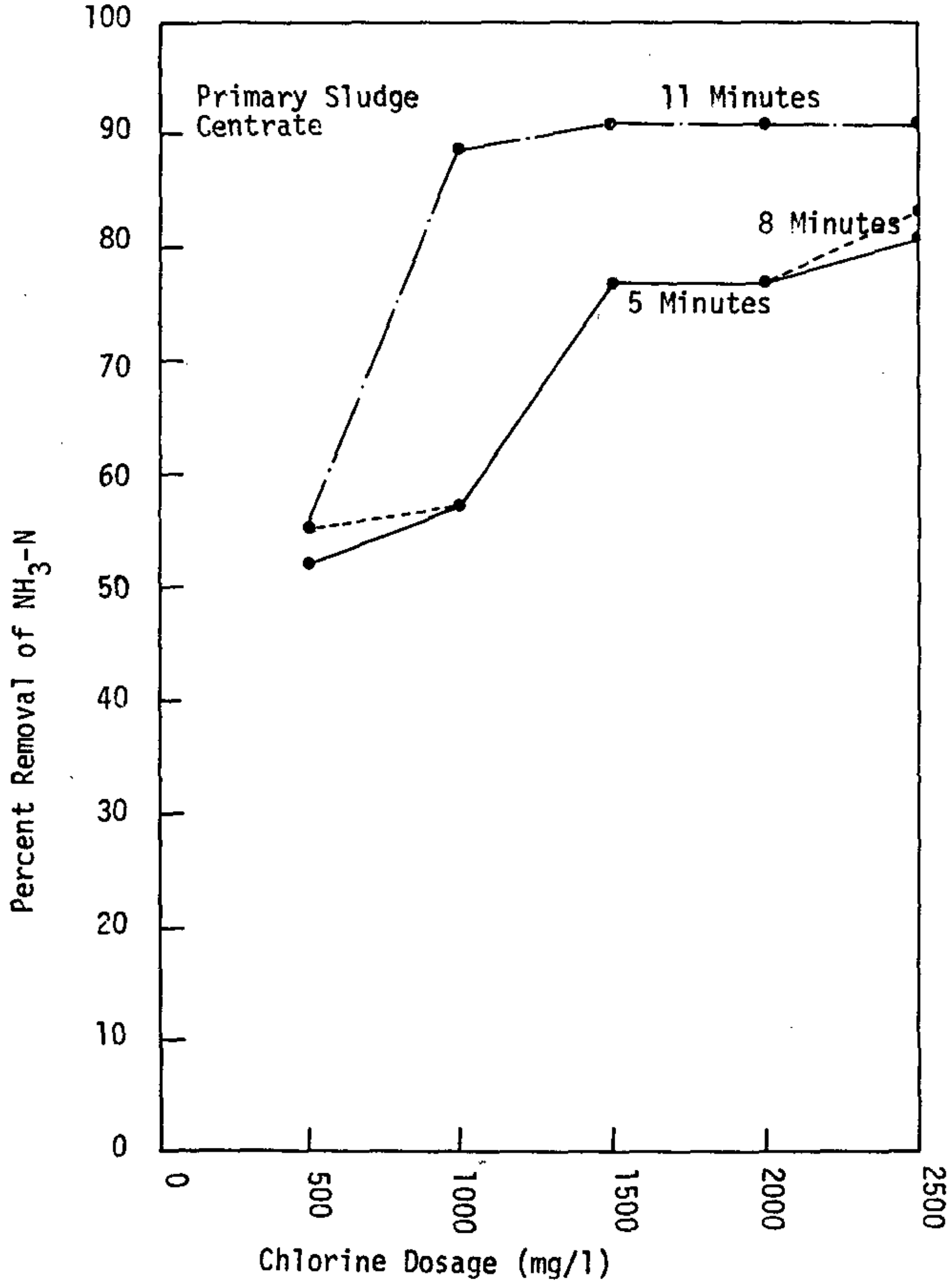


Figure 8.

Percent Removal of NH_3-N in Centrate of Primary Sludge

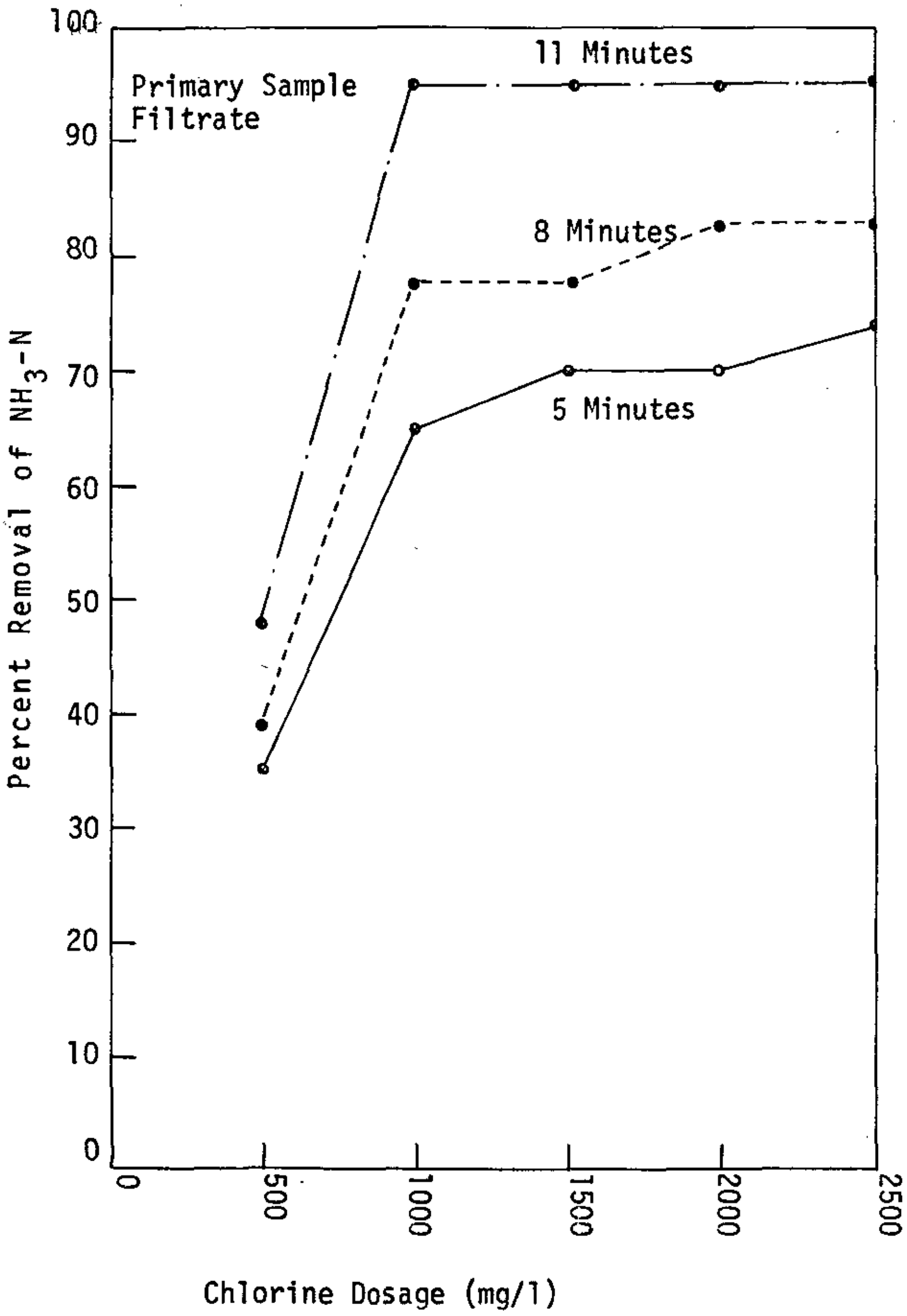


Figure 9.

Fig. 9. Percent Removal of NH_3-N in Filtrate of Primary Sludge

(d) BOD_5:

The removal of BOD_5 by chlorination represents an important form of chlorine demand. The BOD_5 of the septage was 3630 mg/l of which only 18% was soluble. The BOD_5 of the primary sludge was 2800 mg/l of which nearly 50% was soluble.

The removal of BOD_5 as a function of chlorine dosage and mixing time are shown in Figures 10 to 12 for septage, in Figures 13 to 15 for primary sludge.

For the septage, it seemed that at a mixing time extended beyond 8 minutes, the chlorine dosage within the range of 500 mg/l to 2500 mg/l had no significant effects on the reduction of BOD_5. When the mixing time was 5 minutes, however, larger dosages of chlorine resulted in better removal. On the other hand, at a given dosage, longer mixing time produced higher reduction of BOD_5.

For the primary sludge, the removal patterns of BOD_5 followed the general trends as demonstrated for the septage in regard to the removal efficiency as a function of chlorine dosage and mixing time, but with a lessened degree. But, there was one observation which should not be neglected. It seemed that the dissolved portion of BOD_5 in the primary sludge was less readily broken down by chlorination than its counterpart portion of BOD_5 in the septage,and on the other hand the suspended portion of BOD_5 in the primary sludge was more readily broken down by chlorination than its counterpart in the septage.

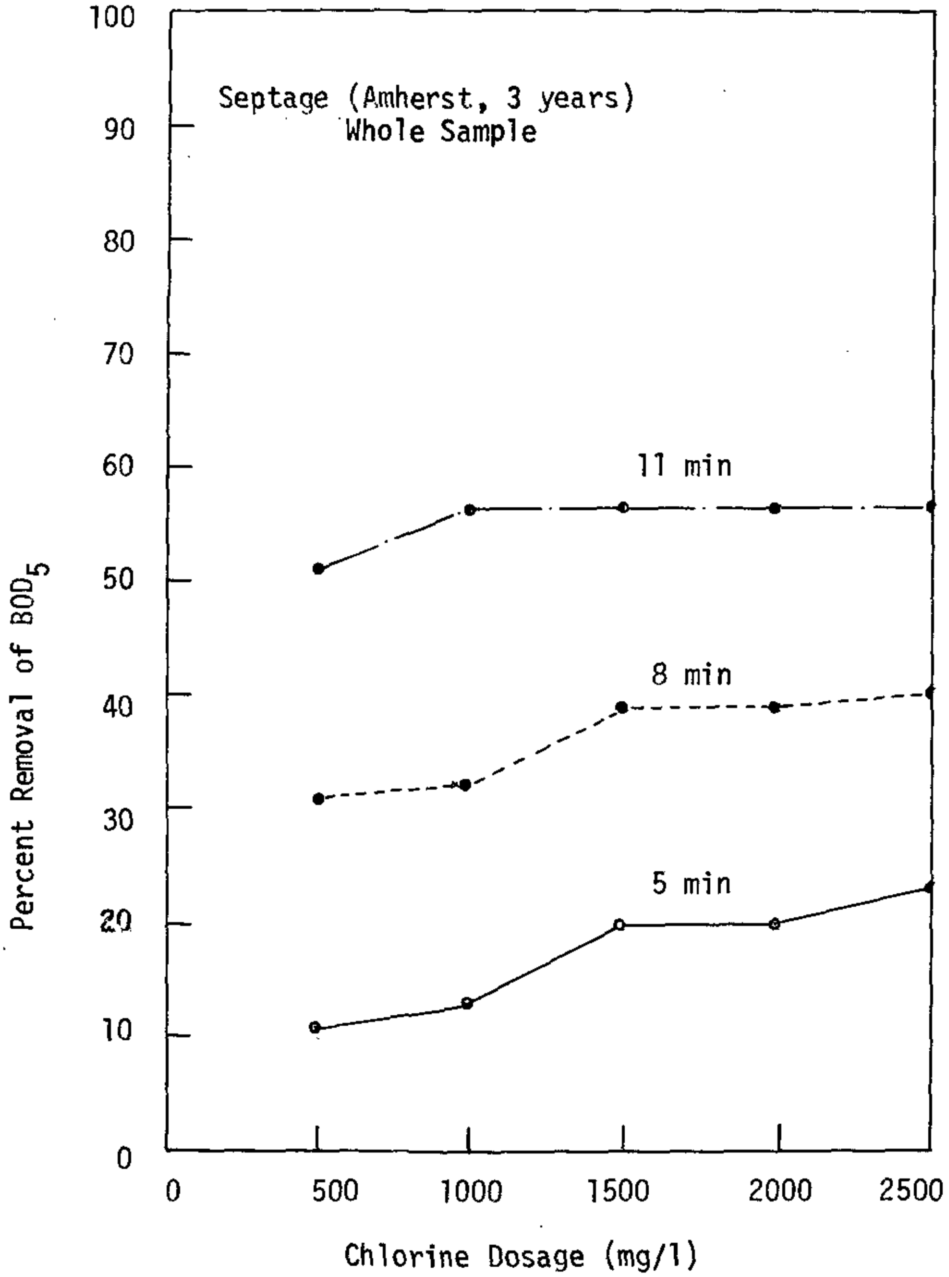


Figure 10.

Percent Removal of BOD_5 in Whole Sample of Septage

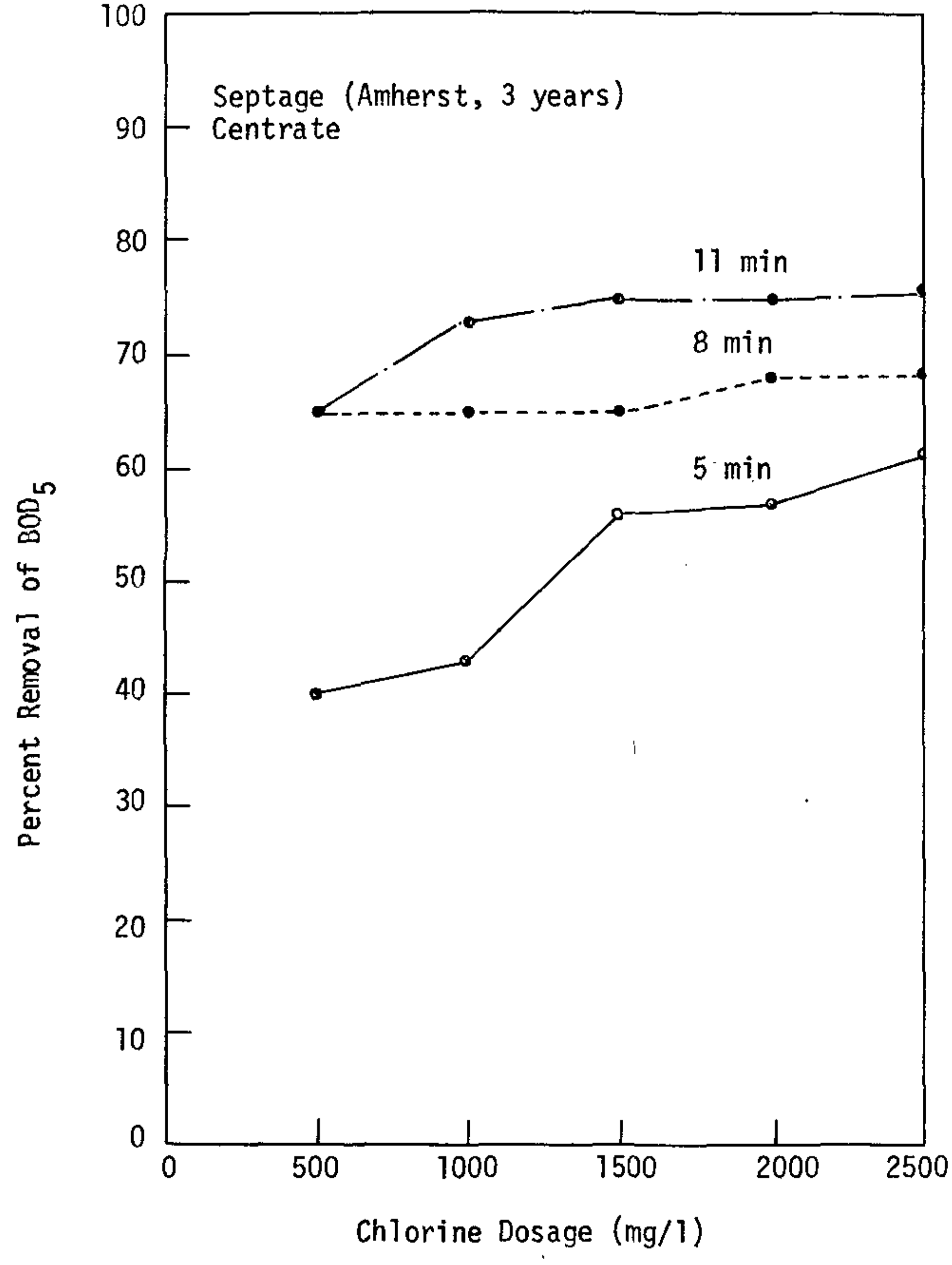


Figure 11.

Percent Removal of BOD_5 in Centrate of Septage

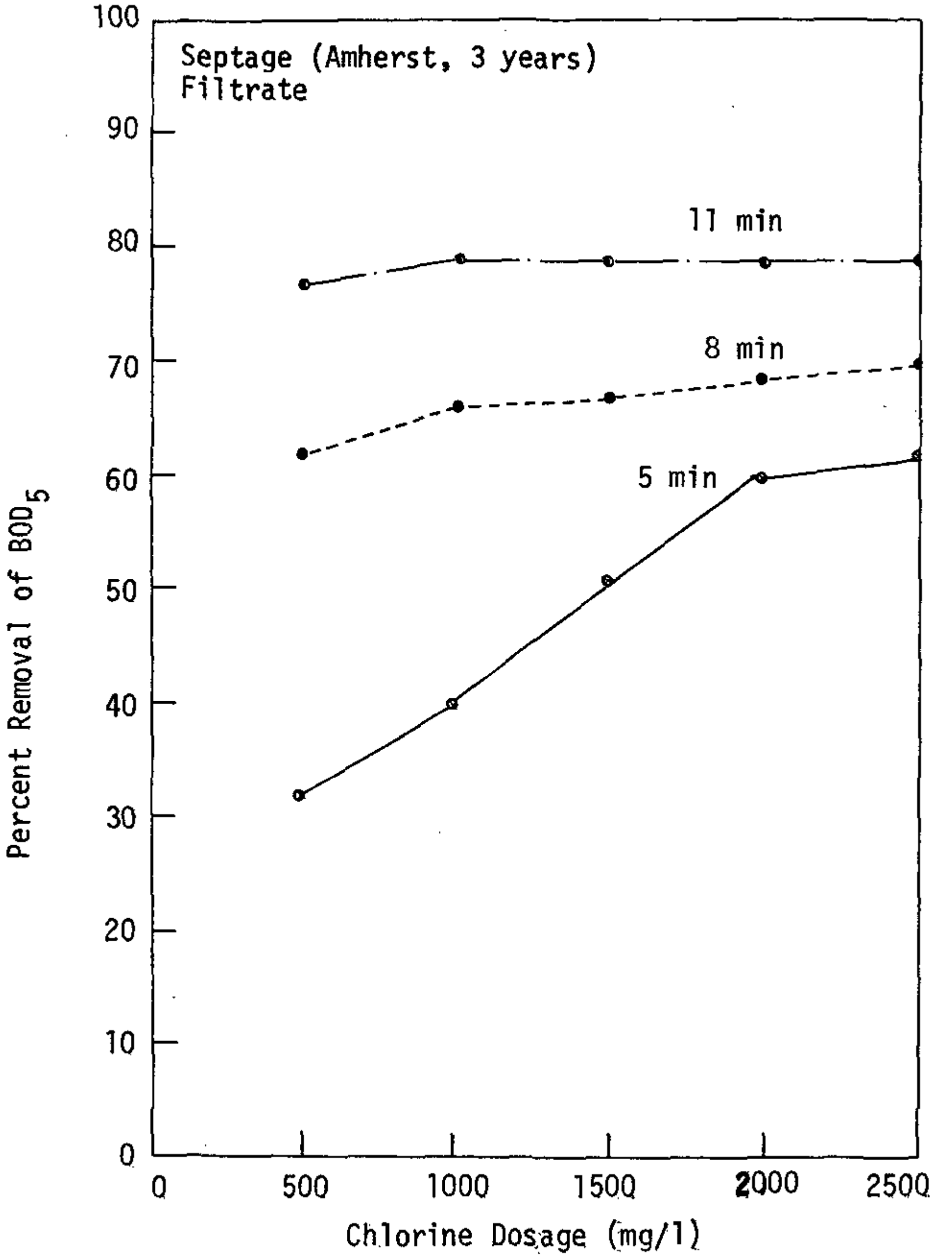


Figure 12.

Percent Removal of BOD_5 in Filtrate of Septage.

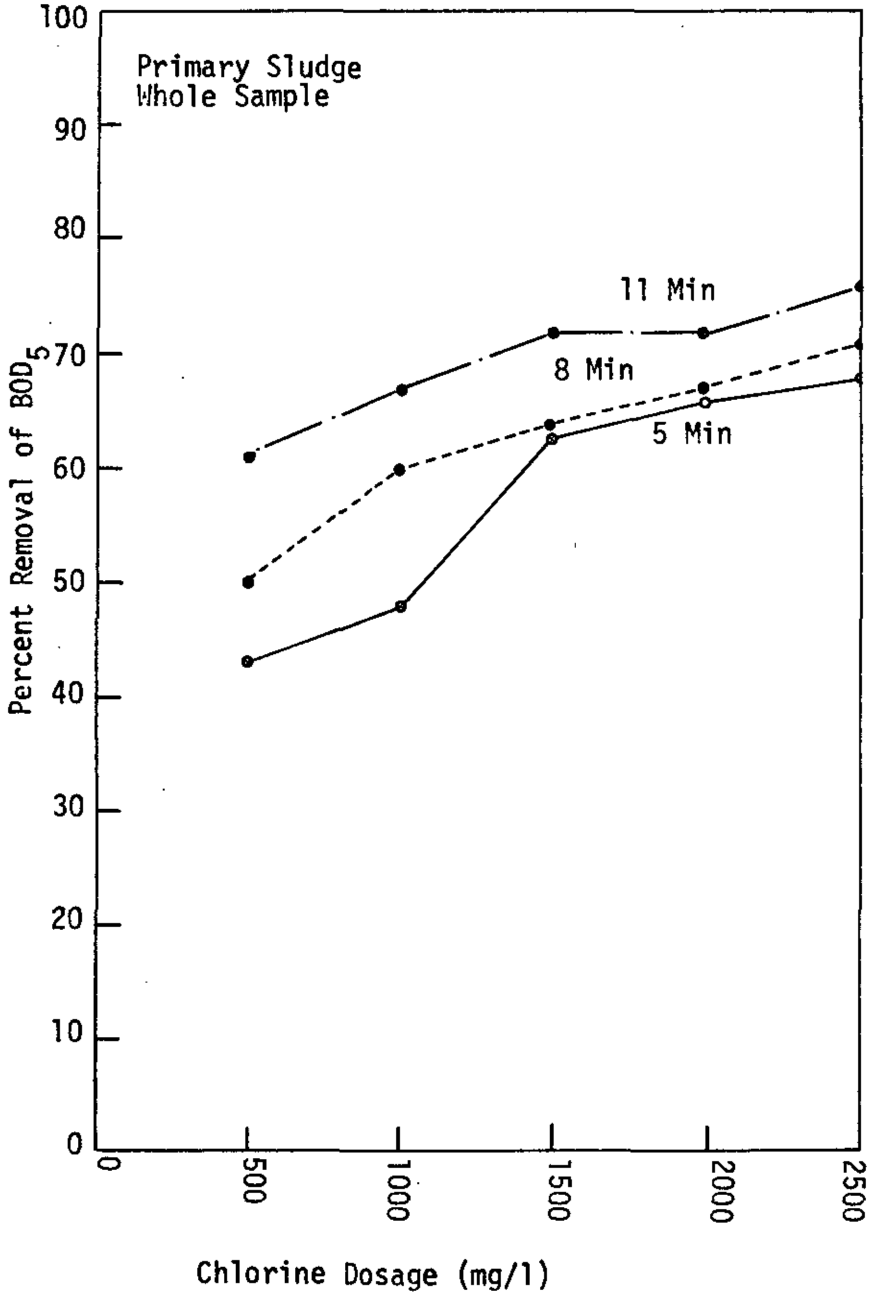


Figure 13.

Percent Removal of BOD_5 in Whole Sample of Primary Sludge

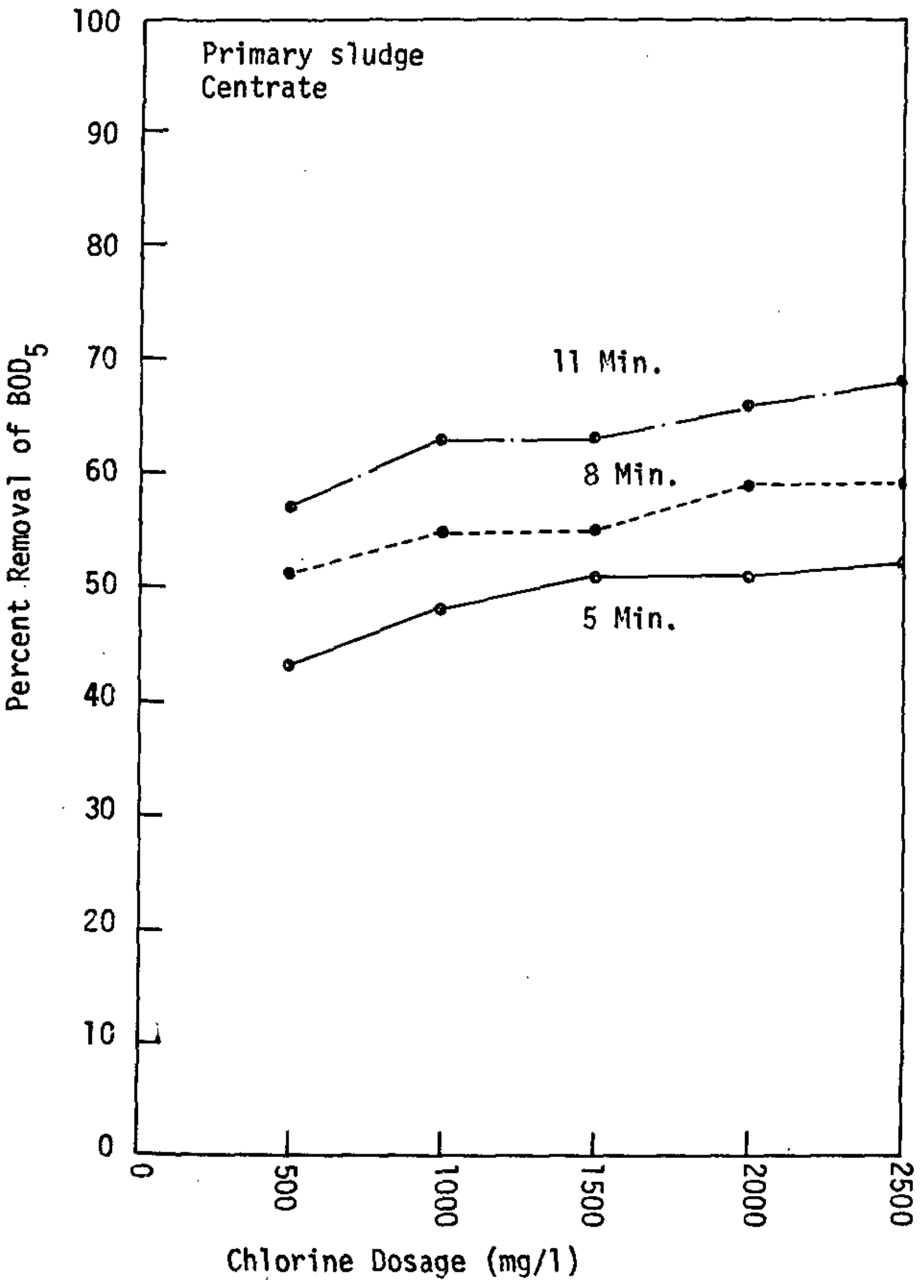


Figure 14. Percent Removal of BOD_5 in Centrate of Primary Sludge.

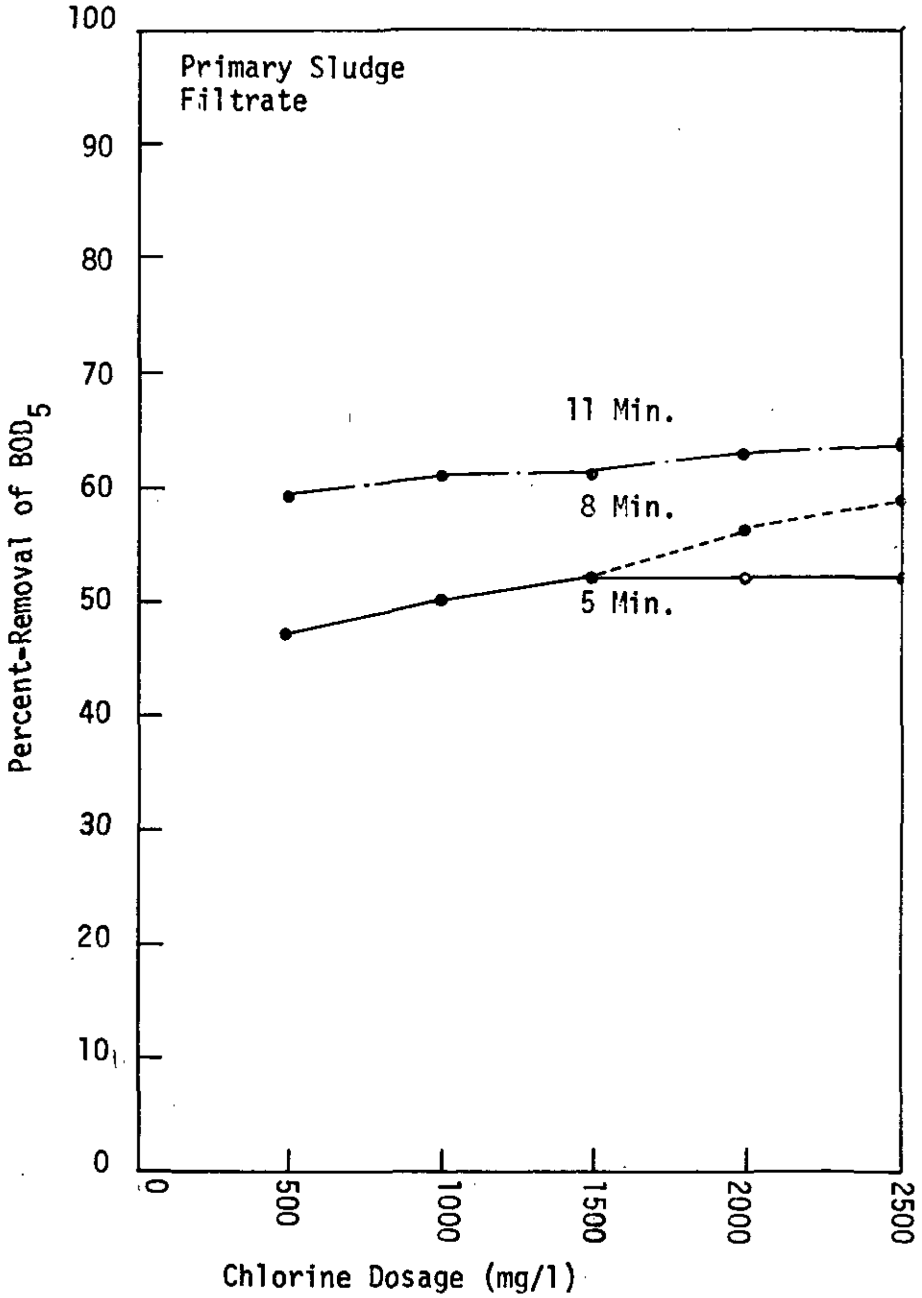


Figure 15. Percent Removal of BOD_5 in Filtrate of Primary Sludge

(e) COD:

Both biodegradable and nonbiodegradable organic compounds with only few exceptions can be oxidized by the action of strong oxidizing agents under acid condition. The removal of COD by chlorination represents one such action. However, the existence of chloride ion (Cl^-) interferes with the determination of COD and results in erroneously high COD values according to the following reaction:

$$6Cl^- + Cr_2O_7^{=} + 14H^+ \rightarrow 3Cl_2 + 2Cr^{+3} + 7H_2O \qquad (3\text{-}1)$$

Such an interference can be eliminated by using excessive amounts of mercuric sulfate which combines with chloride ion to form poorly ionized mercuric chloride:

$$Hg^+ + 2Cl^- \rightarrow HgCl_2\downarrow \qquad (3\text{-}2)$$

The COD value of the septages was as high as 14700 mg/l of which only 14% was soluble. The COD value of the primary sludge was about 6000 mg/l of which 25% was soluble.

For the septage the removal of COD by chlorination expressed as a function of chlorine dosage and mixing time is shown in Figures 13 to 15. The results show: (a) The removal could be further enhanced with dosage higher than 2500 mg/l. (b) The range of mixing time, from 5 minutes to 11 minutes did not improve the removal efficiency significantly. (c) As coupled with the removal of BOD_5 in reference to the data shown in Tables I to III, it seemed the nonbiodegradable organics were more susceptible to oxidation by chlorine than biodegradable ones, especially at high dosages.

For the primary sludge, the removal of COD as varied with chlorine dosage and mixing time is shown in Figures 16 to 18. The results show: (a) The similar trends of increasing removal with higher chlorine dosage and mixing time as demonstrated in Figures 13 to 15 for the septage. (b) In reference to the data shown in Tables IV to VI, the nonbiodegradable organics were less susceptible to oxidation by chlorination than the biodegradable ones which apparently reversed the findings for the septage.

(f) Phosphate:

The phosphate content in the primary sludge and septage has increased greatly since the use of synthetic detergents which contain to over 50% of the poly-phosphates. All the poly-phosphates gradually hydrolyze in aqueous solution and convert to ortho-phosphate. The rate of hydrolysis is increased as pH lowers.

From the results obtained in this study (Tables I to VI), it seemed that nearly no effect was exerted by chlorination on the concentration of phosphates in both the centrate and the filtrate of the samples.

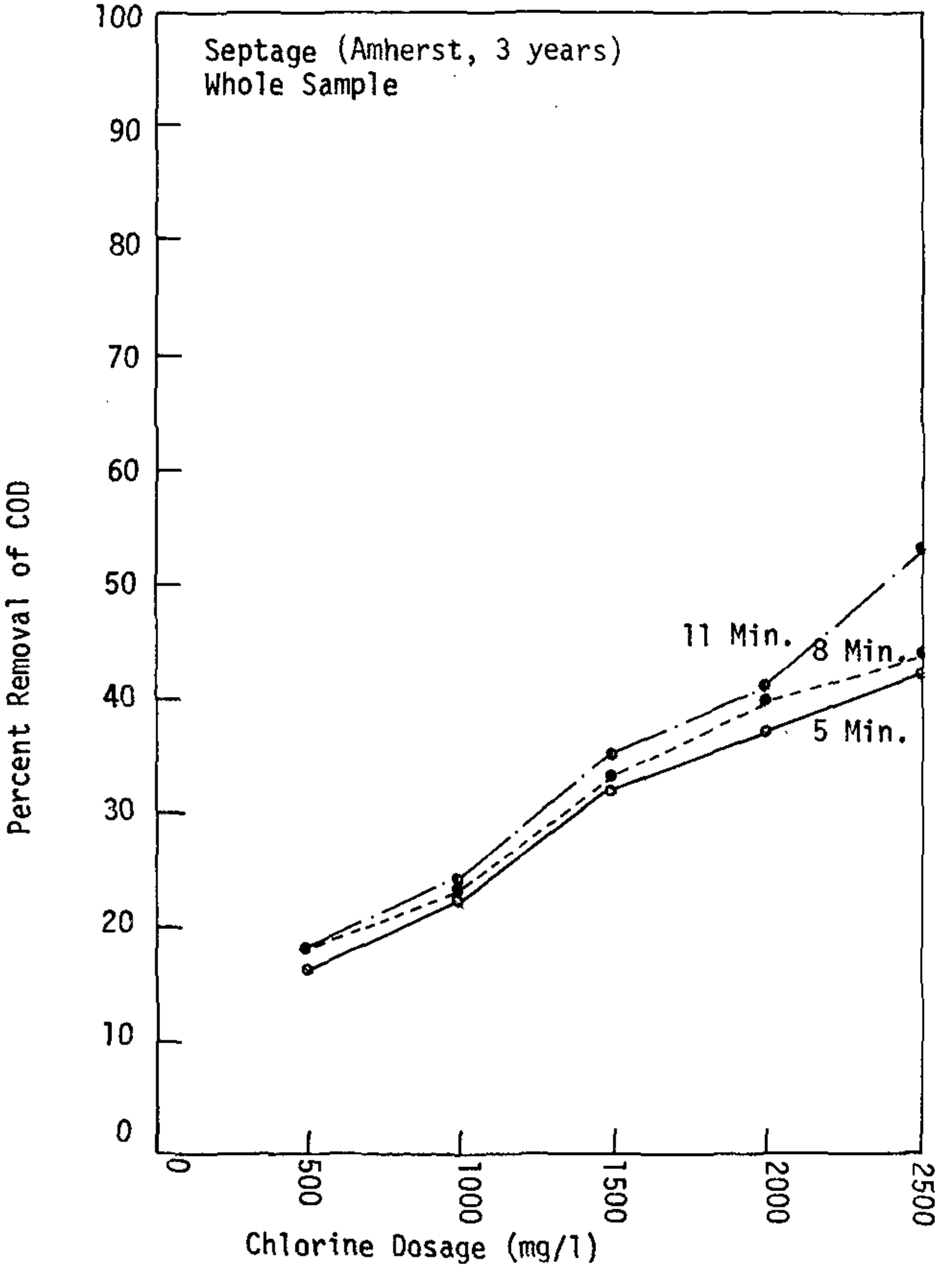


Figure 16. Percent Removal of COD in Whole Sample of Septage.

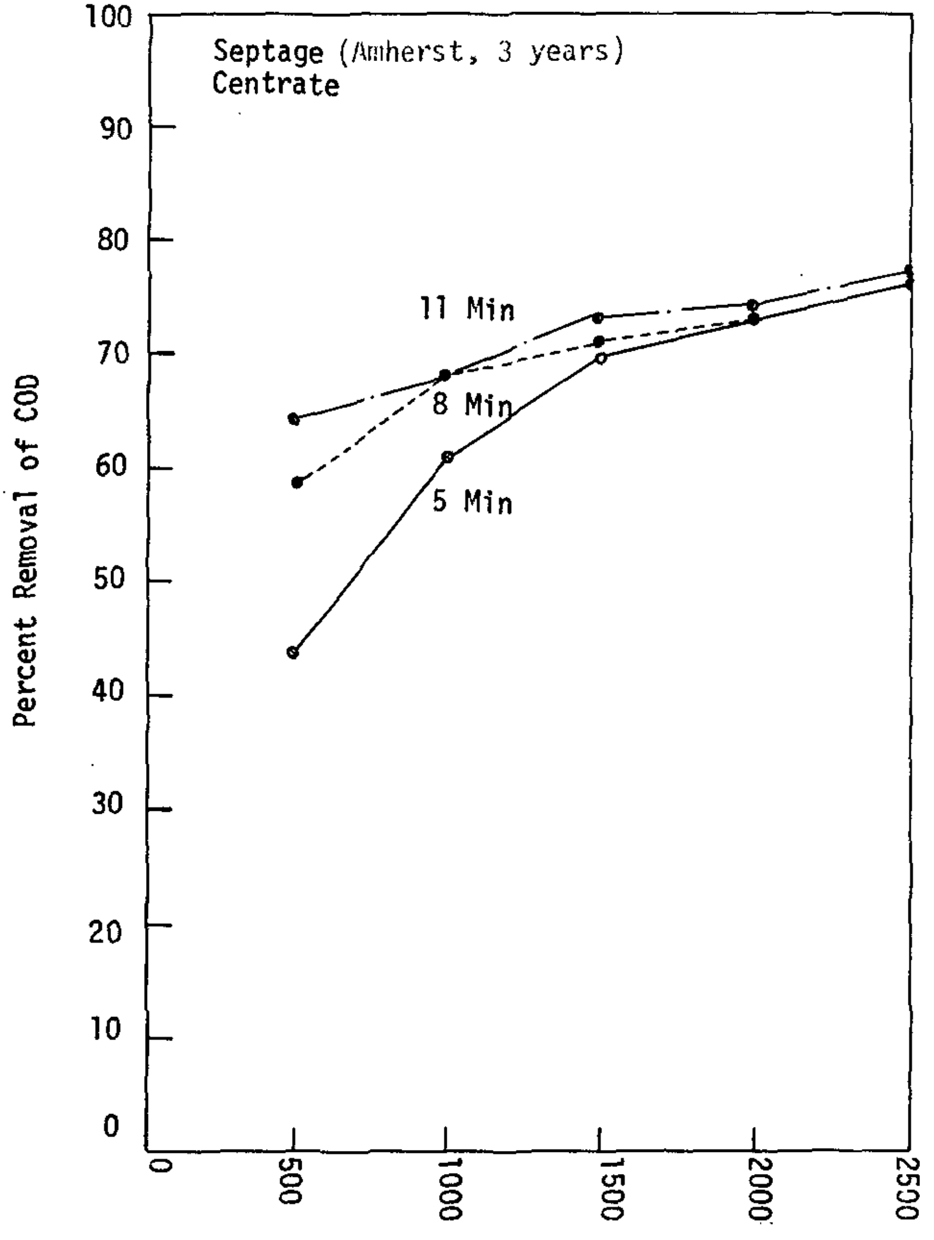


Figure 17. Percent Removal of COD in Centrate of Septage.

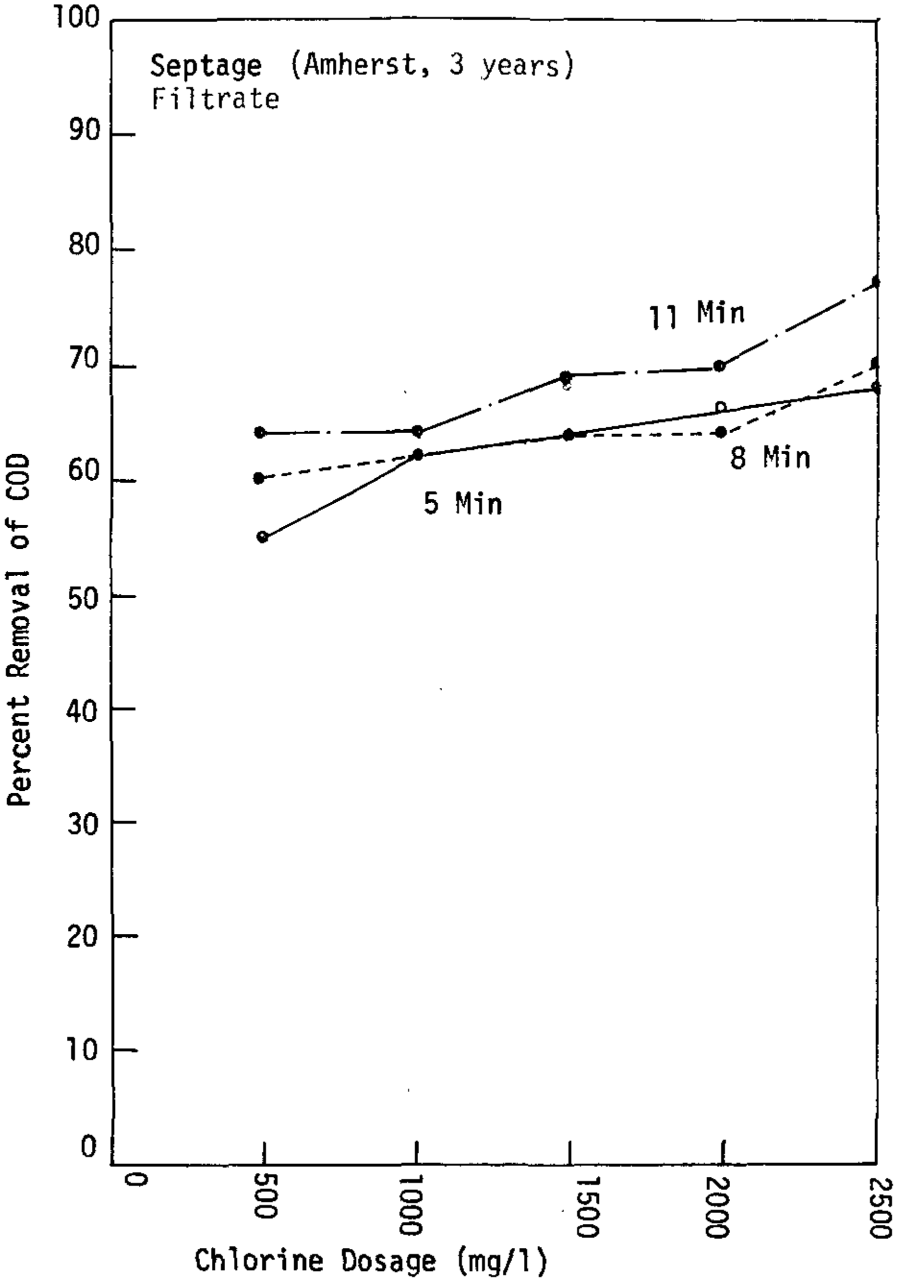


Figure 18. Percent Removal of COD in Filtrate of Septage.

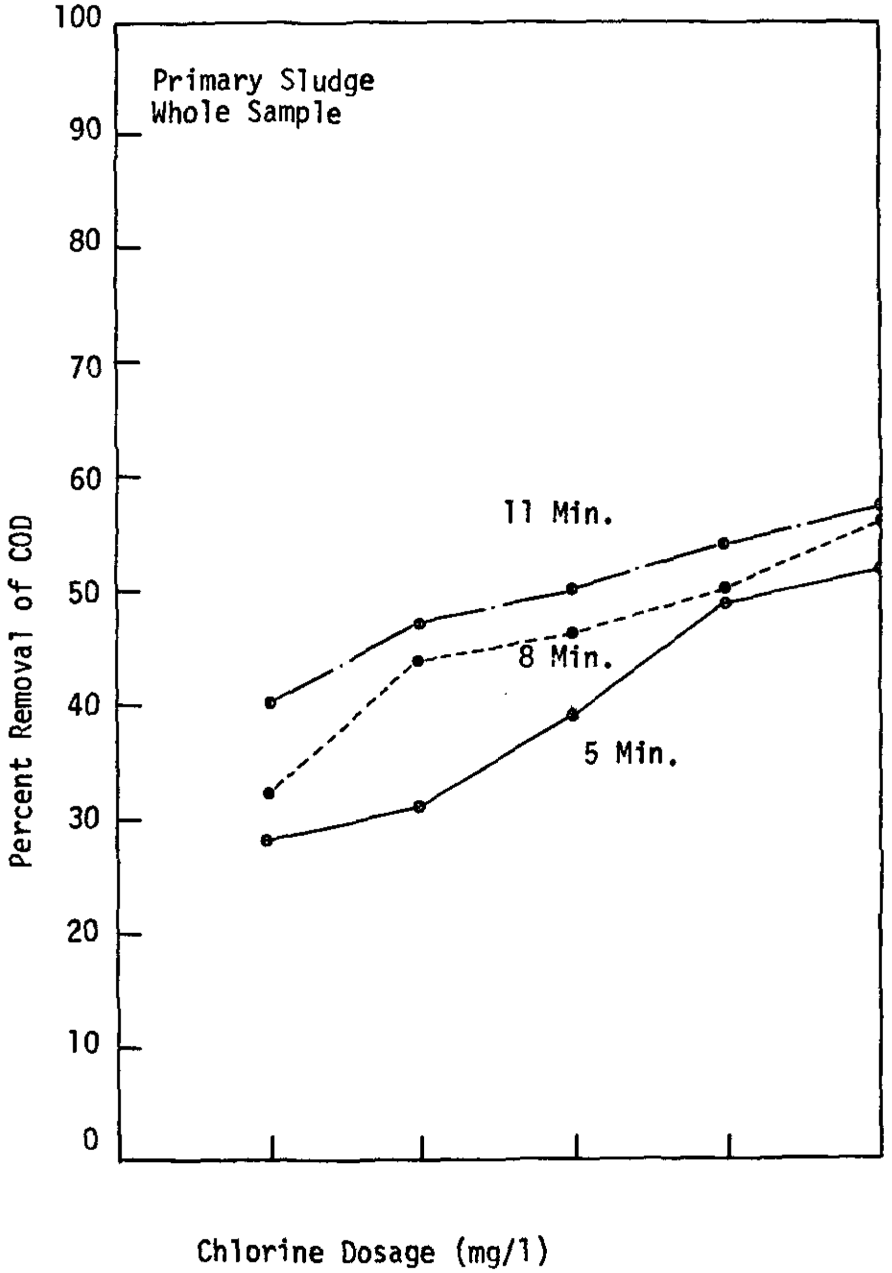


Figure 19. Percent Removal of COD in Whole Sample of Primary Sludge.

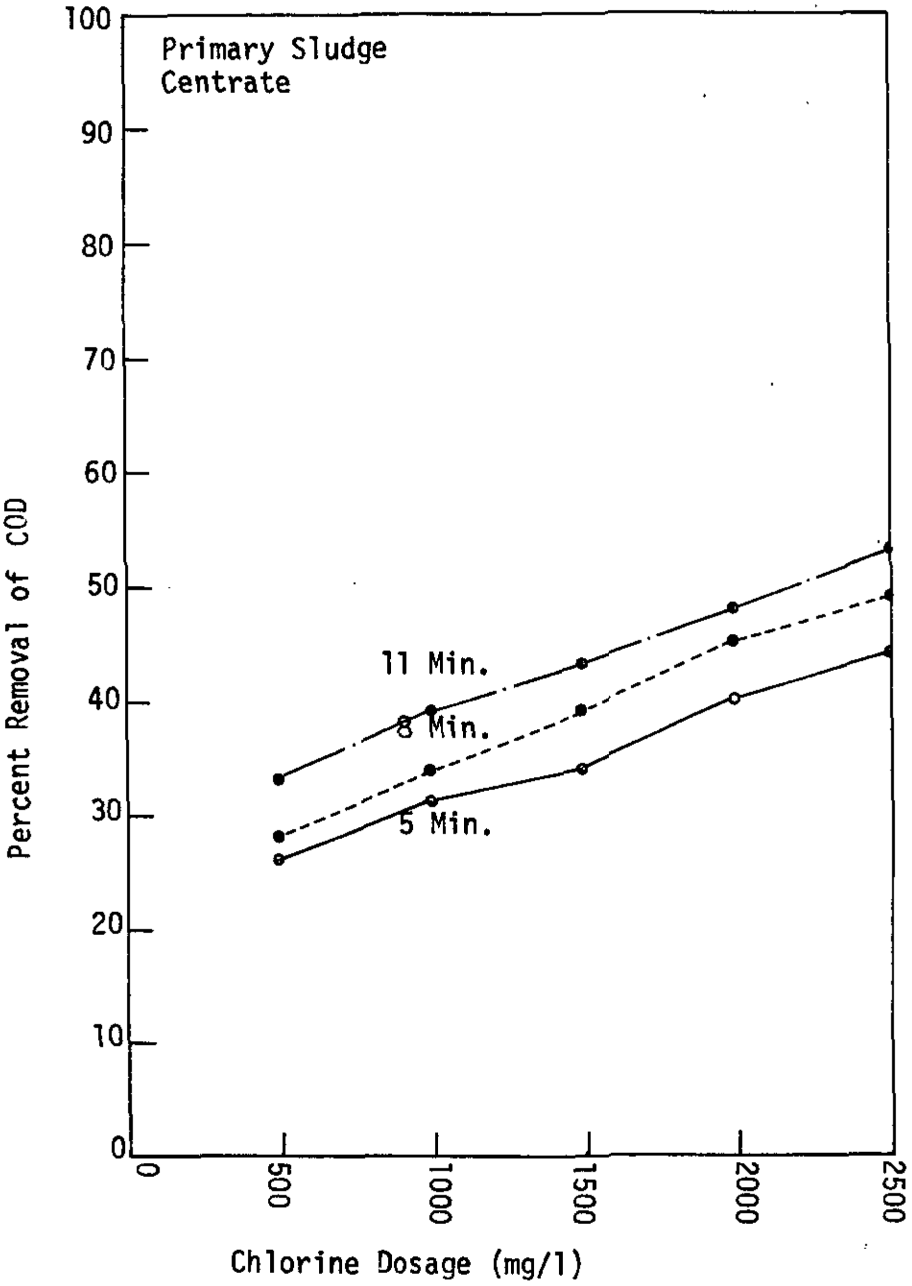


Figure 20. Percent Removal of COD in Centrate of Primary Sludge

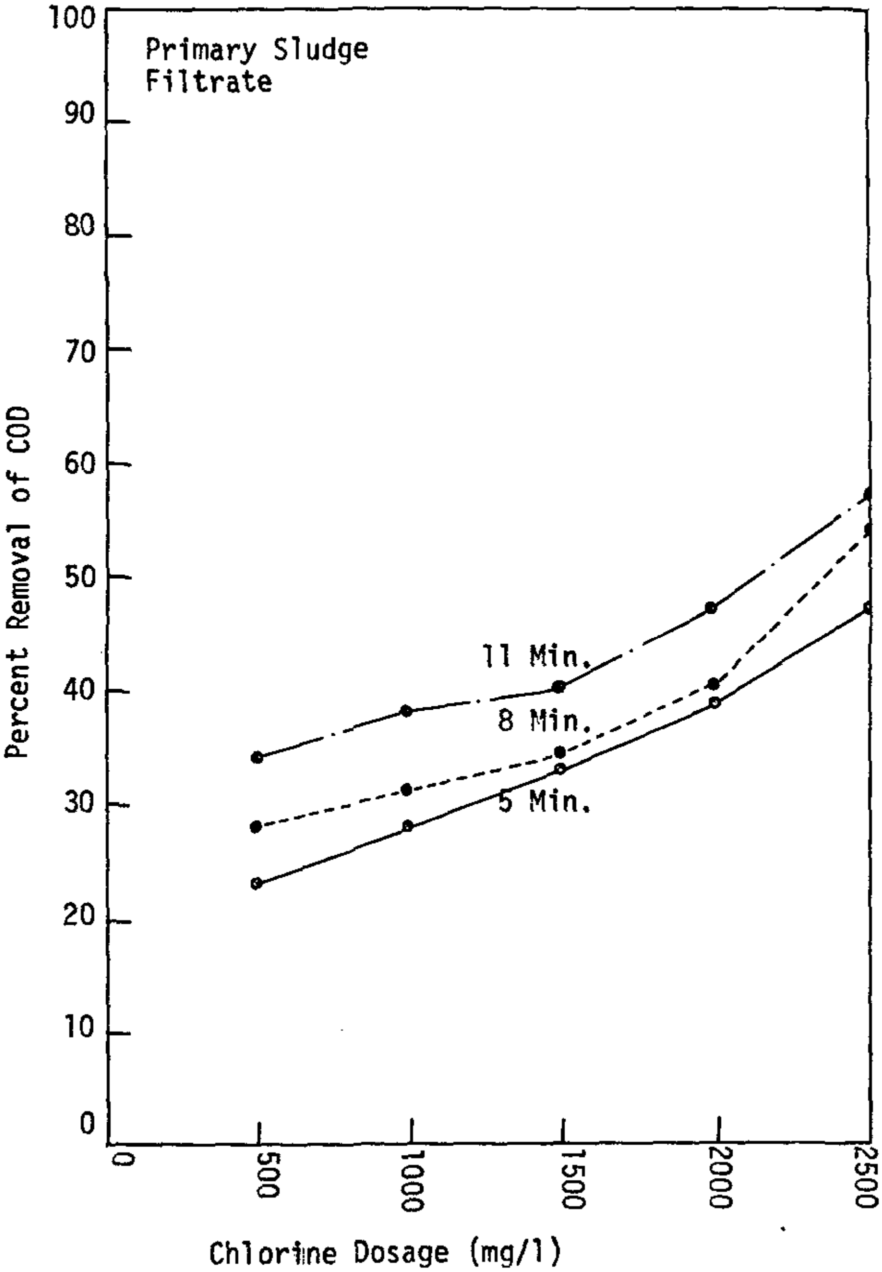


Figure 21. Percent Removal of COD in Filtrate of Primary Sludge.

3. Summary

The findings of this part of the study can be summarized as follows:

(a) The pH values of the purifaxed primary sludge and septage were lowered to around 2 at chlorine dosage of 500 mg/l and to 1.4 at chlorine dosage of 2500 mg/l.

(b) Chlorine residuals, both total and free, increased with chlorine dosage, and at a given dosage decreased with mixing time. For example, for the primary sludge, total chlorine residuals of its centrate were as high as 315 mg/l at a chlorine dosage of 2500 mg/l after 5 minutes of mixing. Of the same primary sludge, the centrate had a total chlorine residual of 50 mg/l at a chlorine dosage of 1000 mg/l after 5 minutes of mixing. It was also found that the chlorine residuals were reduced 50% or more by filtering through Whatmann No. 2 filter paper.

(c) The removal of NH_3-N increased with increase of chlorine dosage and mixing time. But for the septage chlorine dosages higher than 1500 mg/l and mixing time longer than 5 minutes contributed only little improvement in removal. The percentage of removal was around 70% at a chlorine dosage of 1000 mg/l after 5 minutes of mixing. The soluble portion of NH_3-N seemed more readily to be removed than the suspended and colloidal portions. The removal of NH_3-N in the primary sludge had, in general, similar trends as in the septage in regard to chlorine dosage and mixing time.

(d) In the removal of BOD_5, the increase of chlorine dosage and mixing time enhanced, in general, the efficiency, but specifically there were limitations in both accounts beyond which the gain in removal became insignificant. It was observed that the dissolved portion of BOD_5 in the primary sludge was less readily broken down by chlorination than its counterpart in the septage, while the reverse was apparently true for the suspended portions of BOD_5.

(e) For the removal of COD, the increase of chlorine dosage enhanced the efficiency up to the upper limit of 2500 mg/l, but the range of mixing time from 5 minutes to 11 minutes seemingly had little improvement in the removal.

It was observed that while for the septage the nonbiodegradable organics were more susceptible to oxidation by chlorination than the biodegradable, the reverse was apparently true for the primary sludge.

(f) It was shown that nearly no effect was exerted by chlorination on the concentration of phosphates in both the centrate and the filtrate of the samples. The data of this part of the study were not sufficient to delineate whether chlorine would break up the organic phosphates.

Part B.

Investigation of variation in characteristics of different sources of household septages and their treatability by the Purifax Process.

1. General Description and Summary of Data

This part of the study was designed to study the treatment of different sources of septage by the Purifax Process at two high chlorine dosages. 1900 mg/1 and 2400 mg/1 and in four mixing periods: 5, 7. 10, and 13 minutes.

The following characteristics of both untreated and treated samples were analyzed to evaluate their treatability by the Purifax Process:

pH
Solids
NH_3-N
Chlorine Residuals
Specific Resistance
BOD_5
Total Organic Carbon (TOC)

Essentially this part of the study should be regarded as an investigation for the purpose of investigating the variation in characteristics of different sources of household septage in regard to location and age, and the treatability of these sources of septage in terms of mixing time at high chlorine dosage.

The septage and sludge samples were treated with the Purifax Process by means of a Purifax Unit as described elsewhere. The untreated and treated samples were analyzed and the results are presented in Tables VII to XIII. The effect of mixing time on NH_3-N removal is further depicted in Figures 22 to 28, on BOD_5 removal in Figures 29 to 35, and on TOC removal in Figures 37 to 43. A relationship between removal of BOD_5 and total chlorine residuals is shown in Figure 36.

The experiments were performed on seven samples which are identified as follows:

Sample 1: Household septage from Amherst, Massachusetts, 3 years of age. Data presented in Table VII, Figures 22,29 and 37.

Sample 2: Household septage from Pelham, Massachusetts, 5-6 years of age. Data presented in Table VIII, Figures 23, 30 and 38.

Sample 3: Household septage from South Amherst, MA, 3 years of age. Data presented in Table IX, Figures 24, 31 and 39.

Sample 4: Household septage from South Amherst, MA, 5 years of age. Data presented in Table X, Figures 25, 32 and 40.

Sample 5: Primary sludge from Amherst, MA, Wastewater Treatment Plant. Data presented in Table XI, Figures 26, 33 and 41.

Sample 6: Anaerobically digested sludge from Amherst, MA, Wastewater Treatment Plant. Data presented in Table XII, Figures 27, 34 and 42.

Sample 7: Mixture of primary sludge and anaerobically digested sludge, both from Amherst, MA Wastewater Treatment Plant. Data presented in Table XIII, Figures 28, 35 and 43.

TABLE VII. SUMMARY OF EXPERIMENTAL DATA

Sludge Type: Sample 1

Measured Characteristics	Untreated Sample	Mixing Time at Chlorine Dosage 2400 mg/l				Mixing Time at Chlorine Dosage 1900 mg/l			
		5 min	7 min	10 min	13 min	5 min	7 min	10 min	13 min
pH	6.04	2.02	2.02	1.85	1.85	1.85	1.85	1.85	1.85
T.S. (mg/l)	7088	5152	5146	6062	6086	5390	5446	5106	5260
S.S. (mg/l)	5536	3980	4840	5306	5416	4262	4670	4076	4150
V.S.S. (mg/l)	4212	3606	4152	4120	4184	3316	3792	3466	3372
NH_3-N (mg/l)	114	38	33	29	30	45.5	27.5	30	30
BOD_5 (mg/l)	1438	583	479	470	375	689	566	585	545
Chlorine Residual (mg/l)									
Centrate									
Total		152	136	90	124	125	95	106	90
Free		25	28	14	22	18	14	18	10
Filtrate									
Total		35	30	25	23	7	8	12	5
Free	7	7	6	4	5	2	2	3	1
TOC (mg/l)									
Centrate	1064	463	478	458	461	553	533	568	550
Filtrate	600	340	345	380	370	550	510	470	480
Specific Resistance ($sec^2/gm \times 10^8$)	37.4	0.75	1.07	0.38	0.86	1.42	2.67	0.87	0.95

TABLE VIII.

Sludge Type: Sample 2.

Measured Characteristics	Untreated Sample	Mixing Time at Chlorine Dosage 2400 mg/l				Mixing Time at Chlorine Dosage 1900 mg/l			
		5 min	7 min	10 min	13 min	5 min	7 min	10 min	13 min
pH	4.75	1.85	1.95	1.95	1.9	1.95	2	1.98	2
T.S. (mg/l)	22364	21668	18080	19376	19754	21526	21338	21664	20634
S.S. (mg/l)	20404	18552	16624	18132	18204	19624	20246	19894	19056
V.S.S. (mg/l)	16634	15616	14138	15472	15414	12586	13700	14174	14326
NH_3-N (mg/l)	68	40.5	37.5	40.5	38.5	54	52.5	52.5	54.5
BOD_5 (mg/l)	3612	2581	2512	2479	2460	2767	2676	2670	2624
Chlorine Residual (mg/l)									
Centrate									
Total		23	27	24	18	14	7	3	2
Free		5	5	4	4	4	4	2	1
Filtrate									
Total		12	9	8	7	4	3	2	1
Free		1	2	2	1	0.4	0.6	0.6	0.4
TOC (mg/l)									
Centrate	2272	1558	1521	1518	1518	1774	1680	1635	1640
Filtrate	1440	1200	1170	1160	1200	1260	1300	1260	1280
Specific Resistance ($sec^2/gm \times 10^8$)	141	3.42	4.7	3.29	3.09	1.19	2.03	3.58	

TABLE IX.

Sludge Type: Sample 3.

Measured Characteristics	Untreated Sample	Mixing Time at Chlorine Dosage 2400 mg/l				Mixing Time at Chlorine Dosage 1900 mg/l			
		5 min	7 min	10 min	13 min	5 min	7 min	10 min	13 min
pH	5.5	1.7	1.7	1.7	1.7	1.85	1.8	1.8	1.8
T.S. (mg/l)	17066	15784	14316	14588	11968	17086	16966	16988	16972
S.S. (mg/l)	16122	13848	14088	14252	10002	17030	16942	15586	15830
V.S.S. (mg/l)	13856	12258	12868	11942	9006	15204	15166	14012	14298
NH_3-N (mg/l)	83	24	25	26.5	25.5	46.5	43	44	44.5
BOD_5 (mg/l)	2426	963	886	778	759	1336	1055	825	811
Chlorine Residual (mg/l)									
Centrate									
Total		76	76	68	62	29	24	23	24
Free		11	12	14	10	3	5	6	5
Filtrate									
Total		44	29	16	16	19	22	20	17
Free		9	6	4	3	3	5	3	1
TOC (mg/l)									
Centrate	1680	758	746	720	730	857	816	806	798
Filtrate	1060	615	600	588	588	716	701	695	687
Specific Resistance ($sec^2/gm \times 10^8$)	292	0.92	1.27	1.17	2.46	2.72	0.94	1.01	1.23

TABLE X.

Sludge Type: Sample 4.

Measured Characteristics	Untreated Sample	Mixing Time at Chlorine Dosage 2400 mg/l				Mixing Time at Chlorine Dosage 1900 mg/l			
		5 min	7 min	10 min	13 min	5 min	7 min	10 min	13 min
pH	6.4	1.75	1.75	1.8	1.8	1.8	1.8	1.8	1.8
T.S. (mg/l)	8612	8572	7966	7640	7998	8006	6916	6964	8242
S.S. (mg/l)	6640	8116	6660	5776	6782	7412	6002	6162	6524
V.S.S. (mg/l)	5886	7026	5610	5018	5226	6592	5016	5128	4974
NH_3-N (mg/l)	41	11	11	12	11	12.5	10.5	11	11
BOD_5 (mg/l)	856	180	162	162	168	288	198	198	184
Chlorine Residual (mg/l)									
Centrate									
Total		240	200	83	150	127	137	137	38
Free		148	136	50	90	56	67	52	7
Filtrate									
Total		70	13	10	41	33	18	9	15
Free		33	6	4	11	4	4	4	4
TOC (mg/l)									
Centrate	657	161	146	138	137	212	189	189	180
Filtrate	485	141	132	126	125	182	162	160	160
Specific Resistance ($sec^2/gm \times 10^8$)	286	11.24	7.69	7.87	12.7	7.25	2.1	2.22	1.85

TABLE XI.

Sludge Type: Sample 5.

Measured Characteristics	Untreated Sample	Mixing Time at Chlorine Dosage 2400 mg/1				Mixing Time at Chlorine Dosage 1900 mg/1			
		5 min	7 min	10 min	13 min	5 min	7 min	10 min	13 min
pH	5.2	1.65	1.7	1.7	1.65	1.8	1.85	1.85	1.85
T.S. (mg/1)	13150	11732	10968	11146	11156	10824	11274	11048	11672
S.S. (mg/1)	13090	10814	9818	10244	10108	10090	11124	10170	10864
V.S.S. (mg/1)	11116	8938	8046	8492	8878	8858	9348	8556	9020
NH_3-N (mg/1)	40	17	17.5	16	18	17.5	18.5	18.5	18.5
BOD_5 (mg/1)	1205	482	488	412	441	588	576	576	580
Chlorine Residual (mg/1)									
Centrate									
Total		60	50	42	35	46	47	42	36
Free		16	16	10	10	9	9	7	7
Filtrate									
Total		25	16	23	17	20	16.5	21	18
Free		6	4	5	5	4.5	4.5	5	4.5
TOC (mg/1)									
Centrate	794	336	335	298	376	500	490	492	510
Filtrate	418	318	288	295	318	359	356	338	338
Specific Resistance ($sec^2/gm \times 10^8$)	169	2.65	2.32	3.66	3.02	3.25	3.73	3.35	2.96

TABLE XII.

Sludge Type: Sample 6.

Measured Characteristics	Untreated Sample	Mixing Time at Chlorine Dosage 2400 mg/l				Mixing Time at Chlorine Dosage 1900 mg/l			
		5 min	7 min	10 min	13 min	5 min	7 min	10 min	13 min
pH	7.4	1.7	1.75	1.7	1.7	1.9	1.85	1.85	1.85
T.S. (mg/l)	13568	13056	10110	12244	11064	12244	12286	11702	12412
S.S. (mg/l)	12342	8948	7858	9388	10410	10110	10222	9940	10070
V.S.S. (mg/l)	7576	7362	5586	6508	7210	6572	6896	6734	6860
NH_3-N (mg/l)	285	232.5	227.5	227.5	323.5	232.5	232.5	230	205
BOD_5 (mg/l)	577	182	173	121	121	190	150	156	156
Chlorine Residual (mg/l)									
Centrate									
Total		41	40	35	35	40	30	30	29
Free		8	7	7.5	5	8.5	7	6	6
Filtrate									
Total		9.5	11	7.6	5.8	11	8.6	7.2	5
Free		2.5	1.8	1.4	1.2	1.9	1.6	1.4	1
TOC (mg/l)									
Centrate	240	100	90	100	100	110	105	105	100
Filtrate	80	40	35	40	40	60	55	50	50
Specific Resistance ($sec^2/gm \times 10^8$)	3.89	1.25	1.34	1.61	2.26	1.59	1.84	2.07	1.83

TABLE XIII.

Sludge Type: Sample 7.

Measured Characteristics	Untreated Sample	Mixing Time at Chlorine Dosage 2400 mg/l				Mixing Time at Chlorine Dosage 1900 mg/l			
		5 min	7 min	10 min	13 min	5 min	7 min	10 min	13 min
pH	6.6	1.8	1.8	1.8	1.85	1.8	1.9	1.9	1.95
T.S. (mg/l)	13858	13420	8130	11332	13082	13234	13676	13482	12358
S.S. (mg/l)	13976	11070	5962	10458	10580	10486	10652	11628	10920
V.S.S. (mg/l)	8961	7750	4254	7672	6870	7248	7169	7413	6958
NH_3-N (mg/l)	205	127.5	127.5	117.5	117.5	140	140	152.5	152.5
BOD_5 (mg/l)	748	336	312	244	267	390	335	358	403
Chlorine Residual (mg/l)									
Centrate									
Total		35	21	22	21	22	13.7	14	13.7
Free		6	3	3	3	5.5	4	3	3
Filtrate									
Total		12	9	10	10	8	5	4	4
Free		2.5	1.5	1.5	1	1.5	1	1	1
TOC (mg/l)									
Centrate	400	240	225	196	200	285	270	266	260
Filtrate	210	140	140	125	120	160	165	157	160
Specific Resistance ($sec^2/gm \times 10^8$)	4.42	1.56	1.34	1.83	2.40	1.78	2.24	2.31	1.54

The data for the samples presented in their respective tables are the average of 2 or 3 experimental runs of the same sample. All the samples were adjusted to 25°C by heating or cooling before undergoing the treatment.

2. Discussion of Experimental Results

The discussion of the experimental results is presented in the following aspects:

(a) pH

(b) Solids

(c) Ammonia nitrogen

(d) Chlorine residuals

(e) Specific resistance

(f) BOD_5

(g) TOC

(a) pH

The pH values of all the treated samples fell below 2 despite their origins, ages, and characteristics. Heavy dosages of chlorine tend to direct the reactions rightward as shown by (2-1), (2-6), (2-8), (2-10) and (2-11). The formation of hydrochloric and sulfuric acids depressed the pH. Such low pH values are significant in the following aspects: (a) enhancement of disinfection; the lower the pH value , the greater the concentration of HOCl which is a powerful disinfectant; (b) formation of chloramines: the formation of chloramines as depected by (2-3), (2-4), and (2-5) is pH-dependent. According to Morris,[9] to convert 99 percent of free chlorine to monochloramine at 25°C with a molar ratio of 0.2×10^{-3} mole/l HOCl to 1.0×10^{-3} mole/l NH_3 it will take 421 seconds at pH 2, but only 0.069 seconds at pH 8.3. However to convert 90 percent of monochloramine to dichloramine as shown by (2-4) it may take up to 5 hours at pH 8.5 and the reaction speeds up appreciably as pH approaches 5.

It may be also interesting to note that as pH drops to 5 or less, NCl_3 forms even at equimolar ratio of chlorine to ammonia nitrogen.

The two dosages of chlorine used in this study had no significant effect on the pH values of the treated samples.

(b) Solids

Practically there was no change of solids concentration as the results of treatment by the Purifax Process. However, it was observed that the dark color of sludge solids (from dark gray to black) was changed to light yellow color for all the treated samples. It was also observed that as a treated sample was first discharged from the reactor, a portion of the solids rose and floated on the liquid surface. The percentage of floating solids decreased for various samples in the following order: septages, primary sludge, mixture of primary and digested sludges, and digested sludge. It was apparent that the CO_2 evolved in the oxidation of carbonaceous matter by chlorination and the NCl_3 produced by the reaction between $NHCl_2$ and HOCl at low pH and the applied chlorine gas caused the floatation of solids. It may be surmised that a higher percentage of the solids would be floated in case more gases were produced. It was found that chlorine demand which is the difference between chlorine dosage and chlorine residual increased with the increase of initial suspended solids concentration. These findings conform with the findings of Lee and Waller[13] which stated that for high dosages of chlorine, chlorine demand increases with increased initial volatile suspended solids concentration.

The most important and significant change in the treated samples was the improvement of their dewatering quality. Such an improvement can be measured analytically by the reduction of specific resistance of a treated sludge, which will be discussed elsewhere. However, some observed phenomena during the experimentation can be used as a qualitative indication of the dewatering characteristics. It seemed that the more floating solids the better was the dewatering quality. It was also observed that when more solids were changed to floc-like particles after treatment, the sample was better improved in its dewatering quality.

(c) Ammonia Nitrogen

The concentration of ammonia in the septage and sludge samples used for this study varied greatly depending on their origin and age. The amount of ammonia in the primary sludge sample was fairly constant at an average concentration of about 40 mg/l as N. In the anaerobically digested sludge sample ammonia content was as high as 285 mg/l as N. The ammonia content of septage samples varied from 41 to 114 mg/l as N. Septages with longer detention time in septic tanks contained less ammonia than those with shorter detention time.

The ammonia removal by chlorination can be shown stoichiometrically by reactions (2-3), (2-4) and (2-5). The extent of these reactions depends on many factors such as temperature, pH, contact time and initial molar ratio of ammonia to chlorine. Both pH and temperature affect the relative distribution of HOCl and OCl^- and in turn the reaction between ammonia and chlorine. The maximum rates of reactions (2-3) and (2-4) fall within narrow ranges of pH and reduce rapidly as pH changes to values outside these ranges. The low pH values resulted in this study would have slowed down the reaction rates between ammonia and chlorine. According to the stoichiometry of these reactions, reaction (2-3) starts at initial molar ratio of chlorine to ammonia at 1:1, reaction (2-4) at 2:1, and reaction (2-5) at 3:1. Longer contact time and higher temperature enhance both the extent and the rate of reactions.

Another factor which must be considered is the competition for chlorine in the Purifax Process between ammonia and other substances such as amino acids, hydrogen sulfide, and carbonaceous materials. In the case of septages and anaerobically digested sludges, organic acids become significant competitors. Acetic acid, a major organic acid, present in septages and anaerobically digested sludges, reacts with chlorine in the presence of a small amount of phosphorus as follows:

$$\begin{aligned} &CH_3COOH \xrightarrow[P]{Cl_2} ClCH_2COOH \xrightarrow[P]{Cl_2} Cl_2CHCOOH \\ &\quad \xrightarrow[P]{Cl_2} Cl_3CCOOH \qquad (4.1) \end{aligned}$$

The ammonia content of sludge may be controlled by pH; at high pH ammonium ions are reduced to NH_3 and evolve from the liquid.

All the factors mentioned above would result in such complex interactions in the chlorination of septages and sludges that the optimal condition for ammonia removal may be only determined experimentally if ever possible.

The percentage removal of ammonia as related to the processing or mixing time of the sludge with chlorine is shown in Figures 22 to 28.

In the case of septages, as shown in Figures 22 to 25, the removal of ammonia was around 70 percent except Sample 2 and Sample 3. In the case of Sample 2, the 6 year old septage from Pelham, the removal of ammonia was as low as 20 to 40 percent. Suspended solids and BOD_5 of Sample 2 were 20404 mg/l and 3612 mg/l respectively. Such high values of suspended solids and BOD_5 may partially account for the low ammonia removal. In the case of Sample 3, the 3 year old septage from Pelham with suspended solids of 16122 mg/l and BOD_5 of 2426 mg/l the removal was reduced to less than

50 percent at the lower chlorine dosage of 1900 mg/l while at the higher dosage the removal was about 70 percent. It seemed to indicate that suspended solids and BOD_5 competed with ammonia for chlorine in the Purifax Process.

As shown in Figures 24 and 25, the age of septage could play an important role in the removal of ammonia. The results showed that the removal was higher for the five year old septage than the 3 year old septage. The lower values of both suspended solids and BOD_5 of the older septage indicated that it was more stable, had a less chlorine demand and consequently may have less substrates competitive with ammonia for chlorine. It must be kept in mind that such a statement may be applied only to septage of similar origin.

A variation of mixing time from 4 to 13 minutes did not have noticeable effect on the removal efficiency of ammonia in all samples except Sample 1, in which the efficiency improved with increased mixing time.

The removal of ammonia from primary sludge by chlorination was around 60 percent and practically not affected by the variation of mixing time as shown in Figure 26.

Chlorination was not effective in removing ammonia from anaerobically digested sludge, even with the higher chlorine dosage and longer mixing time as shown in Figure 27. The average removal was only 20 percent. Organic acids, partially stabilized compounds, CH_4, H_2S and others, were the possible competitors for chlorine. It was also observed that a large amount of lubricating oil was present in the digested sludge. As a result of the chlorination the oil was completely broken down. Apparently the oil could be a substantial source of chlorine demand.

The mixture of primary and digested sludges was experimented as Sample 7. The results shown in Figure 28 as compared with the results of treating the two sludges separately shown in Figures 26 and 27 respectively indicate that two different sludges, treated in mixture could undergo chlorination as two "immiscible" components without interaction.

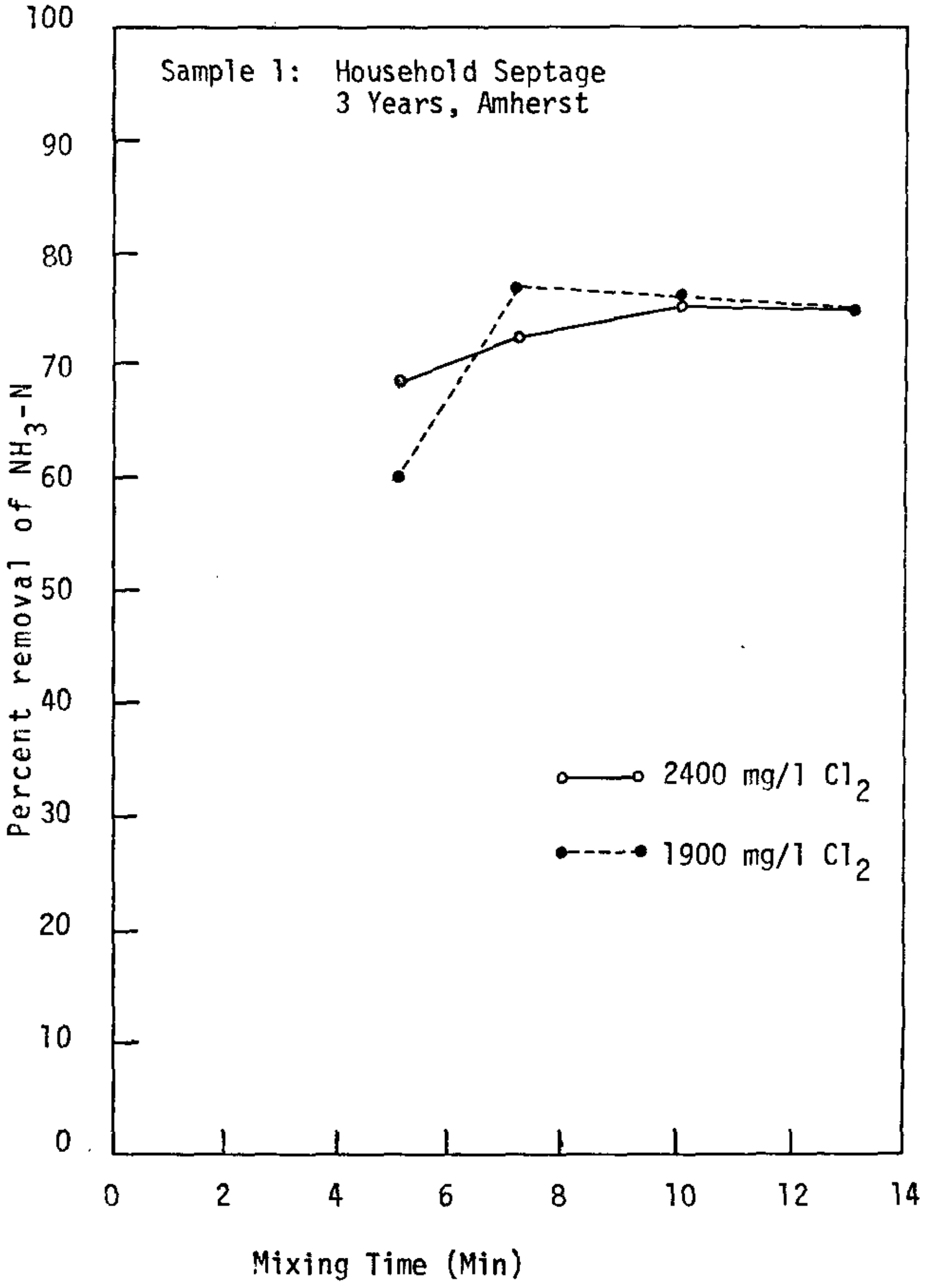


Figure 22. Percent Removal of NH_3-N vs. Mixing Time.

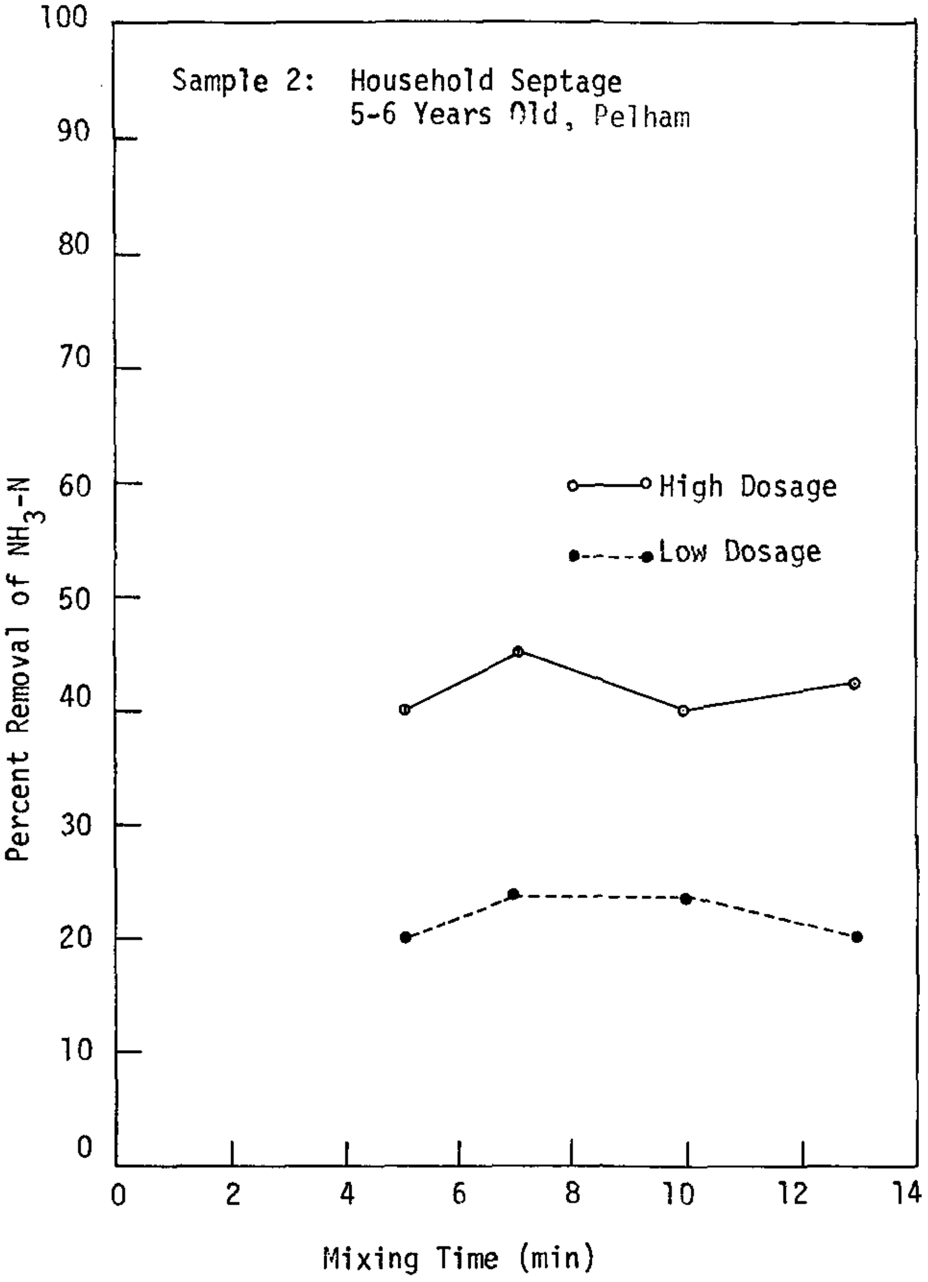


Figure 23. Percent Removal of NH_3-N vs. Mixing Time.

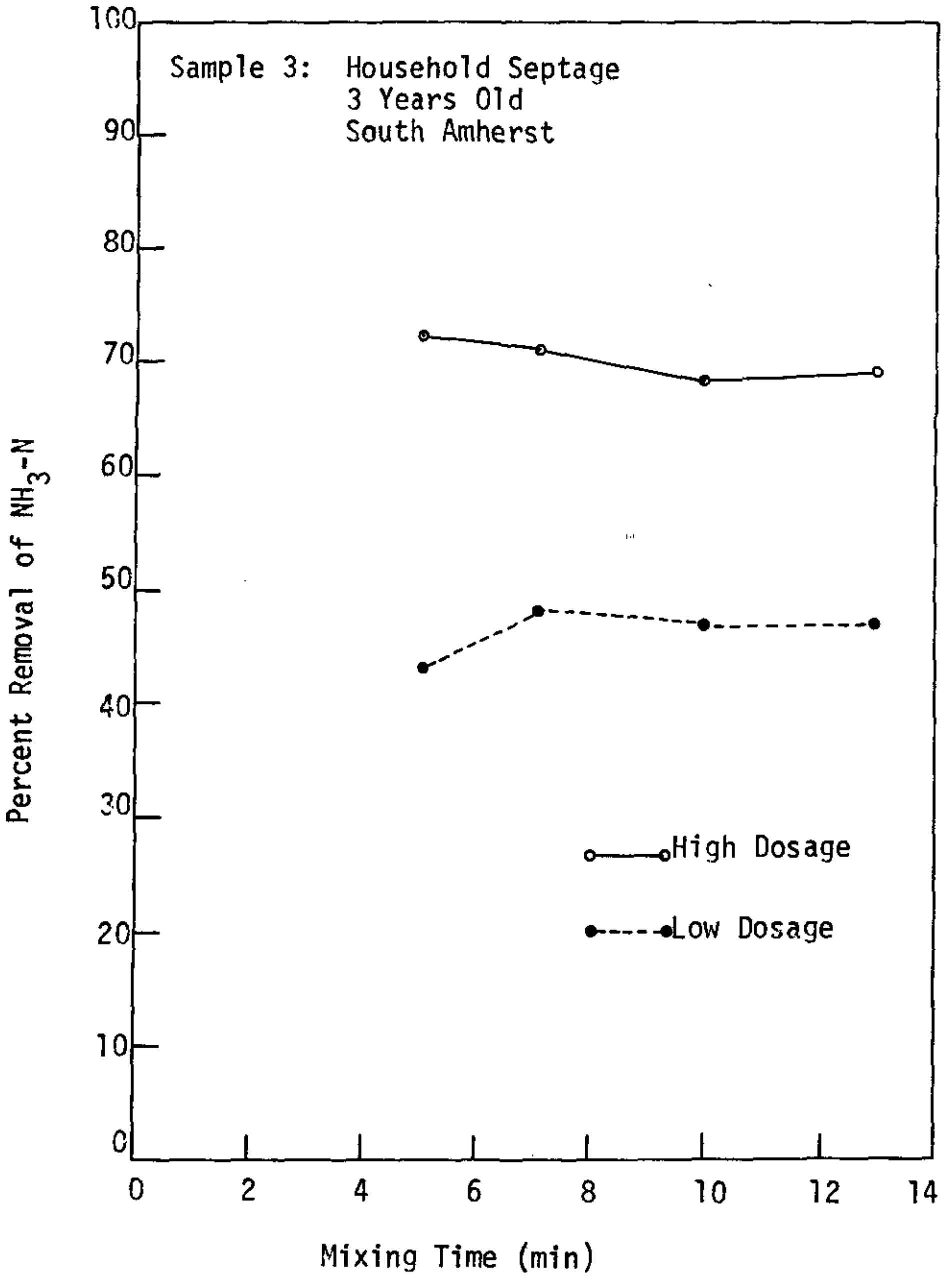


Figure 24. Percent Removal of NH_3-N vs. Mixing Time.

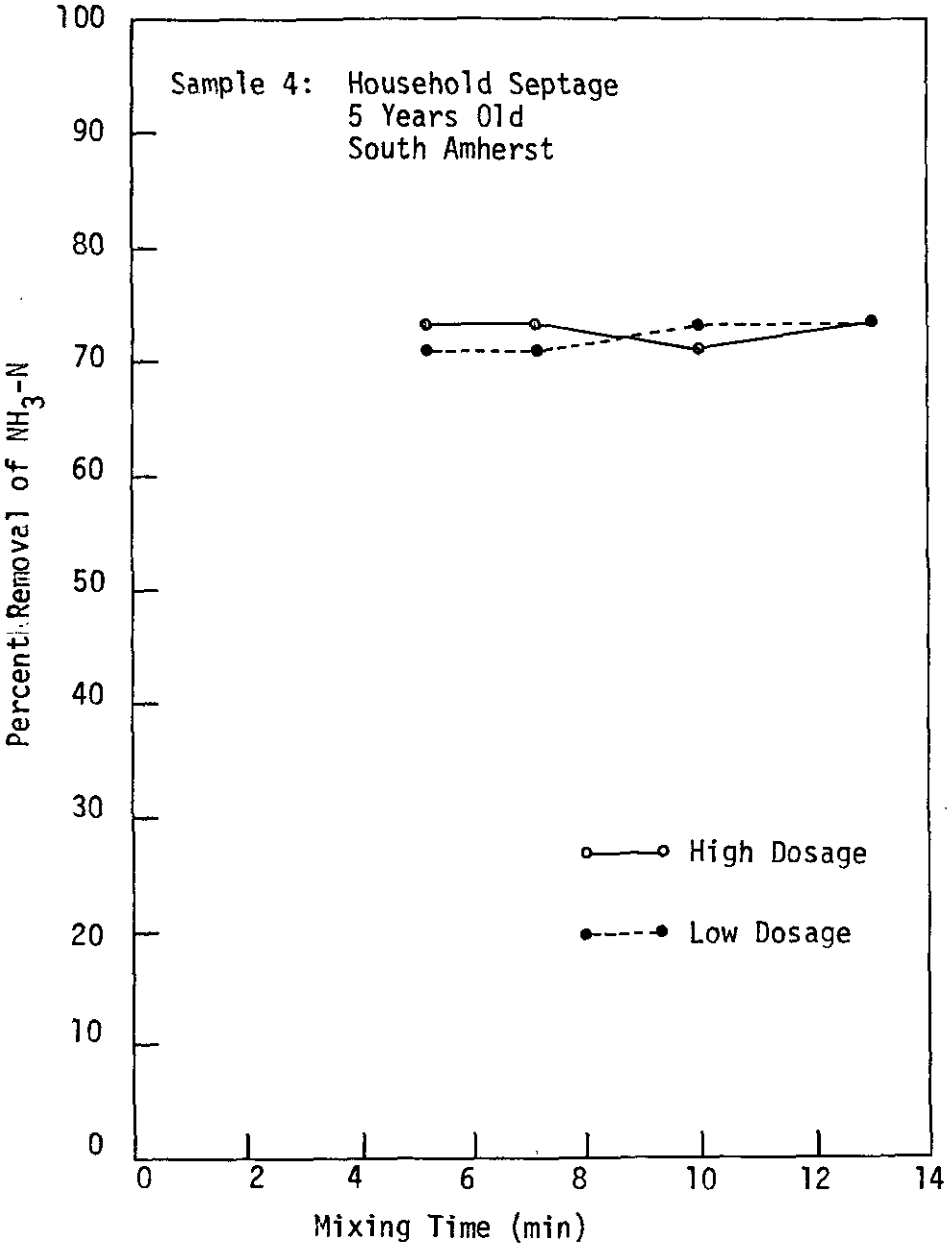


Figure 25. Percent Removal of NH_3-N vs. Mixing Time.

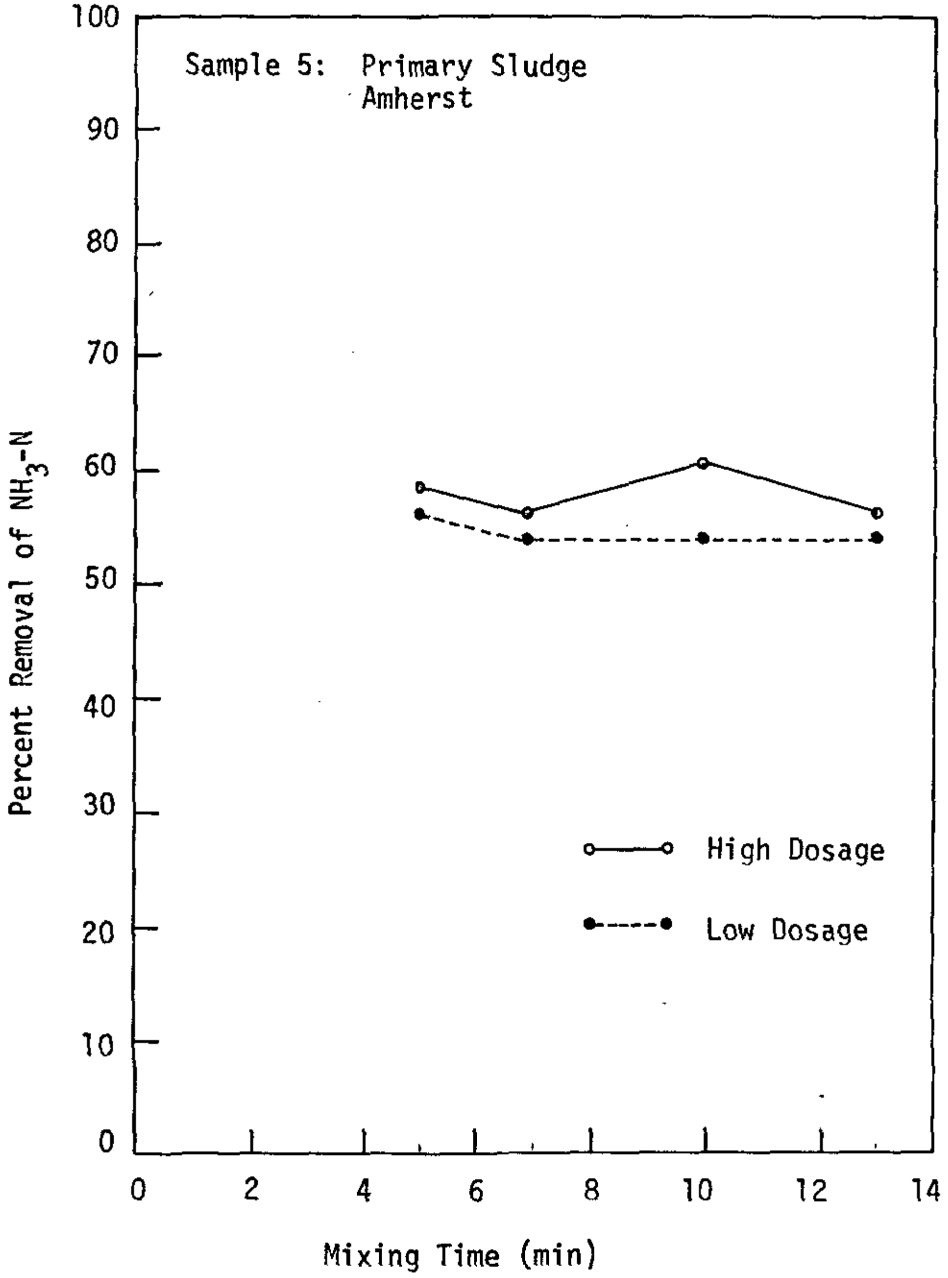


Figure 26. Percent Removal of NH_3-N vs. Mixing Time.

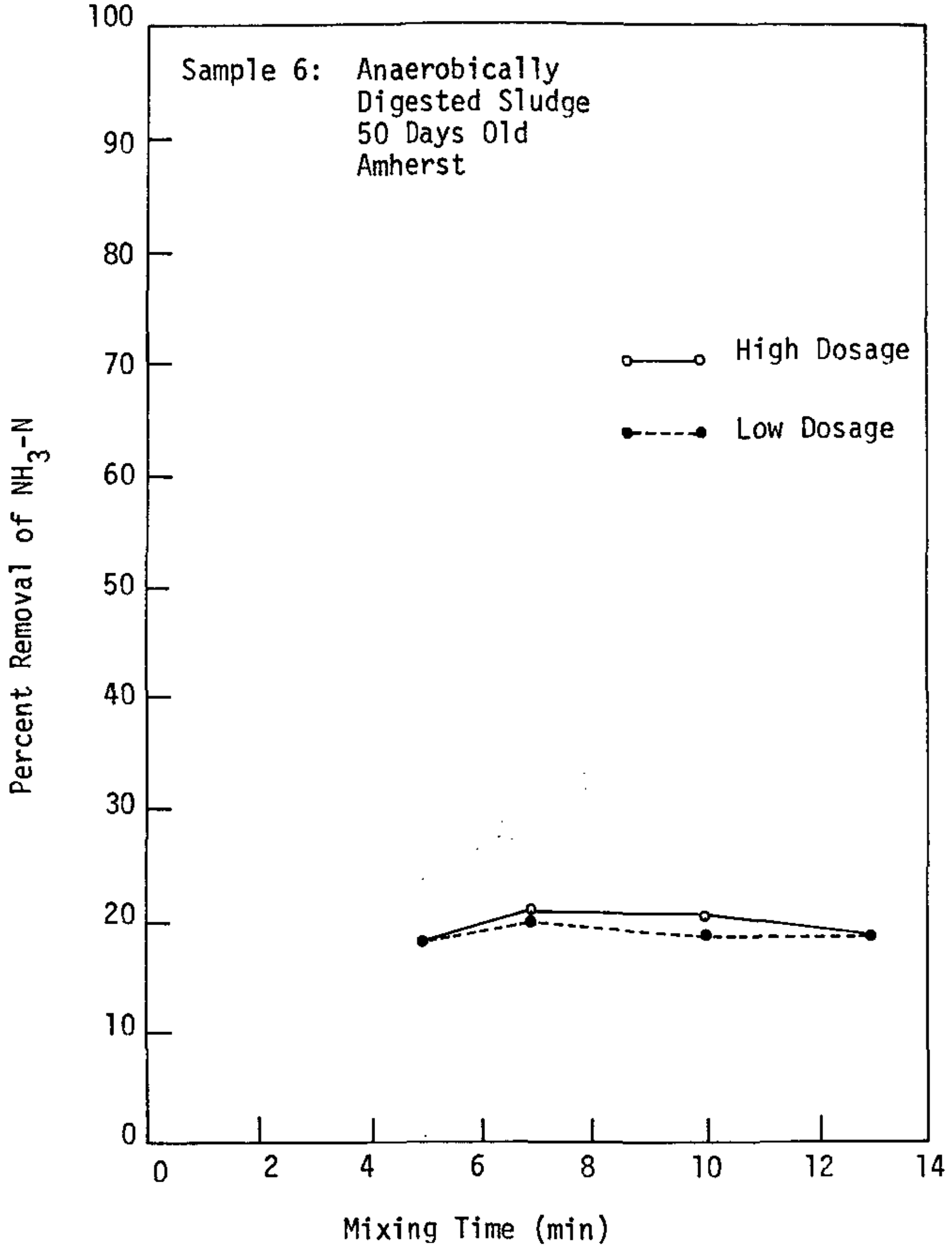


Figure 27. Percent Removal of NH_3-N vs. Mixing Time.

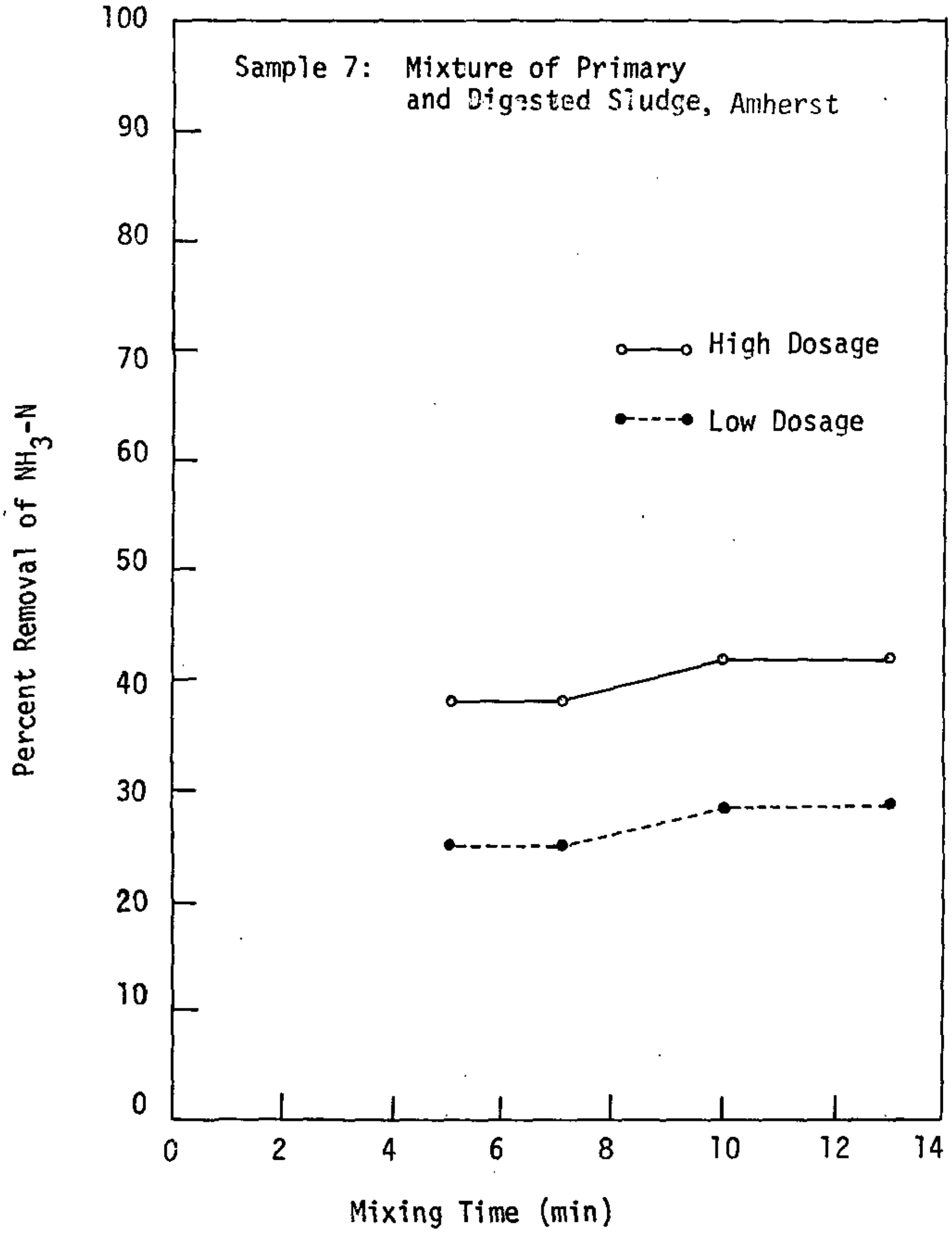


Figure 28. Percent Removal of NH_3-N vs. Mixing Time.

(d) Chlorine Residuals

The composition of sludges is highly heterogeneous (especially in organic matter), and it is practically impossible in chlorination of a sludge to establish a quantitative relationship between chlorine residuals and its organic contents. Since chlorine residuals are needed to calculate chlorine demand and may measure a source of toxic materials, it is important to determine chlorine residuals in evaluation of the performance of the Purifax Process.

During the early stage of this study it was found that suspended solids might have interfered with the determination of chlorine residuals. It is apparent that suspended solids, especially those organic in nature, can react or simply adsorb a certain amount of chlorine. In order to delineate the role of suspended solids in exerting chlorine demand, the chlorinated sludge was both centrifuged and filtered as described previously. The centrate and filtrate were analyzed for chlorine residuals. The results as shown in Tables VII and XIII indicate that chlorine residuals of the centrates were far greater than their corresponding filtrates. Since the solids concentrations of the filtrates were far lower than those of the centrates, it is reasonable to assume that the sludge solids exerted a substantial chlorine demand and competed for chlorine with the dissolved organic matters. Furthermore, the suspended solids of the chlorinated sludges seemed to "hold" a major portion of the chlorine residuals.

Free available chlorine residuals of all the treated samples were below 30 mg/l in their centrates and 10 mg/l in their filtrates as shown in Tables VII to XIII. According to "Standard Methods"[10] to determine free available chlorine residuals a sample must be chilled to 1°C and should never exceed 20°C so that the co-existing combined chlorine residuals would not react with the orthotolidine reagent in the specified short duration of 5 seconds. However, it would take 20 minutes to lower the temperature of a sample from room temperature to 1°C in a refrigerator during which period the chlorine residuals may undergo changes. Therefore it was decided to make the determination of chlorine residuals at 18°C which can be obtained immediately by diluting the sample with distilled water having been cooled to 4°C. Therefore the measured free available residuals could be higher than the actual value.

Combined available chlorine residuals which consist of NH_2Cl, $NHCl_2$, and NCl_3 are the difference between total available chlorine residuals and free available chlorine residuals. No attempt was made to differentiate the various species of combined available chlorine residuals.

In this study the heavy dosages of chlorine and the resulted low pH had provided a favorable condition for the formation of NCl_3 which is only slightly soluble in water and therefore expected to be released from the liquid phase by the vigorous agitation in the reactor.

(e) Specific Resistance

A specific term known as specific resistance has been used for estimating filter yields and measuring filterability in dewatering sludge by filtration. It is numerically equal to the pressure difference required to produce a unit rate of filtrate flow of unit viscosity through a unit weight of cake.

A mathematical formula of specific resistance was given by Carmen and Coakley[11,12] who described the filtration rate of sludge according to Poiseuille's and Darcy's laws as follows :

$$\frac{dV}{dt} = \frac{PA^2}{\mu(rcV + R_m A)} \qquad (4\text{-}2)$$

where

V = volume of filtrate (ml)

t = time of filtration (second)

P = vacuum applied (gm/cm^2)

A = filter area (cm^2)

μ = filtrate viscosity (gm/cm-sec)

r = specific resistance (sec^2/gm)

c = weight of solids per unit volume of filtrate (gm/ml)

R_m = initial resistance of filter media (can be neglected) (sec^2-cm/ml)

Integration and rearrangement of (4-2) yields:

$$\frac{t}{V} = \frac{\mu rc}{2PA^2} V + \frac{\mu R_m}{PA} \qquad (4\text{-}3)$$

A plot of (t/V) against (V) will result in a linear relationship, the slope of which is equal to b defined as follows:

$$b = \frac{\mu rc}{2PA^2} \qquad (4\text{-}4)$$

A rearrangement of (4-4) gives r, the specific resistance as follows:

$$r = \frac{2bPA^2}{\mu c} \qquad (4\text{-}5)$$

For this study specific resistance was used to quantitatively evaluate the dewatering quality of sludges. Necessary experimental data were gathered and Equation(4-3) was used to determine the term, $\mu rc/2PA^2$ by the linear regression method. The correlation coefficients obtained were in the range of 0.85 to 0.96. Then by using Equation (4-5), the specific resistance values of untreated and treated sludge and septage samples were calculated. The results are listed in Tables VII to XIII.

Specific resistance of the septage samples varied from 1.41 x 10^{10} sec^2/gm to 3.74 x 10^{10} sec^2/gm, dependent on their source and age. Primary sludge had a slightly less specific resistance of about 1.69 x 10^{10} sec^2/gm. Anaerobically digested sludge had the largest specific resistance of about 3.89 x 10^{10} sec^2/gm among all the sludges studied.

The Purifax Process greatly improved the dewatering quality of the septage and primary sludge samples as shown by the reduction of their specific resistance given in Tables VII to XI. However, it did not alter appreciably the dewatering quality of the digested sludge sample. For most of the treated samples a volume of 100 ml could be completely dewatered within one minute, using a 5 in Buchner funnel with Whatmann No. 2 filter paper at a vacuum of 10 in of mercury, while for untreated samples a duration of 30 to 35 minutes was needed for dewatering 100 ml of the primary sludge. Therefore, it may be stated that the Purifax Process was effective in improving the dewatering characteristics of septages and primary sludge but not effective in the case of anaerobically digested sludge. Finally it should be reported that apparently both mixing time and chlorine dosage had no noticeable effect on the improvement of this quality.

(f) BOD_5

The removal of BOD_5 by chlorination reflects the oxidation of the biodegradable portion of the carbonaceous organic matter. Although there are no stoichiometrical relations established between BOD and carbonaceous organic content of a substrate, the reduction of BOD_5 content of a sludge by the Purifax Process remains to be a significant parameter in an evaluation of the process.

In this study the removal of BOD_5 generally increased with the increase of chlorine dosage and mixing time. However, the degree of removal at a same dosage and mixing time varied appreciably for sludge and septage from different sources as shown in Figures 29 to 35.

For septages, BOD_5 removal was as high as 70 to 80 percent except Sample 2, the removal of which was 30 percent. It should be noted that the removal of ammonia was also poor for Sample 2. It should also be noted that for Sample 2, both dosage of chlorine and mixing time did not significantly alter the efficiency in removing BOD_5, as shown in Figure 30.

As shown in Tables IX and X and Figures 31 and 32, the removal of BOD_5 was higher percent wise for the 5 year septage than for the 3 year septage. It may be surmised that in the former case a larger percent of the organic compounds was reduced to simpler forms by hydrolysis and biodegradation and the oxidation by chlorination of the degraded and simpler organics was more effective. Therefore, the septages of longer age should be stabilized more readily by the Purifax Process.

For sludges the BOD_5 removal of primary sludge was between 50 percent to 75 percent. As shown in Figure 33, the higher chlorine dosage increased the removal 5 to 10 percent, but a longer mixing time at either dosage did not enhance the removal appreciably. These results are agreeable with the findings as shown in Figures 13 to 15 of Part A of this study.

The BOD_5 removal of anaerobically digested sludge was higher, 65 percent to 80 percent. Organic matters in digested sludge should be simpler in structure and therefore easier to be attacked by chlorine. However, it should be noted that the NH_3-N removal of primary sludge was in a similar order of its BOD_5 removal, while the NH_3-N removal of anaerobically digested sludge was much lower percent-wise than its BOD_5 removal.

It was found that total chlorine residuals decreased linearly with BOD_5 removal as shown in Figure 36 which is a plot of percentage of BOD_5 removal versus total chlorine residuals of the centrate. It is shown that the chlorine consumed per unit of BOD_5 removed, that is, the slope of the curves in Figure 36 , varied with sludge and septage of different sources but was practically independent of chlorine dosage within the range of 1900 mg/l to 2400 mg/l for a same source of sludge or septage. It seemed that a larger amount of organic matters was oxidized at the very on-set of the thrust of a higher dosage of chlorine. Thereafter the oxidation of organic matters per unit amount of chlorine consumed was indifferent to the level of chlorine dosage within the range used for this study.

For a continuous process of sludge chlorination in order to take advantage of the initial thrust of a high chlorine dosage, a rapid and complete mixing becomes one of the essential design requirements.

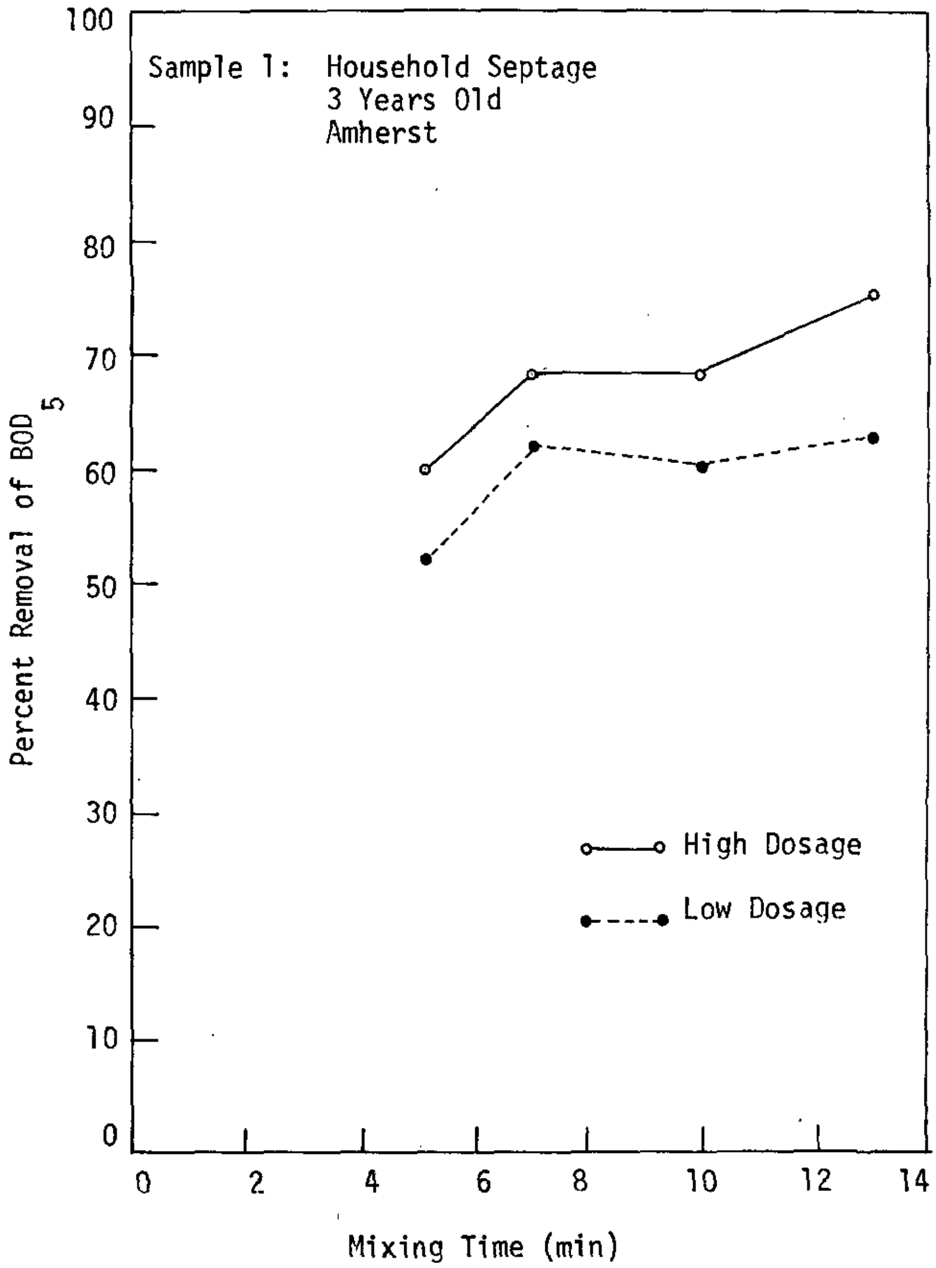


Figure 29. Percent Removal of BOD_5 vs. Mixing Time.

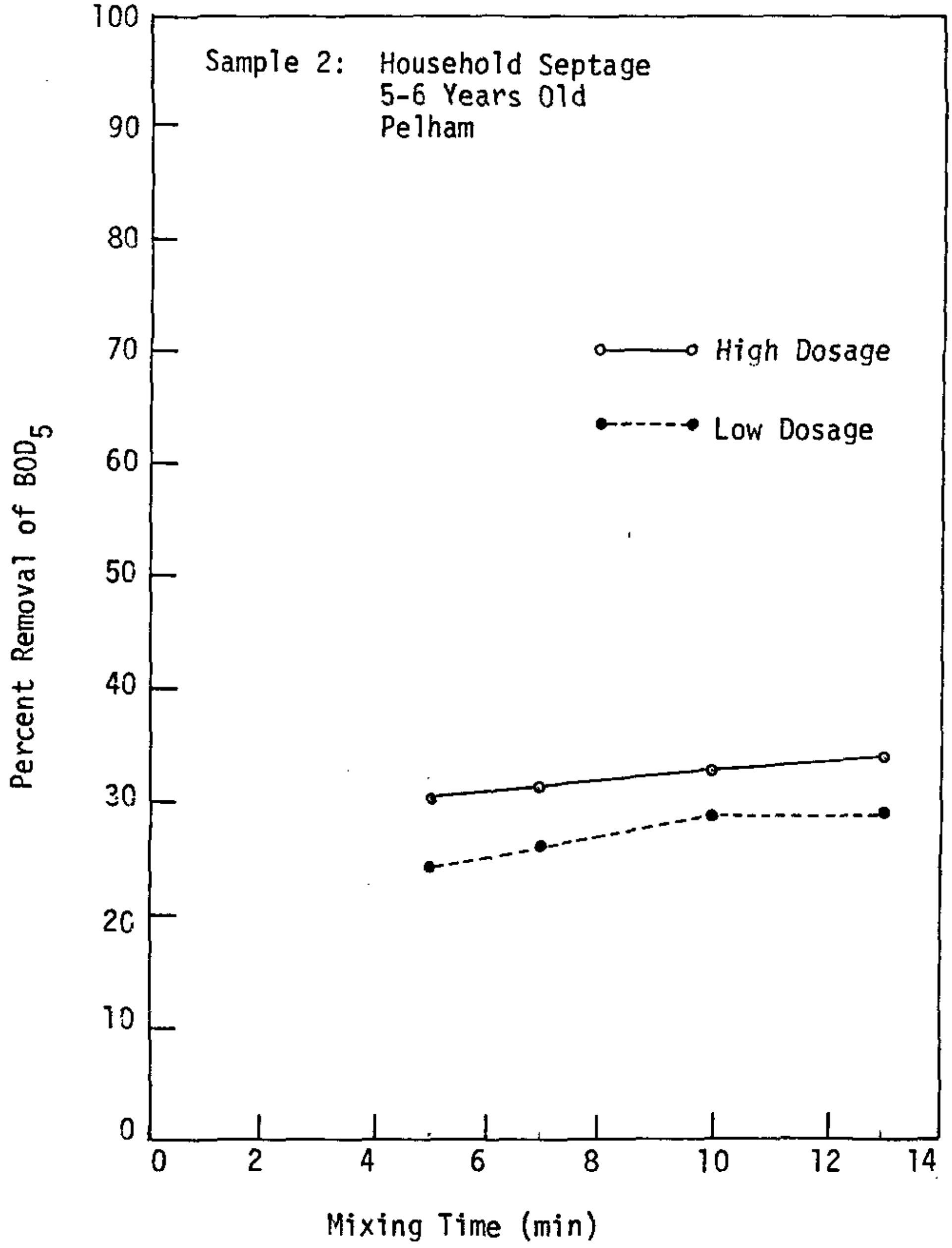


Figure 30. Percent Removal of BOD_5 vs. Mixing Time.

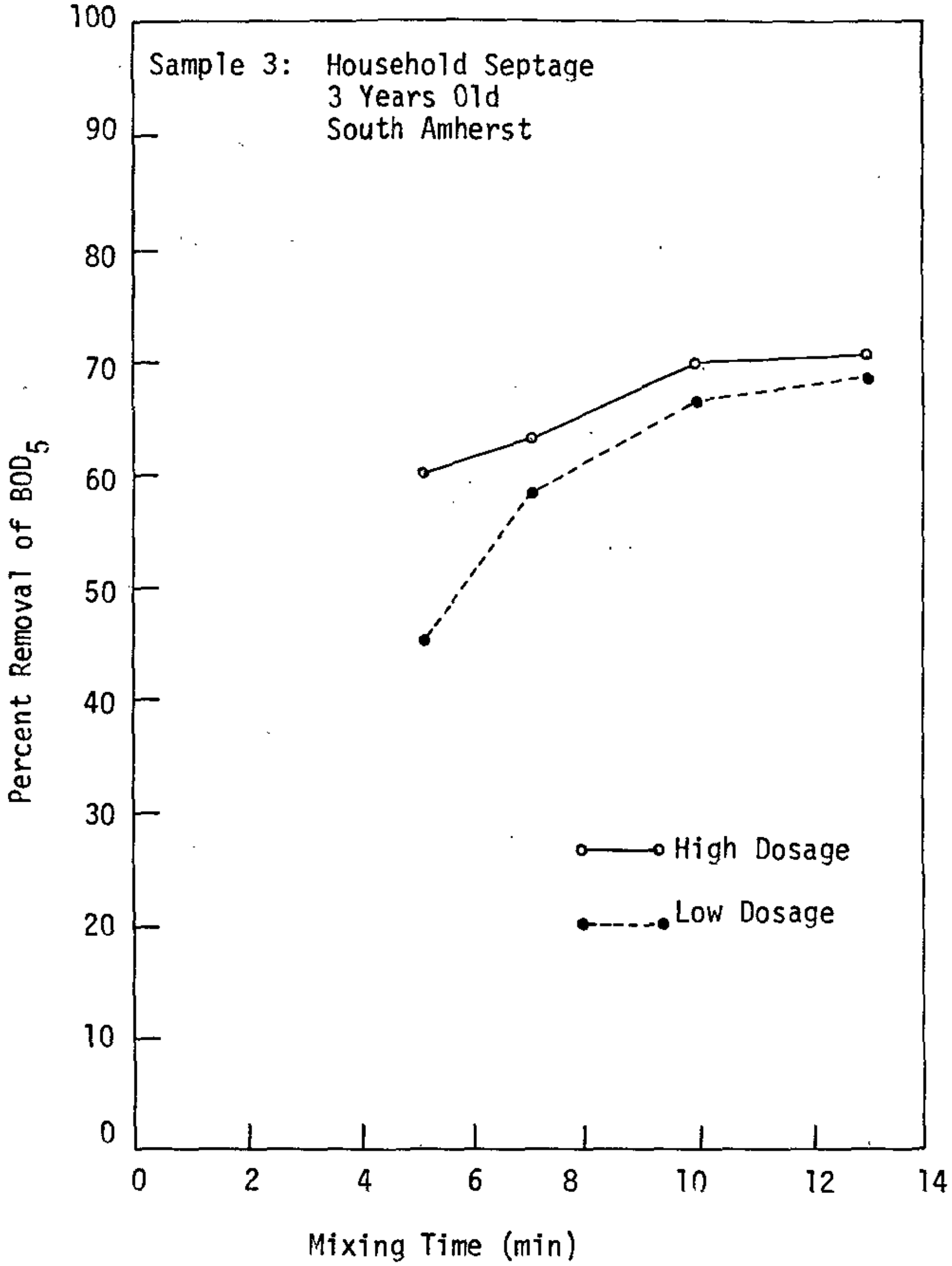


Figure 31. Percent Removal of BOD_5 vs. Mixing Time.

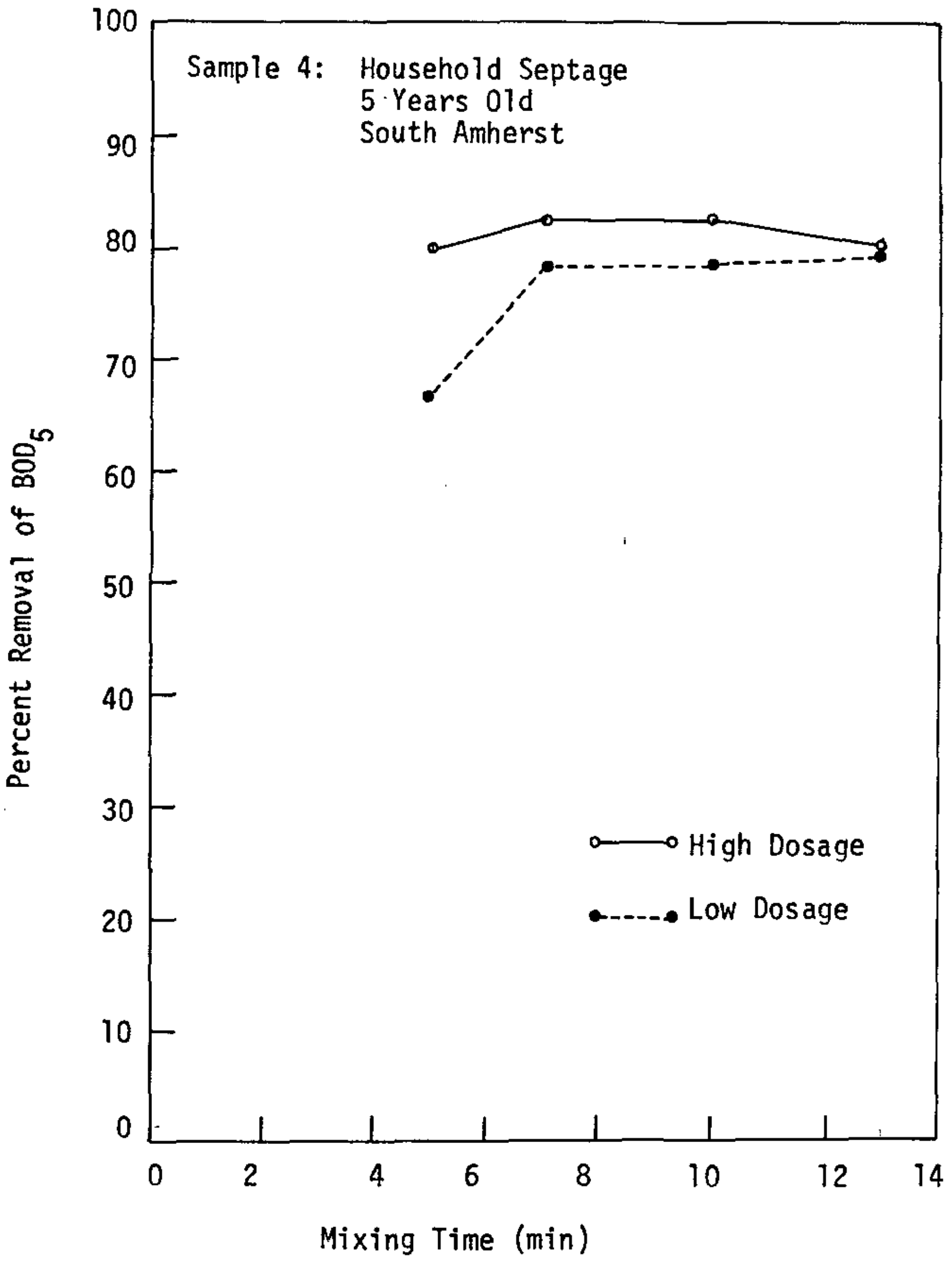


Figure 32. Percent Removal of BOD$_5$ vs. Mixing Time.

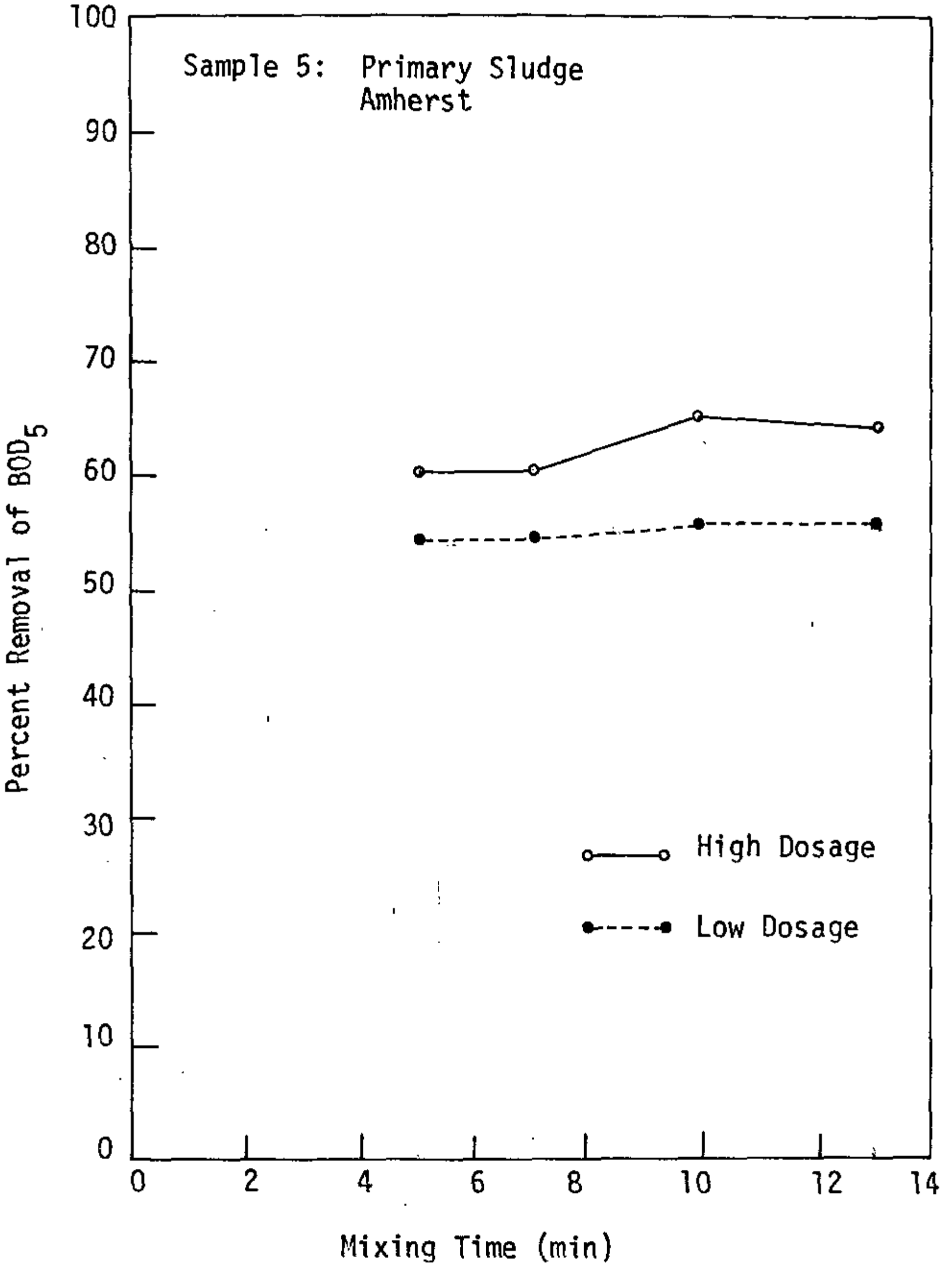


Figure 33. Percent Removal of BOD_5 vs. Mixing Time.

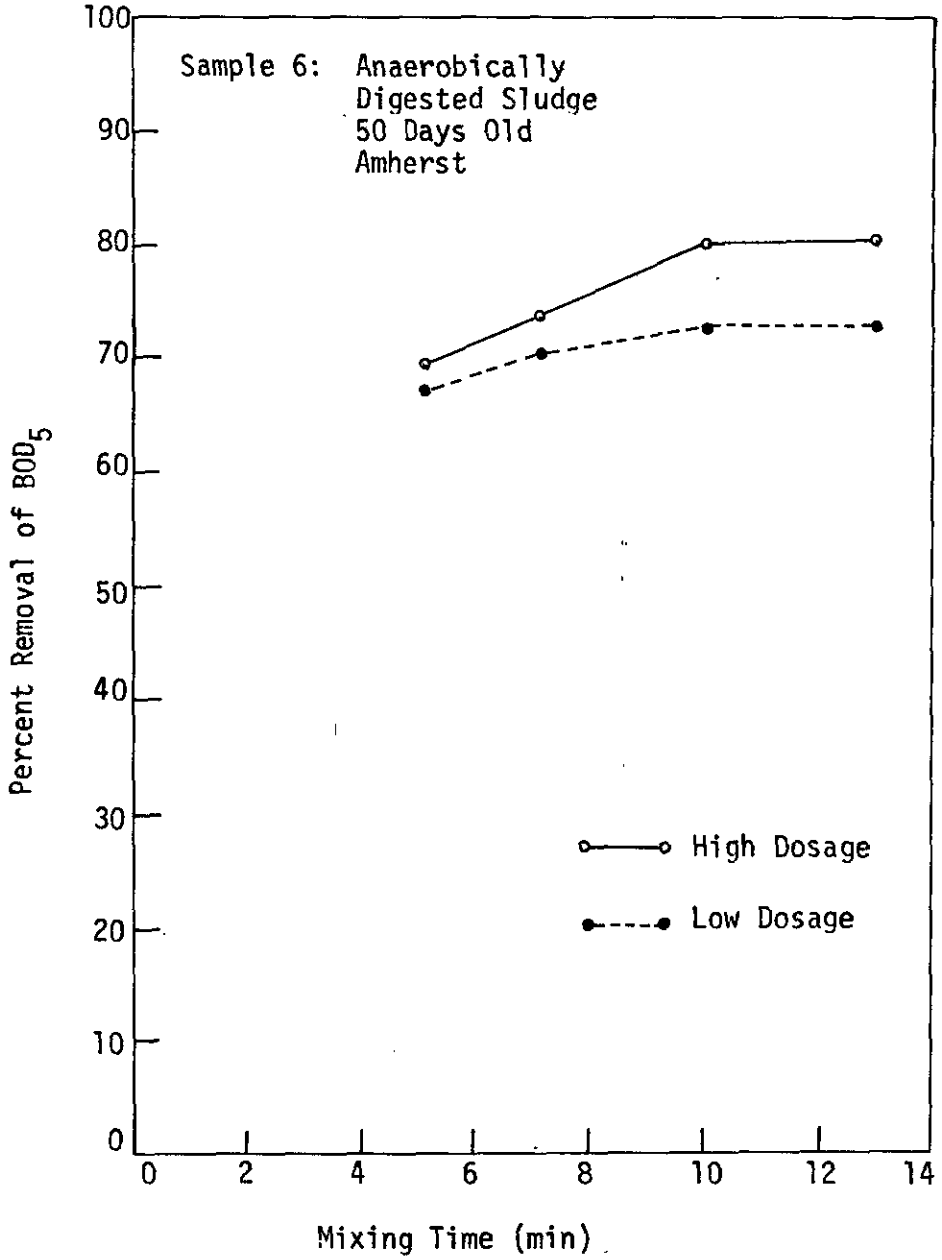


Figure 34. Percent Removal of BOD_5 vs. Mixing Time.

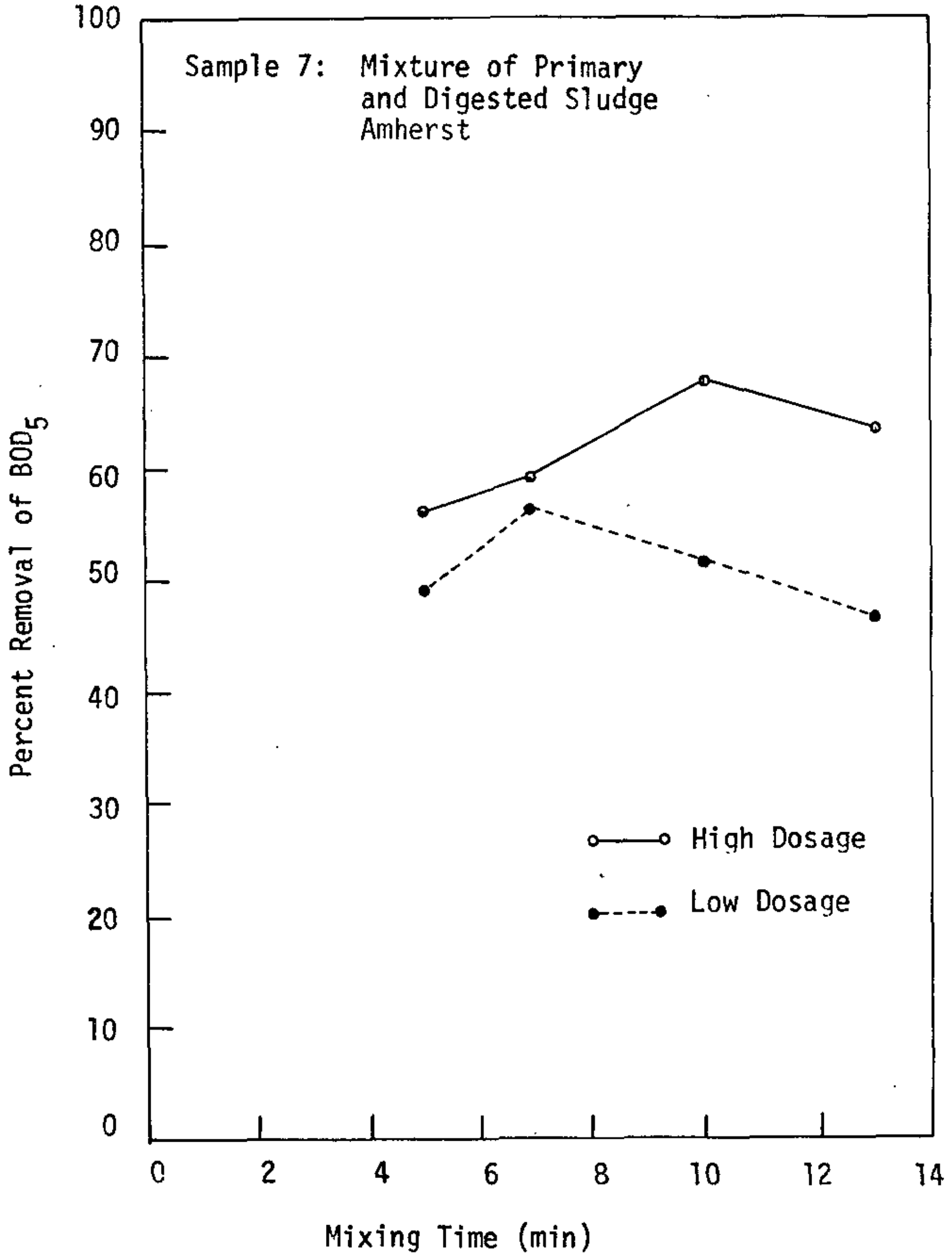


Figure 35. Percent Removal of BOD_5 vs. Mixing Time.

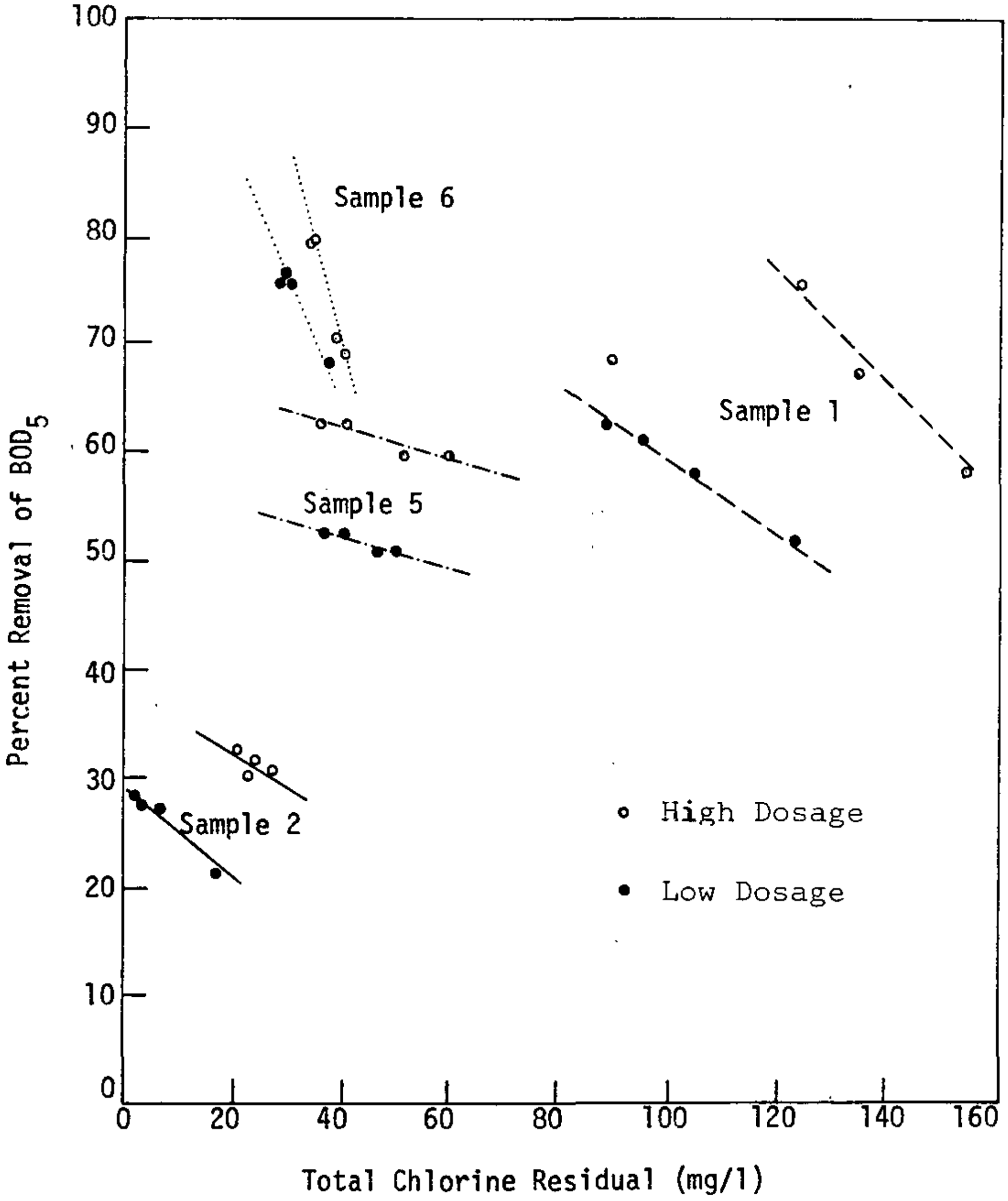


Figure 36. Linear Relationship Between Percent Removal of BOD_5 & Total Chlorine Residual of Centrifugal Supernatant.

(g) Total Organic Carbon (TOC)

In order to determine the efficiency of the Purifax Process in removing carbonaceous organic matters which are major competitors for chlorine in septage and sludge of domestic origin, a TOC test was performed in addition to BOD_5. The experimental results are listed in Tables VII to XIII. The percent removal of TOC as a function of mixing time and chlorine dosage is shown in Figures 37 to 43.

Both the centrate and the filtrate of the chlorinated samples were analyzed for their TOC values. The TOC value of a filtrate essentially represents a measurement of the concentration of the dissolved carbonaceous organic matters. A portion of the TOC value of a centrate represents a measurement of the concentration of the suspended carbonaceous organic matters which still remain in the centrate after centrifugation at a specified G-value, which can be calculated by the COD values of the centrate and the filtrate. Obviously centrifugation at different G-values will result in different concentrations of the suspended TOC remaining in the centrate.

As shown in Figures 39 and 40, the percentage removal of TOC in the septage samples widely varied. In general it may be stated that the removal of TOC in centrates at the higher chlorine dosage of 2400 mg/l ranged from 30 percent to 80 percent, and at the lower dosage of 1900 mg/l ranged from 25 percent to about 70 percent. The removal of TOC in the filtrates was lower respectively. It was also shown that the mixing time extended beyond four minutes did not improve the removal.

For the primary sludge, as shown in Table XI and Figure 41, the centrate TOC removal was about 60 percent at the higher chlorine dosage and about 35 percent at the lower one, while the filtrate TOC removal was about 30 percent and less than 20 percent respectively. It seemed that the suspended portion of TOC in the centrate was more readily removed then the dissolved portion. However it could be also interpreted as the results of the breakdown of suspended solids to dissolved forms by the chlorination. In Figure 41, it can also be observed that while the chlorine dosage had signficant effect on the removal, the mixing time longer than 4 minutes did not play an important role in the removing.

For the anaerobically digested sludge, as shown in Table XII and Figure 42, the removal of centrate TOC was about 60 percent at both chlorine dosages while the removal of filtrate TOC was significantly affected by the different dosages, while only affected by mixing time at the lower dosage. Similar to the primary sludge, the removal of centrate TOC was apparently higher than the removal of filtrate TOC.

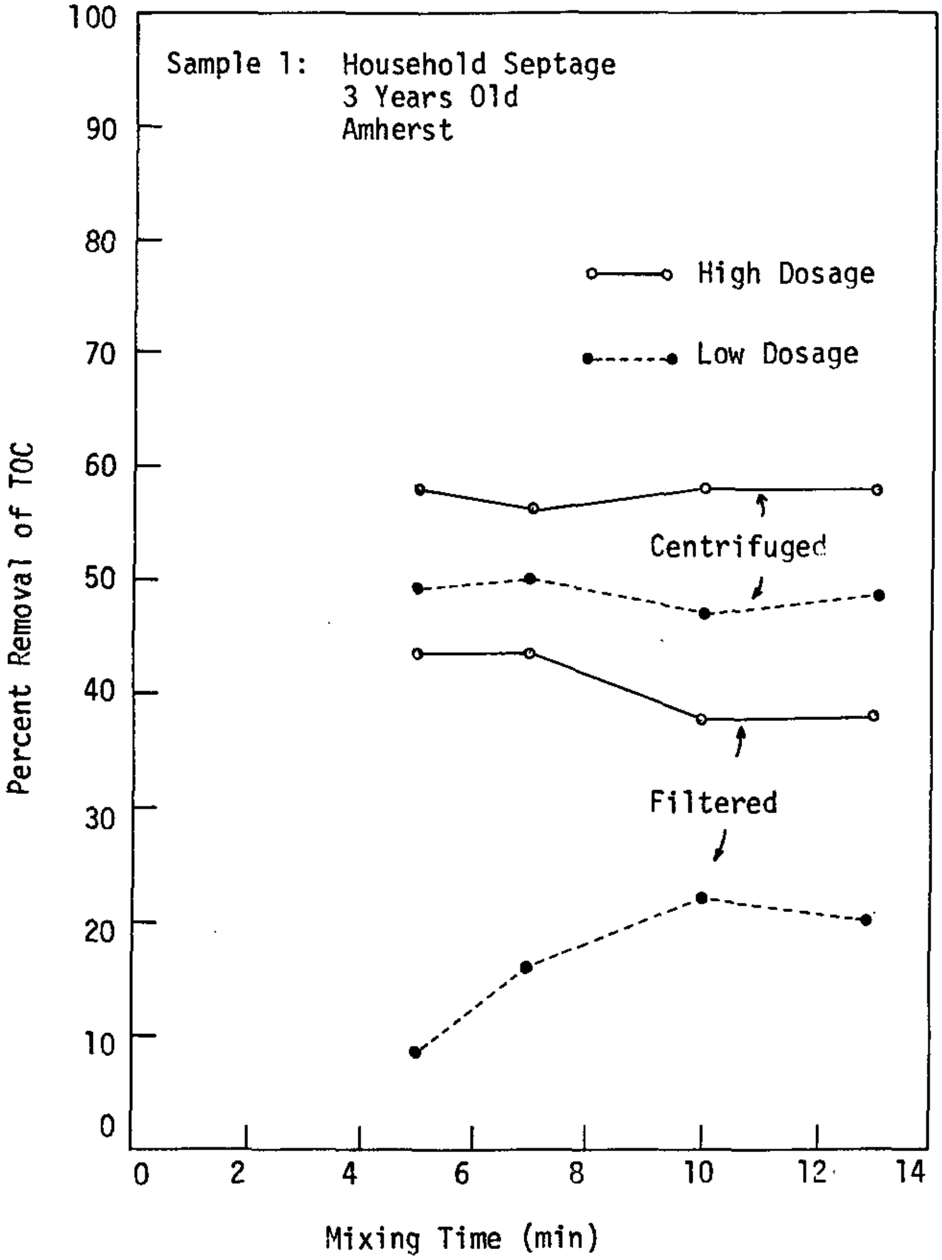


Figure 37. Percent Removal of TOC vs. Mixing Time.

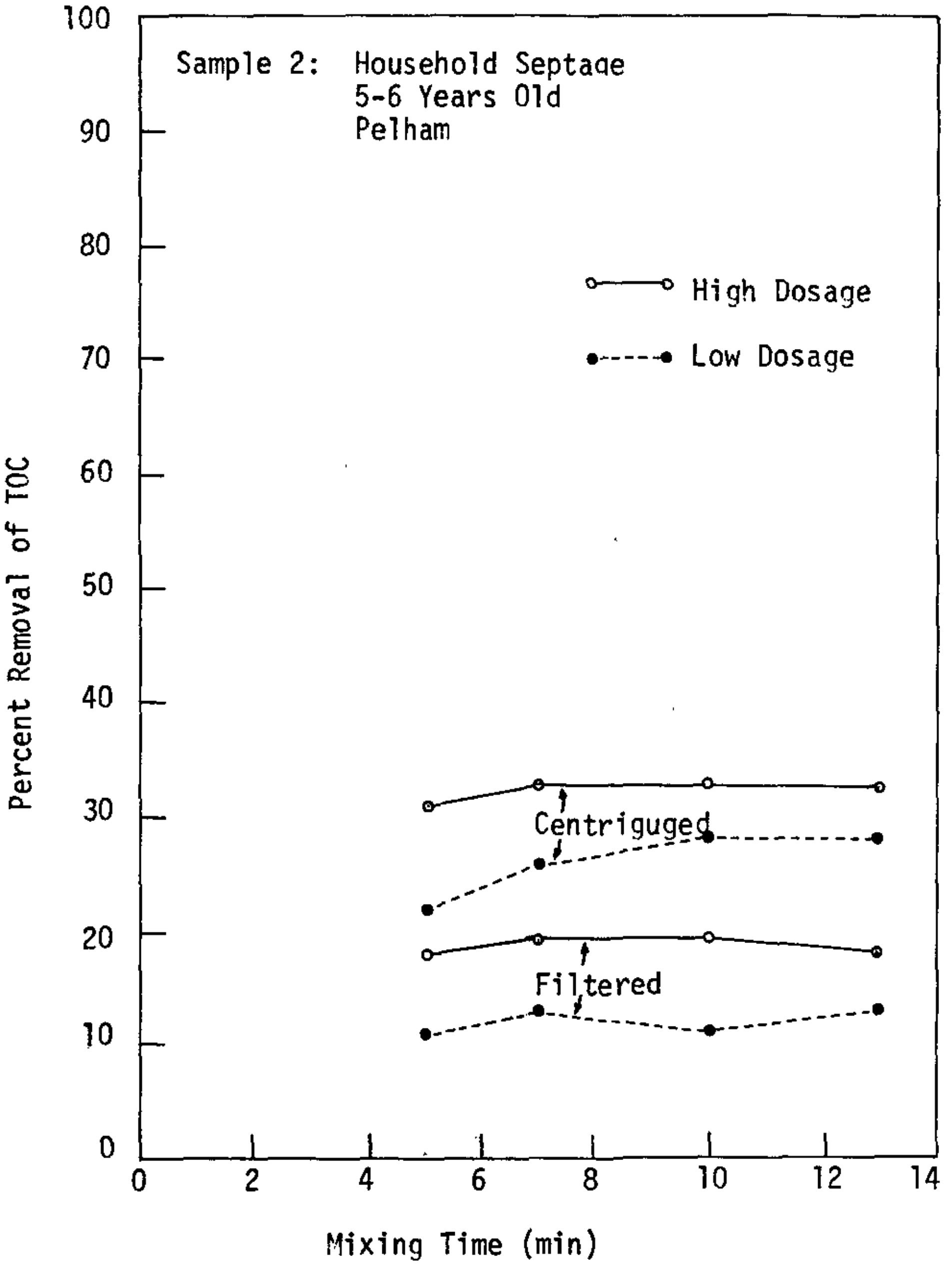


Figure 38. Percent Removal of TOC vs. Mixing Time.

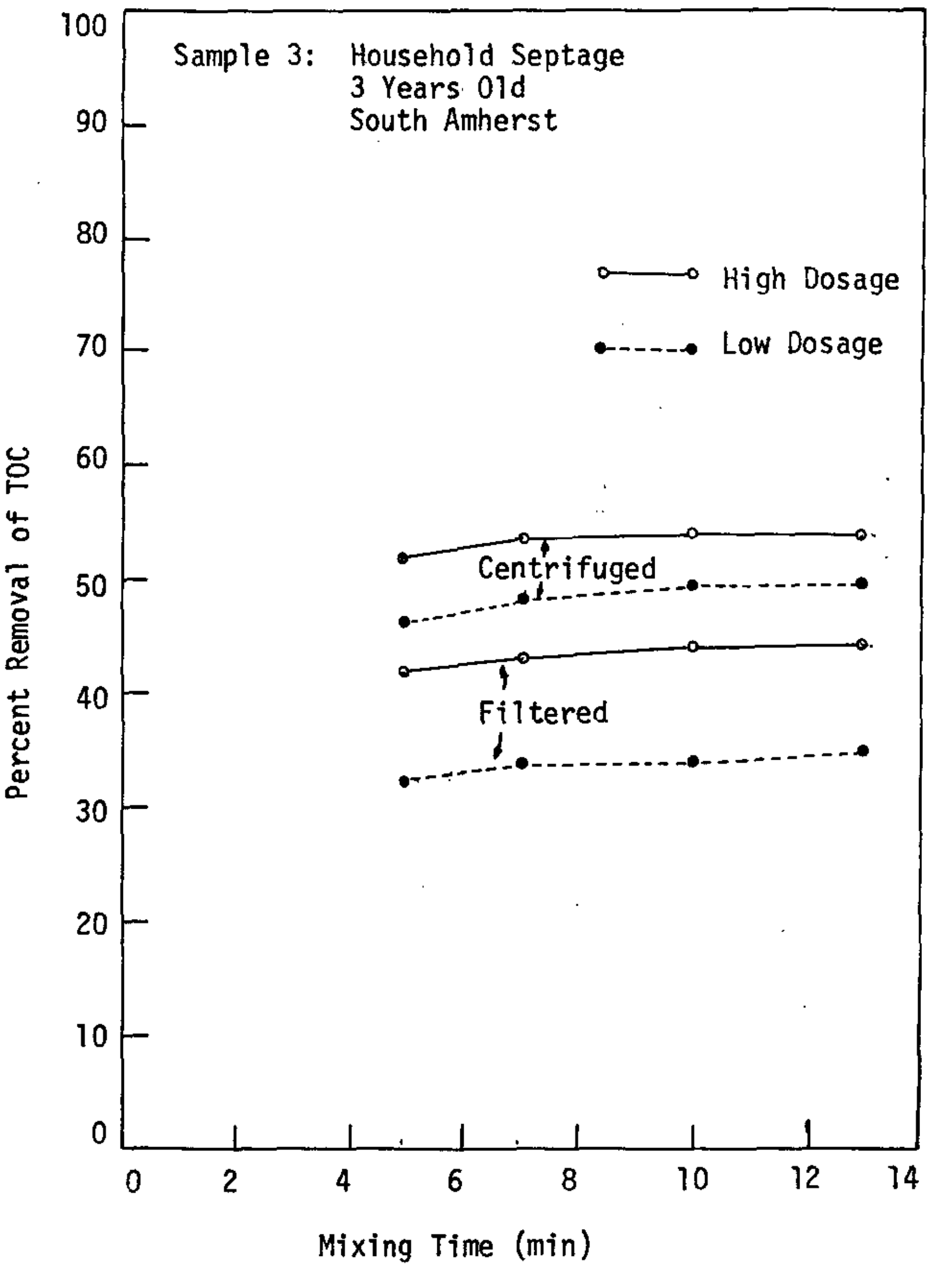


Figure 39. Percent Removal of TOC vs. Mixing Time

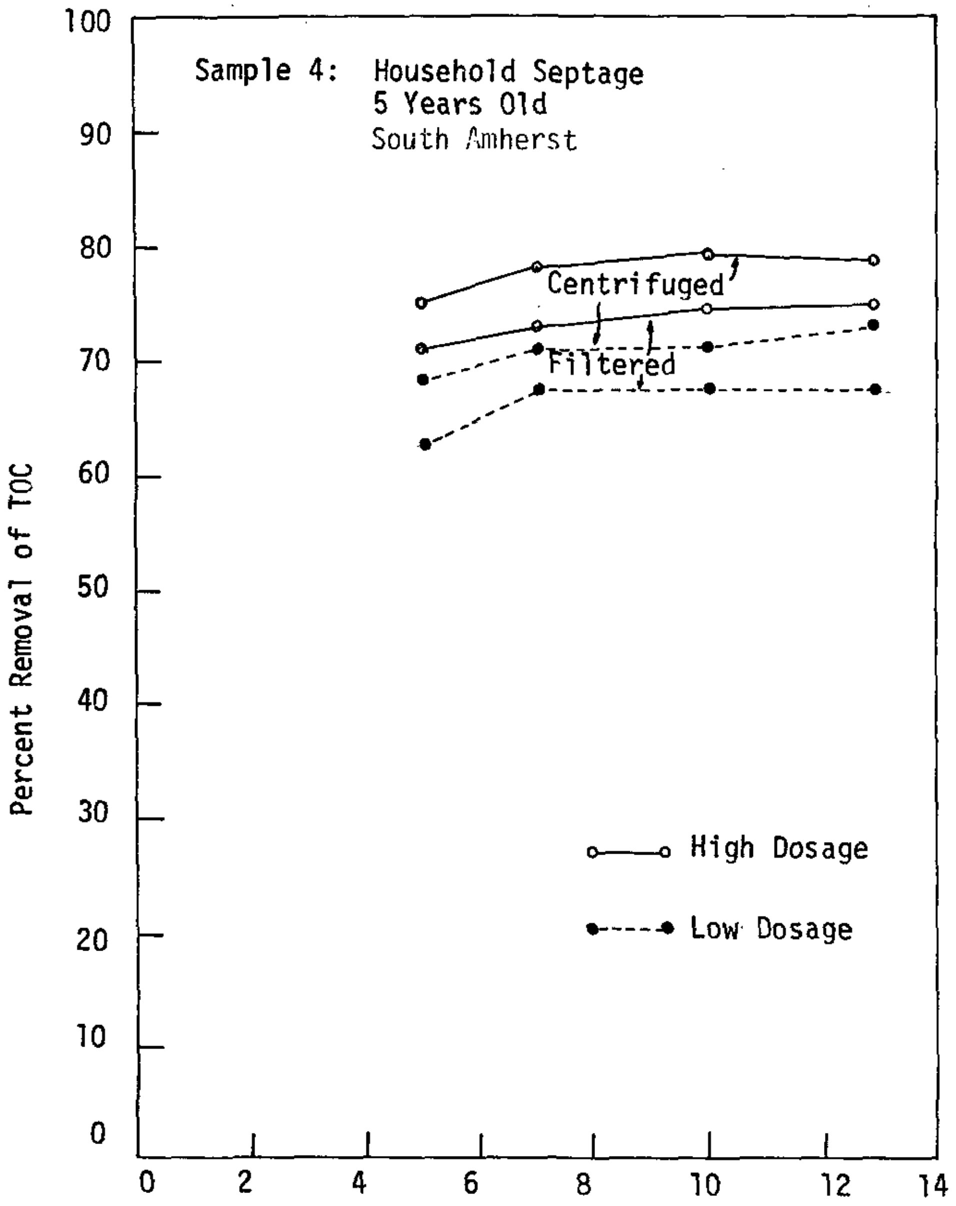


Figure 40. Percent Removal of TOC vs. Mixing Time.

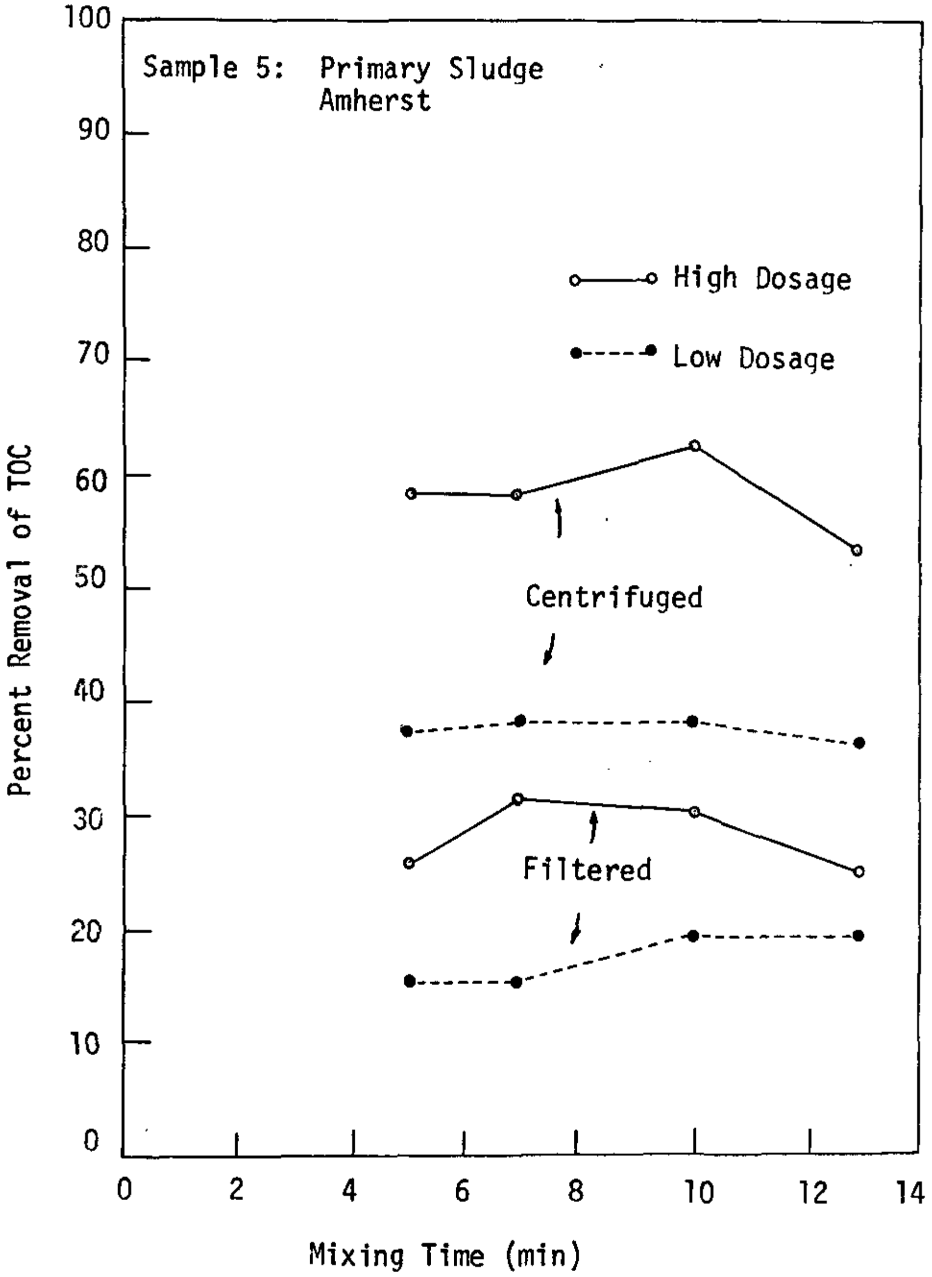


Figure 41. Percent Removal of TOC vs. Mixing Time.

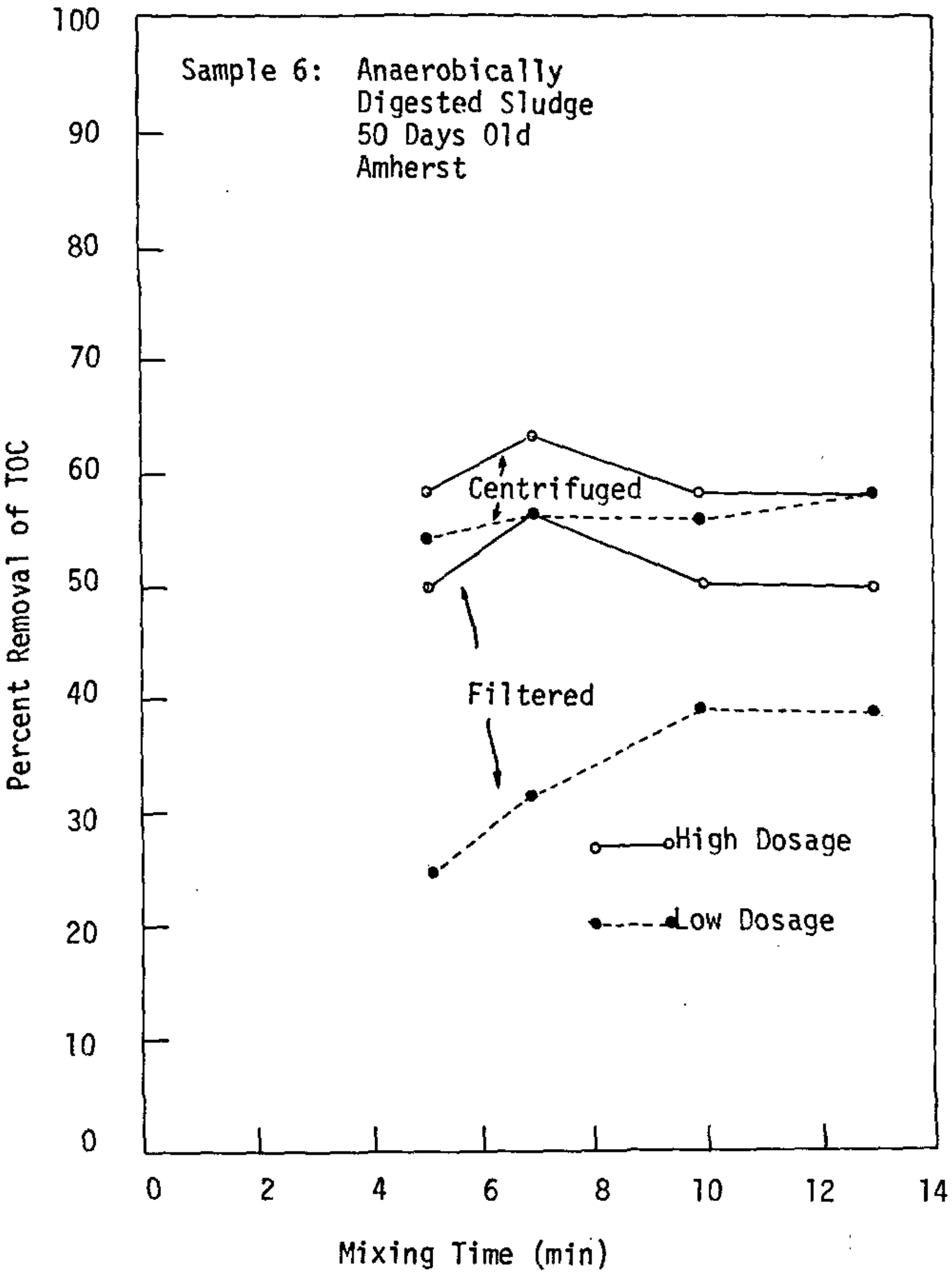


Figure 42. Percent Removal of TOC vs. Mixing Time.

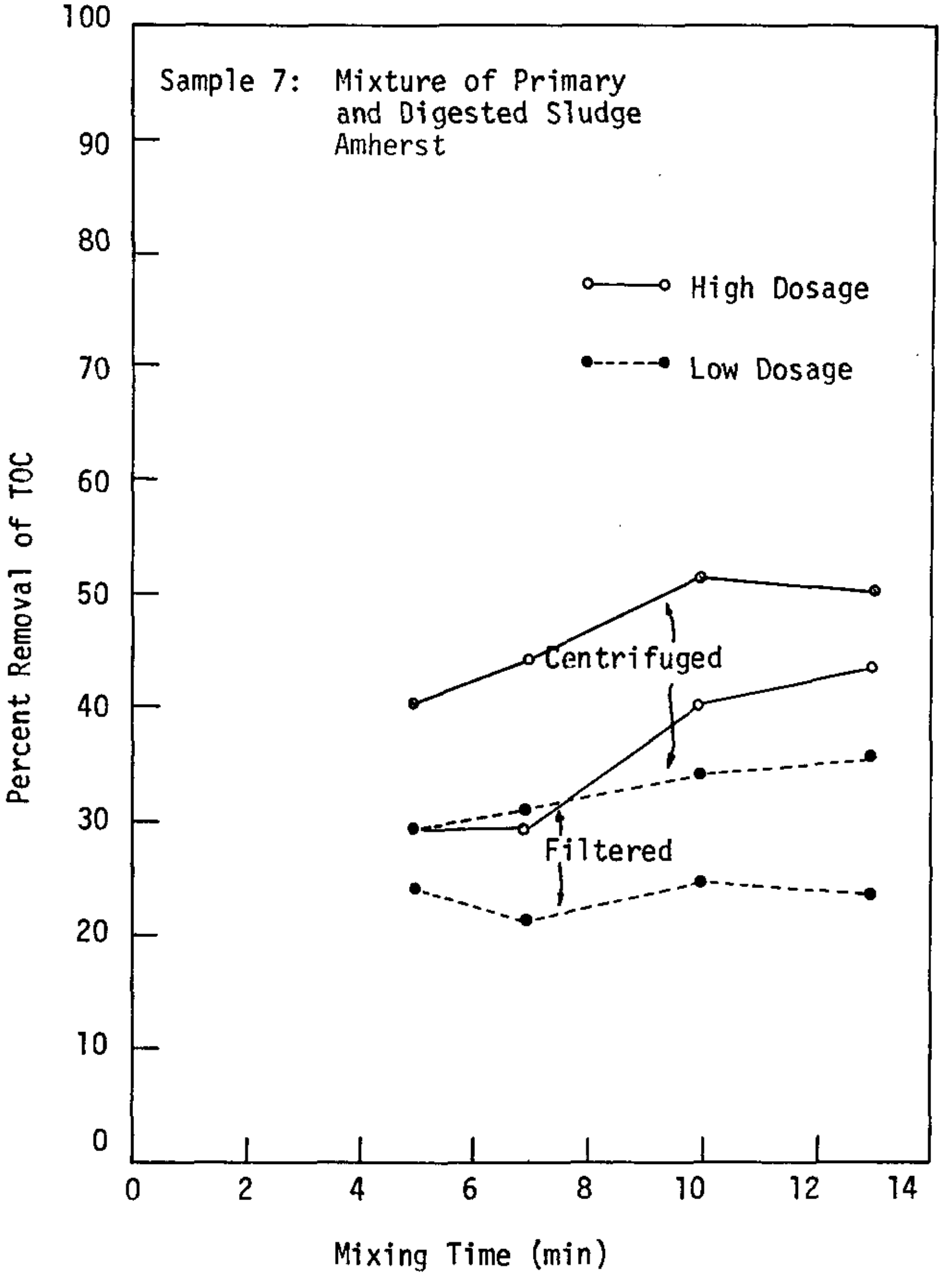


Figure 43. Percent Removal of TOC vs. Mixing Time.

3. Summary

From the experimental results of this part of the study, several conclusions can be made as follows:

(a) The pH values of all the treated samples fell below 2 despite their origin , age and characteristics. The two chlorine dosages used in this study had no significant effect on the pH values of the treated samples.

(b) Practically there was no change of solids concentration as the results of treatment by the Purifax Process. However, it was observed that the dark color of sludge solids was changed to light yellow color for all the treated samples. The odor of sludge solids was also completely removed. The most important and significant change in the treated samples was the improvement of their dewatering quality.

(c) Chlorination was effective in removing ammonia nitrogen from both septages and primary sludge but not effective for the anaerobically digested sludge. It seemed that mixing time had no significant effect on the removal efficiency of ammonia nitrogen.

(d) It seemed that the sludge solids can exert a substantial chlorine demand and competed for chlorine with the dissolved organic matters. The chlorine demand of the samples increased with their initial suspended solids concentration. Furthermore, the suspended solids of the chlorinated samples seemed to "hold" a major portion of the chlorine residuals. The heavy dosages of chlorine used in this part of the study and the resultant low pH had provided a favorable condition for the formation of NCl_3 which is slightly soluble in water and therefore expected to be released from the liquid phase by the vigorous agitation in the reactor.

(e) The Purifax Process greatly improved the dewatering quality of the septage and primary sludge samples but did not alter appreciably the dewatering quality of the digested sludge sample. For most of the treated samples a volume of 100 ml could be completely dewatered within one minute, using a 5 in Buchner funnel with Whatmann No. 2 filter paper at a vacuum of 10 inches of mercury while for untreated samples a duration of 30 to 45 minutes was needed for septages and primary sludge, and as long as 2 hours for the digested sludge.

(f) The removal of BOD_5 by chlorination generally increased with the increase of chlorine dosage and mixing time. The BOD_5 removal for most treated samples of the septage was about 70 percent to 80 percent, 50 percent to 75 percent for treated sample of the primary sludge and 65 percent to 80 percent for the digested sludge. It was found that total chlorine residuals decreased linearly with BOD_5 removal. The chlorine consumed per unit of BOD_5 removed varied with sludge and septage of different sources but was practically independent of chlorine dosage with the range of 1900 mg/l to 2400 mg/l for a same source of sludge or septage. Furthermore, it seemed that a larger amount of organic matters was oxidized at the very on-set of the thrust of a higher dosage of chlorine.

g) The removal of TOC by chlorination increased with the increase of chlorine dosage from 1900 mg/l to 2400 mg/l, but not with the increase of mixing time from 4 minutes to 13 minutes. In general the TOC removal from the septage and sludge sample varied widely, from as low as 10 percent to as high as 80 percent. In all cases, the removal of TOC in the centrate was significantly higher than the removal of TOC in the corresponding filtrate. It could be interpreted as the results of the breakdown of the suspended solids in the centrate to dissolved forms.

APPENDIX I.

References

1. J. W. Clark, W. Viessman, Jr. and M. J. Hammer, "Water Supply and Pollution Control." Second Edition, pp. 550-560, International, Scranton, PA (1971).

2. G. M. Fair, J. C. Geyer and D. A. Okun, "Water and Wastewater Engineering." Vol. 2, pp. 36/33-36/36, Wiley, New York, New York (1967).

3. H. E. Babbitt and E. R. Baumann, "Sewerage and Sewage Treatment." Eighth Edition. Wiley, New York, New York (1968).

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

5. J. L. S. Hickey and David L. Duncan, "Performance of Single Family Septic Tank Systems in Alaska", Jour. Water Poll. Control Fed., 38, 1298 (1966).

6. Water Pollution Control Federation, "Anaerobic Sludge Digestion." WPCF Manual of Practice, No. 16, 6 (1968).

7. J. E. Pfeffer, M. Leiter and J. R. Worland, "Population Dynamics in Anaerobic Digestion." Jour. Water Poll. Control Fed., 39, 1305 (1967).

8. C. E. Woods and J. F. Malina, Jr., "Stage of Digestion of Wastewater Sludge." Jour. Water Poll. Control Fed., 37, 1495 (1965).

9. G. C. White, "Handbook of Chlorination." pp. 182-227. Van Nostrand Reinhold, New York,New York (1972).

10. "Standard Methods for the Examination of Water and Wastewater." 13th Edition. American Public Health Association, New York, New York (1971).

11. B. J. McCabe and W. W. Eckenfelder, Jr., "Biological Treatment of Sewage and Industrial Wastes." Vol. 2, Reinhold Publishing Company, New York New York (1955).

12. W. W. Eckenfelder, Jr., "Water Quality Engineering for Practicing Engineers." Barnes & Noble, Inc. (1970).

13. W. C. Lee and D. H. Waller, "Effect of Solids on Sewage Disinfection." Proceedings of the National Specialty Conference on Disinfection, July 8-10, 1970, at the University of Massachusetts in Amherst, pp. 203-222.

14. C. N. Sawyer and P. L. McCarty, "Chemistry for Sanitary Engineers." 2nd Edition, pp. 368-375. McGraw-Hill, New York, New York (1967).

APPENDIX II.

Calibration Curves

Figure A-1. Relationship between TOC and BOD_5 of Purifaxed primary sludge.

Figure A-2. Relationship between TOC and BOD_5 of Purifaxed septage.

Figure A-3. Calibration curve for NH_3-N.

Figure A-4. Calibration curve for chlorine residuals.

Figure A-5. Calibration curve for total carbon.

Figure A-6. Calibration curve for inorganic carbon.

Figure A-7. Calibration curve for phosphate.

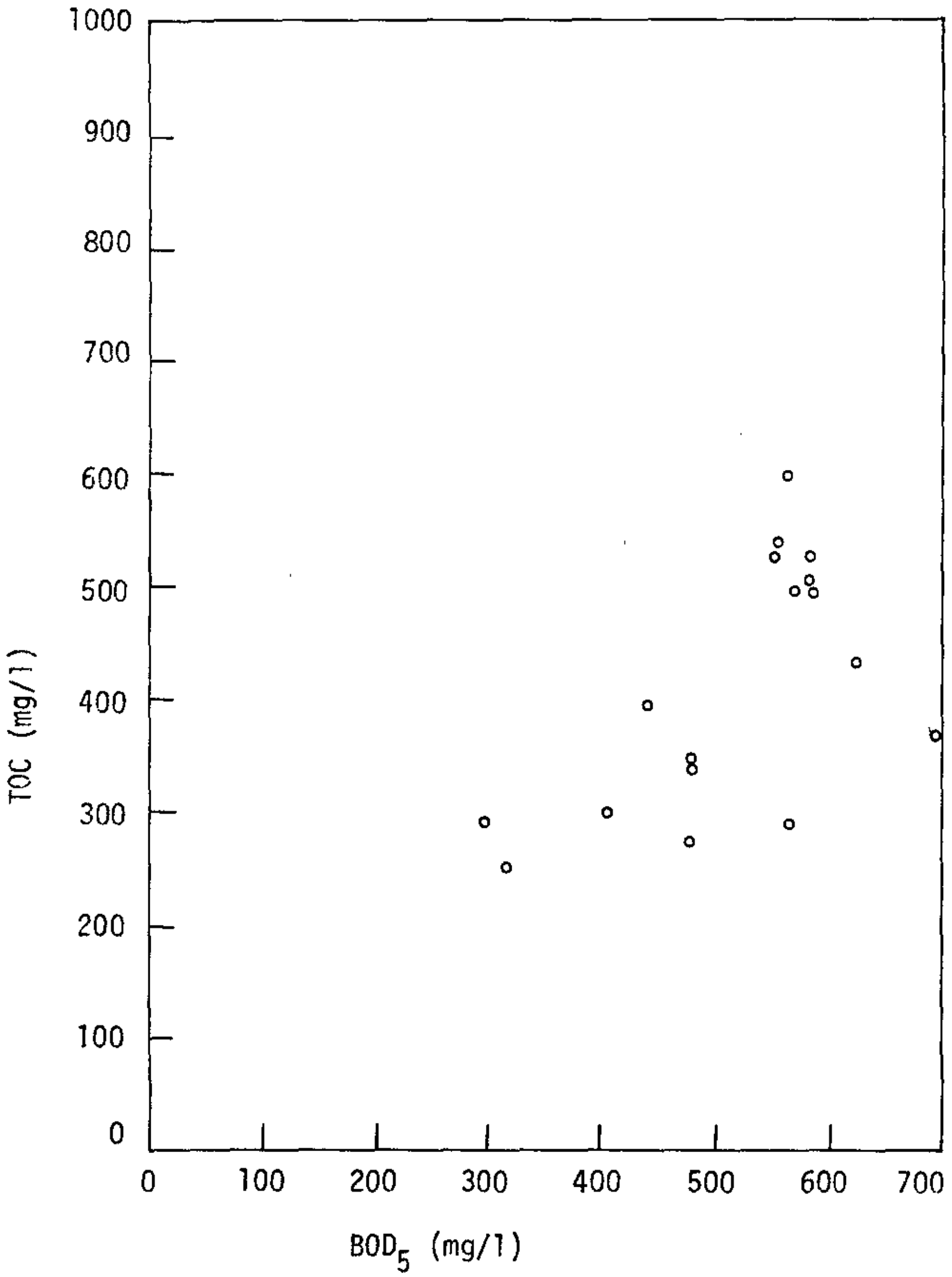


Figure A-1. Relationship Between TOC and BOD_5 of Purifaxed Primary Sludge.

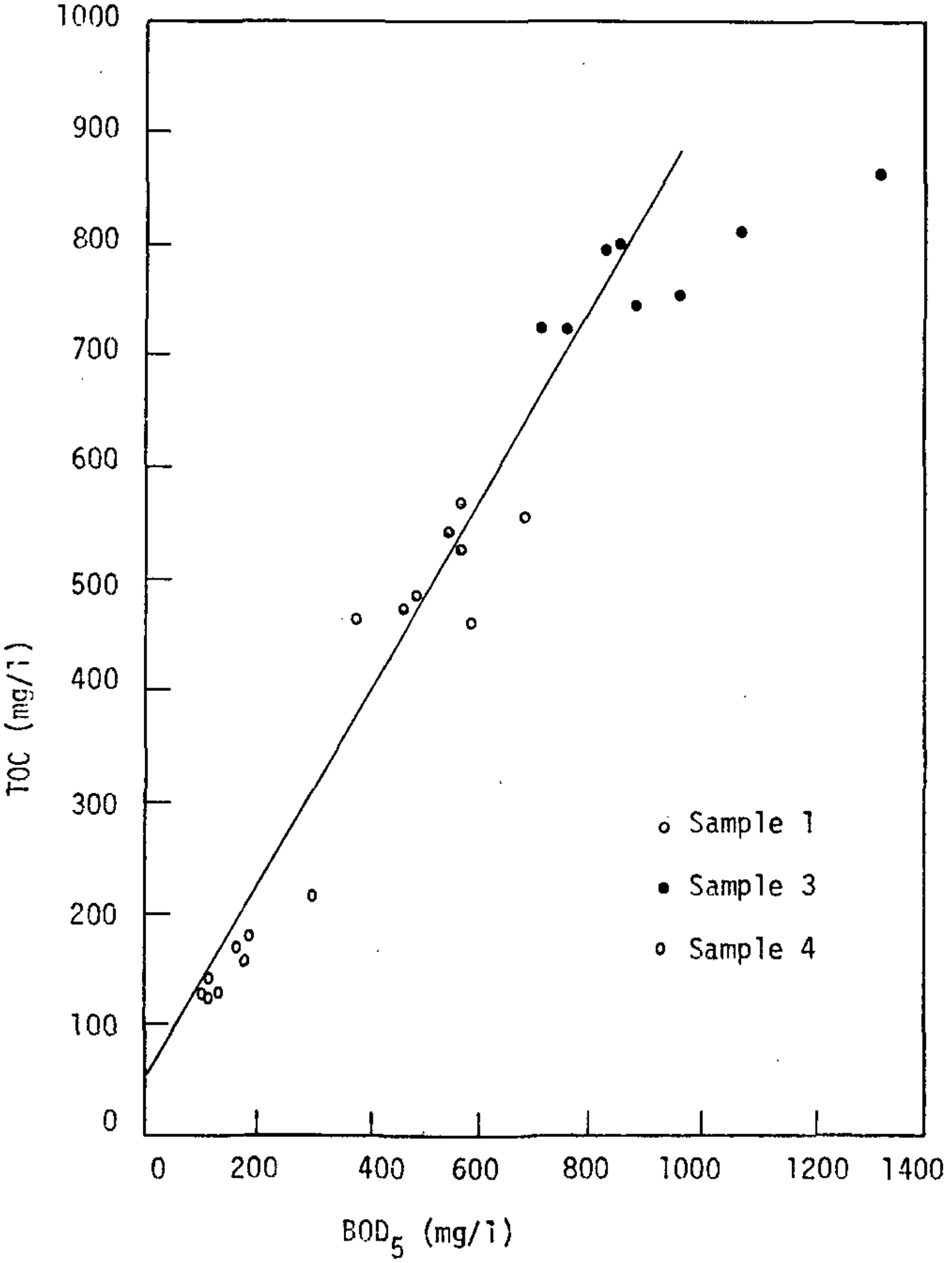


Figure A-2. Relationship Between TOC and BOD_5 of Purifaxed Septage.

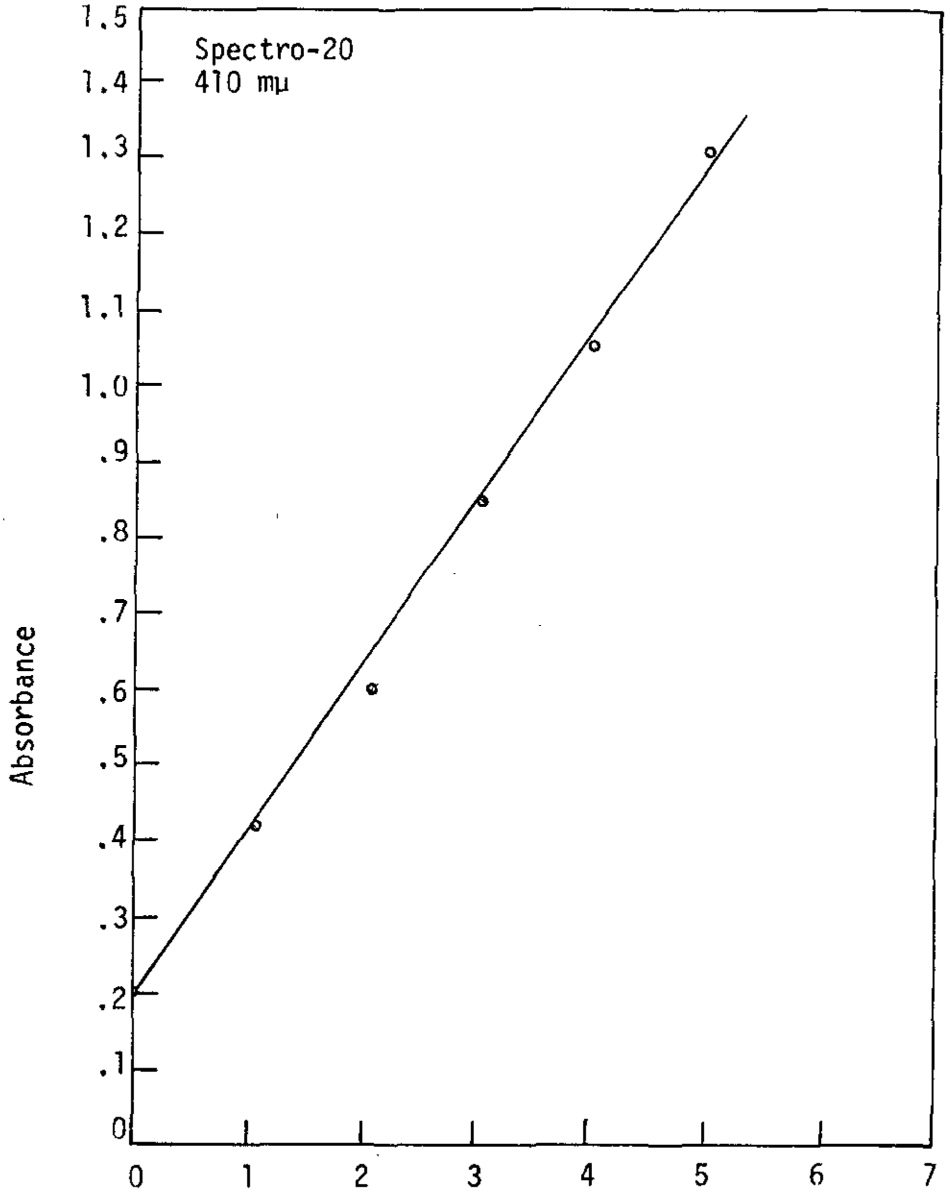


Figure A-3. Calibration Curve for NH_3-N.

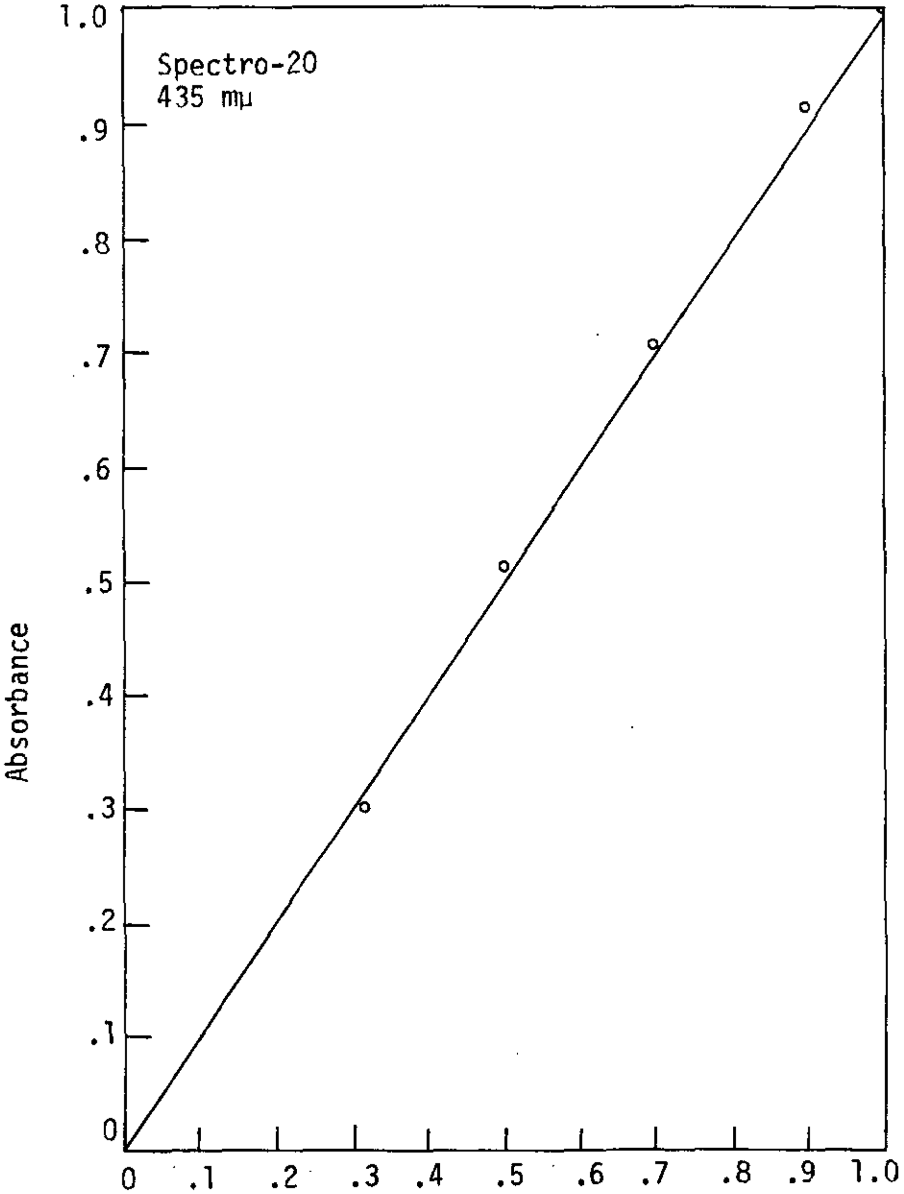


Figure A-4. Calibration Curve for Chlorine Residual.

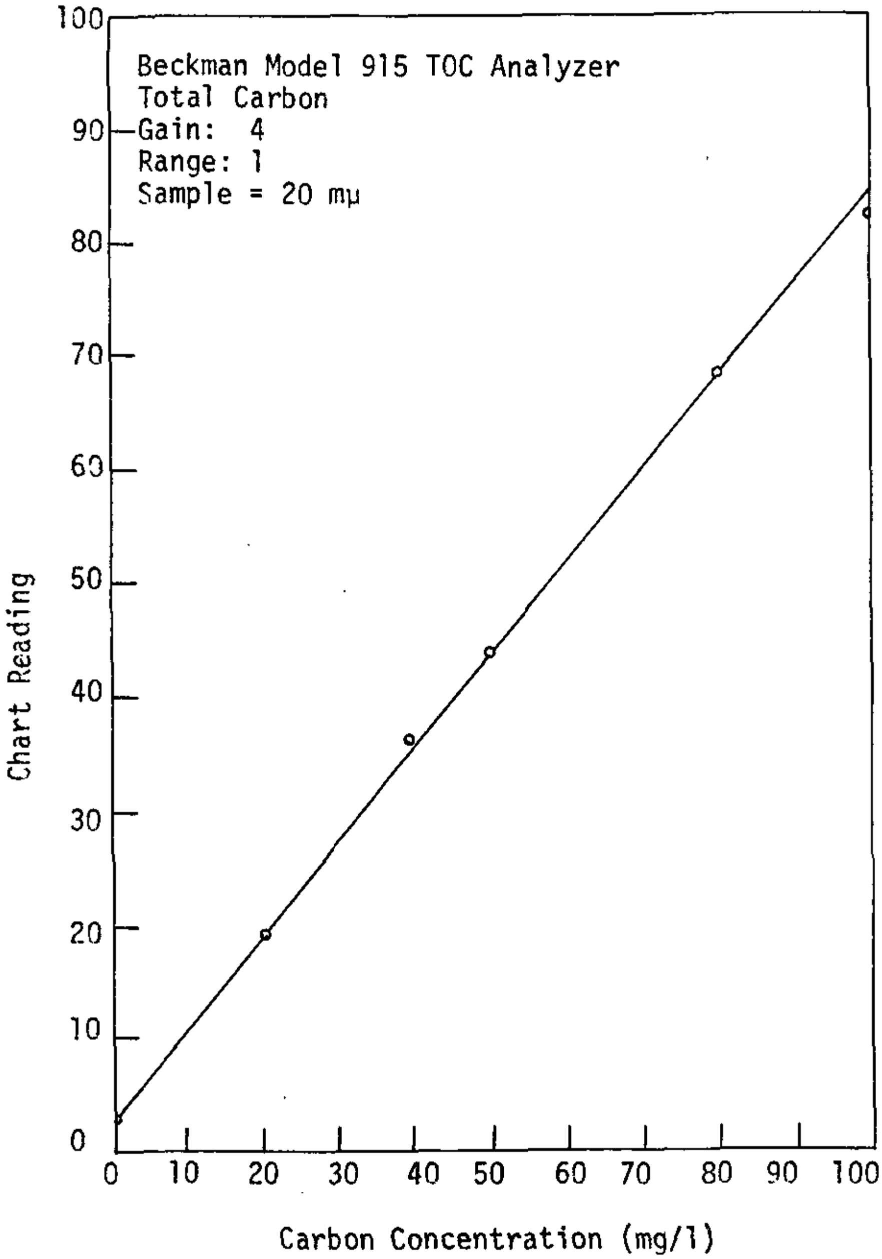


Figure A-5. Calibration Curve for Total Carbon.

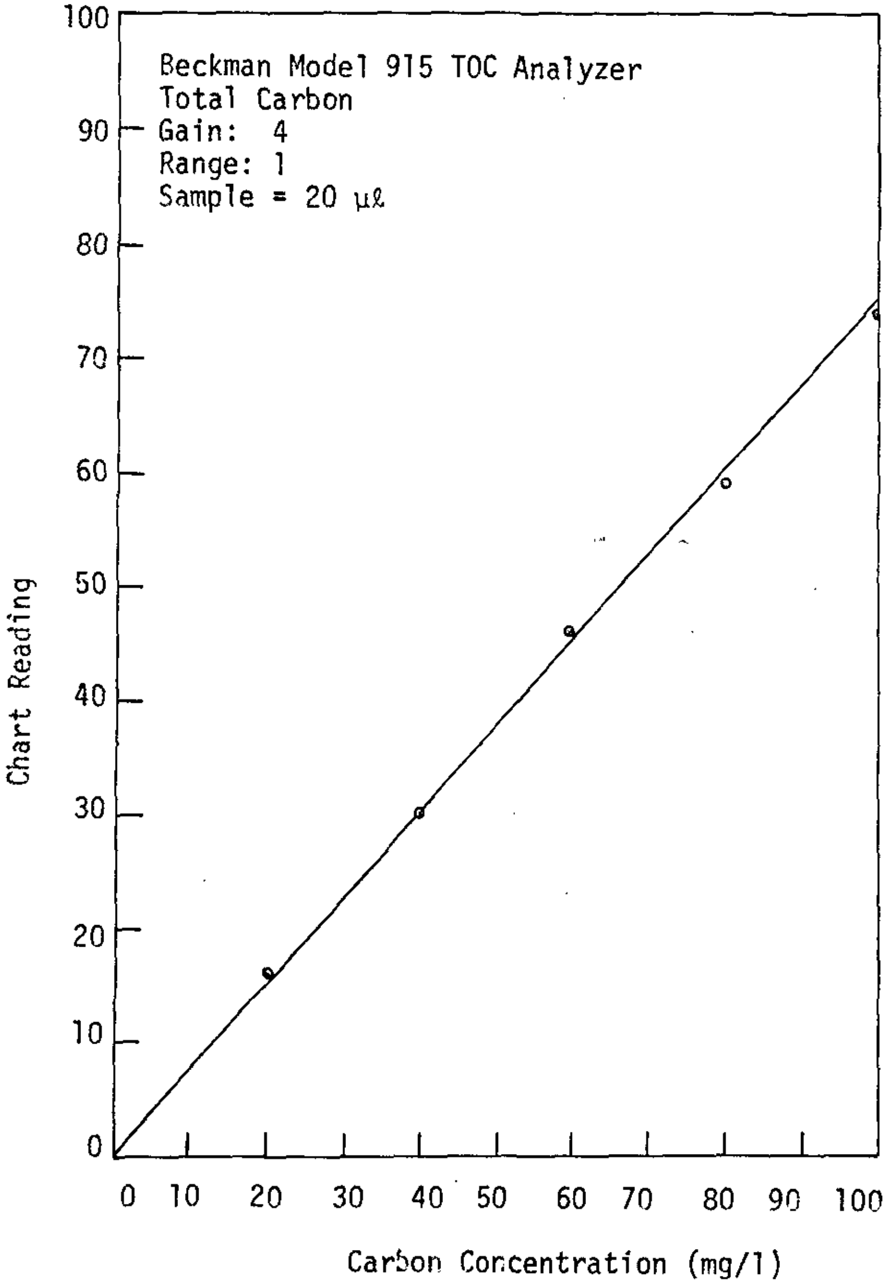


Figure A-6. Calibration Curve for Inorganic Carbon.

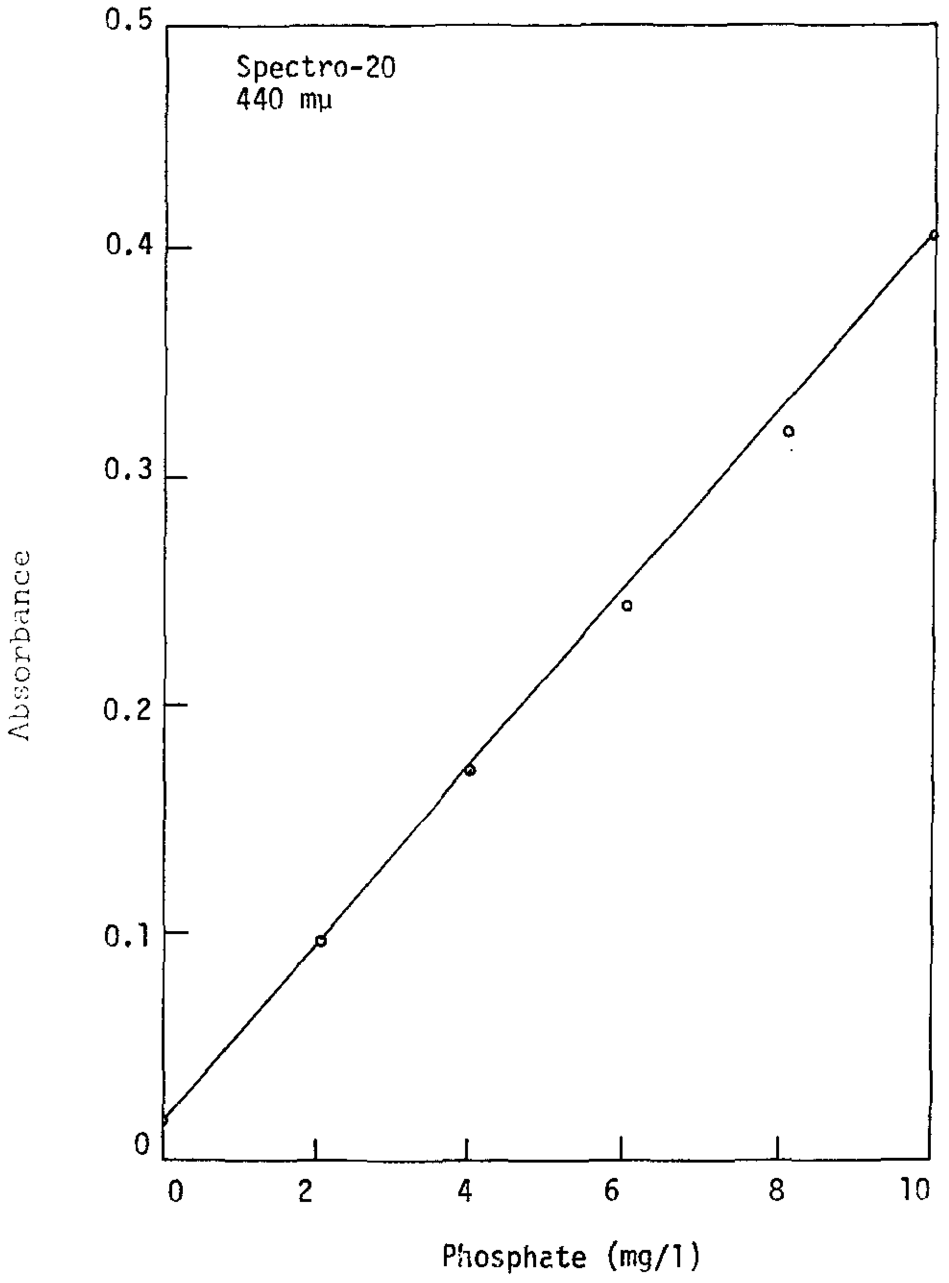


Figure A-7. Calibration Curve for Phosphate.