THE STABILIZATION OF SEPTAGE
BY HIGH DOSAGES OF CHLORINE

Tsuan Hua Feng
Wen-Kang Shieh

Report for Division of Water Pollution Control
Massachusetts Water Resources Commission
Contract Number 73-07(3)
THE STABILIZATION OF SEPTAGE BY
HIGH DOSAGES OF CHLORINE

By

Tsuan Hua Feng
Professor of Civil Engineering

Wen-Kang Shieh
Research Assistant

Division of Water Pollution Control
Massachusetts Water Resources Commission
Contract Number MDWPC 73-07(3)

Environmental Engineering Program
Department of Civil Engineering
University of Massachusetts
Amherst, Massachusetts 01002

May 1975
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.

Tsuan Hua Feng, PhD
Professor of Civil Engineering
and Thesis Adviser
TABLE OF CONTENTS

Abstract

I. Introduction and Objectives  
   A. Characteristics of Septages  3
   B. Biochemistry of Septic Tank Systems  6
   C. Application of the Purifax Process to Septage Treatment  8

II. Chemistry of Chlorination  10
   A. Nitrogenous Compounds  12
   B. Carbonaceous Compounds  15
   C. Hydrogen Sulfide  17
   D. Methane  18

III. Experimental Apparatus and Methods  19
   A. Experimental Apparatus  19
   B. Determination of Chlorine Dosage  22
   C. Preparation of Sludges  23
   D. Operation Steps  24
   E. Analysis of Sludge Characteristics  27
IV. Experimental Results and Discussion


1. General Description and Summary of Data.

2. Discussion of Experimental Results
   a. pH
   b. Chlorine Residuals
   c. NH₃-N
   d. BOD₅
   e. COD
   f. Phosphates

3. Summary

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.  

2. Discussion of Experimental Results  
   a. pH  
   b. Solids  
   c. NH₃-N  
   d. Chlorine Residuals  
   e. Specific Resistance  
   f. BOD₅  
   g. Total Organic Carbon (TOC)  

3. Summary  

Appendix I: References  
Appendix II: Calibration Curves
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 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. 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 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 information available on the general nature of septages.

Kolega, 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:

\[
\begin{align*}
\text{BOD}_5 &= 4794 \text{ mg/l} \\
\text{COD} &= 26162 \text{ mg/l} \\
\text{Total Solids} &= 22400 \text{ mg/l} \\
\text{Suspended Solids} &= 2350 \text{ mg/l} \\
\text{Volatile Suspended Solids} &= 531 \text{ mg/l} \\
\text{Org-N} &= 26 \text{ mg/l} \\
\text{NH}_3-N &= 72 \text{ mg/l}
\end{align*}
\]
Septic Tank Supernatant:

- $\text{BOD}_5 = 1948 \text{ mg/l}$
- $\text{COD} = 6343 \text{ mg/l}$

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

- $\text{pH} = 7.26$
- $\text{BOD}_5 = 77.6 \text{ mg/l}$
- $\text{Alkalinity (as } \text{CaCO}_3) = 318 \text{ mg/l}$
- $\text{Org-N} = 3.4 \text{ mg/l}$
- $\text{NH}_3-N = 37 \text{ mg/l}$
- $\text{Acetic Acid} = 36.4 \text{ mg/l}$
- $\text{Propionic Acid} = 3.8 \text{ mg/l}$
- $\text{Butyric Acid} = 0.8 \text{ mg/l}$
- $\text{Total Solids} = 450 \text{ mg/l}$
- $\text{Suspended Solids} = 27.7 \text{ mg/l}$

The septic tank gas had the following compositions:

- $\text{CO}_2 = 2.2 \text{ percent}$
- $\text{O}_2 = 4.9 \text{ percent}$
- $\text{N}_2 = 90.7 \text{ percent}$
- $\text{CH}_4 = 2.1 \text{ percent}$
According to Babbitt, 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 $\text{NO}_3^-$, $\text{CO}_2$, $\text{SO}_4^{2-}$ and organic compounds as hydrogen acceptor.

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 \( \text{CH}_4, \text{CO}_2, \text{H}_2\text{S} \) 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 showed that molecular oxygen existed in the gaseous products and \( \text{CH}_4 \) 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 \( \text{CH}_4 \).
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. BOD₅ removal, NH₃-N removal, COD removal, TOC removal, P0₄ 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: (1) ammonia, (2) amino acids, (3) proteins, (4) carbonaceous material, (5) nitrates, (6) hydrogen sulfide, (7) cyanides, (8) iron, and (9) manganese.

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:

\[ \text{Cl}_2 + \text{H}_2\text{O} \rightarrow \text{HOCl} + \text{HCl} \]  \hspace{1cm} (2-1)

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

\[ \text{HOCl} \rightarrow \text{H}^+ + \text{OCl}^- \]  \hspace{1cm} (2-2)
Both $\text{HOCl}$ and $\text{OCl}^-$ are called free available chlorine. $\text{OCl}^-$ is more than 90 percent at pH above 9. $\text{HOCl}$ becomes predominant at pH below 6. Molecular chlorine starts to appear at pH below 4.
A. Nitrogenous Compounds

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

\[ \text{HOC}_1 + \text{NH}_3 \rightarrow \text{NH}_2\text{Cl} + \text{H}_2\text{O} \] \hspace{1cm} (2-3)

\[ \text{HOC}_1 + \text{NH}_2\text{Cl} \rightarrow \text{NHC}_1\text{Cl} + \text{H}_2\text{O} \] \hspace{1cm} (2-4)

\[ \text{HOC}_1 + \text{NHC}_1\text{Cl} \rightarrow \text{NC}_1\text{3} + \text{H}_2\text{O} \] \hspace{1cm} (2-5)

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 NC1 3 will be formed. NC1 3 readily envolves as gas because of its low solubility in water. 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:

\[ \text{NO}_2^- + \text{HOC}_1 \rightarrow \text{NO}_3^- + \text{H}^+ + \text{Cl}^- \] \hspace{1cm} (2-6)
Besides, nitrites will react with chloramines at favorable pH values and thus complicate the relative distribution of chlorine residuals.

The presence of organic nitrogenous 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 nitrogenous compound, as far as chlorination is concerned, is urea. Urea hydrolyzes with ammonia as one of the end products.

\[ \text{CO(NH}_2\text{)}_2 + \text{H}_2\text{O} \rightarrow 2\text{NH}_3 + \text{CO}_2 \]  

(2-7)

Urea functions as a reservoir for supplying ammonia which keeps consuming 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.
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:

\[
C + 2\text{Cl}_2 + 2\text{H}_2\text{O} \rightarrow 4\text{HCl} + \text{CO}_2
\]  \hspace{1cm} (2-8)

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

\[
\text{H} \quad \text{H} \quad \quad \text{Cl} \quad \text{OH} \\
\text{H} \quad \text{H} \\
\text{H} \quad \text{H}
\]

\[
-\text{C} = \text{C} \rightarrow \text{HOCl} 
- \quad - \text{C} - \text{C} - \\
\text{H} \quad \text{H} \\
\]  \hspace{1cm} (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\textsubscript{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.

\[ H_2S + 4Cl_2 + 4H_2O \rightarrow H_2SO_4 + 8HCl \] (2-10)

\[ H_2S + Cl_2 \rightarrow S^+ + 2HCl \] (2-11)

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 for methane gas, a main end product of anaerobic digestion, to react with chlorine gas to form CCl₄ at temperature of 300°C and higher, as follows:

$$\text{CH}_4 + 4\text{Cl}_2 \rightarrow \text{CCl}_4 + 4\text{HCl} \quad (2-12)$$

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
BOD₅
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" (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 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". 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 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
- \( \text{BOD}_5 \) (whole sample, centrate and filtrate)
- COD (whole sample, centrate and filtrate)
- Total Phosphate (centrate and filtrate)
- Ortho Phosphate (centrate and filtrate)
- \( \text{NH}_3-N \) (whole sample, centrate and filtrate)
- Chlorine Residuals (centrate and filtrate)

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

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 \( \text{NH}_3-N \) of Septage
- Figures 7 to 9: Removal of \( \text{NH}_3-N \) of Primary Sludge
- Figures 10 to 12: Removal of \( \text{BOD}_5 \) of Septage
- Figures 13 to 15: Removal of \( \text{BOD}_5 \) 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>
<thead>
<tr>
<th>Measured Characteristics</th>
<th>Untreated Sample</th>
<th>Chlorine Dosage (mg/l)</th>
<th>500</th>
<th>1000</th>
<th>1500</th>
<th>2000</th>
<th>2500</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH(Units)</td>
<td>5.6</td>
<td></td>
<td>2.4</td>
<td>2.2</td>
<td>2.3</td>
<td>2.1</td>
<td>1.85</td>
</tr>
<tr>
<td>NH₃-N(mg/l)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole Sample</td>
<td>42</td>
<td></td>
<td>27</td>
<td>14</td>
<td>13.5</td>
<td>13</td>
<td>12.5</td>
</tr>
<tr>
<td>Centrate</td>
<td>30</td>
<td></td>
<td>16</td>
<td>11</td>
<td>11</td>
<td>9.5</td>
<td>7.5</td>
</tr>
<tr>
<td>Filtrate</td>
<td>23</td>
<td></td>
<td>14.5</td>
<td>6.7</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>COD(mg/l)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole Sample</td>
<td>14700</td>
<td></td>
<td>12402</td>
<td>11524</td>
<td>10000</td>
<td>9280</td>
<td>8528</td>
</tr>
<tr>
<td>Centrate</td>
<td>3293</td>
<td></td>
<td>1882</td>
<td>1278</td>
<td>978</td>
<td>900</td>
<td>800</td>
</tr>
<tr>
<td>Filtrate</td>
<td>2000</td>
<td></td>
<td>902</td>
<td>752</td>
<td>720</td>
<td>677</td>
<td>640</td>
</tr>
<tr>
<td>BOD₅ (mg/l)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole Sample</td>
<td>3630</td>
<td></td>
<td>3217</td>
<td>3160</td>
<td>2910</td>
<td>2810</td>
<td>2790</td>
</tr>
<tr>
<td>Centrate</td>
<td>788</td>
<td></td>
<td>475</td>
<td>450</td>
<td>345</td>
<td>335</td>
<td>330</td>
</tr>
<tr>
<td>Filtrate</td>
<td>657</td>
<td></td>
<td>450</td>
<td>393</td>
<td>322</td>
<td>262</td>
<td>247</td>
</tr>
<tr>
<td>Total P(mg/l)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td>25</td>
<td></td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Filtrate</td>
<td>25</td>
<td></td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Ortho P(mg/l)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td>25</td>
<td></td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Filtrate</td>
<td>25</td>
<td></td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Total Chlorine Residual (mg/l)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td>14.8</td>
<td></td>
<td>34</td>
<td>160</td>
<td>248</td>
<td>365</td>
<td>35</td>
</tr>
<tr>
<td>Filtrate</td>
<td>11.2</td>
<td></td>
<td>16</td>
<td>37.5</td>
<td>50</td>
<td>58</td>
<td></td>
</tr>
<tr>
<td>Free Chlorine Residual (mg/l)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td>0.6</td>
<td></td>
<td>10</td>
<td>80</td>
<td>170</td>
<td>337.5</td>
<td></td>
</tr>
<tr>
<td>Filtrate</td>
<td>0</td>
<td></td>
<td>2.8</td>
<td>22.5</td>
<td>33</td>
<td>38</td>
<td></td>
</tr>
</tbody>
</table>
TABLE II.
Septage
Reaction Time: 8 Minutes

<table>
<thead>
<tr>
<th>Measured Characteristics</th>
<th>Untreated Sample</th>
<th>Chlorine Dosage (mg/l)</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>500</td>
<td>1000</td>
<td>1500</td>
<td>2000</td>
<td>2500</td>
</tr>
<tr>
<td>pH (Units)</td>
<td>5.6</td>
<td>2.4</td>
<td>2.1</td>
<td>2.2</td>
<td>2.0</td>
<td>1.9</td>
</tr>
<tr>
<td>NH₃-N (mg/l)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole Sample</td>
<td>42</td>
<td>22</td>
<td>16</td>
<td>15</td>
<td>13.5</td>
<td>11.5</td>
</tr>
<tr>
<td>Centrate</td>
<td>30</td>
<td>16.5</td>
<td>10</td>
<td>7.5</td>
<td>7.5</td>
<td>7.5</td>
</tr>
<tr>
<td>Filtrate</td>
<td>23</td>
<td>16</td>
<td>5.5</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>COD (mg/l)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole Sample</td>
<td>14700</td>
<td>12112</td>
<td>11348</td>
<td>9900</td>
<td>8810</td>
<td>8200</td>
</tr>
<tr>
<td>Centrate</td>
<td>3293</td>
<td>1360</td>
<td>1058</td>
<td>960</td>
<td>880</td>
<td>790</td>
</tr>
<tr>
<td>Filtrate</td>
<td>2000</td>
<td>800</td>
<td>752</td>
<td>720</td>
<td>720</td>
<td>602</td>
</tr>
<tr>
<td>BOD₅ (mg/l)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole Sample</td>
<td>3630</td>
<td>2516</td>
<td>2460</td>
<td>2216</td>
<td>2216</td>
<td>2164</td>
</tr>
<tr>
<td>Centrate</td>
<td>788</td>
<td>275</td>
<td>275</td>
<td>275</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>Filtrate</td>
<td>657</td>
<td>247</td>
<td>225</td>
<td>218</td>
<td>210</td>
<td>195</td>
</tr>
<tr>
<td>Total P (mg/l)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td>25</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Filtrate</td>
<td>25</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Ortho P (mg/l)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td>25</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Filtrate</td>
<td>25</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Total Chlorine Residual (mg/l)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td>10</td>
<td>24.5</td>
<td>72</td>
<td>158</td>
<td>200</td>
<td>44</td>
</tr>
<tr>
<td>Filtrate</td>
<td>8.5</td>
<td>13.6</td>
<td>21.5</td>
<td>40</td>
<td>44</td>
<td>37</td>
</tr>
<tr>
<td>Free Chlorine Residual (mg/l)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td>0.4</td>
<td>0.6</td>
<td>44</td>
<td>148</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>Filtrate</td>
<td>0</td>
<td>0</td>
<td>14.5</td>
<td>22</td>
<td>25</td>
<td>37</td>
</tr>
</tbody>
</table>
TABLE III.
Septage
Reaction Time: 11 Minutes

<table>
<thead>
<tr>
<th>Measured Characteristics</th>
<th>Untreated Sample</th>
<th>Chlorine Dosage (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>500</td>
</tr>
<tr>
<td>pH(Units)</td>
<td>5.6</td>
<td>1.8</td>
</tr>
<tr>
<td>NH$_3$-N(mg/l)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole Sample</td>
<td>42</td>
<td>22</td>
</tr>
<tr>
<td>Centrate</td>
<td>30</td>
<td>12.5</td>
</tr>
<tr>
<td>Filtrate</td>
<td>23</td>
<td>16</td>
</tr>
<tr>
<td>COD(mg/l)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole Sample</td>
<td>14700</td>
<td>12014</td>
</tr>
<tr>
<td>Centrate</td>
<td>3293</td>
<td>1200</td>
</tr>
<tr>
<td>Filtrate</td>
<td>2000</td>
<td>720</td>
</tr>
<tr>
<td>BOD$_5$(mg/l)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole Sample</td>
<td>3630</td>
<td>1785</td>
</tr>
<tr>
<td>Centrate</td>
<td>788</td>
<td>275</td>
</tr>
<tr>
<td>Filtrate</td>
<td>657</td>
<td>150</td>
</tr>
<tr>
<td>Total P(mg/l)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>Filtrate</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>Ortho P(mg/l)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>Filtrate</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>Total Chlorine Residual (mg/l)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td>7.8</td>
<td>19</td>
</tr>
<tr>
<td>Filtrate</td>
<td>7.3</td>
<td>11.2</td>
</tr>
<tr>
<td>Free Chlorine Residual (mg/l)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td>0.3</td>
<td>0.6</td>
</tr>
<tr>
<td>Filtrate</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Measured Characteristics</td>
<td>Untreated Sample</td>
<td>Chlorine Dosage (mg/l)</td>
</tr>
<tr>
<td>--------------------------</td>
<td>------------------</td>
<td>------------------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>500</td>
</tr>
<tr>
<td>pH(Units)</td>
<td>5.6</td>
<td>2.0</td>
</tr>
<tr>
<td>NH₃-N(mg/l)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole Sample</td>
<td>45</td>
<td>23</td>
</tr>
<tr>
<td>Centrate</td>
<td>31</td>
<td>15</td>
</tr>
<tr>
<td>Filtrate</td>
<td>23</td>
<td>15</td>
</tr>
<tr>
<td>COD(mg/l)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole Sample</td>
<td>6050</td>
<td>4348</td>
</tr>
<tr>
<td>Centrate</td>
<td>2286</td>
<td>1694</td>
</tr>
<tr>
<td>Filtrate</td>
<td>1513</td>
<td>1167</td>
</tr>
<tr>
<td>BOD₅(mg/l)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole Sample</td>
<td>2800</td>
<td>1600</td>
</tr>
<tr>
<td>Centrate</td>
<td>1478</td>
<td>846</td>
</tr>
<tr>
<td>Filtrate</td>
<td>1240</td>
<td>662</td>
</tr>
<tr>
<td>Total P(mg/l)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td>52</td>
<td>50.5</td>
</tr>
<tr>
<td>Filtrate</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Ortho P(mg/l)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td>49</td>
<td>46</td>
</tr>
<tr>
<td>Filtrate</td>
<td>49</td>
<td>46</td>
</tr>
<tr>
<td>Total Chlorine Residual(mg/l)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td>17</td>
<td>50</td>
</tr>
<tr>
<td>Filtrate</td>
<td>15</td>
<td>13</td>
</tr>
<tr>
<td>Free Chlorine Residual (mg/l)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td>2.5</td>
<td>22.5</td>
</tr>
<tr>
<td>Filtrate</td>
<td>1.6</td>
<td>5.8</td>
</tr>
</tbody>
</table>
### TABLE V.

**Primary Sludge**  
Reaction Time: 8 Minutes

<table>
<thead>
<tr>
<th>Measured Characteristics</th>
<th>Untreated Sample</th>
<th>Chlorine Dosage (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>500</td>
</tr>
<tr>
<td>pH (Units)</td>
<td>5.6</td>
<td>2.2</td>
</tr>
<tr>
<td>NH₃-N (mg/l)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole Sample</td>
<td>45</td>
<td>22</td>
</tr>
<tr>
<td>Centrate</td>
<td>31</td>
<td>14</td>
</tr>
<tr>
<td>Filtrate</td>
<td>23</td>
<td>14</td>
</tr>
<tr>
<td>COD (mg/l)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole Sample</td>
<td>6050</td>
<td>4105</td>
</tr>
<tr>
<td>Centrate</td>
<td>2286</td>
<td>1635</td>
</tr>
<tr>
<td>Filtrate</td>
<td>1513</td>
<td>1090</td>
</tr>
<tr>
<td>BOD₅ (mg/l)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole Sample</td>
<td>2800</td>
<td>1410</td>
</tr>
<tr>
<td>Centrate</td>
<td>1478</td>
<td>720</td>
</tr>
<tr>
<td>Filtrate</td>
<td>1240</td>
<td>652</td>
</tr>
<tr>
<td>Total P (mg/l)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td>52</td>
<td>49</td>
</tr>
<tr>
<td>Filtrate</td>
<td>50</td>
<td>49</td>
</tr>
<tr>
<td>Ortho P (mg/l)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td>49</td>
<td>45</td>
</tr>
<tr>
<td>Filtrate</td>
<td>49</td>
<td>45</td>
</tr>
<tr>
<td>Total Chlorine Residual (mg/l)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td>15</td>
<td>39.5</td>
</tr>
<tr>
<td>Filtrate</td>
<td>7.5</td>
<td>13.2</td>
</tr>
<tr>
<td>Free Chlorine Residual (mg/l)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td>1.0</td>
<td>3.2</td>
</tr>
<tr>
<td>Filtrate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Measured Characteristics</td>
<td>Untreated Sample</td>
<td>Chlorine Dosage (mg/l)</td>
</tr>
<tr>
<td>--------------------------</td>
<td>-----------------</td>
<td>-----------------------</td>
</tr>
<tr>
<td>pH(Units)</td>
<td>5.6</td>
<td>2.1 1.9 1.8 1.8 1.8 1.4</td>
</tr>
<tr>
<td>NH₄-N(mg/l)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole Sample</td>
<td>45 18 16.5 13 12 11</td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td>31 13 3 2.5 2.5 2.5</td>
<td></td>
</tr>
<tr>
<td>Filtrate</td>
<td>23 12 1.2 1.2 1.2 1.2</td>
<td></td>
</tr>
<tr>
<td>COD(mg/l)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole Sample</td>
<td>6050 3623 3204 3004 2800 2672</td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td>2286 1527 1394 1302 1194 1069</td>
<td></td>
</tr>
<tr>
<td>Filtrate</td>
<td>1513 993 940 900 797 652</td>
<td></td>
</tr>
<tr>
<td>BOD₅ (mg/l)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole Sample</td>
<td>2800 1080 930 780 780 660</td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td>1478 630 545 540 520 480</td>
<td></td>
</tr>
<tr>
<td>Filtrate</td>
<td>1240 510 485 480 467 445</td>
<td></td>
</tr>
<tr>
<td>Total P(mg/l)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td>52 49 48 49 46 46</td>
<td></td>
</tr>
<tr>
<td>Filtrate</td>
<td>50 49 48 49 46 46</td>
<td></td>
</tr>
<tr>
<td>Ortho P (mg/l)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td>49 45 45 44 44 44</td>
<td></td>
</tr>
<tr>
<td>Filtrate</td>
<td>49 45 45 44 44 44</td>
<td></td>
</tr>
<tr>
<td>Total Chlorine Residual(mg/l)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td>13 25.5 87 135 172.5</td>
<td></td>
</tr>
<tr>
<td>Filtrate</td>
<td>7.5 12.4 13 37.5 40</td>
<td></td>
</tr>
<tr>
<td>Free Chlorine Residual (mg/l)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td>1.7 5 52 102 127.5</td>
<td></td>
</tr>
<tr>
<td>Filtrate</td>
<td>0.8 0.8 3 19 29</td>
<td></td>
</tr>
</tbody>
</table>
(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.
Septage (Amherst, 3 years)
Whole Sample

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
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 BOD₅ in the septage, and on the other hand the suspended portion of BOD₅ 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 BOD₅ in Centrate of Septage
Figure 12.

Percent Removal of BOD$_5$ in Filtrate of Septage.
Figure 13.
Percent Removal of BOD\textsubscript{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:

\[
6\text{Cl}^- + \text{Cr}_2\text{O}_7^{2-} + 14\text{H}^+ \rightarrow 3\text{Cl}_2 + 2\text{Cr}^{3+} + 7\text{H}_2\text{O} \quad (3-1)
\]

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

\[
\text{Hg}^+ + 2\text{Cl}^- \rightarrow \text{HgCl}_2 \quad (3-2)
\]

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 2.1. 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/l and 2400 mg/l 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 $\text{NH}_3$-$\text{N}$ removal is further depicted in Figures 22 to 28, on $\text{BOD}_5$ removal in Figures 29 to 35, and on TOC removal in Figures 37 to 43. A relationship between removal of $\text{BOD}_5$ 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**

<table>
<thead>
<tr>
<th>Measured Characteristics</th>
<th>Untreated Sample</th>
<th>Mixing Time at Chlorine Dosage 2400 mg/l</th>
<th>Mixing Time at Chlorine Dosage 1900 mg/l</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>5 min</td>
<td>7 min</td>
</tr>
<tr>
<td>pH</td>
<td>6.04</td>
<td>2.02</td>
<td>2.02</td>
</tr>
<tr>
<td>T.S. (mg/l)</td>
<td>7088</td>
<td>5152</td>
<td>5146</td>
</tr>
<tr>
<td>S.S. (mg/l)</td>
<td>5536</td>
<td>3980</td>
<td>4840</td>
</tr>
<tr>
<td>V.S.S. (mg/l)</td>
<td>4212</td>
<td>3606</td>
<td>4152</td>
</tr>
<tr>
<td>NH₃-N (mg/l)</td>
<td>114</td>
<td>38</td>
<td>33</td>
</tr>
<tr>
<td>BOD₅ (mg/l)</td>
<td>1438</td>
<td>583</td>
<td>479</td>
</tr>
<tr>
<td>Chlorine Residual (mg/l)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>152</td>
<td>136</td>
<td>90</td>
</tr>
<tr>
<td>Free</td>
<td>25</td>
<td>28</td>
<td>14</td>
</tr>
<tr>
<td>Filtrate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>35</td>
<td>30</td>
<td>25</td>
</tr>
<tr>
<td>Free</td>
<td>7</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>TOC (mg/l)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td>1064</td>
<td>463</td>
<td>478</td>
</tr>
<tr>
<td>Filtrate</td>
<td>600</td>
<td>340</td>
<td>345</td>
</tr>
<tr>
<td>Specific Resistance (sec²/gm × 10⁸)</td>
<td>37.4</td>
<td>0.75</td>
<td>1.07</td>
</tr>
<tr>
<td>Measured Characteristics</td>
<td>Untreated Sample</td>
<td>Mixing Time at Chlorine Dosage 2400 mg/l</td>
<td>Mixing Time at Chlorine Dosage 1900 mg/l</td>
</tr>
<tr>
<td>--------------------------</td>
<td>-----------------</td>
<td>----------------------------------------</td>
<td>----------------------------------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 min</td>
<td>7 min</td>
</tr>
<tr>
<td>pH</td>
<td>4.75</td>
<td>1.85</td>
<td>1.95</td>
</tr>
<tr>
<td>T.S. (mg/l)</td>
<td>22364</td>
<td>21668</td>
<td>18080</td>
</tr>
<tr>
<td>S.S. (mg/l)</td>
<td>20404</td>
<td>18552</td>
<td>16624</td>
</tr>
<tr>
<td>V.S.S. (mg/l)</td>
<td>16634</td>
<td>15616</td>
<td>14138</td>
</tr>
<tr>
<td>NH₃-N (mg/l)</td>
<td>68</td>
<td>40.5</td>
<td>37.5</td>
</tr>
<tr>
<td>BOD₅ (mg/l)</td>
<td>3612</td>
<td>2581</td>
<td>2512</td>
</tr>
<tr>
<td>Chlorine Residual (mg/l)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>23</td>
<td>27</td>
<td>24</td>
</tr>
<tr>
<td>Free</td>
<td>5</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Filtrate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>12</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>Free</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>TOC (mg/l)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td>2272</td>
<td>1558</td>
<td>1521</td>
</tr>
<tr>
<td>Filtrate</td>
<td>1440</td>
<td>1200</td>
<td>1170</td>
</tr>
<tr>
<td>Specific Resistance (sec²/gm x 10⁸)</td>
<td></td>
<td>141</td>
<td>3.42</td>
</tr>
</tbody>
</table>
TABLE IX.
Sludge Type: Sample 3.

<table>
<thead>
<tr>
<th>Measured Characteristics</th>
<th>Untreated Sample</th>
<th>Mixing Time at Chlorine Dosage 2400 mg/l</th>
<th>Mixing Time at Chlorine Dosage 1900 mg/l</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>5 min</td>
<td>7 min</td>
</tr>
<tr>
<td>pH</td>
<td>5.5</td>
<td>1.7</td>
<td>1.7</td>
</tr>
<tr>
<td>T.S. (mg/l)</td>
<td>17066</td>
<td>15784</td>
<td>14316</td>
</tr>
<tr>
<td>S.S. (mg/l)</td>
<td>16122</td>
<td>13848</td>
<td>14088</td>
</tr>
<tr>
<td>V.S.S. (mg/l)</td>
<td>13856</td>
<td>12258</td>
<td>12868</td>
</tr>
<tr>
<td>NH₃-N (mg/l)</td>
<td>83</td>
<td>24</td>
<td>25</td>
</tr>
<tr>
<td>BOD₅ (mg/l)</td>
<td>2426</td>
<td>963</td>
<td>886</td>
</tr>
<tr>
<td>Chlorine Residual (mg/l)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>76</td>
<td>76</td>
<td>68</td>
</tr>
<tr>
<td>Free</td>
<td>11</td>
<td>12</td>
<td>14</td>
</tr>
<tr>
<td>Filtrate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>44</td>
<td>29</td>
<td>16</td>
</tr>
<tr>
<td>Free</td>
<td>9</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>TOC (mg/l)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td>1680</td>
<td>758</td>
<td>746</td>
</tr>
<tr>
<td>Filtrate</td>
<td>1060</td>
<td>615</td>
<td>600</td>
</tr>
<tr>
<td>Specific Resistance (sec²/gm x 10⁶)</td>
<td></td>
<td>292</td>
<td>0.92</td>
</tr>
</tbody>
</table>
### TABLE X.

Sludge Type: Sample 4.

<table>
<thead>
<tr>
<th>Measured Characteristics</th>
<th>Untreated Sample</th>
<th>Mixing Time at Chlorine Dosage 2400 mg/1</th>
<th>Mixing Time at Chlorine Dosage 1900 mg/1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>5 min</td>
<td>7 min</td>
</tr>
<tr>
<td>pH</td>
<td>6.4</td>
<td>1.75</td>
<td>1.75</td>
</tr>
<tr>
<td>T.S. (mg/l)</td>
<td>8612</td>
<td>8572</td>
<td>7966</td>
</tr>
<tr>
<td>S.S. (mg/l)</td>
<td>6640</td>
<td>8116</td>
<td>6660</td>
</tr>
<tr>
<td>V.S.S. (mg/l)</td>
<td>5886</td>
<td>7026</td>
<td>5610</td>
</tr>
<tr>
<td>NH₃-N (mg/l)</td>
<td>41</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>BOD₅ (mg/l)</td>
<td>856</td>
<td>180</td>
<td>162</td>
</tr>
<tr>
<td>Chlorine Residual (mg/l)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>240</td>
<td>200</td>
<td>83</td>
</tr>
<tr>
<td>Free</td>
<td>148</td>
<td>136</td>
<td>50</td>
</tr>
<tr>
<td>Filtrate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>70</td>
<td>13</td>
<td>10</td>
</tr>
<tr>
<td>Free</td>
<td>33</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>TOC (mg/l)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td>657</td>
<td>161</td>
<td>146</td>
</tr>
<tr>
<td>Filtrate</td>
<td>485</td>
<td>141</td>
<td>132</td>
</tr>
<tr>
<td>Specific Resistance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(sec²/gm x 10³)</td>
<td>286</td>
<td>11.24</td>
<td>7.69</td>
</tr>
</tbody>
</table>
### TABLE XI.

**Sludge Type: Sample 5.**

<table>
<thead>
<tr>
<th>Measured Characteristics</th>
<th>Measured Untreated Characteristics Sample</th>
<th>Mixing Time at Chlorine Dosage 2400 mg/l</th>
<th>Mixing Time at Chlorine Dosage 1900 mg/l</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>5 min</td>
<td>7 min</td>
</tr>
<tr>
<td>pH</td>
<td>5.2</td>
<td>1.65</td>
<td>1.7</td>
</tr>
<tr>
<td>T.S. (mg/l)</td>
<td>13150</td>
<td>11732</td>
<td>10968</td>
</tr>
<tr>
<td>S.S. (mg/l)</td>
<td>13090</td>
<td>10814</td>
<td>9818</td>
</tr>
<tr>
<td>V.S.S. (mg/l)</td>
<td>11116</td>
<td>8938</td>
<td>8046</td>
</tr>
<tr>
<td>NH$_3$-N (mg/l)</td>
<td>40</td>
<td>17</td>
<td>17.5</td>
</tr>
<tr>
<td>BOD$_5$ (mg/l)</td>
<td>1205</td>
<td>482</td>
<td>488</td>
</tr>
<tr>
<td>Chlorine Residual (mg/l)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrate Total</td>
<td>60</td>
<td>50</td>
<td>42</td>
</tr>
<tr>
<td>Centrate Free</td>
<td>16</td>
<td>16</td>
<td>10</td>
</tr>
<tr>
<td>Filtrate Total</td>
<td>25</td>
<td>16</td>
<td>23</td>
</tr>
<tr>
<td>Filtrate Free</td>
<td>6</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>TOC (mg/l)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td>794</td>
<td>336</td>
<td>335</td>
</tr>
<tr>
<td>Filtrate</td>
<td>418</td>
<td>318</td>
<td>288</td>
</tr>
<tr>
<td>Specific Resistance (sec$^2$/gm × 10$^6$)</td>
<td>169</td>
<td>2.65</td>
<td>2.32</td>
</tr>
</tbody>
</table>
### TABLE XII.

**Sludge Type: Sample 6.**

<table>
<thead>
<tr>
<th>Measured Characteristics</th>
<th>Untreated Sample</th>
<th>Mixing Time at Chlorine Dosage 2400 mg/l</th>
<th>Mixing Time at Chlorine Dosage 1900 mg/l</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>5 min</td>
<td>7 min</td>
</tr>
<tr>
<td>pH</td>
<td>7.4</td>
<td>1.7</td>
<td>1.75</td>
</tr>
<tr>
<td>T.S. (mg/l)</td>
<td>13568</td>
<td>13056</td>
<td>10110</td>
</tr>
<tr>
<td>S.S. (mg/l)</td>
<td>12342</td>
<td>8948</td>
<td>7858</td>
</tr>
<tr>
<td>V.S.S. (mg/l)</td>
<td>7576</td>
<td>7362</td>
<td>5586</td>
</tr>
<tr>
<td>NH$_3$-N (mg/l)</td>
<td>285</td>
<td>232.5</td>
<td>227.5</td>
</tr>
<tr>
<td>BOD$_5$ (mg/l)</td>
<td>577</td>
<td>182</td>
<td>173</td>
</tr>
<tr>
<td>Chlorine Residual (mg/l)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td></td>
<td>41</td>
<td>40</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>Free</td>
<td></td>
<td>9.5</td>
<td>11</td>
</tr>
<tr>
<td>Filtrate</td>
<td></td>
<td>2.5</td>
<td>1.8</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>11</td>
<td>9.6</td>
</tr>
<tr>
<td>Free</td>
<td></td>
<td>17.5</td>
<td>17.5</td>
</tr>
<tr>
<td>TOC (mg/l)</td>
<td></td>
<td>240</td>
<td>100</td>
</tr>
<tr>
<td>Centrate</td>
<td></td>
<td>80</td>
<td>40</td>
</tr>
<tr>
<td>Filtrate</td>
<td></td>
<td>160</td>
<td>60</td>
</tr>
<tr>
<td>Specific Resistance</td>
<td></td>
<td>3.89</td>
<td>1.25</td>
</tr>
<tr>
<td>(sec$^2$/gm $\times 10^8$)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### TABLE XIII.

Sludge Type: Sample 7.

<table>
<thead>
<tr>
<th>Measured Characteristics</th>
<th>Untreated Sample</th>
<th>Mixing Time at Chlorine Dosage (mg/l)</th>
<th></th>
<th>Mixing Time at Chlorine Dosage (mg/l)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>5 min</td>
<td>7 min</td>
<td>10 min</td>
<td>13 min</td>
</tr>
<tr>
<td>pH</td>
<td>6.6</td>
<td>1.8</td>
<td>1.8</td>
<td>1.8</td>
<td>1.85</td>
</tr>
<tr>
<td>T.S. (mg/l)</td>
<td>13858</td>
<td>13420</td>
<td>8130</td>
<td>11332</td>
<td>13082</td>
</tr>
<tr>
<td>S.S. (mg/l)</td>
<td>13976</td>
<td>11070</td>
<td>5962</td>
<td>10458</td>
<td>10580</td>
</tr>
<tr>
<td>V.S.S. (mg/l)</td>
<td>8961</td>
<td>7750</td>
<td>4254</td>
<td>7672</td>
<td>6870</td>
</tr>
<tr>
<td>NH$_3$-N (mg/l)</td>
<td>205</td>
<td>127.5</td>
<td>127.5</td>
<td>117.5</td>
<td>117.5</td>
</tr>
<tr>
<td>BOD$_5$ (mg/l)</td>
<td>748</td>
<td>336</td>
<td>312</td>
<td>244</td>
<td>267</td>
</tr>
<tr>
<td>Chlorine Residual (mg/l)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>35</td>
<td>21</td>
<td>22</td>
<td>21</td>
<td>22</td>
</tr>
<tr>
<td>Free</td>
<td>6</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>5.5</td>
</tr>
<tr>
<td>Filtrate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>12</td>
<td>9</td>
<td>10</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>Free</td>
<td>2.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>TOC (mg/l)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrate</td>
<td>400</td>
<td>240</td>
<td>225</td>
<td>196</td>
<td>200</td>
</tr>
<tr>
<td>Filtrate</td>
<td>210</td>
<td>140</td>
<td>140</td>
<td>125</td>
<td>120</td>
</tr>
<tr>
<td>Specific Resistance (sec$^2$/gm x 10$^4$)</td>
<td>4.42</td>
<td>1.56</td>
<td>1.34</td>
<td>1.83</td>
<td>2.40</td>
</tr>
</tbody>
</table>
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 HOCI which is a powerful disinfectant; (b) formation of chloramines: the formation of chloramines as depicted by (2-3), (2-4), and (2-5) is pH-dependent. According to Morris, to convert 99 percent of free chlorine to monochloramine at 25°C with a molar ratio of $0.2 \times 10^{-3}$ mole/l HOCI to $1.0 \times 10^{-3}$ 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 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 H0Cl 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:

\[
\begin{align*}
\text{CH}_3\text{COOH} & \xrightarrow{\text{Cl}_2} \text{ClCH}_2\text{COOH} & \xrightarrow{\text{Cl}_2} \text{Cl}_2\text{CHCOOH} \\
& \xrightarrow{\text{Cl}_2} \text{Cl}_3\text{CCOOH}
\end{align*}
\]
The ammonia content of sludge may be controlled by pH; at high pH ammonium ions are reduced to \( \text{NH}_3 \) 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 \( \text{BOD}_5 \) of Sample 2 were 204.04 mg/l and 3612 mg/l respectively. Such high values of suspended solids and \( \text{BOD}_5 \) 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 \( \text{BOD}_5 \) 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\textsubscript{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\textsubscript{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, CH₄, H₂S 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.
Sample 1: Household Septage
3 Years, Amherst

Figure 22. Percent Removal of NH$_3$-N vs. Mixing Time.
Sample 2: Household Septage
5-6 Years Old, Pelham

Figure 23. Percent Removal of NH$_3$-N vs. Mixing Time.
Sample 3: Household Septage
3 Years Old
South Amherst

Figure 24. Percent Removal of NH$_3$-N vs. Mixing Time.
Sample 4: Household Septage
5 Years Old
South Amherst

Figure 25. Percent Removal of NH$_3$-N vs. Mixing Time.
Figure 26. Percent Removal of $\text{NH}_3\text{-N}$ vs. Mixing Time.
Sample 6: Anaerobically Digested Sludge 50 Days Old Amherst

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" 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 NH₂Cl, NHCl₂, and NCl₃ 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 NCl₃ 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 who described the filtration rate of sludge according to Poiseuille's and Darcy's laws as follows:

\[
\frac{dV}{dt} = \frac{PA^2}{\mu(\rho cV + R_mA)}
\]

(4-2)

where

\( V \) = volume of filtrate (ml)
\( t \) = time of filtration (second)
\( P \) = vacuum applied (gm/cm²)
\( A \) = filter area (cm²)
\( \mu \) = filtrate viscosity (gm/cm·sec)
\( r \) = specific resistance (sec²/gm)
\( c \) = weight of solids per unit volume of filtrate (gm/ml)
\( R_m \) = initial resistance of filter media (can be neglected) (sec²·cm/ml)
Integration and rearrangement of (4-2) yields:

\[
\frac{t}{V} = \frac{\mu r c}{2PA^2} V + \frac{\mu R_m}{PA} \quad (4-3)
\]

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

\[
b = \frac{\mu r c}{2PA^2} \quad (4-4)
\]

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

\[
r = \frac{2bPA^2}{\mu c} \quad (4-5)
\]

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, \(\mu r c/2PA^2\) 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 $1.41 \times 10^{10} \text{ sec}^2/\text{gm}$ to $3.74 \times 10^{10} \text{ sec}^2/\text{gm}$, dependent on their source and age. Primary sludge had a slightly less specific resistance of about $1.69 \times 10^{10} \text{ sec}^2/\text{gm}$. Anaerobically digested sludge had the largest specific resistance of about $3.89 \times 10^{10} \text{ sec}^2/\text{gm}$ 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\textsubscript{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\textsubscript{5}, as shown in Figure 30.

As shown in Tables IX and X and Figures 31 and 32, the removal of BOD\textsubscript{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\textsubscript{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 BOD₅ 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 NH₃-N removal of primary sludge was in a similar order of its BOD₅ removal, while the NH₃-N removal of anaerobically digested sludge was much lower percent-wise than its BOD₅ removal.

It was found that total chlorine residuals decreased linearly with BOD₅ removal as shown in Figure 36 which is a plot of percentage of BOD₅ removal versus total chlorine residuals of the centrate. It is shown that the chlorine consumed per unit of BOD₅ 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.

Sample 2: Household Septage
5-6 Years Old
Pelham
Figure 31. Percent Removal of BOD\textsubscript{5} vs. Mixing Time.
Figure 32. Percent Removal of BOD<sub>5</sub> vs. Mixing Time.
Figure 33. Percent Removal of $\text{BOD}_5$ vs. Mixing Time.
Figure 34. Percent Removal of BOD$_5$ vs. Mixing Time.
Figure 35. Percent Removal of BOD\textsubscript{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 BOD₅. 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 than 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 significant 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.
Sample 1: Household Septage
3 Years Old
Amherst

- High Dosage
- Low Dosage

Centrifuged
Filtered

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
Sample 4: Household Septage
5 Years Old
South Amherst

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.
Sample 7: Mixture of Primary and Digested Sludge Amherst

- High Dosage
- Low Dosage

Centrifuged
Filtered

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 NCl₃ 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.

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


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 $\text{BOD}_5$ 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.
Beckman Model 915 TOC Analyzer
Total Carbon
Gain: 4
Range: 1
Sample = 20 µL

Figure A-6. Calibration Curve for Inorganic Carbon.
Figure A-7. Calibration Curve for Phosphate.