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Chemical Treatment of Septage

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CHEMICAL TREATMENT OF SEPTAGE

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I. INTRODUCTION

State and federal regulations regarding disposal of septage have recently become more stringent, creating a need for better methods of treatment and disposal. In the past septage could be disposed of in landfills and other open areas, but recent environmental considerations and restrictions have made treatment of septage a necessity, either in combination with wastewater treatment plants or prior to final disposal, e.g. by special facilities, lagooning, or land spreading in rural areas. Direct introduction of septage into the inlet works of a wastewater treatment plant often creates shock loads and other undesirable effects due to the strength of these wastes. Thus a need exists for pretreatment of septage prior to combined treatment with domestic sewage. In addition, appropriate separate treatment processes are needed for special facilities in areas not close to wastewater treatment plants. This report investigates chemical treatment of septage as a means of satisfying these needs.

II. OBJECTIVES

Septage is a waste, strong and variable in characteristics. The best method for its handling and disposal will depend on circumstances in a particular community or region. One process being investigated is chemical treatment due to its ability to (a) thicken the septage, (b) clarify the resulting supernatant, and (c) condition the settled solids or sludge for dewatering. These attributes make chemical treatment of septage useful in a number of situations.

Pretreatment of septage at wastewater treatment plants enables its liquid and solid portions to be separated and combined with the influent sewage flow and sludge stream respectively for further treatment. This chemical pretreatment and separation is necessary, especially where septage is a noticeable fraction of the combined waste to be treated, to prevent overloaded secondary units, to meet effluent limitations, and to facilitate sludge handling and disposal. In areas not close to such municipal facilities, chemical treatment and separation of septage will still be important so that the sludge can be properly dewatered and disposed of, while the liquid portion can be further improved in an oxidation pond or by other means.

This study of bench-scale, batch experiments on the chemical treatment of septage had as its objectives to determine:

 the best coagulant and operating conditions for septage treatment,

2. the best dosage for a given coagulant,

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3. the reduction of supernatant strength and improvement in sludge dewatering properties which could be expected after treatment.

III. LITERATURE REVIEW

A. Septages

Septic Tank Systems

Conventional septic tanks consist of containers where sludges from liquid streams are accumulated and digested under anaerobic conditions. Approximately one-third of the individual housing units in this country, as well as isolated public and private service facilities, use septic tanks for the disposal of wastewater (1). Most septic tanks are single storied, continuous flow, settling basins in which the sludge is held sufficiently long to undergo partial and possibly complete digestion, while the effluent disperses through a subsurface leaching system. The capacity and hydraulic design of the system, as well as other factors, influence septic tank performance, and thus septage characteristics.

In a properly operating system the settled solids undergo a biological process known as anaerobic digestion. The bacteria involved are obligatory or facultative anaerobes which reduce certain organic compounds from higher to lower levels of oxidation. The two-stage process of anaerobic digestion, acid formation and then methane generation, results in the evolution of methane, hydrogen sulfide, and carbon dioxide gases, as well as the production of cells and stable degradation substances which remain in the tank with the solids that resist anaerobic decomposition. While most of the solid residuals accumulate in the bottom of the tank, gas-lifted solids rise and collect in a digestion retarded scum layer at the liquid surface.

Over a period of time the accumulation of scum and sludge reduces the effective liquid capacity of the tank, and solid particles fail to settle out effectively. As a result, approximately every two to four years, septic tanks must be cleaned. These septic tank pumpings are referred to as septage, and consist of a mixture of the accumulated sludge and scum as well as the liquid present in the tank during cleaning (1,2, 3,4,5).

Characteristics of Septage

Septic tank performance influences not only the effluent of the system, but can also affect both the desired frequency of tank cleaning and the characteristics of the septage pumped. Sufficient tank capacity is important to allow proper sedimentation to occur and to provide necessary storage for digesting solids. An undersized tank can also fail to dilute chemicals harmful to the digestion process and allows digesting solids to be discharged when surge flows from bathing and laundry occur. The hydraulic design determines storage efficiency and the extent of shortcircuiting, and thus determines the percentage of the capacity that is effectively used (1).

Frequency of pumping (age of the septage) and other effects of capacity and design are not the only factors which can influence the properties of septage. Climate, family habits and size, and tank location can also create variation in septage characteristics from load to load (5,6).

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As Kolega (5) notes, very little data on the physical, chemical, and biological characteristics of septage have been collected. He undertook research in 1969 to investigate the nature of septage in the Hartford, Ct. area and to obtain distributions and mean values for a number of parameters. Table I compares the mean values for selected raw septage characteristics obtained by Kolega to those found in this investigation.

	Kolega	(1969)	Present Investigation			
Measured Characteristic	Mean (<u>mg</u>) Value (<u>1</u>)	Number of Samples	Mean (<u>mg</u>) Value (<u>1</u>)	Number of Samples	Standard Deviation	
BOD ₅	4,794	180	14,282	33	9,617	
COD	26,162	180	31,958	33	14,984	
Total Solids	22,400	180	30,603	33	17,215	

Table I. Comparison of Septage Characteristics

As can be seen, the values found in the present research indicate somewhat stronger wastes than the septages analyzed by Kolega. In addition, the diversity of septage studied in this investigation is evidenced by the magnitude of the standard deviations for the measured characteristics presented in Table I. This points to one of the most striking features of septage - its variability.

Unlike municipal wastewater treatment plants where wastes from a variety of urban sources are combined and treated together, septic tank systems are designed for individual sources. As a result the characteristics of septage are affected by discrete factors and are not as uniform as those found in the sludges of municipal wastewater treatment plants (7). This variation makes it impossible to optimize the operation of a chemical process for septage treatment in an area. Therefore in full-scale operation the efficiency is expected to be lower than the laboratory controlled experimental results.

B. Sludge Conditioning

Septage can be considered an aqueous suspension of solids and thus falls into the category of sludge. The objectives of septage treatment therefore are essentially to separate supernatant liquor from settled solids and dispose of the two portions separately. The liquid is reduced in polluting characteristics and the solids portion is improved in its dewatering characteristics. These objectives are commonly achieved by some combination of the processes of thickening, conditioning, dewatering, conversion, and drying. In this investigation chemical conditioning, and its effects on thickening, supernatant quality, and dewatering characteristics of settled solids were studied.

Sludge conditioning refers to techniques for altering sludge characteristics to make removal of water in subsequent thickening or dewatering processes more efficient. Chemical conditioning involving coagulation of sludge solids with metal salts and/or polymers is most commonly employed (8). Thus effective chemical treatment of sludges depends upon an understanding of the chemistry of coagulation.

Chemistry of Coagulation

Whether chemical treatment of water, sewage, or sludge is being considered, the basic objective is the same - to separate the liquid and solid constituents. This is achieved by aggregating the dissolved and colloidal substances in water to promote settling which follows. Aggregation is a two step process. The first step consists of particle destabilization by chemical addition to permit attachment when contact

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occurs and is achieved as coagulants are dispersed through the fluid by rapid mixing. The second step, which consists of particle transport to effect particle contacts follows, and is achieved by gentle stirring (flocculation). The term coagulation is applied to the overall process of particle aggregation, including both particle destabilization and particle transport. The chemical aspects of coagulation are concerned with the first step of aggregation, particle destabilization mechanisms.

Colloids may be stable due to charge effects or because of their affinity for water. Either situation can prevent colloids from combining when collisons take place. The action of changing colloid stability by the addition of chemicals (destabilization) is complex due to the large number of variables involved. For each treatment situation one or more of four distinct mechanisms may be applicable. These four destabilization methods are: (1) adsorption; (2) double layer compression; (3) bridging; and (4) enmeshment in a precipitate.

Adsorption for the purpose of charge neutralization is a destabilization mechanism associated with metal (Al(III) or Fe(III)) salts. When these salts are added to water they form positively charged species with anions which are present. Since most colloids in water have a negative charge, the strong adsorption of these positively charged metal species to the colloid surface reduces the negative charge of the colloid. However, due to the chemical nature of this surface adsorption, it can proceed well beyond the point at which zero charge is reached (optimum destabilization) and cause charge reversal and restabilization. Obviously under this model the optimum dose for destabilization is proportional to colloid surface area.

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The double layer compression model illustrates an important contrast to adsorption. Cations are added to solution to compress the negative ion atmosphere around the colloid. The range of the repulsive interaction forces between similar colloidal particles decreases, and attractive forces, called van der Waal's forces, can cause aggregation. The added cations are not adsorbed onto the colloid surface, and thus charge reversal and restabilization does not occur. The amount of cation necessary to compress the negative ions sufficiently is thus related to the bulk solution and nature of the colloid, rather than the amount of colloid present.

Bridging is a third destabilization mechanism, and is more closely associated with synthetic polymers than metal salts. To be effective, the polymer molecule must contain chemical groups which can interact with sites on the surface of the colloidal particle. After the initial contact of polymer with colloid, secondary adsorption occurs as free ends of an adsorbed polymer attach to an open adsorption site on a second colloid. This constitutes the formation of a bridge. Optimum destabilization occurs, theoretically, when approximately one half of the available adsorption sites are taken up by initial adsorption. Although charge appears irrelevant to this model, restabilization can occur at larger than optimum doses. This is due to the fact that initial adsorption increases, and fewer bridging adsorption sites are available. Again, since bridging is a surface phenomenon, there is a direct correlation between colloid surface area and optimum coagulant dose.

Enmeshment in a precipitate, a fourth model to describe certain

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coagulation situations, is not so much a destabilization mechanism as it is a "brute force" approach. Colloid properties are of minor importance, and they serve mainly as nuclei for the formation of metal hydroxide precipitates when metal salts are used as coagulants in high concentrations. Thus the rate of precipitation increases with increasing concentration of the colloidal particles to be removed (8,9,10).

For any given treatment situation, the predominance of one or more of the mechanisms just described will depend on the amount and kind of destabilizing chemical(s), the type and concentration of colloid, and the ions in the water. All models except double layer compression appear to be applicable to sludge conditioning, although the actual mechanisms involved are not clearly understood for metal salts (11). As Parsons notes: "chemical conditioning involves the addition of coagulants to improve sludge dewatering properties by mechanisms somewhat analogous to chemical coagulation but more complex" (12). Some of the reasons for this complexity include the high concentrations and great variety of solids present in sludges, the diversity of coagulants and the large doses usually employed, and the fact that the dewatering properties of the precipitate formed must be considered in addition to the supernatant quality. These factors are related and must be applied to the coagulation models for a greater understanding of sludge conditioning.

Sludge Properties

The chemical and physical nature of a sludge prior to conditioning

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is affected by the nature of the process producing the sludge. Septage, having gone through a digestion process, is somehow very difficult to dewater. Since the characteristics of a sludge which affect its being dewatered by vacuum filtration are (a) size, shape, and density of the solid particles, (b) viscosity of filtrate and of sludge, (c) solids concentration, (d) chemical composition, and (e) compressibility of solid particles, it is desirable in conditioning to bring about the formation of a sludge with a dense, porous, granular structure from the hydrous, gel-like masses and fines often encountered (13). The fact that septage is a digested sludge has other important ramifications also, especially as regards conditioning by inorganic chemicals. As mentioned earlier, during the process of anaerobic digestion the putrescible compounds are converted to methane, carbon dioxide, and ammonia. The CO₂ and ammonia then combine in the sludge liquor to Thus the digestion process reduces increase the alkalinity. the ratio of organic matter to mineral matter (volatile to ash ratio) while increasing the amounts of dissolved decomposition products as bicarbonates of ammonium and calcium left in the water fraction of the remaining sludge. These factors are related to inorganic chemical requirements. For this reason, the bicarbonate alkalinity which is dissolved in the free water present in the sludge is termed the liquid demand, while the solids demand is dependent upon the volatile to ash ratio. As can be deduced, digestion reduces the solids demand while greatly increasing the liquid demand (14). A discussion of sludge conditioning by inorganic chemicals will illustrate the importance of this

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liquid demand.

Inorganic Chemicals

The inorganic chemicals used in sludge conditioning include compounds of iron, aluminum, and calcium. Ferric sulfate, ferric chloride, and aluminum sulfate (alum) are the most commonly used inorganic chemicals, with calcium hydroxide (lime) often serving auxiliary functions. Aluminum and iron coagulants react in much the same manner. Stumm and 0'Melia (10) have described the reactions involved when Fe(III) or Al(III) salts in excess of the solubility limit are introduced into water. The free aquo-metal ions immediately undergo a series of hydrolytic reactions leading to the formation of a metal hydroxide precipitate. During this kinetic transition, simple hydroxocomplexes and colloidal hydroxometal polymers are formed. The ionic nature of these Al(III) and Fe(III) polymers are dependent upon pH; as the pH decreases, the average positive charge of the metal species tends to increase. Since these hydroxometal complexes are readily adsorbed at interfaces, it is plausible that they may cause charge neutralization with the possibility of restabilization in colloidal systems. This neutralization of negative colloids will obviously be more efficient (less coagulant) at lower pH levels where the average positive charge of the hydroxometal polymers is greater. Due to solubility considerations, however, the pH should not be reduced below 5 for aluminum salts or 4 for ferric iron salts.

It should be remembered that in sludge conditioning, metal salts

can destabilize colloids in more than one manner. The high colloid concentrations encountered in sludge conditioning require large coagulant doses for adsorption and charge neutralization. Even at the lower coagulant doses possible at lower pH levels, concentrated suspensions are difficult to restabilize due to the fact that before this can occur, sludges may be coagulated by enmeshment in precipitated metal hydroxides if a modicum of alkalinity is present to prevent drastic pH reduction. Thus it is desirable to condition sludge in a somewhat acidic pH region to reduce chemical coagulant doses but to maintain pH above solubility limits for the metal hydroxides. This is where the liquid demand of sludge mentioned earlier is an important consideration. Before coagulants can combine with the solids fraction of the sludge, they must satisfy the coagulant demand of its liquid fraction. As the following equations illustrate, the bicarbonate alkalinity present acts as a buffer to prevent pH reduction.

$$A1_{2}(S0_{4})_{3} + 6H_{2}0 + 2A1(OH)_{3} + 3H_{2}S0_{4}$$

$$\frac{3Ca(HCO_{3})_{2} + 3H_{2}S0_{4} + 3CaSO_{4} + 6CO_{2} + 6H_{2}0}{A1_{2}(S0_{4})_{3} + 3Ca(HCO_{3})_{2} + 2A1(OH)_{3} + 3CaSO_{4} + 6CO_{2}}$$
(3-1)

There are two commonly employed methods of reducing this coagulant demand to permit more effective or economical sludge conditioning. One method is to add lime to precipitate carbonate as calcium carbonate. The other method is to wash out a portion of the bicarbonate in a process known as elutriation.

Regardless of what processes are used, the use of inorganic chemicals for sludge conditioning can be costly and create problems. Recent years have seen the development and use of synthetic organic polyelectrolytes (polymers) in sludge conditioning, in the search for more economical or effective treatment methods. As a result, polymer conditioning before dewatering has now become more common (3,8,10).

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Polymers

Polymers are defined as a series of repeating chemical units (monomers) making up the molecule (15). The total number of subunits can be varied to produce polymers with molecular weights ranging from 200,000 to 10 million. They may be linear or branched and may sometimes contain two or three different kinds of subunits. These subunits may contain ionizable groups, in which case the polymer is termed a polyelectrolyte. Anionic polyelectrolytes carry a negative charge, usually have very high molecular weights, and function by bridging. In contrast, cationic polyelectrolytes carry a positive charge, usually have moderate molecular weights, and can also function by charge neutralization. Polymers without ionizable groups are termed nonionic, while those with both positive and negative groups are called ampholytic polyelectrolytes. In addition to weight, shape, and charge considerations, the ability of a polymer to act as a flocculent depends upon its ability to bond to the surface of colloidal particles. In water and wastewater treatment, polymers have been used both as coagulant aids and primary coagulants with varying degrees of success (8,16,17,18,19).

Experiences have also been far from consistent or conclusive in the area of sludge conditioning. While some have reported good results with polymers, others have reported unsatisfactory or uneconomical performance. These seemingly conflicting reports are probably caused by the large number of different polymers used and the diversity of sludge types (8). As Novak (20) notes: "The use of organic polyelectrolytes as coagulants and sludge conditioners has greatly increased the availability of

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and demand for these materials, but, unfortunately, the rationale for applying these polymers to sludge dewatering systems has been greatly lacking ... (due to) the lack of information available on polyelectrolyte characteristics and incomplete descriptions of the basic sludge characteristics before and after conditioning". Presently, trial and error testing methods are used to determine polymer type and dosage for a particular sludge, but some general observations have been made.

Polymer conditioning has been most effective with raw primary sludge, while digested sludge is more difficult. Digested activated sludge has been very difficult to condition with polymers. Polymer dose requirements appear to decrease as polymer molecular weights increase, possibly because long chain organic polymers form a porous matrix which permits rapid draining of water. However, polymer dose requirements appear to increase somewhat linearly as sludge solids concentrations increase, as the bridging model predicts. Sludge pH can also influence polymer dose to some extent. Cationic polymers function effectively in the neutral and slightly acidic range, but due to their lower molecular weights they generally have greater dose requirements than anionic and nonionic polymers. In addition, research seems to indicate that while nonionic to moderate-activity anionic polymers function well between pH 6 and 8.5, high activity anionics function best at even higher pH values. Regardless of treatment conditions however, it appears that the best dewatering properties obtainable (as measured by specific resistance) is dependent primarily upon the initial specific resistance of the sludge (8, 20).

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Additional Considerations

Aggregation mechanisms are only one way in which sludge conditioning by polymers and inorganic chemicals differ. Inorganic chemicals are much more effective in supernatant phosphorus removal than polymers. This is due to the fact that multivalent metal ions used for coagulation (Fe(III), Al(III), Ca(II)) function as precipitants of phosphate rather than as coagulants. As a result of this "phosphorus demand", the quantity of these chemicals needed for coagulation is increased. The efficiency of phosphorus precipitation varies with pH for the various metal ions depending upon the solubility relationships of the metal phosphate and metal hydroxide, the hydrolysis of the metal ions, and other competing reactions. In some instances polymers have been used effectively in conjunction with inorganic chemicals for the removal of phosphorus (16,21,22).

A very similar situation exists in the realm of heavy metals removal from the liquid portion of sludge. Any removal of these elements at wastewater treatment plants is achieved primarily by two mechanisms. They are (1) precipitation of metal hydroxides, which are removed with the sludges, and (2) sorption of soluble trace metals by sludges. Again, it is precipitation, not coagulation, which provides for heavy metals removal when inorganic chemicals are added to water. Similarly, the effectiveness of heavy metals removal is pH dependent due to solubility relationships and other factors. Heavy metal reduction by chemical treatment is most commonly achieved using lime, since many metals form insoluble hydroxides at high pH as a result of solubility product considerations. However, experiments on heavy metals removal using aluminum sulfate and certain polyelectrolytes have met with some degree of success also (23,24,25,26).

Finally, there is a great contrast in cost and dosage requirements between polymers and inorganic chemicals used in sludge conditioning. Dick (8) notes that typical polymer doses are less than 1% of the weight of dry solids while the total amount of inorganic chemicals used in sludge conditioning may be as much as 20% of the weight of the solids. He adds that this does not necessarily mean a lower cost, as synthetic polymers cost appreciably more per pound than inorganic conditioners. However, regardless of what chemicals are used, after successful flocculation has occurred, thickening or settling can remove most of the water between the colloidal particles, while dewatering equipment such as vacuum filters can be used to remove most of the adhesion and capillary water and change the physical form of the sludge from that of a fluid to that of a damp solid (3,8).

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IV. EXPERIMENTAL METHODS AND PROCEDURES

A. Experimental Design

The initial stages of this investigation were of a screening and exploratory nature. This portion of the investigation provided information on what analyses would be most useful, and on the general characteristics of septage. The effects of various alum dosages on septage were studied, and separate treatment of the supernatants of thin septages was also investigated. Thereafter, a comparison of three inorganic chemicals - lime, ferric chloride, and alum - at different dosages was undertaken regarding their effects on supernatant quality and sludge dewatering characteristics. A number of polymers were also investigated, and those with promise were run for comparative purposes against In addition, certain treatment by inorganic chemicals. physical conditions, such as flocculation speed and duration, were varied to determine their effect on resultant supernatant and sludge characteristics. Lime treatment of the settled solids of chemically treated septage to improve dewatering characteristics further was briefly investigated, as was the use of polymers in combination with inorganic chemicals as coaquiant aids. Finally analysis of heavy metals present in septage and supernatant, before and after treatment, was undertaken.

B. Samples

Septage samples of different ages from Amherst, Mass. and the surrounding area were obtained as they were discharged at the inlet works to the Amherst wastewater treatment plant. Although origin and age could usually be obtained from the operators, no guarantee that the septage was a representative and well mixed sample of the stated household unit(s) could be made. Nonetheless, the samples obtained over the course of this investigation displayed a wide range of characteristics. The septage was transported to the laboratory in plastic jugs and subjected to vigorous mixing before being used for the tests. In some of the early tests, septage samples were allowed to settle and the supernatant was drawn off for treatment in comparison with the treatment of the thoroughly mixed counterpart.

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C. Procedures for Treatment

A conventional six-unit jar test stirrer was used throughout the investigation. The general procedure involved chemical addition during rapid mixing, followed by flocculation and settling. In all instances rapid mix was carried out at 75 RPM, for a duration of 1, 2, or 3 minutes. In most instances a 2 minute rapid mix was employed. In some cases, because of the high concentration of solids in a sample or the added chemical being in powder form, such as lime, it was difficult to achieve chemical dispersion throughout the sample. Additional manual mixing using a fork was employed simultaneously with the rapid mix step as equitably as possible in all six beakers in these instances. Flocculation was most frequently carried out at 30 RPM for 30 minutes. In some instances the effect of flocculation time and rate were investigated with flocculation times of 10, 20, 45, or 60 minutes and rates of 10 or 20 RPM. These variables have an important effect on energy requirements in a chemical treatment system, and they can also affect floc stability. A settling period of 30 minutes was always allowed. At the end of settling the percent of supernatant was recorded. This supernatant was carefully poured off into sample jars and stored at 4°C until analysis. Where scum layers formed after treatment, the scum layer was removed before the supernatant was decanted. The remaining settled solids after removal of supernatant were then stirred manually to get a representative mixture and poured into sample jars which were stored at room temperature. The only modification to the procedures just described occurred when the settled solids were subjected to a "second-stage" lime

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treatment to improve specific resistance. In this case the usual procedure was employed to the point of decanting the supernatant. The settled solids were then subjected to a rapid mix phase during which lime was added, followed by flocculation. This mixture was then poured into sample jars for specific resistance measurements.

A number of chemicals were used in this investigation. The inorganic chemicals used included:

1. liquid alum (solution strength of 49% $A1_2(S0_4)_3 \cdot 14H_2(0)$

- 2. ferric chloride (FeCl₃, purified, anhydrous sublimed)
- 3. lime (Ca(OH)₂, dry)

Initially a wide range of doses was employed for all the chemicals, but for the most part dosages ranged from 500 to 2000 mg $Al_2(SO_4)_3 \cdot 14H_2O$, 500 to 3000 mg FeCl₃, and 1000 to 6000 mg Ca(OH)₂ per liter of septage. Ferric chloride was sometimes dissolved in distilled water prior to use, and this did not seem to have any effect on the results. A number of polymers were tested, but only one appeared effective. All but Nalcolyte 675 were manufactured by Calgon. Cationic polymers tested included ST-266, Cat floc B, E-207-L, and WT-2640. Nonionic polymers were represented by ST-269 and ST-270. Nalcolyte 675, weakly anionic WT-2700, and strongly anionic WT-2900 and WT-3000 comprised the anionic polymers tested. All except ST-266 were ineffective in bringing about desired changes in the nature of the septage. Sludge conditioner ST-266 is a polyalkylene polyamine. It is made by a condensation polymerization reaction between a polyamine, ethylene dichloride, and epichlorohydrin (27). ST-266 is a honey-colored, very viscous liquid, similar to molasses, and usually was diluted by mixing 1/4 to 1 ml of the polymer with 25 ml of distilled water prior to use in the jar test experiments.

D. Methods of Analysis

The following analyses were made for raw septage samples and supernatants of Type I and II septages (see Section V-A) before and after treatment:

(a) Percent scum and percent supernatant after 30 minutes of settling. The level of the solid-liquid interface was observed and recorded using the graduated marks on 1-liter beakers.

(b) pH.

(c) Biochemical oxygen demand (BOD₅).

(d) Chemical oxygen demand (COD).

(e) Total residue (referred to as total solids).

(f) Total volatile residue (referred to as total volatile solids).

(g) Orthophosphate phosphorus (vanadomolybdate method).

Tests (b) through (f) were carried out in accordance with <u>Standard Methods</u> (28). Due to difficulties encountered initially in orthophosphate determinations, later orthophosphate determinations were made on supernatant or septage samples after they had been filtered through Whatman 2 paper. Suspended solids determinations were not performed in this investigation. As noted in <u>Standard Methods</u>, for samples such as sediments and sludges it is difficult and usually unnecessary to distinguish between filterable and non-filterable residue. In retrospect, however, it was a mistake in judgment not to perform these determinations on the treated supernatants.

Ammonia nitrogen determinations were discontinued after inorganic chemical treatment was found to have little effect on its removal. Tests for total phosphorus were also subsequently discontinued after a close relationship between orthophosphate and total phosphorus was found.

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Alkalinity measurements, when made, employed a slight modification in that septage filtrate, instead of supernatant, was analyzed to assure sufficient liquid for analysis.

During the latter part of this research, an analysis of heavy metals present in septage and their degree of removal after treatment was made. The metals of interest were iron, copper, and zinc. Their concentrations were determined using a Perkin-Elmer 303 atomic adsorption spectrophotometer after the samples had been digested and filtered to remove solids that might clog the aspirator. Instrumental conditions such as slit width, fuel to air ratio, wavelength setting, etc., were set according to procedures prescribed by Perkin-Elmer.

Settled solids and raw septage samples were subjected to specific resistance determinations, an index of sludge dewatering properties. Specific resistance is useful in comparing the effects of coagulants and various methods of conditioning sludges. Being a true measure of the filterability of a sample, this measurement makes it possible to compare dewatering properties of samples numerically. For example a sludge with a specific resistance of 4.7 x $10^{8} \sec^{2}/\text{gm}$ is 100 times more "filterable" than one with a resistance of 4.7 x $10^{10} \sec^{2}/\text{gm}$ (29).

Specific resistance has been defined as the pressure required to produce a unit rate of flow through a cake having a unit weight of dry solids per unit area when the viscosity is unity. It has its basis in the hydraulics of filtrate flow using Poiseuille's and Darcy's laws and the Carmen-Kozeny equation and was adapted to sludge filtration by Coackley and others (3). For the case of compressible filter cakes,

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Carmen and Coackley have shown that the filtration rate equation for sludge dewatering is:

$$\frac{dV}{dt} = \frac{PA^2}{\mu(rcV + R_mA)}$$
(4-1)

)

where

- V = volume of filtrate (ml)
- t = cycle time (sec)
- P = vacuum applied (dyne/cm²)
- A = filtration area (cm^2)
- μ = filtrate viscosity (gm/cm-sec)
- r = specific resistance (sec²/gm)

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

R_m = initial resistance of a unit area of filtering surface
 (sec²-cm/ml)

Equation (4-1) can be integrated and rearranged to give:

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

When (t/V) is plotted against V, a straight line of slope b = $(\mu rc)/(2PA^2)$ is obtained which can be rearranged to give the specific resistance, r, as follows:

$$r = \frac{2bPA^2}{\mu c}$$
(4-3)

Therefore specific resistance to filtration of waste solids can be

found experimentally by determining in a Buchner funnel test correlative values of t and V, and the values of P, A, c, and temperature. In this investigation the value of b in equation (4-3) was determined for each sample by using the method of least squares to fit pairs of (V,t/V) data points to the linear functions $\frac{t}{V} = bV + I$, where I is the $\frac{t}{V}$ - intercept of the line. An applied vacuum of 20 cm of Hg was employed in all runs. Other necessary values to calculate specific resistance using equation (4-3) were also recorded for each sample and all results are expressed in \sec^2/gm in accordance with the definition of specific resistance which was used for this study.

Coefficient of compressibility, while not performed in this investigation, is another parameter describing the filtration characteristics of sludge. Specific resistance is dependent on the pressure differential at which the test is run since some sludges, when subjected to pressure, pack together, increasing the density of the sludge cake and reducing the rate of sludge dewatering; the coefficient of compressibility is an empirical measure of the effect of this pressure differential across the sludge. Values of the coefficient of compressibility are obtained by developing a log-log plot of specific resistance determinations obtained at various pressure differentials; the slope of this plot gives the coefficient of compressibility (3,7,8,16,20,29,30).

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V. EXPERIMENTAL RESULTS AND DISCUSSION

Effectiveness of septage treatment should be measured by the degree of improvement achieved, rather than the absolute value of various quality parameters. As was noted previously, characteristics such as best obtainable specific resistance by treatment depend greatly upon the initial characteristics of the sludge. Table II shows some of the characteristics of the septages studied in this investigation prior to treatment. From this table it can be seen that septage is indeed a strong and variable waste. In gauging the effectiveness of septage treatment it is important to consider the original characteristics of the septage, as well as the results obtained after treatment.

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Table II. Characteristics of Untreated Septage

Run	Septage Origin	Age (yrs)	BOD ₅ (mg/1)	COD (mg/1)	Total Solids (mg/l)	pН	Specific Resistance (sec ² /gm)	% Supern. after 30 min.settl.
1	S. Amherst	2	8,700	34,000	44,000	6.8	2.0 x 10 ¹⁰	24
2	S. Amherst	4	6,400	21,000	34,000	5.9	1.7 x 1011	64
3	Amherst	4	17,000	45,000	40,000	6.8	6.9 x 10 ¹⁰	16
4	S. Amherst	3	18,000	38,000	34,000	5.7	7.6 x 10 ⁹	17
5	S. Amherst	1	5,400	28,000	18,000	6.4	1.7 x 10 ¹¹	65
6	Amherst	2	>38,000	>50,000	48,000	5.3	1.0×10^{11}	0
7	Amherst	Ĩ	23,000	41,000	29,000	5.3	1.4×10^{11}	12
8	S. Amherst	3	13,000	30,000	28,000	6.7	5.8 x 10^{10}	45
9	S. Amherst	3	12,000	32,000	29,000	6.7	4.7×10^{10}	20
10	S. Amherst	4	>35,000	>53,000	52,000	5.6	1.6×10^{11}	0
וו	S. Amherst	4	10,600	21,000	19,000	6.3	1.0×10^{11}	70
12	S. Amherst	3	27,000	58,000	31,000	6.8	1.0 x 10 ¹¹	0
13	Pelham	4	8,800	15,000	20,000	6.4	2.2×10^{10}	27
14	Pelham	3	11,000	26,000	25,000	6.3	1.3 x 10 ¹¹	40
15 ்	Pelham	4	25,000	70,000	74,000	6.5	5.4 x 10^{10}	0
16	Pelham	2	11,000	21,000	16,000	6.8	1.6 x 10 ¹¹	28
17	Pelham	3	5,500	19,000	17,000	7.0	5.1 x 10 ¹⁰	52
18	Amherst	3	>40,000	59,000	56,000	7.2	7.1 x 10 ⁹	3
19	N. Amherst]	18,000	27,000	32,000	6.9	2.9 x 10 ⁹	23
20	S. Amherst	3	10,000	32,000	58,000	6.8	6.4 x 10 ⁹	38
21	Amherst	2	7,400	32,000	22,000	7.2	5.6 x 10 ⁹	30
22	-		-	-	-		1.2×10^{10}	10
23A	S. Amherst	3	6,200	7,600	6,700	7.3	7.8 x 10 ⁹	58
23B	S. Amherst	3	11,000	24,000	21,000	-	1.4 x 10 ¹⁰	18
23C	S. Amherst	3	7,000	11,000	6,300	6.8	2.2 x 10 ¹⁰	63
24	-	- 1	24,000	48,000	54,000	5.6	1.3 x 10 ¹⁰	12
25	Amherst	3	3,500	11,000	8,000	6.7	1.4 x 10 ¹⁰	84
26	S. Amherst	5	9,200	25,000	20,000	5.6	1.4 x 10 ¹⁰	17
27	Amherst	4	11,000	28,000	17,000	6.4	8.3 x 10 ⁹	26
28	Amherst	3	15,000	37,000	31,000	7.2	4.8 x 10 ¹⁰	20
29	Pelham	6	5,400	32,000	28,000	7.2	1.9 x 10 ¹⁰	15
30	S. Amherst	4	11,000	41,000	63,000	6.0	8.3 x 10 ⁹	5
31	-	-	8,200	25,000	19,000	7.4	1.4 x 10 ¹⁰	30
32	S. Amherst	2	9,000	13,000	9,900	6.3	2.5 x 10 ¹⁰	78
A. Three Types of Septage

The best coagulant and dosage for a given waste depends upon the goals which are sought. Three broad types of septage were found in this investigation and different criteria for treatment were established for these three types. Some septages (Type I) are watery, settle well, and have relatively low solids content. Other septages (Type III) which settle very little if at all, usually have high solids levels. Between these two extremes are septages (Type II) which evidence some settling and have characteristics in the median range. Approximately half of the samples analyzed in this investigation were Type II septages, with the rest being fairly evenly divided between Type I and Type III. Table III lists the ranges for certain measured characteristics which can be expected in each of these three types of septage.

Evidently a large amount of overlying supernatant liquor was pumped with the accumulated sludge from a septic tank which gave Type I septage. Constituting approximately one-fourth of all samples studied, this type of waste must be treated with the purpose of producing good quality supernatant. This type of septage had the lowest values for parameters such as BOD_5 , COD, and solids both before and after the chemical treatment. The mode of treatment for Type I septages should be to achieve the optimization with respect to chemical clarification of the supernatant, and to further condition the sludge after the liquid-solid separation if required.

As mentioned previously, Type II septages were most commonly encountered and in properly maintained septic tanks this type would be

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Septage	Sample	BOD5	COD	Total Solids	Specific Resis.*	Percent
Type		(mg/1)	(mg/l)	(mg/l)	(sec ² /gm)	Supern.
TYPE I	Untreated Septage Untreated Supern. Treated Supern.	5,000 - 15,000 500 - 3,500 100 - 1,500	10,000 - 30,000 2,000 - 10,000 250 - 2,500	5,000 - 35,000 1,000 - 5,000 500 - 2,500	5x10 ⁹ - 1x10 ¹¹ (5x10 ⁹ - 1x10 ¹¹) (1x10 ⁷ - 5x10 ⁹)	- 40 - 85 35 - 75
TYPE II	Untreated Septage Untreated Supern. Treated Supern.	7,500 - 25,000 2,000 - 10,000 100 - 1,500	15,000 - 45,000 5,000 - 15,000 250 - 2,500	15,000 - 45,000 2,500 - 10,000 500 - 2,500	5x10 ⁹ - 1x10 ¹¹ (5x10 ⁹ - 1x10 ¹¹) (1x10 ⁷ - 5x10 ¹⁰)	- 10 - 40 10 - 40
TYPE	Untreated Septage	25,000 - 50,000	45,000 - 75,000	45,000 - 75,000	5x10 ⁹ - 1x10 ¹¹	-
	Untreated Supern.	-	-	-	(5x10 ⁹ - 1x10 ¹¹)	0 - 10
	Treated Supern.	-	-	-	(1x10 ⁸ - 5x10 ¹⁰)	0 - 15

Table III. Characteristics of Three Types of Septage

*Numbers in parentheses represent values associated with the settled solids of the respective sample.

expected. This septage contains a fairly large quantity of digested sludge, which if not cleaned out would start to interfere with the proper operation of a septic tank. At the time of cleaning the overlying supernatant becomes mixed and removed with the sludge. This type of septage requires treatment to improve both sludge dewatering characteristics and supernatant quality, with the emphasis on the former criterion.

Type III septages were usually the most objectionable in terms of physical and chemical characteristics, and the treatment should focus on sludge conditioning. They are representative of septages from tanks long overdue in cleaning. The tanks are filled essentially with digested sludge. It is well known that such sludges are the most difficult to be conditioned for dewatering.

Type I Septage

Septages of this type were encountered in runs 2, 5, 8, 11, 17, 23-A, 23-C, and 25. After settling for 30 minutes, all untreated septages except sample 8 had a supernatant portion in excess of 50% by volume. Chemical treatment reduced supernatant volume in all cases, at times by as much as 30%. Three factors - chemical addition, clarification, and a more porous sludge structure - presumably account for this volume reduction. However, both supernatant quality and sludge dewatering properties were improved as a result of this chemical treatment.

BOD₅, which averaged over 7,000 mg/l in untreated septage for these 8 runs, and over 2,000 mg/l in untreated supernatant, could be

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reduced to an average of 500 mg/l after chemical treatment. Reductions of similar percentage after treatment were evidenced in such quality parameters as COD, total solids, and total volatile solids. The specific resistance of the 8 Type I septage samples averaged 7.5 x $10^{10} \text{ sec}^2/\text{gm}$. After treatment the average specific resistance of the settled solids had been reduced to $1.1 \times 10^9 \text{ sec}^2/\text{gm}$, suggesting a seventy fold improvement in filterability. In some instances the chemical and/or dosage which produced the best supernatant quality for a particular septage was not the same one which gave the lowest specific resistance and to that extent the values just discussed may exaggerate the improvement obtainable by chemical treatment. Nevertheless, these experiments showed that treatment of Type I septages with other than optimum chemicals or doses still resulted in very great improvement of dewatering characteristics and supernatant quality.

In addition to being the most easily treated and conditioned, Type I septages are the only ones for which separate treatment of supernatant might be considered. This possibility was investigated in runs 2 and 5 by allowing untreated septage to settle and drawing off supernatant for treatment. As Figures 1 and 2 show, at the best alum dosages the total solids and COD values were less in samples in which only the liquid portion of the septage was treated. However, the difference is not of sufficient magnitude to justify separate treatment.

Another important point, the effect of overdosing, is also illustrated by these two figures. Although higher alum dosages resulted in only slight increases in COD values beyond those obtained at optimum doses, total solids in the resultant supernatant increased almost linearly

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Figure 1. Effect of Separate Chemical Treatment of Supernatant on Total Solids Reduction.



Figure 2. Effect of Separate Chemical Treatment of Supernatant on COD Removal.

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with alum dosage beyond a certain point regardless of whether septage or supernatant alone was treated. This appeared to be due to the unfavorable pH which resulted at higher alum doses. As was previously discussed, pH plays an important role in coagulation by inorganic chemicals. Enmeshment of solids is less effective when the pH is driven to lower values than those at which the metal hydroxide $(Al(OH)_3 \text{ or Fe}(OH)_3)$ is precipitated out. In addition dissolved solids increase due to the addition of the unprecipitated polyvalent metal ion. In the situation shown in the figures just discussed, the pH decreased from an average of 5.2 at the best alum dosage (650 mg/l) to 4.6 and 4.3 at dosages of 1300 and 1900 mg/l respectively.

Later runs compared the effects of different chemicals and flocculation RPM on Type I septage. Ferric chloride depressed the pH faster than alum for similar doses due to the fact that there are more metal ions per unit weight of FeCl₃ than $Al_2(SO_4)_3 \cdot 14H_2O$. Their effectiveness was similar and both appeared superior to lime for improving water quality. They were also superior to all polymers investigated except ST-266, a cationic polymer, in achieving improved supernatant quality and dewatering characteristics. Finally it appeared that flocculation RPM had little effect on supernatant quality when treating thin septage types.

Type II Septage

This type of septage, as previously noted, was encountered twice as frequently as either Type I or Type III in this investigation. A 30 minute settling period produced supernatants which ranged from 12 to 40% by volume, with an average of 23%. These septages demonstrated some inter-

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esting, but definite trends regarding settling after chemical treatment. Of the 18 septages which fell into this category, only the three lowest in percent supernatant (12%, 12%, 15%) showed an increase in this fraction after chemical treatment. The next four showed virtually no change in the liquid fraction after treatment, while nine of the remaining eleven, including the six highest in supernatant, showed a decrease in this portion after treatment. In all samples where comparisons were made, ST-266 achieved noticeably better settling of solids than inorganic salts, while at the same time removing more solids from the supernatant portion. Sample 19, with a supernatant fraction of 23%, showed this situation clearly; the six progressively larger doses of ST-266 gave supernatant fractions of 32, 30, 30, 30, 30, and 29 percent respectively while the five progressively larger doses of FeCl₃ gave fractions of 15, 21, 20, 22, and 21 percent respectively. Supernatant fractions which were approximately 10% larger after ST-266 treatment then treatment with other chemicals were commonly observed in other trials. However, run 19 illustrates it best due to the increase in supernatant fraction after ST-266 treatment and the decrease in this fraction after FeCl₃ treatment; in other runs ST-266 only increased the supernatant fraction more than other chemicals, or decreased it less than the other chemicals. Again, the decrease in supernatant fraction would appear to be due to the factors mentioned previously for Type I septages. Increases of supernatant in those septages low in this fraction appear to be comparable to conventional thickening. These runs also seem to confirm a statement in the EPA's Process Design Manual for Sludge Treatment and Disposal (3) that "cationic polyelectrolytes have been the most successful chemicals used in wastewater sludge thickening."

Again, supernatant quality and dewatering characteristics were

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greatly improved as a result of chemical treatment. Values for BOD_5 , which averaged approximately 13,000 mg/l for untreated septage of this type and 4,000 mg/l for untreated supernatants, were reduced to an average of approximately 725 mg/l after chemical treatment. Relative improvements in other guality parameters were similar to those just noted for BOD₅. Specific resistance decreased from an average of 4.2 x 10^{10} sec^2/gm in untreated septage to 3.8 x $10^9 sec^2/gm$ in treated settled solids. A word of caution is in order however regarding interpretation of these values. When specific resistance measurements are averaged as was just done, one or two high readings can completely obscure the beneficial effects being obtained in most cases. While only 5 of the untreated septage samples had specific resistance values of less than $1 \times 10^{10} \text{ sec}^2/\text{gm}$, the settled solids of 8 of the 18 could be reduced to less than 1 x 10^8 sec²/gm and another 5 to less than $1 \times 10^9 \text{ sec}^2/\text{gm}$ after treatment. As mentioned before, the improvements just discussed may exaggerate results obtainable in practice since the best supernatant quality and best dewatering characteristics were not always obtained with the same chemical or dosage. Some general observations regarding treatability of Type II septage by chemicals follow.

Again the phenomenon of overdosing, this time with FeCl₃, is evident as shown in Figure 3. For most samples of this type, total solids could be reduced to a level of 1,000 to 2,000 mg/l, and this usually occurred at dosages of from 500 to 1,500 mg/l of ferric chloride or alum. Figure 4 shows that the lowest COD values for inorganic chemical treatment were also recorded at these dosages, and ranged from about 500 to 2,000 mg/l. While these values for COD and total solids might appear high, it must

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Figure 4. Reduction of COD with Ferric Chloride.

be remembered that this treatment achieved reductions of up to 97% from those found in the original septage samples, and in many cases greater than 90% reductions over those observed in untreated supernatants of the same samples. ST-266 was consistently able to reduce total solids and COD values for Type II septage to 1500 mg/l at polymer dosages of less than 1 ml/l (1040 mg/l). Although ST-266 was nearly always able to clarify Type II supernatants, there were a few septages of this type in which treatment with inorganic chemicals resulted in dark, very cloudy, or "globby" supernatants. For those chemicals in which this would occur over the whole range of doses, analysis of supernatant characteristics was sometimes not performed and a physical description of the supernatant would be substituted

Not only was ST-266 superior to inorganic chemicals for improvement in supernatant quality and settling characteristics, but as Figure 5 shows, it was vastly superior to inorganic chemicals in improving dewatering properties of Type II septages. Figure 5 also illustrates the remarkably similar effectiveness of alum and ferric chloride at equivalent chemical doses. At equivalent doses, the ion concentration of Al(III) is about half that of Fe(III), and so these results are unexpected. Lime was not as effective as either alum or ferric chloride in improving supernatant quality, but could effectively condition some septages while failing miserably with others. Lime used in conjunction with ferric chloride, while greatly improving the dewatering characteristics of the settled solids, gave poorer supernatant quality than ferric chloride used alone. However, a remedy was to add lime to the settled solids of a septage

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Figure 5. Comparison of FeCl₃ Alum, and ST-266 in Sludge Conditioning (Run 21).

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sample treated with ferric chloride. In some cases, the dewatering characteristics of these solids could be thus conditioned to a level comparable to that achieved using ST-266 (Fig. 6). Other than ST-266, most polymers tested were totally ineffective in improving supernatant quality or sludge dewatering characteristics. Two polymers, E-207-L and WT-2640, were somewhat useful, but alum at doses of 650 mg/l was usually more effective at meeting both treatment objectives than either of these chemicals.

Type III Septage

Septage samples 6, 10, 12, 15, 18, 22, and 30 represent Type III septages. Only one sample had a supernatant portion in excess of 5% after settling, and four showed no settling at all. No inorganic chemical was able to establish or increase the supernatant portion of this septage type. ST-266 usually achieved a supernatant fraction of 5 to 10 percent when used in large dosages (above 1 ml/l); in one case, sample 12, it achieved an astounding 26% supernatant fraction at a dosage of only 1 ml/l while all 3 inorganic chemicals failed completely to produce any settling. BOD_5 values in this septage type ranged from 25,000 mg/l to over 40,000 mg/l, total solids generally ranged from 50,000 to 75,000 mg/l, and all but one sample had COD values in excess of 50,000 mg/l. Unfortunately these septages, in addition to being the most putrescible and objectionable of the three septage types, were also the most difficult to condition for dewatering.

With an average specific resistance of 6.3 x 10^{10} sec²/gm, they could

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Figure 6. Effect of Lime on Treated Settled Solids (Run 20).

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only be conditioned to a specific resistance which averaged 1.7 x 10^{10} sec²/am. The average specific resistance of all three septage types was very similar. That is, prior to treatment Type I and Type II septages were virtually no easier to dewater than those of Type III, vet these three types of septages responded very differently to chemical conditioning. Three of these Type III samples exhibited little or no improvement in dewatering characteristics after treatment with chemicals, either organic or inorganic. The other four were treated with various degrees of success, although this usually required excessively high dosages or combinations of chemicals. Again the best results were achieved with ST-266. Intermediate in effectiveness were ferric chloride and alum, while lime demonstrated little ability to condition this type of septage. Other polymers tested were also totally ineffective. The effect of flocculation time on specific resistance was also investigated (Figure 7) and found to have negligible effect.

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Figure 7. Effect of Flocculation Time on Specific Resistance (Run 18).

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B. Effectiveness of Chemicals

Clarification - Supernatant Quality

Only three of the chemicals tested, ferric chloride, alum, and ST-266, were consistently effective in achieving large degrees of improvement in septage supernatant quality. These improvements can be seen, as reflected in chemical oxygen demand and total solids concentrations, in Figures 3, 4, 8, 9, 10, and 11. The previous discussion of septage types alluded to some of the major points shown in these figures.

The similar behavior of alum and ferric chloride in treating septages can be observed by comparing Figures 3 and 8 or Figures 4 and 9. It is seen that were supernatant quality the only consideration, alum and ferric chloride dosages in the range of 500 to 1500 mg/l are best. With thinner and low alkalinity septages, both cost and quality considerations would make it preferable to operate in the lower end of this range. The cause of overdosing in Figures 3 and 8 can be seen by reference to Figures 12 and 13, which show the effect of pH on total solids reduction by inorganic chemicals.

Figures 12 and 13 demonstrate that coagulation efficiency drops rapidly as the pH falls from 5 to 4. This decrease in pH occurs with increasing chemical addition due to the acidic nature of alum and ferric chloride. Thus for best clarification, these figures indicate that the pH should be maintained above pH 5; this is as solubility equilibria of amorphous $A1(OH)_3(s)$ and $Fe(OH)_3(s)$ would suggest. Since alkalinity present in septage acts as a buffer to prevent pH reduction, it plays an



Figure 8. Reduction of Total Solids with Alum.

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Figure 9. Reduction of COD with Alum.



Figure 10. Reduction of Total Solids using ST-266.

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Figure 11. Reduction of COD using ST-266.

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Figure 12. Effect of pH on Total Solids Reduction by Alum.



Figure 13. Effect of pH on Total Solids Reduction by FeCl₃.

important role in chemical clarification. From weight relationships (Equation (3-1)) it is known that 1 mg/1 of $Al_2(SO_4)_3 \cdot 14H_2O$ will destroy approixmately 0.5 mg/l of alkalinity as CaCO3, while 1 mg/l of FeCl3 will destroy just under 1 mg/l of alkalinity. The average alkalinity of septage samples 28 through 32 was approximately 1300 mg/l as $CaCO_3$, while the filtrate alkalinity of these samples was approximately 625 mg/l. Thus some of the alkalinity is seen to be tied up with the solids. Based on titration results, it appears that some of this "tied up" alkalinity may become soluble as the pH is lowered. These values are lower than those often encountered in digested sludges, but are within the limits of normal digestion (3) and may be accounted for in part by the relatively low alkalinities found in Amherst water (31) and the fact that digestion in septic tanks is presumably much less efficient than that which is controlled at treatment plants. Based on these considerations, it is seen that the alkalinity in septage will be neutralized by alum at doses in the range of 1200 to 2500 mg/l, or by ferric chloride at doses half this large. As one of the results the pH drops. It is fortunate that those septages in which supernatant quality is the most important due to its percentage by volume, are those in which chemical clarification is most readily achieved at lower dosages such that the pH is not greatly reduced. Often thicker septages, those which usually have a small supernatant fraction, are very difficult to clarify with inorganic chemicals at any dose, and for all practical purposes the change of pH should not be a matter of serious consideration.

Figures 10 and 11 demonstrate the improvement in supernatant quality achieved using Calgon polymer ST-266. Unlike most polymers, resta-

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bilization of floc particles was not evident, and it appears probable that mechanisms in addition to bridging account for the effectiveness of ST-266. Thin septages could be satisfactorily clarified at doses of 1/4 m1/1 (260 mg/1), while thicker septages might require two to four times this dosage for optimum clarification. Were cost and supernatant quality the only considerations, doses of 500 mg/l would probably be the most attractive compromise. It is seen that at this dosage, the majority of those septages that are going to be amenable to chemical clarification can obtain supernatant COD and total solids values of less than 1,000 mg/l. Unfortunately Calgon ST-266, the most effective chemical under all conditions in terms of supernatant quality and sludge dewatering properties is no longer produced. It was a victim of raw material cost increases that rendered it unprofitable(27). Nevertheless, its tremendous and uniform effectiveness under nearly all conditions justifies its discussion and it is hoped that at some time a similarly effective and less costly polymer might be found by other researchers.

Lime was the most unpredictable of all chemicals tested. In many instances lime was ineffective in improving supernatant quality, and even for those samples where improvements were achieved, supernatant quality was still not as good as that achieved using alum or ferric chloride. There seemed to be no characteristics of a particular septage that would allow one to predict ahead of time how effective lime would be for clarification. Thus the only definite conclusion that can be drawn with regard to lime clarification of septages is that it is rather unreliable as compared with alum, ferric chloride or ST-266.

No anionic or non-ionic polymers tested were effective in improving supernatant quality at all. However two other cationic polymers, E-207-L and WT-2640, were somewhat useful. The pH of septage may be a factor in these results. As was previously mentioned, research by Novak (20) indicates that a neutral or slightly acidic pH is desired for conditioning with cationic polymers, while anionic and non-ionic polymers function best at slightly higher pH values. Both E-207-L and WT-2640 become colorless, viscous solutions when dissolved in water. They appear capable of improving supernatant quality at doses of less than 250 mg/l for most Type I and Type II septages. However, these improvements were no better, and were usually slightly poorer than those achieved using alum at doses of 1000 mg/l or less.

Dewatering of Settled Solids

Generally it seemed that those chemicals which were more effective in supernatant clarification were also most effective in creating settled solids with desirable dewatering characteristics. However conditioning was seen to have larger chemical requirements than clarification. The effects of septage treatment with various chemicals on specific resistance is seen in Figures 14 through 17, and Figures A-1 through A-5 (Appendices).

Figures 14 through 17 show dosage operating ranges by septage type for alum, ferric chloride, ST-266, and lime respectively. Alum treatment of Type III septages and lime and ferric chloride treatments of Type I septages were not extensively analyzed as alum is essentially used in

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Figure 14. Operating Range for Septage Conditioning with Alum.









Figure 17. Operating Range for Septage Conditioning with Lime.

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practice for chemical coagulation, while lime and ferric chloride are more commonly employed in sludge conditioning. Thus the analytical data are not shown in Figures 14, 15, and 17 due to the small and inconclusive number of runs which represent these situations.

Figures A-1 (alum), A-2 (ferric chloride), A-3 (ST-266), A-4 (lime), and A-5 (E-207-L and WT-2640) plot the results of various runs using these chemicals. The unconventionally large number of runs plotted in each figure, while making it difficult to follow a particular run, enables one to discern general trends much more easily. Reference to some of these trends was made previously when discussing various septage types.

Alum and ferric chloride, very similar in clarification effectiveness, show this same similarity in sludge conditioning (Figures A-1 and A-2 respectively). With all but a few septage samples, specific resistance could be improved by one to two orders of magnitude. This suggests that after treatment these septage samples are from ten to one hundred times more readily being dewatered. This sometimes required doses in excess of 2000 mg/1 (Fig. 14 and 15) with more difficult septages, although great improvements were noticed at increasing doses up to 1000 to 1500 mg/1 for many septages. In general, most septages could be treated to the range of 1 x $10^9 \sec^2/gm$ by these chemicals.

Treatment by ST-266 was by far the most effective method found for conditioning septage. Decreases in specific resistance of two orders of

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magnitude or more were common (Figure A-3). This hundredfold increase in filterability was achieved at ST-266 doses ranging from 0.5 to 1.5 mg/l (approximately 500 to 1500 mg/l) and almost always resulted in specific resistance measurements of less than 1 x $10^9 \text{ sec}^2/\text{gm}$ and often less than 1 x $10^8 \text{ sec}^2/\text{gm}$. Whether a septage could be conditioned with 500 mg/l of ST-266 or required two to three times this dosage usually depended on whether a septage was thin and somewhat granular or thicker and gel-like (Figure 16). However most septages had a very clear-cut optimum ST-266 dosage within this range of 500 to 1500 mg/l for best conditioning, and increases in ST-266 beyond this range in their respective cases did not even result in incremental further improvement as was evidenced somewhat with alum and ferric chloride at their best dosages.

As Figures 17 and A-4 show, conditioning with lime was not nearly as effective as ST-266, ferric chloride or alum. Only slight improvements in dewatering properties using lime were noted, and those instances in which it achieved good results were as often counterbalanced by total ineffectiveness. As mentioned earlier, lime's only role in septage treatment might be in further conditioning the alum or ferric sludges produced after initial chemical treatment of septage.

Figure A-5 shows the improvement in specific resistance achieved by the only polymers other than ST -266, that gave even the slightest indication of ability to improve septage characteristics. Like lime, as often as not these two similar polymers, E-207-L and WT-2640, were ineffective; in addition, doses in excess of 500 mg/l were required for

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those septages which were amenable to treatment by these two polymers. No other polymer was found that was effective in any dose under any situation of the nearly dozen which were tested.

Phosphorus Removal

According to the results of this study, most phosphorus is present in septage as dissolved orthophosphate, usually in concentrations of from 20 to 50 mg/l P, and averaging around 30 mg/l P. Supernatant concentrations of orthophosphate were usually slightly higher than concentrations in septage as a whole. Stoichiometric weight considerations would suggest alum requirements of approximately 300 mg/l and ferric chloride requirements of 150 mg/l to precipitate this phosphorus according to the following reactions:

> $A1_2(S0_4)_3 \cdot 14H_20 + 2P0_4^{-3} \rightarrow 2A1P0_4 + 3S0_4^{-2} + 14H_20$ FeC1_3 + P0_4^{-3} \rightarrow FeP0_4+ + 3C1^-

Phosphate reductions using lime depend upon pH levels above 9.5 for phosphorus precipitation, and the amount of lime required is independent of initial phosphorus concentrations.

Early techniques for determination of phosphorus concentrations proved unsatisfactory and thus the bulk of reliable phosphorus reduction data was obtained from runs 5 through 14, especially 5, 8, and the latter four. Orthophosphate reductions to less than 5 mg/l P at all doses of lime, ferric chloride, and alum used for clarification and conditioning were readily achieved. Phosphate reduction is one area of septage treatment in which the inorganic chemicals are vastly superior to ST-266. This polymer was not able to noticeably reduce orthophosphate concentrations present in the supernatant, despite achieving the best reductions in BOD₅, COD, and solids in this portion of the sewage. This gives further evidence that most of the phosphorus present in septage is soluble.

Heavy Metals Removal

As with other characteristics, the reported concentrations by other researchers of heavy metals in septage vary greatly from sample to sample. Removing these metals from the liquid portion of the septage may be as critical as reducing oxygen demand. Three metals, iron, copper, and zinc, were studied in the latter portion of this investigation. On the basis of eight samples of septage analyzed, concentrations of iron, while variable, usually exceeded 50 mg/l, while copper and zinc were commonly encountered at concentrations of 10 to 20 mg/l. A much higher concentration of all three metals is found in the settled solids portion of septage than the supernatant, and it appears that this disproportion may increase with increasing supernatant fraction.

A comparison of metals removal from supernatant and settled-solids filtrate was made for a number of chemicals in run 32. This septage had a supernatant portion of approximately 75% before treatment and 60 to 65% after treatment. Its concentrations of iron, copper, and zinc were 88.0, 8.1, and 13.0 mg/l respectively. The untreated settled-solids portion (sludge) had much higher concentrations of these metals; they were two to three times those of the septage and seven to ten times those in untreated

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supernatant. Alum, ferric chloride, lime, and polymers (ST-266, E-207-L, and WT-2640) all reduced zinc and copper to less than 0.5 mg/l in both supernatants and filtrates. Significant iron reductions were only achieved with lime however. In most cases filtrate concentrations of all three metals were less than those found in supernatants. It can be safely concluded that vacuum filtration of septage will not result in recycling large amounts of these metals (especially copper and zinc) back into the plant's liquid stream with the filtrate, as most appeared tied up with the solids.
C. Summary

Optimum Treatment

Septage has been divided into three types and/or a supernatant fraction and settled solids portion in all discussions of results to this point. Since in practice distinctions between septage types might not be made prior to treatment, the general nature of a region's septage should be analyzed. Treatment can then be based on the distribution of various types of septage within the area, i.e. whether overall its characteristics conform to Type I, Type II, or Type III septage.

When the characteristics of the 34 septage samples analyzed in this investigation are averaged together, a composite waste with the following characteristics emerges. This composite Amherst area sample has an age just over three years, and a supernatant fraction of 28% after settling for 30 minutes. This septage has a BOD₅ of 14,000 mg/1, a COD of 32,000 mg/1, a total solids concentration of 31,000 mg/1, and a total volatile solids level of 21,000 mg/1. Its pH is around 6.5 (arithmetic) or 6.1 (exponential) and its specific resistance is 5.4×10^{10} \sec^2/gm . Since just over one-fourth of this septage is supernatant, this fraction will not change appreciably upon conditioning and settling. Thus conditioning is a more important objective than clarification, and in the Amherst area, obviously, Type II treatment would be recommended. Other regions however might have much weaker and thinner septages overall (e.g. Kolega's investigations of Hartford, Ct. septage (5)), and a Type I mode of treatment might be desired. Conversely,

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septages which are generally much stronger and thicker than those encountered in the Amherst area would require a method similar to that used for treating Type III septage.

A summary of treatment methods and optimum dosages for the three types of septages follows.

Type I septage

primary objective: supernatant clarification

secondary objective: settled solids conditioning - usually significant conditioning is achieved at doses used for chemical clarification.

number of treatment methods: 2

description of treatment methods:

(1) low alum or ferric chloride dosages in the range of 400
to 800 mg/l (3.3 to 6.7 lbs/ 1000 gal). At these dosages, pH will usual ly remain in the critical coagulation region, i.e. greater than 4.8.

(2) ST-266 at a dosage of 260 mg/l (2.2 lbs/ 1000 gal).

Type II septage

primary objective: settled solids conditioning secondary objective: supernatant clarification number of treatment methods: 3

description of treatment methods:

(1) moderate alum or ferric chloride dosages of from 1000 to 2000 mg/l (8.3 to 16.7 lbs/ 1000 gal). In some instances these dosages will reduce pH to a level at which clarification suffers. In addition dewatering characteristics will not be quite as good as with the next two methods.

(2) ST-266 at a dosage of 1000 mg/1 (8.3 lbs./1000 gal) or less. Clarification is achieved at dosages only half as large, but specific resistance can usually be decreased further, sometimes almost linearly with increasing doses up to 1000 mg/1. Supernatant quality does not suffer at larger than optimum doses.

(3) two-stage ferric chloride and lime treatment - Ferric chloride at dosages of approximately 1250 mg/l (10.4 lbs/ 1000 gal) to clarify and partially condition septage and further conditioning of settled solids using lime at 2000 mg/l (16.7 lbs/ 1000 gal). This treatment method allows lower doses of ferric chloride resulting in better supernatant quality than if higher doses of ferric chloride alone were used. With the more difficult Type II septages, higher dosages of one or both of the chemicals may be required.

Type III septage

primary objective: septage conditioning

secondary objective: none

number of treatment methods: 3

description of treatment methods:

(1) alum or ferric chloride dosages in excess of 3000 mg/l(25 lbs/ 1000 gal).

(2) ST-266 at a dosage of 1500 mg/1 (12.5 lbs/ 1000 gal).

(3) one-stage combined ferric chloride and lime treatment. Ferric chloride in excess of 2000 mg/l (16.7 lbs/ 1000 gal) and lime in excess of 3000 mg/l (25 lbs/ 1000 gal) will be needed, but it is very

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difficult to give definite requirements using this method for Type III septage.

Additional comments: Even at these sizable doses, a noticeable improvement in septage dewatering properties is not always assured. Degree of difficulty in conditioning this type of septage varies greatly. A region in which difficult Type III septages predominate should seek methods other than chemical treatment for disposal of this waste.

Cost Considerations

Cost sometimes make physically effective treatment methods unfeasible. Cost comparisons between various ways of accomplishing an objective often show that a method that is experimentally superior is less cost effective than other methods. Table IV presents a comparison of chemical costs for the septage treatment methods which have just been discussed.

A treatment plant superintendent should be willing to consider an increase in chemical costs as justified if this higher investment in chemicals results in smoother and more efficient treatment of septage. Pretreatment of septage at wastewater treatment plants will also result in certain capital costs for plant expansion or modification and additional operating costs being incurred, in addition to these chemical costs. At the present time, many treatment plants in the New England area charge only two or three dollars to septic tank cleaners who wish to dump a standard (1500 gal) load of septage at treatment plants. However, these contractors receive 35 dollars or more from homeowners to pump a septic tank. At present installed septic tanks are usually 1000 gallons in volume while older ones (pre-1966) are usually 500 gallons or 750 gallons in volume (32). Thus if sewage treatment plants raise septage

		Chemical Reqts. (1b/ 1000 gal septage)				Chemical Cost (\$/ 1000 gal septage)					
Sept. Type	Method of Treatment	Alum	FeC13	ST-266	Lime	Alum (\$.05/1b)	FeCl3 (\$.10/1b)	ST-266 (\$.50/1b)*	Lime (\$.031/1b)	Total Cost, Chemicals	
type I	la. Alum	3.3 - 6.7	- ····	, -	-	.1734	-	-	.	.1734	
	lb. FeCl ₃	-	3.3 - 6.7	-	-	. -	.3367	. –	-	.3367	
	2. ST-266	-	-	2.2	-	-	-	1.10	-],10	
TYPE II	la. Alum	8.3 - 16.7	••	-	-	.4284	-	-	- i	.4284	
	1b. FeCl ₃	-	8.3 - 16.7	-	-	-	.83 - 1.67	-	-	.83 - 1.67	
	2. ST-266	-	-	8.3	-	-	÷	4.15	-	4.15	
	3. Two-stage, FeCl ₃ &Lime	- .	10.4	-	16.7	- .	1.04	.	.52	1.56	
TYPE III	la. Alum	>25.0	-	-	-	>1.25	-	-		>1.25	
	lb. FeCl ₃	-	>25.0	-	- ,	-	>2.50	-		>2.50	
	2. ST-266	-	- ·	12.5	-	-	• _	6,.25	-	6.25	
	3. Combined, FeCl ₃ &Lime	-	>16.7	-	>25.0	-	>1.67	.=	>.78	>2.45	

Table IV. Comparison of Chemical Costs (1976)

* Last price for ST-266 was \$.50/1b in late 1974.

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dumping charges to contractors to cover increased treatment costs, when passed on to the septic tank owner it will represent only an incremental increase over what the owner now pays.

The establishment of total costs for the treatment of septage at special facilities is difficult. There is a paucity of operating experience with these plants, which are in essence wastewater treatment facilities designed to handle only septage. Of the three chemical conditioning plants which were originally planned for Long Island, New York, one is currently under construction while a second facility has ceased operation. The third facility, located in Islip, New York, handles 120,000 gpd of septage and consists of a bar screen, grit chamber, equaliization tank, flash mixer, clariflocculator, chlorination unit, and vacuum filters. The total construction cost of this chemical coagulation plant was approximately \$535,000. However, the quantities of septage which are handled on Long Island are much greater than those in most areas of comparable size in New England. According to a survey undertaken by Kwiatkowski (32), the total septic tank volume in 44 communities in Western Massachusetts (encompassing a large geographical area) is 22,000,000 gallons. Even assuming that it were feasible (which it obviously is not) to transport these wastes to a central location and that tanks were pumped relatively often (every three years), total volume of septage to be treated would barely reach 20,000 gallons per day.

Rough preliminary estimates of septage treatment costs at special chemical conditioning facilities follow for design flows of 10,000 and 100,000 gallons of septage per day. Table V presents estimates for the various units which would most likely be required at these special

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		10	,000 gpd		100,000 gpd			
Unit(s)	Assumptions	Size	Constr. Cost	Annual 0 & M Costs	Size	Constr. Cost	Annual O & M Costs	
Sludge Holding Tank	2 day holding time	2675 w.ft.	\$35,000	\$ 3,800	26,750 w.ft.	\$ 10,500	\$ 9,500	
Sludge Pumping	- ·	7 gpm	\$26,600	\$ 2,400	70 gpm	\$ 52,000	\$10,000	
Preliminary Treatment and Clariflocculator	÷	-	\$70,000*	\$ 4,200*	_` 	\$280,000*	\$28,000*	
Oxidation Pond for Supernatant and Filtrate	60 lb BOD/day/acre Supernatnat & Filtrate BOD ₅ = 3000 mg/l	4.2 acres	\$56,000	\$ 1,700	42 acres	\$310,000	\$ 4,600	
Sludge Drying Beds	3% solids in septage sludge loading dry solids (22 lb/sq ft/yr)	41,500 sq.ft.	\$70,000	\$15,400	415,000 sq.ft.	\$630,000	\$154,000	
Subtotal		-	\$257,600	\$27,500		\$1,377,000	\$206,000	
Annual Construction Cost	-	-	\$ 12,900	_	-	\$ 68,900	_	
Indirect Annual Costs	15%		\$ 1,900	\$ 4,100	-	\$ 10,300	\$ 30,900	
TOTAL ANNUAL		\$46,4	.00	\$316,200				
COST/1000 GAL. SEPTAGE (Excl.Chemicals)			\$12.71			\$8.66		

Table V. Costs of Septage Treatment at Special Facilities

*Represents "guesstimate"

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facilities. Most of the costs for the various units were obtained by using values from the EPA report <u>Estimating Costs and Manpower</u> <u>Requirements for Conventional Wastewater Treatment Facilities</u> (33) and adjusting them to the second quarter of 1976. It is seen that, even excluding the costs of chemicals, the construction and operation of these special facilities for the treatment of septage will be expensive. It would appear that total treatment costs (including chemical costs) in the range of \$10 to \$15 per thousand gallons of septage could be expected, depending upon the size of the facility.

VI. CONCLUSIONS

Based on the results of this investigation, the following conclusions can be made.

(1) Septage is a strong and variable waste and thus each sample has different characteristics and chemical requirements. The use of the same inorganic chemical dosage for all septages, regardless of septage type or characteristics, will result in inefficient treatment. Thin septages will be overdosed resulting in poorer supernatant quality and higher chemical costs than are necessary. Thicker septages will be underdosed and as a result will be very difficult to dewater in most cases.

(2) On the basis of samples encountered in this investigation, approximately ten percent of septages appear to be untreatable by any chemical method.

(3) Ferric chloride and alum appear equally effective in treating septage. Cost considerations give alum a competitive edge in this part of the country.

(4) With some Type II septages the optimum inorganic chemical dosage for conditioning is higher than would be used if supernatant quality were the sole criterion, and thus supernatant quality suffers. Two-stage treatment could be a favorable alternative, using lime as a second conditioner.

(5) A cationic polymer, ST-266, was found which achieved excellent results in all aspects of septage treatment except phosphorus removal. At a dosage of 8 lbs. per thousand gallons of septage it would be able

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to effectively condition almost all septages while at the same time producing a clear supernatant. Unfortunately it is no longer marketed.

(6) No other polymers tested were found effective in septage treatment, although two other cationic polymers sometimes achieved limited improvements. However, polymers which can achieve results similar to ST-266, and hopefully at lower costs, should be sought. The advantage of ST-266 over inorganic chemicals is that regardless of septage type a single dosage can be prescribed, and thus chemical treatment operations are made simpler. VII. THE APPLICATION OF CHEMICAL TREATMENT IN SEPTAGE HANDLING

 Wastewater treatment plants are attractive locations for septage treatment due to the fact that sludge dewatering facilities and wastewater treatment processes are already available. However, chemical pretreatment of septage at these plants may be desirable for the reasons mentioned at the beginning of this report - prevention of overloaded secondary units, compliance with effluent limitations, and facilitation of sludge handling and disposal. Presently many treatment plants attempt to avoid overloaded units and meet effluent limitations by either refusing or limiting the amount of septage they will accept. In order to accommodate septage beyond its normal capacity, a wastewater treatment plant must either increase the units of existing facilities, or reduce the impact of septage by some form of pretreatment. The final decision of course should be based upon cost analysis. It is conceivable that chemical treatment could be a competitive alternative for pretreatment of septage. The results and conclusions of this study will provide useful guidelines in determining treatment methods and chemical requirements for the modification and expansion of treatment plants to handle larger volumes of septage.

In areas where septage transportation costs to nearest wastewater treatment plants are prohibitive, other methods must be sought. One of the alternatives could be the installation of special treatment facilities utilizing chemical treatment processes studied and presented in this report. Further consideration must be given to the fact that sep-

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tage is a very strong waste, and even after effective chemical treatment, septage supernatant often has BOD₅, COD, and total solids values which are higher than those commonly found in raw domestic sewage. While this is not a problem in combination with municipal plants, since it then becomes diluted with influent sewage and undergoes further treatment, at these separate treatment facilities further supernatant treatment in oxidation ponds or by other means will be required. After chemical conditioning the solids can be dewatered by vacuum filtration, drying beds, or other means before final disposal.

At the present time, rigorous treatment of septage before its final disposal is not in great demand in most rural areas because government regulations are such that various forms of lagooning and disposal on land are permitted. These circumstances have resulted in the construction of very few special facilities for septage treatment and these few have been constructed only in areas where high population densities combined with an absence of wastewater treatment plants have produced high volumes of septage and made aesthetic considerations, public health concerns, and property values of primary importance. It is expected that this situation will continue in the foreseeable future unless more stringent regulations regarding septage disposal are enacted and enforced. Should this come to pass, special facilities for treatment of septage in rural areas, including chemical treatment, will be in much greater demand.

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APPENDICES

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Figure A-1. Specific Resistance Reduction with Alum.

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Figure A-3. Specific Resistance Reduction with ST-266.

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Figure A-4. Specific Resistance Reduction with Lime.

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Figure A-5. Specific Resistance Reduction with other Cationic Polymers.

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