PROCESSING AND DISPOSAL OF WASTE ACTIVATED SLUDGE

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INTRODUCTION

A. Purpose

This study examines the processing and disposal of waste activated sludge. In a wastewater treatment facility waste activated sludge is either processed by itself or in combination with the primary sludge. The combining of the two sludges can be done at various points in the process. This study is concerned principally with the processing of the waste activated sludge processed entirely by itself.

The number of possible systems or combination of systems for treating sludge has increased rapidly in the last several years. This study is a review of the literature to determine what systems are now being used, the success of these systems and possible alternatives.

B. Definition

The activated sludge process for treatment of sewage was developed in England in the early 1900's. In April of 1914 the first paper on the process was presented to the Society of Chemical Industry by Edward Arden and William Lockett. The paper entitled "Experiments on the Oxidation of Sewage Without the Aid of Filters" reported the high purification levels which were achieved by the use of an aeration system. In November of 1914 Arden and Lockett presented a second paper entitled "Oxidation of Sewage Without the Aid of Filters". (16)

After the first studies were made little was done to better understand the fundamentals of the process until the early 1950's. At that time, close scientific study of the process began. Several mathematical models have been proposed, tested and revised to a point that the process can now be accurately modeled.

The activated sludge process is a relatively simple system. Biologically degradable waste is aerated for a period of time until a mass of settleable solids form. The settleable solids or activated sludge is an active mass of microorganisms made up of bacteria, fungi, protozoa, rotifiers and nematodes. The microorganisms aerobically stabilize the organic matter in the tank. (25)

When operated properly, the activated sludge process has a high efficiency of BOD removal. This has made it popular for the design of treatment plants required to meet the existing regulations of removal of 85 percent or more influent BOD. This high removal rate has generated increased sludge volumes that previously had been discharged.

Prior to the regulations established by the U.S. Environmental Protection Agency, little work had been done to improve the processing of biological sludges. When government funded secondary plants began to be built, the extent of the problems in sludge management became evident. Haines (18) reported that the cost of sludge treatment and disposal presently accounts for 25%-50% of the total cost of wastewater treatment. In most cases the cost leans toward the higher figure.

These high costs for sludge handling have caught the attention of many people, including the equipment manufacturers. Extensive studies have been done on the processing of waste activated sludge. This has generated not only improvements in existing systems, but also the introduction of many new processes.

Activated sludge presents problems not encountered with primary sludges. (31) It is inherently more variable. This variation can be caused by a number of things, but is generally due to the configuration and operation of the particular treatment process.

The major problem encountered in processing activated sludge is its resistance to settling. The activated sludge particle is finer than that of the primary sludge, contains about 60% to 90% cellular organic material and a great amount of water. As these particles settle they tend to aggregate through bioflocculation. The settlement of the particle is hindered by interparticle interferences, fluid forces and the degree of flocculation.

The degree of flocculation will vary with the operation of a particular plant. In some cases the sludge will not settle at all and even tend to float at times.

Processing of sludge is generally divided into seven categories. Each category is subdivided into several alternate systems. Figure 1 illustrates the unit processes for sludge handling and disposal as defined by the U.S. Environmental Protection Agency (EPA). (31) The seven categories are defined as follows:

1. Sludge Thickening (Blending). Increasing the solids concentration and uniformly blending primary and secondary sludges in plants where combined processing is practiced.
2. Sludge Stabilization (Reduction). Converting sludge to more stable and less offensive form. Reduction is often a benefit of sludge stabilization.
3. Sludge Conditioning. A pretreatment to aid in dewatering.
4. Dewatering. The removal of sufficient water to change the form of the sludge.
5. Heat Drying. The process of using heat to remove moisture from the sludge.
6. Reduction. A process that produces a major reduction in the volatile sludge solids.
7. Final Disposal. The ultimate location of the processed sludge.

In practice many combinations of these seven categories have been used. These vary from stabilization and direct land application to very elaborate systems using all seven categories.

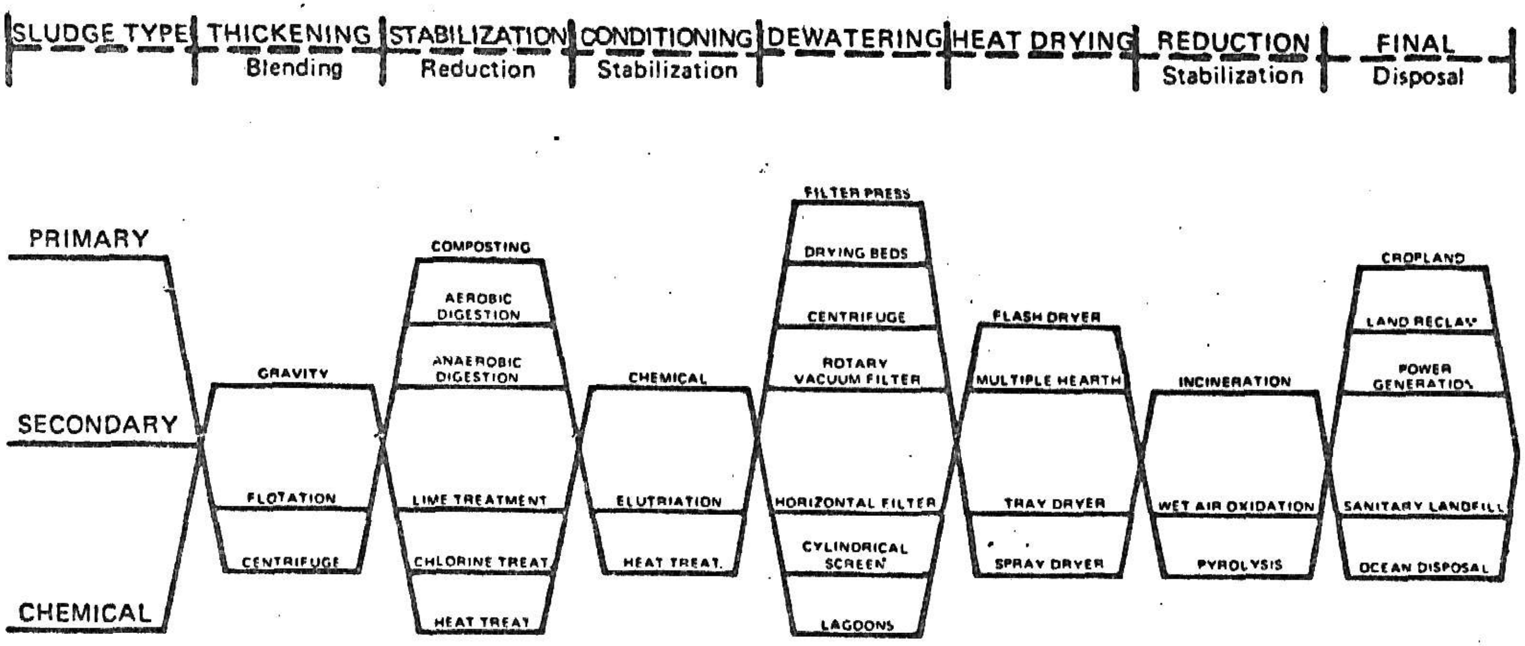

Figure 1. Unit Processes for Sludge Handling and Disposal (31)

II DISCUSSION OF LITERATURE

A. Introduction

The great increase in the number of activated sludge plants in the past several years has stimulated much discussion on possible methods for handling the sludge that is generated. Some of these methods have been used for years and have had extensive performance data accumulated. Other methods are new and have only been used in pilot plants. In evaluating the potential of a sludge handling system for waste activated sludge, it is important to know how it operates under actual treatment conditions. As discussed earlier, activated sludge will vary with plant operation, temperature and the type of waste being treated. The true test of a process is how it will handle these variations.

The evaluation of a sludge handling system involves several parameters. These parameters include initial cost, operating cost, equipment life and performance. To determine the true usefullness of a system each of these must be evaluated.

B. Thickening

Figure 1 contains three unit processes in the sludge thickening category. These are gravity, flotation and centrifuge. In actual practice centrifuges are seldom used for thickening because of their high maintenance and operation costs. The major use of centrifuges is in dewatering. These is discussed in section E.

Gravity Thickening

Gravity Thickening is presently the most common process for sludge concentration. The process is basically the same process that takes place in any sedimentation tank except that thickening is somewhat slower because of the higher solids concentrations. A cross section of a typical thickener is shown in Figure 2. These higher concentrations cause a thickener to operate almost entirely in the hindered zone of settling. A sedimentation basin will operate in both the free and hindered settling zones.

The use of gravity thickening for activated sludge is extremely limited because of two common problems. (26) One problem is rising sludge after a short settling period. The sludge receives its buoyancy from nitrogen gas which is formed by denitrification. The second problem is caused by bulking sludge or a sludge that settles poorly. This bulking is generally caused by filamentous organisms or by bound water in the bacterial cells.

Although problems lead most authors to label gravity thickening of waste activated sludge an impractical process, some design standards are available. Recommended solids loading rates are 4 lbs./sq. ft./day by Culp, (9) 5-6 lbs./sq. ft./day by the EPA (31) and 12-30 lbs./sq. ft./day by Metcalf and Eddy. (26) The large range of values is partially due to the fact that none of the authors give any definite underflow concentrations. The EPA in a later table does give a 2.5 - 3.0% underflow concentration for a gravity thickener but does not indicate the corresponding loading rate.

There are two general practices for wasting sludge to a gravity thickener. One opinion uses return sludge assuming that a thicker influent concentration will give a thicker effluent concentration. Metcalf and Eddy (26) propose that direct wasting of mixed liquor will produce a higher solids concentration than return sludge. They gave no reason for this nor was any data found that would substantiate this idea.

The general design of a gravity thickener as discussed in this section is the same as a sedimentation basin. They are usually a circular basin with a center feed, a scraper for sludge removal and a surface skimmer. If they are in an area where odor might cause a problem, the basin is covered.

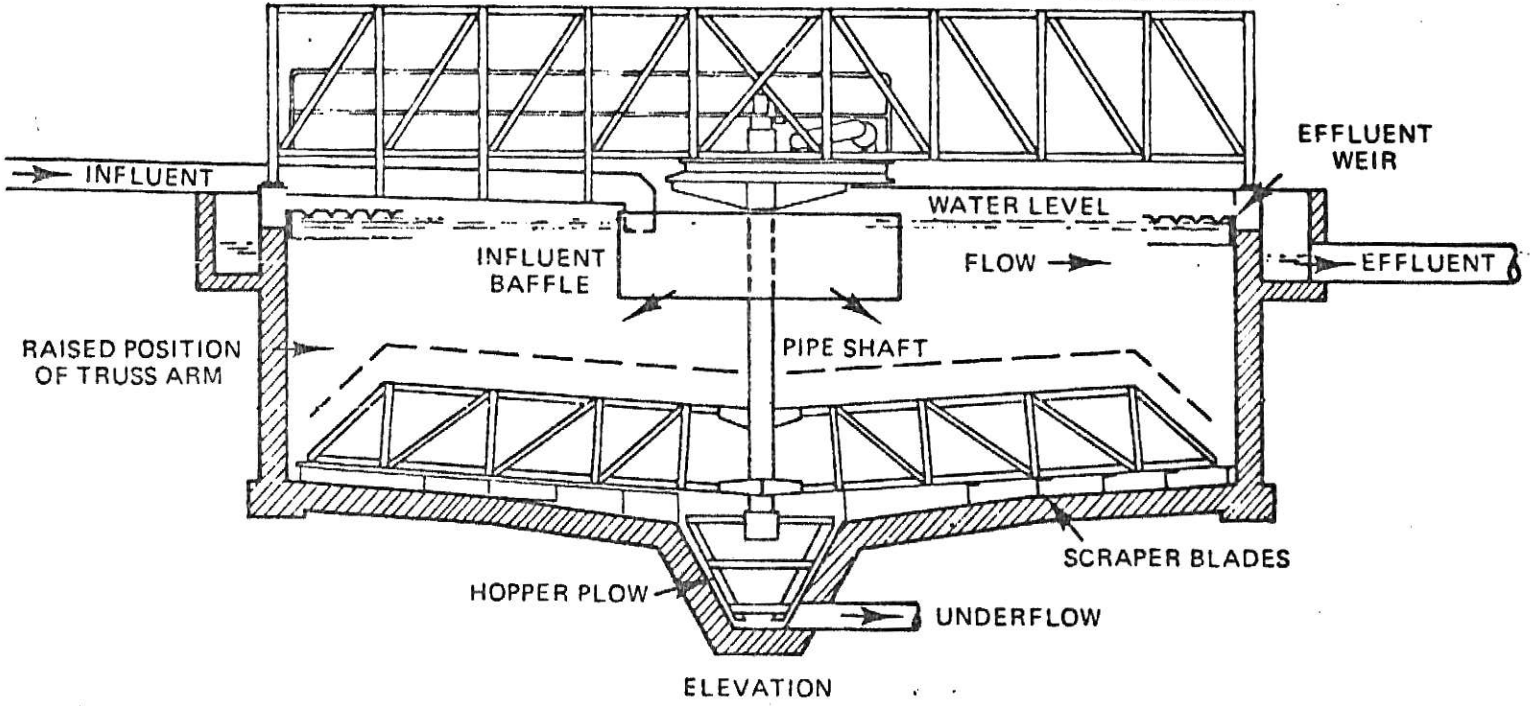
Courtesy Link Belt

Figure 2. Gravity Thickener (31)

Although gravity thickening of waste activated sludge is possible, it is not considered to be an alternative by most design engineers because of the potential operational problems. One possible solution to this problem could be chemical conditioning or stabilization of the sludge prior to settling. Polymers such as used in sedimentation basins might provide one alternative. Although polymer manufacturers claim that polymers improve the operation of a gravity thickener, there is little data available to prove this. Stabilization of waste activated sludge with lime or other material might also be considered to obtain better settling characteristics and reduce operational problems. Available data on this type of process, however, are scarce.

Air Flotation Thickening

Flotation thickening is the use of gas bubbles to increase the buoyancy of solids which causes them to rise and concentrate at the surface. Culp (9) gives four methods of flotation thickening used in waste treatment. They are:

1. Dispersed Air Flotation. Bubbles are generated by introducing air through a revolving impeller.
2. Dissolved Air-Pressure Flotation. Air is fed to the system under pressure and released to the atmosphere.
3. Dissolved Air-Vacuum Flotation. A vacuum is applied to wastewater aerated at atmospheric pressure.
4. Biological Flotation. Gases which are formed by biological activity are used to lift solids.

Only dissolved air-pressure flotation is discussed in this section. This process has been used in the United States more than the other systems and has become especially popular for the thickening of waste activated sludge. Figure 3 illustrates an air-pressure flotation unit.

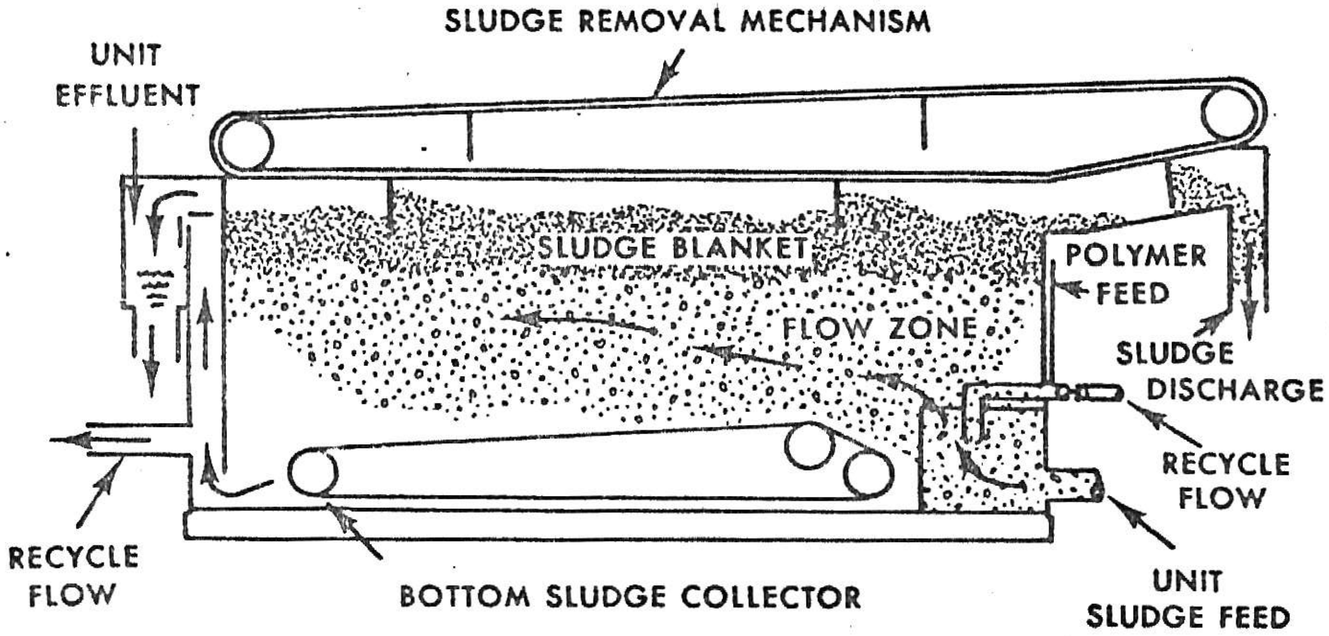

Figure 3. Air Flotation Unit (31)

A dissolved air-pressure flotation system generally operates in one of two design schemes. These are the full flow unit and the recycle unit.

In the full flow unit the waste influent is fed by a pump into a pressurized retention tank at 60 - 70 psig. Air is metered into the pump discharge. This mixture then flows into the flotation tank. In most cases chemical aids are added at this point. In the flotation tank the sludge is removed by surface skimmers from a sludge layer 8 - 24" thick. (9)

The recycle system uses effluent from the flotation tank to inject the air and develop the pressure. This recycled air-effluent mixture is mixed in the front of the flotation tank. The recycle flow will vary with the unit. Adams and Eckenfelder (1) developed a relationship for the recycle flow rate as being a function of influent flow, influent suspended solids, air quantity, gage pressure and the fraction of saturated air in the pressurized system.

The recycle unit has the disadvantage of requiring more area in the flotation tank, but with activated sludge produces better results. This is due to the fact that the floc is not broken down by passing it through the pressurized system.

The loading rates for a unit generally range from 1 - 4 lb./hr/ft.^{2} but with the use of polymers some plants now operate as high as 8 lb./hr/ft.^{2}. (31) The amount of polymer required varies with the type of sludge, the type of polymer and the results required. In 1974 the EPA (19) gave the cost of polymers at several plants that varied from $2.50 - $4.50/T. Several other chemicals, most being inorganic, have been used in the past but are presently not competing well in terms of overall cost and performance as compared to the polymers.

The amount of air required for an air flotation system is primarily controlled by the type of sludge. Culp (9) states that for waste activated sludge an air to waste volumetric ratio of 0.02 is commonly used.

The selection of dissolved air flotation over gravity thickening has been based on the following criteria: (31)

1. Lower capital cost
2. Higher solids loading rate
3. Thicker sludge underflow
4. Better solids capture
5. Maintenance of sludge in an aerobic condition
6. Reliability

The major disadvantage is the high operating cost.

C. Stabilization

The purpose of stabilization is to reduce the pathogenic organisms and make the sludge less odorous. In general, waste activated sludge is considered to be stabilized if the volatile suspended solids have been reduced to about 50% of the suspended solids or the pH has been raised above 11. If stabilization is accomplished by reduction of the volatile fraction there is also a suspended solids reduction. Stabilization by pH adjustment will increase the solids in most cases. Because the volatile solids reduction method is generally used, many authors speak of this step as the stabilization reduction process.

Composting

Composting of sludge has been so limited in the United States that little data is available on the process. Furthermore, available data does not distinguish between the types of sludge used.

The major disadvantage in composting has been finding a market for the composted sludge. The cost of composting has been reported to be $2 to $20 per ton. (31) To offset this high cost and to make the process feasible the composted sludge must be sold.

Composting is done by one of two general procedures. It can be done in a windrow operation or in a mechanical aeration system. (31) In both cases a moisture content for the composted material between 45 and 65 percent is needed for good digestion. The required moisture content of the sludge can be reduced if the sludge is mixed with solid waste. Normal sludge to refuse ratios of .05 - 1.0 (W/W) have been used.

Pilot plant operations in composting of sewage sludge have been carried out in Beltsville, Maryland by the U.S.D.A. Agricultural Research Service in conjunction with the Maryland Environmental Service and the Blue Plains Wastewater Treatment Plant in Washington, D.C. (11) They used sawdust, shredded paper and wood chips as bulking agents with composting being done by the two common procedures as well as a third procedure. This method consisted of only a compost pile. After preliminary testing they decided to use the windrow system.

In the work at Beltsville, two major operational problems hindered the process, composting in adverse weather conditions and composting raw sludge without producing odors. Epstein and Willson (11) in discussing these problems felt that the major part of these problems could be solved by closer management.

Epstein and Willson (11) in the conclusion of their report on composting at Beltsville stated that cities must remember to think of the process not as a means of making money but as a means of disposing of sludge.

Even when mixed with refuse, the sludge must be dried beyond that required for most ultimate sludge disposal systems. Because of the excessive cost and the limited market, composting cannot be considered a workable alternative for treatment of waste activated sludge at the present time.

Aerobic Digestion

Aerobic Digestion is one of the newest methods of treating waste activated sludge. The principle of the system is the fact that microorganisms will utilize their own cellular material when there is no exogenous food available.

Reynolds (28) gives several advantages of aerobic digestion over anerobic digestion.

1. Volatile solid reduction equal to an anerobic system.
2. Lower BOD concentration in supernatant.
3. Produces odorless end product.
4. Sludge has excellent dewatering characteristics.
5. Recovery of more of the basic fertilizer values in the sludge.
6. Fewer operational problems.
7. Lower capital cost.

Aerobic Digestion is a modification of the activated sludge process. The design and operation of the tank is basically the same as that used for the conventional activated sludge system. The major differences in aerobic digestion are the increased solids in the mixed liquor and the longer sludge age.

Aerobic digestion can be used in several different ways in a sludge handling system. It can be used to follow a thickener. The present trend, however, is to feed the digester with either mixed liquor directly from the aeration basin or with sludge return. The digester is then followed by a gravity thickener. The thickened sludge is returned to the digester to allow operation at a much higher solids level. The level generally ranges from 15,000 to 25,000 mg/l. By increasing the solids concentration, plants can easily operate a week without withdrawing sludge. When sludge is withdrawn it can be taken from the thickener underflow or the air to the digester can be shut off for three to four hours and a portion of the sludge drawn from the bottom. Reynolds (28) reports that Texas A & M University has been drawing sludge directly from the digester and has been able to approximately double the underflow solids content of the digested sludge.

The use of aerobic digestion has become quite popular in plants that use land application not only for the stabilization aspect, but also because of the potential storage capacity. The required storage for a land application system varies from area to area but for the Midwest it is about 30 days. By increasing the solids content and accounting for solids destroyed, an aerobic digester can be designed that will incorporate the storage and still be competitive with other processes.

The amount of solids destroyed varies between sludges. Reynolds (28) reported 51 percent destroyed in lab tests and 53 percent destroyed in field tests. Lindstedt (22) studied the operation of the treatment facilities of the Metropolitan Denver Sewage Disposal Distict No. 1. During a four month period he found 26.5 percent of the total waste activated sludge solids had been destroyed. Cohen (8) also worked at the Denver plant and found that V.S.S. reduction approached 50 percent under ideal conditions.

The variability of these numbers can be explained by several parameters. Loehr (23) reported that different solids reduction rates are often due to different starting points. He pointed out that authors seldom report the sludge age entering the digester. If a sludge has a high sludge age, it will in turn have a smaller solids reduction. Cohen (8) contradicted Loehr's (23) idea that sludge age was the most important factor in solids reduction. He felt that data from the Denver plant showed that sludge was much more sensitive to temperature. Adams (1) preducted a two-fold rate of change for a 10^{o} C temperature change.

In some cases a lower solids reduction can be traced to lack of oxygen. Reynolds (28) found the oxygen requirements to be 1.9 lb./lb. of solids destroyed. In the majority of digesters the air required for mixing will be greater than that needed for oxygen supply. Both Reynolds (28) and Folk (12) suggest an air supply of about 30 cubic feet per minute for each 1000 cubic feet of digester volume. If the oxygen transfer efficiency is low and the aeration rate does not supply the required oxygen, solid reductions will be hindered. Adams (1) outlined procedures for determining solids reduction and air requirements through laboratory studies. Although these parameters can be predicted mathematically almost all authors agreed that a pilot study was important.

The volume of an aerobic digester is generally determined by the design population. Reynolds (28) suggests 1.5 cubic feet per capita while Folk (12) suggests 2.0 cubic feet per capita. Both authors suggest a depth of 11-15 feet. Folk (12) also suggests that there be a minimum of 2 digesters.

Aerobic digesters have presented problems at certain plants. Jacke (20) reported that the digesters at the Escanaba, Michigan plant failed to operate as expected. Waste activated sludge was fed in at about 1 percent solids. When the air was shut off the solids would not settle. After testing they found that polymers could be used to produce better settling. They tried several polymers and found that Hercules No. 814 produced the best results. For solids concentrations of 0.9 to 1.1 percent, it was found that 25 to 30 mg/l of polymer was required. This produced a concentrated sludge of 1.8 to 2.2 percent sludge.

Anaerobic Digestion

The use of anaerobic digesters for sludge stabilization has been quite popular in the past, but their use for strictly waste activated sludge is extremely limited. The main use of digesters has been with primary sludge or a combination of primary and secondary sludges. Digesters operating with primary sludge produce very good results, but as secondary sludges are added the quality of treatment is depressed.

The major problem with treatment of combined sludges is the poor quality of the digester supernatant. Primary sludge alone will produce a supernatant with a BOD_5

of 500 to 3,000 mg/l and a suspended solids of 200 to 1000 mg/l. When activated sludge is added the BOD_5 increased up to 1,000 to 10,000 mg/l and the suspended solids to 5,000 to 15,000 mg/l. (21)

This poor quality supernanant must then be returned either to the primary settling tank, the aeration basin or treated separately. In each of these alternative locations, an additional burden is added to the plant.

The author could find no information to indicate what the quality of supernatant from an entire digester of waste activated sludge might be. The results from the combination of sludges, however, indicate that it would be of even poorer quality. Anaerobic digestion of waste activated sludge, therefore, would be of little use. The one exception to this might be a digester followed by a land application disposal system in which the supernatant could be applied to the land in the same manner as the digested sludge.

Lime Stabilization

As stated earlier, stabilization is generally considered to be complete when the pH reaches 11. Recent literature tends to show that this is not sufficient. The EPA (31) indicated the pH should be between 12.2 and 12.4 and above 11 for at least 14 days. The EPA (31) also presented data of Paulsrud and Eikum on the lime dosage required to keep the pH of sludge above 11 for 14 days. They predicted 600 to 1,000 pounds of lime would be required for each ton of biological sludge.

Lime stabilization presents two major problems. The first is the chemical cost and the second is the increased solids that must be handled. Lime stabilization does not reduce the volatile solids concentration and may increase the total solids by 25-50%.

The principal advantages of lime addition are not in sludge stabilization, but rather in the subsequent processes. Lime helps to condition the sludge by coagulating the solids. This is helpful in advance of vacuum filtration and centrifugation. (26) The use of these systems is discussed in the section on Dewatering.

Although lime stabilization is being used very sparingly in the Midwest, it may become important in the future. The process is relatively simple to operate, thus making it valuable to smaller plants that do not have a laboratory or technicians available to monitor an aerobic or anerobic system. Although it has a high chemical requirement, it has a low power requirement which is extremely important in plant design.

Chlorine Treatment

Stabilization of sludge with chlorine requires a dosage of about 2000 mg/l. This dosage will leave the pH as low as 2. In many cases this will require additional chemicals be used to raise the pH before final disposal. After stabilization the sludge will dewater quite well on a sand bed.

The high chemical cost makes this process unsuitable for most plants. The EPA (31) estimates a cost of $5/ton of dry sludge. In extreme cases chlorine treatment is feasible, but for general use the high chemical cost eliminates it from consideration.

Heat Treatment

Heat treatment is a combination of two processes since it not only stabilizes the sludge but also serves to condition it. The process itself is relatively new in the United States but has been used for many years in Europe. Both West Germany and Switzerland require heat treatment of sludge before it can be applied to the land.

One of the important results of heat treatment is production of a sludge that has greatly improved dewatering properties. Cheremisinoff and Maglio (7) discussed heat treatment and predicted about a 50 percent reduction in sludge mass with heat treatment and digestion. These two facts lead to several important advantages of heat treatment. Among them are a greatly increased solids content, the elimination of chemicals for conditioning and the elimination of any feed requirements for incineration.

The actual process of heat treatment involves heating the sludge under pressure. This results in a breakdown of the microbial cells, coagulation of the solids and a reduction of the water affinity. (26) The two best known systems for heat treatment are the Porteus and the low-pressure Zimpro system.

In the Porteus system the sludge is heated and then fed into the reactor. Steam is injected to raise the reactor temperature to 290 to 390 degrees F. The pressure is kept in a range of 150 to 200 psi. A 30 minute detention time is used. The resultant sludge can be filtered to produce a solids content ranging from 40 to 59 percent.

The low-pressure Zimpro process adds air with the sludge as it is fed to the reactor. The temperature is raised by steam to 300 to 400 degrees F with pressures ranging from 150 to 300 psi. The dewatered sludge will have solids concentrations of 30 to 50 percent.

The major drawback to both the processes is the poor quality supernatant caused by the breakdown of the cells. Fisher and Swanwick (14) predicted the BOD_5 of this water will be 5,000 to 15,000 mg/l. This supernatant must be fed back to the treatment plant. In design of the treatment plant this load must be taken into account. This additional cost must be considered when calculating the cost of a sludge handling system.

The real importance of heat treatment for sludge in the Midwest is in plants that follow with incineration. Heat treatment with dewatering produces a sludge cake having a solids content that is higher than needed for land application or landfilling and in most cases is not justifiable unless followed by incineration.

D. Conditioning

Sludge conditioning is used to improve the removal of water in a dewatering system. The EPA (31) names three categories in conditioning. These are chemical, elutriation and heat treatment. Elutriation should probably have been added as a subsection under chemical conditioning because it does not directly improve dewatering but does reduce the chemical requirement for conditioning. (26)

Conditioning has traditionally been considered to precede dewatering in a sludge processing system, but is presently being used at almost all points in the treatment plant. This is due mainly to increased use of high molecular weight polymers in chemical conditioning.

Chemical Conditioning

Due to the continued increase in the use of polymers in waste treatment, chemical conditioners can be broken into two main divisions: inorganic and synthetic. The inorganic coagulants have been used for years. These consist of iron salts, lime, alum and others. The synthetic coagulants are newer and consist of the high molecular weight polymers. (29)

Although chemical conditioners are used at various locations within a plant, the goal is the same at each point. That goal is to coagulate the particles for better dewatering. This objective, however, is resisted by three primary factors.

The first is a double layer repulsion. These layers consist of the charged surface on the solid particle and its counter-ion charge in the surrounding liquid. The electrical potential of this area is the zeta potential of the particle. Before coagulation can take place, these charges must be reduced. This will allow the Van der Walls forces to pull the particles together.

Short range hydration repulsion is the second stabilizing factor. This simply refers to absorbed solvent molecules coating the solid particles. Even when electrolytes are present they cannot act through the layer. In this case a flocculent must be used that can penetrate this shell and destabilize the particle system.