EFFECT OF CONDITIONING ON THE PERFORMANCE OF A PLATE AND FRAME FILTER PRESS

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(Abstract)

Experiments were performed on samples of alum, anaerobically digested, and aerobically digested sludges to determine optimum polymer dosages for various mixing intensities produced during conditioning by a high-stress mixing unit. Mean velocity gradient (G) values were established for each of the mixing speeds used ranging from 250 sec^{-1} to 4,000 sec^{-1}. Using the optimum conditioning dosages determined at each mixing speed, batches of optimally conditioned sludge were introduced into a pilot scale plate and frame filter press. Filtrate volume per unit time and final cake solids were used to characterize the press performance. Results indicated that filter press performance can be optimized by selecting mixing speeds during conditioning that simulate the shear conditions produced in the filter press during operation. It was shown that press performance was

substantially reduced using sludge conditioned at a mixing speed of 200 rpm corresponding to a Gt equal to 17,000. Tests using mixing speeds of 400 rpm and 1800 rpm corresponding to Gt values of 32,000 and 230,000, respectively indicated better performance and, thus, the filter press is thought to generate Gt values within this range. A substantial increase in polymer requirements is shown for sludge conditioned at a mixing speed of 1800 rpm, and therefore, it was concluded that sludge conditioned at a mixing speed of 400 rpm best characterized the filter press producing optimum operational conditions. It was also postulated that the filter press may not be characterized by a single Gt value, but, by a range of values dependent on press run time.

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I. INTRODUCTION

Sludge handling and disposal has become one of the most important concerns in water and wastewater treatment. These sludges are generated during most physical, chemical and/or biological treatment processes and contain a large percentage of water, along with varying amounts of organic and inorganic particulate matter.

As sludge disposal in landfills becomes more restricted due to groundwater contamination concerns and the sludge incineration industry expands (which by no means is an inexpensive disposal alternative), sludge disposal costs escalate. One can, therefore, easily see the necessity to remove these large quantities of water from sludge.

The employment of sludge dewatering processes not only can reduce the sludge volume thereby reducing disposal costs but also can facilitate sludge handling. While many different sludge dewatering processes are presently used, mechanical systems are becoming more prevalent. Most non-mechanical dewatering processes such as drying beds or lagoons demand larger land areas and longer time requirements. Although mechanical dewatering does result in high percentages of water removal, a chemical conditioner is usually used to enhance sludge dewatering. Sludge conditioning by polymer application has been shown to improve the rate of water removal by means of sludge particle coagulation. These rates are most significantly affected by polymer dosages, mixing time and mixing intensity.

Research has shown that polymer conditioning of water and wastewater sludges is an efficient method of producing a readily dewaterable sludge. Although full-scale dewatering operations using polymer conditioned sludge have not been widely used it is suspected that treatment facilities have been achieving less than desirable results in their dewatering efforts. When trying to obtain optimal performance from dewatering processes it becomes necessary to understand the factors that affect performance. Mechanical dewatering processes are such that large shearing forces, caused by turbulence within various areas of the device, may be exerted on destabilized sludge floc particles. These forces can substantially deteriorate the flocs if not properly conditioned, thus, decreasing the dewaterability of the sludge and thereby decreasing the performance of the equipment. Many conditioning operations in use today determine polymer dosage requirements through the use of low intensity mixing devices (to mix the polymer and sludge). This type of mixing produces a floc that has experienced small shearing forces and is, therefore, susceptible to deterioration in high stress dewatering systems. It seems reasonable that a polymer dose mixing scheme for conditioning should simulate the condition experienced within the dewatering process. Unfortunately, little information is available about the shear forces that exist in sludge dewatering equipment.

In this study an attempt is made to determine the magnitude of the shear stresses generated in a filter press and to determine the effect of this shear on polymer requirements for proper conditioning. The following objectives were proposed for this study:

(1) to determine the effect of polymer dose and mixing intensity on the dewatering rate of water and wastewater sludges;

(2) to determine the effect of polymer dose and mixing intensity on the performance of a plate and frame filter press;

(3) to determine if the filer press can be characterized by a single Gt value; and

(4) to broaden the information base on filter press performance characterization.

II. LITERATURE REVIEW

This chapter contains a review of the literature pertinent to conditioning of water and wastewater sludges for use in plate and frame filter press operations. Many factors can influence the dewaterability of a sludge. These include the characteristics of the sludge, the type of conditioner used, the method of conditioning and the type of dewatering equipment.

A thorough understanding of the effect of sludge characteristics aids in the decision of what conditioner and dewatering process to use. Such characteristics include particle size and distribution, pH, solids content, particle surface charge, degree of compressibility, degree of hydration, rheology, temperature, salt concentration and biochemical composition. Much has been written on these characteristics and a list of references is provided to help gain an understanding of their influences on sludge dewatering (4, 10, 12, 15, 21-23, 27, 29, 33, 35).

1. Coagulation and Flocculation Theory

Sludge conditioning leads to particle aggregation which aids in solid/liquid separation. These particles range in size from large suspended materials (on the order of hundreds of microns) to very small colloidal and dissolved material (less than one micron). While sedimentation and gravity settling processes can be used to remove the larger suspended material, other methods must be employed to remove colloidal solids. Coagulation and flocculation processes are used to aggregate particles into larger flocs which facilitates solid/liquid separation.

The theory of coagulation and flocculation involves two distinct steps: (1) particle transport which promotes particle contact and (2) particle destabilization which permits attachment when contact occurs. Coagulation involves both steps, while flocculation involves only particle transport. The purpose of coagulation and flocculation is to enhance the rate of particle aggregation by increasing particle collision frequency (transport) and efficiency (destabilization) (41). Particle transport is accomplished by three possible mechanisms which include Brownian motion, bulk fluid motion and differential settling. These mechanisms are dependent on temperature, stirring or fluid shear (velocity gradients), and particle size, respectively. Particle destabilization involves overcoming the repulsive electrostatic forces between particles which is accomplished by four possible mechanisms. The addition of chemical coagulants such as aluminum or ferric salts and synthetic organic polymers can destabilize these particles and allow for particle aggregation.

Before the mechanisms of destabilization are discussed, one must understand the concept of a stabilized particle. Water and wastewater sludge particles (especially colloids) typically develop a negative primary electrical charge (which is affected by the pH and ionic strength of the solution). Since the net charge in solution is neutral, the negative charge on the particle must be balanced. This is accomplished by the positive charges of counter-ions located in the water and is described by the widely accepted electric double layer theory. This theory assumes that particle interaction can be described by a combination of attractive van der Waal's forces (which are affected by atomic structure and particle density) and repulsive coulombic forces between similar double layers of two particles. The Guoy-Chapman colloidal model (38), describes the electric double layer concept in which the negatively charged particle surface is surrounded by a bound layer of water containing an equivalent excess of counter charged ions drawn in from the bulk of solution. The electrostatic forces attracting these counter ions to the particle surface are thought to be in equilibrium with the diffusive forces transporting these counter ions back into the bulk of solution. This dynamic state demonstrates the concept of particle stability in which repulsion occurs between two approaching particles due to the electrostatic forces from similarly charged double layers.

Chemical coagulation involves particle destabilization by four possible mechanisms (41). These include: (1) compression of the double layer, (2) adsorption to produce charge neutralization, (3) enmeshment in a precipitate, and, (4) adsorption to allow interparticle bridging. Double layer compression involves the addition of high concentrations of counter ions into solution which lowers the volume of the double layer necessary to maintain electroneutrality. This, therefore, lowers the magnitude of charge (zeta potential) within the double layer which in turn reduces the thickness of the double layer and allows for a decrease in the repulsive forces between particles. Adsorption to produce charge neutralization involves a similar mechanism in which coagulant is adsorbed directly to the particle surface. These counter ions react with the particle surface charge thus causing neutralization. The mechanism of enmeshment or "sweep floc" involves the addition of metal salts in which the metal reacts with the hydroxide of the solution water to form metal hydroxide precipitates. These flocs settle downward and trap colloidal particles in the enmeshed precipitates. The final mechanism involves the use of long chained polyelectrolytes of high molecular weight that adsorb onto available sites on the particle surface. Upon contact with another particle, the polymer chain extending into solution adsorbs to the surface of the other particle forming a polymer-particle complex or bridge. A matrix of this type of bridge allows for particle agglomeration and destabilization.

As mentioned previously, flocculation is a process involving particle contact through transport. Once particles have been destabilized, particle contacts must be increased to allow for agglomeration. Brownian motion (perikinetic flocculation) and differential settling are mechanisms that do not permit sufficient contact for particle agglomeration in a practical time frame. The rate of particle contact is increased by fluid agitation (orthokinetic flocculation), typically induced by mixing or stirring. This transport mechanism increases the rate of particle contacts and floc formation. In such a system, both the fluid and particles will have different velocities which allows for further particle collisions. Spatial changes in solution velocity have been represented by a velocity gradient, G.

Camp and Stein (1943) have described this flocculation process by stating "the rate of flocculation caused by the motion of the fluid (at a point) is directly proportional to the space rate of the change of velocity (or velocity gradient) at that point and is directly proportional to the concentration of flocculable particles at that point" (8). Camp has developed the following formula to determine the velocity gradient:

$$G = (W/u)^{1/2} \text{ sec}^{-1} \qquad (1)$$

where W = mean power dissipation due to shear (from the mixing device) per unit fluid volume

u = absolute viscosity of the fluid

One must realize that this equation represents the root-mean-square velocity gradient throughout the control volume since velocity gradients vary throughout the volume (i.e., G values are greatest at solid boundaries such as wall surfaces) (7). Also, the power loss term is equal the total work performed by the mixing device and is a function of rotor speed, torque and tank volume.

According to Camp's aforementioned statement, an increase in G (or mixing intensity) would result in an increase in the rate of floc formation, which is desirable. However, a practical limit of G exists for any flocculation process which is determined by the required floc size (7). As the velocity gradient increases due to a more turbulent mixing regime, so does the magnitude of the fluid shearing forces. Since floc particles become weaker as they increase in size, a point is reached where the fluid shearing forces exceeds the shear strength of the floc particles, thus causing floc breakup. It has been shown that floc breakup is caused by the surface erosion of interparticle bonds due to the turbulent drag forces of the fluid (1, 11). Therefore, the minimum required floc size necessary for an efficient solid/liquid separation process dictates the magnitude of the velocity gradient to be used.

Since the time required to form flocs of a desired quality is proportional to the velocity gradient, Camp (1955) proposed the dimensionless term, Gt, to characterize flocculation performance (7). This method becomes very useful in describing mixing regimes for determining optimum coagulant dosages for sludge conditioning. This topic will be elaborated upon later.

2. Polymer Conditioning of Sludges

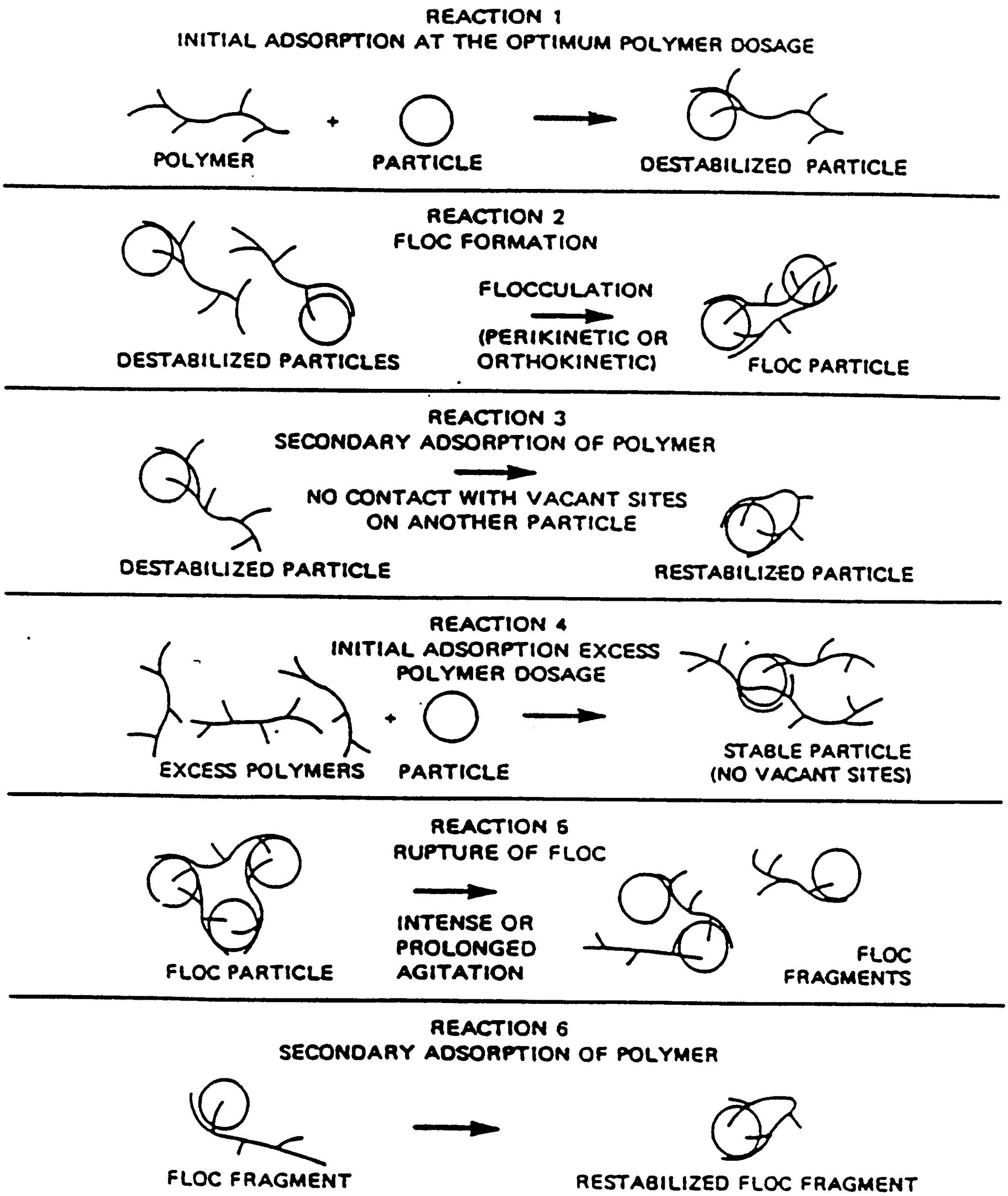
Sludge conditioning using inorganic chemical coagulants has been practiced for over two hundred years. Such products as ferric chloride, lime and aluminum sulfate have been used for sludge treatment and their conditioning mechanisms well known. Within the past ten years, the study and use of synthetic organic polymers as chemical coagulants for sludge dewatering operations has gained much attention. The reasons for this include: (1) very little additional sludge mass is produced, (2) polymers do not lower the fuel value of the sludge (for incineration concerns), and (3) the reduction in operation and maintenance problems including a cleaner material handling operation (12).

Polymers are long chain, water soluble, specialty chemicals made up of individual units called monomers. Various polymerization reactions produce polymers from these monomeric sub-units. The molecular weight of a polymer depends on the total number of monomeric units. If a monomeric unit in a polymer contains ionizable groups (i.e. carboxyl, amino, or sulfonic groups) then the polymer is termed a polyelectrolyte. The type of ionizable groups used dictates if a polyelectrolyte is cationic, carrying a positive charge, or anionic, carrying a negative charge. The backbone monomer most widely used in synthetic organic polyelectrolytes is acrylamide which is usually non-ionic in its natural state. When combined with anionic or cationic monomers, a long, thread-like molecule with a high molecular weight is formed. Polyelectrolytes with varying degrees of charge can be formed by varying the proportion of acrylamide to the ionized monomer during copolymerization (12, 41).

The ability of a polymer to act as a flocculant depends on its ability to adhere to the particle surface. Polymer characteristics that affect this ability include molecular weight, magnitude of charge, and degree of branching. Sludge characteristics that affect this ability include pH and the concentration of divalent ions. Novak and O'Brien (1975) have shown that sludge pH and polymer molecular weight to be the most important factors in selecting a polymer for use as a flocculant. They further concluded that non-ionic to moderate activity anionic polymers function best between pH 6 and 8.5. It was also shown that cationic polymers perform best at neutral to slightly acidic pH (29). Weber (1972), has suggested that divalent metal ions are generally necessary for anionic polymers to flocculate negatively charged particles, regardless of the types of destabilization mechanisms involved (41). Posselt et al. (1968), have shown that a broader range of effective coagulant dose is produced for a cationic polymer flocculating negatively charged particles when divalent metal ions are present in solution (33).

Although polyelectrolytes have not been used extensively for sludge conditioning, those full-scale operations using polymers have obtained good results (12, 25, 32, 36). These studies indicate that a variety of sludge types can be readily conditioned using polyelectrolytes, including raw/primary, waste activated, digested and alum sludges. To fully understand the proper use of polyelectrolytes for conditioning these sludges, it becomes necessary to know how polymers function. Presently, two accepted concepts exist concerning polymer flocculation mechanisms.

Interparticle bridging is the first possible mechanism. Many researchers have concluded that this theory offers the most satisfactory explanation of polymer conditioning (5, 24, 38, 40). The theory states that a polymer molecule attaches itself to one or more available adsorption sites on the particle surface. The remainder of the molecule extends into solution and can attach itself to vacant charge sites on other sludge particles (Figure 1, reactions 1 and 2). Many interactions of this type will form a three dimensional bridging matrix (or a floc particle) made up of destabilized particles. It has been shown that optimum destabilization occurs when only a portion of the available charge sites on the particle surface are occupied (38, 40). The bridging model can be



Figures 1. Schematic representation of the bridging model for the destabilization of colloids by polymers. (After O'Melia, reference 31)

extended to describe polymer-sludge interactions in a poorly designed process. Particle restabilization can occur when polymer dosages are excessive and all available sites are saturated. Since no sites remain available for polymer bridging, floc formation does not occur (Figure 1, reactions 3 and 4). Excessive mixing can cause particle restabilization, since interparticle bridges are destroyed due to the over-stressing of polymer-surface bonds (Figure 1, reactions 5 and 6) (12).

Bugg et al. (1970), have shown that the stronger, short range chemical forces of polymer-surface interactions overwhelm the electrostatic forces present between like charges of the polymer and the particle (5). This explains why anionic polymers can effectively condition negatively charged particles (most sludges). Weber (1972) suggested that interparticle bridging is the mechanism used in this situation. He goes on to say that destabilization is accomplished by charge neutralization and/or bridging when cationic polymers are used to destabilize negatively charged particle (41). This leads to the second possible mechanism; charge neutralization.

As discussed earlier, particle stability has been attributed to the electrostatic double-layer theory. When a polyelectrolyte is added to the sludge solution, polymer ions of opposite charge immediately adsorb to the particle surface through electrostatic attraction. This results in charge neutralization on the particle surface and a subsequent reduction in repulsive forces between particles. These particles are now free to agglomerate to form settleable flocs.

3. High-Stress Sludge Conditioning with Polymers

Within the past two decades, research efforts in conditioning with polymers has been centered on the effects of mixing intensity (velocity gradients) and mixing time with respect to dewatering rates and polymer dosage requirements. While Hannah et al. (1969), suggested that polymer coagulated particles should be resistant to shearing forces produced by velocity gradients (16), it has been shown that increased mixing intensities will tend to disaggregate larger floc particles (3), and increased mixing times will lead to a reduction in the dewatering rate of the sludge (5). This work has led to important conclusions and has laid the foundation for further research; however, these results have limited applicability for full scale operations. The reason is that the standard jar testing apparatus was used in these experiments which generates a limited range of G values (up to 150 sec^{-1}).

High G values (up to 2500 sec^{-1}) are thought to be generated in mechanical dewatering processed such as centrifuges and filter presses. These high velocity gradients can be caused by turbulence produced in pumps, piping and mechanisms of the dewatering process itself. More recent research has shown that conditioning data obtained from jar tests may severely under-predict polymer performance when the conditioned sludges are dewatered in these high-stress processes (28, 39, 43). Therefore, it may be necessary to condition sludges at high mixing intensities to simulate the high-stress conditions experienced in mechanical dewatering processes. System operation time and costs can be minimized while optimizing polymer dosage requirements. The following studies, conducted over the past decade, have increased the knowledge available on high-stress sludge conditioning using polymers.

Stump and Novak (1979), using cationic polymers of varying molecular weights and synthetic wastewater prepared from Kaolin powder, concluded that the high molecular weight polymers (greater than 100,000) performed best at G = 600 - 1000 sec^{-1}, while the lower molecular weight polymers performed best at G = 300 sec^{-1} (39). Novak and Piroozfard (1981), using both anionic and cationic polymers and water plant sludge (i.e., lime and alum sludges), concluded the following: (1) intensely mixed polymer requirements are not adequately predicted using low mixing energies for optimum polymer dose selection, (2) stable sludges produced by optimal conditioning at low mixing energies become unstable at high mixing intensities or with the addition of polymer dosing, (3) a stable, readily dewaterable alum sludge can be obtained if conditioned with high polymer dosages and intense mixing, (4) a reduction in lime sludge dewaterability is observed with excessive mixing which can not be corrected by additional polymer dosing, and (5) polymer dosage requirements increase with increasing mixing energies for both lime and alum sludges (30). These studies indicate the inadequacy of jar tests for predicting polymer dosage requirements for high energy processes.

Novak and Haugan (1979, 1980) reproduced some of the previously mentioned results, concluding that high molecular weight polymers conditioned sludges more effectively under high mixing intensities than low molecular weight polymers and that polymer dose predictions using jar test (using low G mixing energies) will under-predict polymer requirements. They concluded that while polymer dose requirements are minimized when sludge is conditioned using low mixing energies, additional mixing input will reduce the good dewatering characteristics of sludge. In contrast, when sludge is conditioned using high mixing intensities, the polymer requirements are substantially increased although a sludge more resistant to deterioration is produced. From these conclusions, it was stated that since both gentle and intense mixing produces a readily dewaterable sludge, mixing intensities and, therefore, optimum polymer dosage, should be determined by the type of dewatering process used (i.e., a low shear devise verses a high shear devise) (27, 28).

Werle et al. (1983), using both anionic and cationic polymers with alum, activated and primary sludges, demonstrated the significance of the total mixing energy input (Gt) with respect to polymer dosing. These investigators showed that once an optimum Gt had been selected for a given polymer, any combination of G and t within an ideal range and will yield optimal dewatering results (for activated and alum sludges only). The significance of Gt with respect to the dewatering process is also established. This study suggested a range of Gt selection for a given dewatering process dependent on the shearing forces experienced in the equipment. For example, if drying beds (a low stress process) are used for dewatering, a Gt = 8000 (also, low stress) may yield optimal results. On the other hand, if a high-speed centrifuge (a high stress process) is used for dewatering, a Gt = 800,000 (also high stress) may be the optimal choice (43). Although this appears to be a logical conclusion, especially siting all the previously discussed literature, little research has been performed on determining actual G or Gt values generated in these dewatering processes. Further studies are needed in this area to verify these conclusions.

4. Sludge Dewatering Process Descriptions

A recent EPA publication (1987) estimated the total municipal sludge production at over six and one half million dry tons per year (11). While this value does not even account for the production of water (chemical) treatment sludges, one can see the apparent need for efficient means of water removal considering the fact that dry sludge solids often accounts for less than two percent of the total sludge weight. Numerous techniques have been developed over the years for water removal from sludges. While some are more effective than others, one must keep in mind the inherent influence of both the prior wastewater and/or sludge treatment processes as well as the expected use or disposal practice when either evaluating or selecting a dewatering process. Other factors that effect their use are the type and amount of sludge being treated, its characteristics, and available land area.

Sludge dewatering processes can, generally, be classified as either "air drying" systems or mechanical systems. "Air drying" techniques are those by which moisture is removed by evaporation and gravity or induced drainage. Sand beds and drying lagoons are examples of this type of system, which are usually less complex, easier to operate, and require less energy than mechanical systems. These processes do, however, required large land areas, more time to dewater, and more labor while producing a cake with a low solids content (less than 20%) (11). These processes are thought to generate a low G condition.

Mechanical dewatering techniques can be divided into two categories, namely centrifugal and filtration dewatering processes. These processes are typically favored for the following reasons: (1) mechanical systems are not land intensive and usually confine offensive odors within a closed building, (2) adverse weather conditions do not affect mechanical systems since they are indoors, unlike "air drying" processes and (3) higher cake percent solids are usually produced in mechanical systems, therefore reducing hauling costs. These processes are thought to generate a moderate to high G condition.

Centrifuges dewater sludges on the principle of centrifugal forces in which a basket or bowl type structure is filled with sludge and the structure is rotated. In the basket centrifuge, water exits through the cake that adheres to the inside wall as it rotates, and through small holes in the basket wall. In solid bowl centrifuges, the solids also adhere to the wall surface, however, water is drained out either at the same or opposite end from which the unit was filled. These processes are commonly used today and can produce final cake solids of up to 35% (11).

Filtration dewatering processes are those "which remove solids from a liquid stream by passing the stream through a porous medium which retains the solids " (12). These processes require a pressure drop in order for the liquid portion to pass through the porous medium. Filtration theory originates from Darcy's work and can be expressed by an equation in the form:

$$Q = KA \Delta P/uL \qquad (2)$$

where Q = filtrate flow rate

A = filtration face area

u = viscosity of sludge

K = bed permeability constant

L = Bed thickness

p = driving pressure

One can see that the filtrate flow rate is directly proportional to the driving force or applied pressure through the porous medium.

One such filtration dewatering device is the vacuum filter. A rotary vacuum filter consists of a cylindrical drum covered with a filter medium that rotates partially submerged in a trough of sludge. A vacuum is applied across the drum and filter of the submerged section drawing filtrate through the drum and leaving a sludge cake on the filer medium surface. Upon emerging from the trough, the sludge is air dried as the drum rotates and is eventually mechanically scraped off when cake thickness reaches a desired thickness. It is evident that the filtrate flow rate is limited by the driving force which is equal to atmospheric pressure (produced by the applied vacuum). This process is seeing less use lately, as more cost-effective filtration methods are being employed (11).

A belt filter press is another filtration dewatering device that operates according to a very simple concept. A well conditioned sludge is allowed to drain on a moving belt for a few minutes, at the end of which it is sandwiched between two tensioned porous belts that pass over and under a series of different diameter rollers. Filtrate passes through the porous belts while a cake is formed on the belt surface. As the roller diameter decreases, an increased driving pressure (Δp) is exerted on the sludge. This pressure can be widely varied and an additional vacuum pressure may also be applied to aid in dewatering. This process is widely used today and produce a final sludge cake with up to 35% solids (11).

A plate and frame filter press is yet another filtration dewatering device which produces the highest filter cake percent solids (up to 50%) (11). This device consists of a series of plates, each with a recessed section that forms the volume into which sludge is pumped for dewatering. A filter medium or cloth is fitted over each plate and the assembly is then closed hydraulically or with a screw mechanism. Sludge is pumped in through a center feed hole while filtrate exits through the cloth and into filtrate openings located within the plates (Figure 2). A sludge cake is formed on the cloth, filling the chambers until a maximum pressure is reached or a desired filtrate flow rate is obtained. The press is then opened and sludge cake falls into a hopper for removal. The driving force necessary for filtration is the applied pumping pressure of the sludge which must overcome the pressures produced as the chambers fill with sludge. The driving pressure can be varied depending on if the unit operates on a low pressure system (100 psi maximum) or on a high pressure system (250 psi maximum). Feed pressure

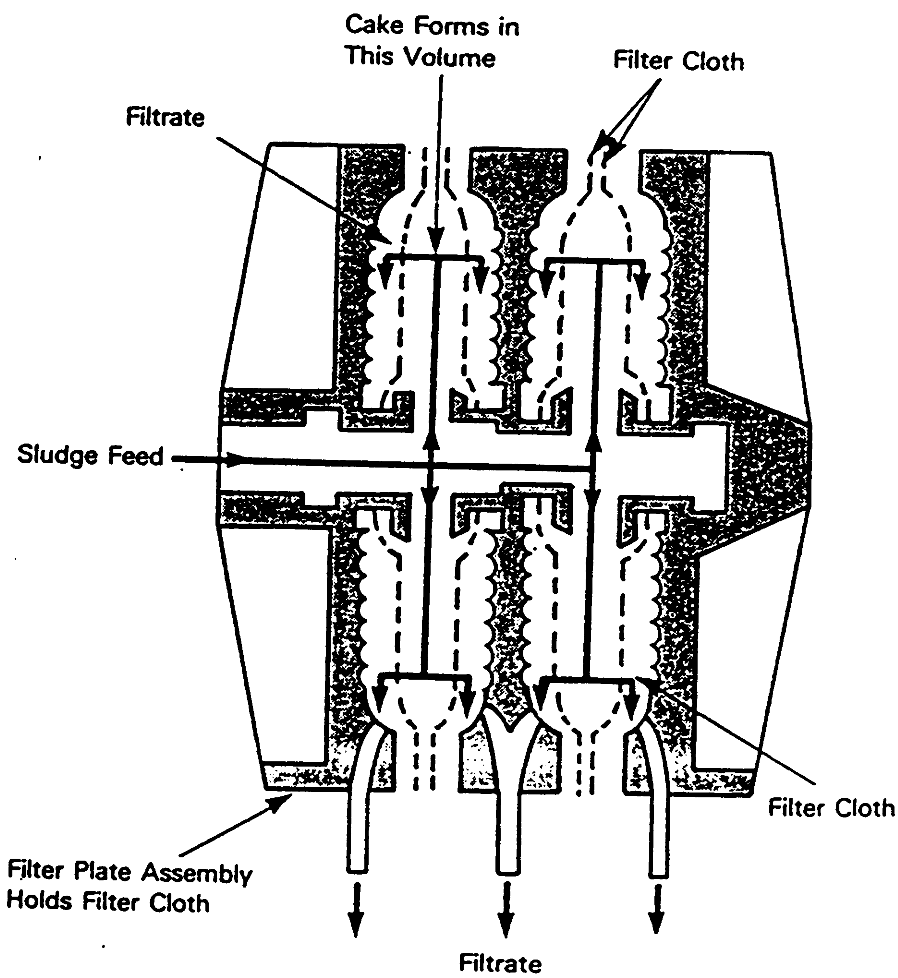


FIGURE 2. Schematic representation of sludge flow in two chambers of a plate and frame filter press. (After EPA, reference 11)

is normally gradually increased to the design maximum pressure over a 20 - 30 minute period independent of the type of system, at which time the design maximum pressure is maintained until completion (12). Diaphragm plate and frame filter presses are now becoming popular, and operate similarly to the previously described units except that a soft rubber membrane (built into the plates) is expanded once the sludge filling period is over. This allows for further dewatering due to additionally applied pressure and has yielded a higher cake percent solids then the conventional equipment (11).

While a variety of other mechanical dewatering processes do exist, this summary of the more promising processes is necessary to compare the differences in operations and performance. Since this study solely used a conventional plate and filter press for dewatering, the literature presented here-in deals with the operation and characterization of this type of equipment. Plate and frame filter presses will be referred to as filter presses throughout the rest of this chapter for sake of convenience.

5. Filter Press Performance and Characterization

Filter press performance can be characterized by filtrate flow rate, final cake solids, filtration time or any combination of these parameters. These parameters can be effected by a number of controllable and uncontrollable variables. Variables by which the press operator can control include: (1) pressure of the feed sludge, (2) rate at which pressure is applied, (3) overall filtration time, (4) the type, dosage, location, and mixing intensity of the conditioning chemical, (5) filter cloth washing frequency, (6) nature of the filter media, and (7) use of a media precoat (i.e. fly ash) which reduce fines build-up in the cloth. Uncontrollable variables include: (1) type of sludge, (2) age and freshness of the conditioned sludge, (3) prior chemical conditioning before the dewatering process which confounds further chemical conditioning, (4) feed solids concentration, and (5) prior treatment from which the sludge was produced (11).

Considering the effects of some of the variables listed above, Jones (1956), tried to characterize filter press operation by postulating an equation for filtration in a filter press. He suggested that the rate of filtrate followed a parabolic function as does unrestricted filtration such as in a Buchner funnel (20). This function can be represented on a filtration curve (cumulative filtrate volume verses filtration time). Gale et al. (1967), verified that the filtration curve does, indeed, follow a parabolic function but only for an initial compression period which lasted only 40 minutes in this study. He went on to show that at this point, the curve deviates from a parabola for the rest of the filtration period (up to 3 1/2 hours in this study). He suggested that due to the compressibility of water and wastewater sludges, a restricted filtration is experienced and, therefore, filter press processes are difficult to describe mathematically (14).

Later, Gale (1968), showed that the formation of compressible cakes in a filter press occurs in at least three stages: (1) the filling period, of which the shape of this portion of the filtration curve varies depending on rate of pressure application, (2) the growth phase (or initial compression period) in which the cake grows outward and the filtration curve is parabolic, and (3) the compression phase in which filtration proceeds by increasing the cake solids concentration and the filtration curve is exponential (13). Trying to facilitate the understanding of characterizing press operation, Nelson et al. (1979), suggested that during cake formation, filtrate flow rate is a function of resistance to flow through the filter medium and the cake. They concluded that after an initial compression period, the cake resistance begins to control filtration (26). In 1983, Hoyland and Day verified Gales's three phase filtration model and concluded that during the exponential phase "the filtration rate is controlled both by specific resistance and by the ability of the cakes to flow longitudinally in the press chamber", while during the parabolic phase the rate of filtration is controlled by the apparent specific resistance only (19).

Using this information, Hoyland and Day (1983) developed a model to predict the ultimate filtrate volume by extrapolating the graph of filtrate flow rate (dV/dt) verses cumulative filtrate volume (V) until the x-axis is reached (zero point) (19). If updated continuously by micro computer, an end point can be determined prior to the end of the press run. Thus, the press run can be terminated at the predicted point, reducing the guess work involved in operation. Hart (1987) implemented this model, and obtained successful results on a full-scale filer press (18).

As previously stated, it has been suggested that the rate of feed pressure application effects the dewatering performance of the filter press. Using a slow pressure application rate (0 - 100 psi in one hour) and a fast pressure application rate (0 - 100 psi in three minutes), Baskerville _et al._ (1971), obtained mixed results using a filtration curve to characterize press performance. Using a mixture of primary, activated and humus sludges conditioned with aluminum chlorohydrate, duplicate testing indicated opposite results. It was concluded that the rate of pressure application on the filtration rate is completely overshadowed by the slight change in feed sludge filterability. It was noted, however, that the slow pressure application test yielded a filtrate lower in suspended solids, a cake that released easier from the cloth, and less solids becoming embedded in the filter cloth and drainage grooves (2).

This raises another important point about filter press performance. Good sludge handleability (after completion of the dewatering process) is a key item when characterizing filter press performance. The question is how to determine when a sludge is handleable. Calkins and Novak (1975) suggested that a universal cake solids content cannot be used to determine handleability for all sludges and, therefore, solids concentration is a poor indication of handleability. As a sludge dewaters and becomes a solid, the sludge begins to resist deformation to shear stresses. It was suggested that a sludge shear strength range for a given dewatering process and handling method is a good indication of handleability (6). This study indicates that sludge cake shear strength can be an important factor in determining filter press performance.

Polyelectrolyte conditioning of water and wastewater sludges prior to pressure filtration has seen very little use in full-scale operations. In fact, the United States Environmental Protection Agency (1979), found no published information in the United States on operating experience with polymer conditioning of wastewater sludges prior to filter press operation (12). The references presented in this chapter are proof of the fact that on a laboratory scale, polyelectrolytes can be used effectively as a sludge conditioner and that on a full-scale basis many potential advantages exist for any dewatering operation (as discussed earlier). Also, several studies in England have indicated that polyelectrolyte conditioning can be effectively used for full scale filter press operation (17).

While the attempts to use polyelectrolyte conditioned sludge for filtering pressing operations have met with very limited success, White et al. (1974), have suggested some practical guidelines for an effective filter pressing operation as delineated by successful full-scale operations in England. It was concluded that poor filter press performance using polyelectrolyte conditioned sludge can be attributed to inadequate provision for the discharge of filtrate at high rate, to "blinding" of the filter medium or to incorrect mixing techniques (44). This study demonstrated that dirty filter cloths, filtrate drainage channels and holes contributed significantly to reduction in press performance by restricting the discharge of filtrate at very high rates (caused by the extremely low specific resistance values associated with polyelectrolyte conditioned sludge). Regular cleaning of all drainage surfaces including the back of filter cloths was suggested (44).

Filter cloth "blinding" is a phenomena which exists when the pores in the filter medium become clogged with very fine sludge particles, or, even polymer itself in the case of conditioning using an excess of polymer. Media blinding depends on the efficiency of the conditioner to flocculate the very fine particles. For polyelectrolytes, this depends on type of polymer, the mixing of the sludge and polymer, and the transport of the conditioned sludge to the press (44). These three factors are interrelated. Laboratory tests on various polymers are required to determine their ability to flocculate fine particles. Mixing of the sludge and polymer has been shown to be an important factor in conditioning operations, as previously reviewed in this chapter. This study demonstrates that while an optimum polymer dose may be selected, only optimum stirring conditions will yield the required filtration characteristics. Inadequate conditioning, therefore, will result under non-ideal mixing conditions (43).

Sludge transport to the filter press has been shown to affect press performance. Prolonged conditioned sludge storage and further mixing can deteriorate the floc particles and cause non-ideal conditions. Sludges should be filtered as soon as possible after conditioning to maintain floc integrity. This study, along with others, has shown that floc deterioration can also be attributed to the passing of conditioned sludge through additional high shearing environments such as feed pumps, feed inlets and the press chambers themselves (11, 12, 19, 44). While complete initial mixing of the sludge and polymer is crucial, additional shear produced in transport should be minimized. These studies suggest the use of "in-line" mixing in which the polymer is injected just prior to entering the feed pump or filter press. Complete mixing is, again, essential for effective dewatering; however, the effects of additional turbulence are reduced.

From this review of past literature it is evident that much research has been performed in the areas of sludge conditioning and dewatering. This information not only lays the foundation for additional studies but also provides valuable, practical information for use in full-scale sludge treatment operations. Further research is, indeed, necessary to determine how to properly condition sludges using polyelectrolytes for use in filter presses.

III. MATERIALS AND METHODS

This study was undertaken to determine how to properly condition sludges for dewatering by a plate and frame filter press. Many variables are present which ultimately effect the performance of the filter press. These include sludge type, amount and type of conditioner, mixing intensity, mixing time and filter press operational parameters (such as start-up procedure, cloth type, etc.). This chapter describes the materials and experimental procedures used to characterize filter press operation on a pilot scale level, while accounting for the aforementioned variables.

1. Sludge Source, Characterization and Preparation

All sludges used in this research were obtained from water and wastewater treatment plants in southwest Virginia. Alum sludge was obtained from the Radford Army Ammunition Plant, Radford, Virginia. Anaerobically digested lagoon sludge was collected from the Roanoke Wastewater Treatment Plant, Roanoke, Virginia. Finally, aerobically digested sludge was procured from the Christiansburg Wastewater Treatment Plant, Christiansburg, Virginia.

Alum sludge collected at the water treatment plant of the ammunition facility was obtained through a port on the bottom of a sludge holding tank. As the filter press used in this study requires large volumes of sludge, five separate visits were required over a six month period as experiments proceeded. This posed a problem, in that sludge collected during each visit showed somewhat different properties. Therefore, sludge data presented in later chapters are categorized as alum No. 1, 2, 3, 4, and 5.

Once an adequate volume was collected (approximately 250 L) in 20 L to 80 L carboys, the sludge was transported back to the laboratory for total solids determination. Percent total solids were determined using the method described in the 16th Edition of Standard Methods for the Examination of Water and Wastewater (37). All mixing experiments and filter press runs using alum sludge were performed using a 2% total solids. Since total solids concentrations were typically greater than 2% at collection time and varied throughout the six month testing period, dilutions with tap water were necessary to achieve the desired solids value. Typically, raw sludge percent total solids ranged from 2% to 6%. All alum sludges collected were brown in color and nearly odorless.

Anaerobically digested sludge obtained from the Roanoke plant was procured by dipping below the surface of a sludge storage lagoon and filling the aforementioned carboys. Care was taken not to scrape the buckets along the bottom as not to collect sand and other debris. Again, all mixing experiments and filter press runs using anaerobically digested sludge were performed with a 2% total solids concentration. Dilutions were, again, necessary since the percent total solids ranged from 3% to 7% at collection time. This sludge was black in color and had the characteristic odor of anaerobically digested sludge.

Aerobically digested sludge obtained at the Christiansburg plant was collected directly from a sampling valve in the pump room of the digesters. All experiments using this sludge were performed at a 1% total solids, since typical total solids concentrations at collection time ranged from 1% to 2%. Dilutions were, again, necessary to achieve a 1% total solids concentration. This sludge was dark brown in color and had a putrid odor.

Prior to performing any experiments, all sludge samples were mixed to insure the resuspension of any settled particles. This involved rolling the carboys on their sides for approximately one minute. All samples were stored at 20°C in the laboratory.

2. Polymer Description and Preparation

A single polymer was used in this research as a sludge conditioning chemical. Percol 757, manufactured by Allied Colloids, Inc., is a high molecular weight cationic polymer. Stock solutions of 3000 mg/L were prepared from the granulated product, allowing the polymer to completely solubilize over a 12 hour period. These solutions were maintained at 20° C. New stock solutions were prepared after three days of non-use, thus maintaining product reliability.

3. Mixing Apparatus Description

Two types of experiments using conditioned sludge were performed in this research. One experiment involved the mixing of small volumes of sludge (1.5 L) at various mixing intensities and polymer dosages to produce dewatering rate information using the Buchner Funnel Dewatering Apparatus. The other experiment involved mixing large volumes of sludge (10 L) at various mixing intensities and polymer dosages chosen from the previously described experiment, and feeding this sludge through a pilot scale plate and frame filter press. Thus, press performance can be evaluated using a known set of variables.

The first set of sludge conditioning experiments (small volume) mainly involved determining the optimum polymer dosage for a given mixing speed. A range of polymer dosages were used at one mixing speed, from which the minimum time to filter 50 mL on the Buchner Funnel Dewatering Apparatus obtained corresponded to the optimum polymer dosage for that mixing speed. The mixing time was always 60 seconds.

For mixing speeds of 200 rpm and 300 rpm, a mixing program was developed using a Cole-Palmer 0.5A variable speed motor, Model 4555H, with a Cole-Palmer speed controller, Model 4555-30. A strobe light was used to determine rpm's since the controller did not contain known speed intervals. For mixing speeds of 400, 800, 1200 and 1800 rpm , a Craftsman 13 in. variable speed drill press was used to condition sludge. Speeds on this device were checked with a strobe light and came with ± 12 rpm of the manufacturer's designated speed. For both large and small volume experiments described in the previous paragraph, the same mixing devices were used to condition the sludge.

The small volume experiments utilized a cylindrical Plexiglass mixing chamber measuring 30.5 cm in height and 12.7 cm in diameter. As mentioned earlier, a volume of 1.5 L was used in all experiments of this type, corresponding to a fluid depth of 12.2 cm. Four baffles running 25.5 cm high were spaced at 90 degree increments around the inside circumference. These baffles had a measured width of 1.2 cm and a thickness of 0.6 cm.

The large volume experiments utilized a cylindrical Plexiglass mixing chamber measuring 50.0 cm in height and 19.5 cm in diameter. A volume of 10.0 L was used in these experiments as larger volumes were needed for filter press experiments. This volume corresponded to a fluid depth of 33.0 cm. Only two baffles were used running 43.5 cm high, spaced at 180 degrees apart around the inside circumference. Thorough mixing of sludge and conditioner was observed at speeds equal to or greater than 400 rpm with this baffle arrangement. However, at mixing speeds less than 400 rpm the small mixing chamber was used to prepare sludge for the filter press since poor polymer-sludge contact was observed with the large mixing chamber.

When the mixing device was installed, the paddle was 1.0 cm above the bottom of the chamber. This height was maintained for both mixing devices and both chambers. For the small chamber one paddle arrangements existed which consisted of four blades equally spaced at 90 degrees around the shaft. Each blade measured 3.2 cm in length, 2.6 cm in height and 0.6 cm in thickness. The blades were positioned at 45 degrees to the horizontal. For the large chamber, and additional paddle was installed at a height of 24.0 cm above the one previously described. This paddle consisted of six blades equally spaced around the shaft and positioned at 45 degrees to the horizontal. Individual blades measured 2.8 cm in length, 1.2 cm in height and 0.2 cm in thickness. This additional paddle was necessary to ensure complete mixing in the upper regions of the large mixing chamber. The overall diameter of both paddles measured 9.2 cm and 7 - 8 cm, respectively.

4. Sludge Conditioning

Small chamber mixing experiments were performed according to the following procedure. Once a desired mixing speed was chosen (thus dictating what mixing device to use) the mixing apparatus was installed into the chamber containing the sludge. A large range of polymer dosages were then chosen for testing. A pipette with suction bulb or a graduated cylinder was used to administer the polymer into the chamber, depending on the dosage used. Since 3000 mg/L stock solutions of polymer were used, required volumes of polymer were exactly half of the numerical value of the dosage. For example, if a 300 mg/L dosage was desired, 150 mL of 3000 mg/L polymer was needed per 1500 mL of sludge. This was done to simplify the experiment, since many dosages were tested at various mixing speeds.

The desired dosage was added simultaneously as the mixing device was turned on. The mixing time was set at one minute. This value was used for all mixing experiments with all three sludges. Immediately upon shutting the mixer off, 500 mL of conditioned sludge was gently poured into a beaker for testing on the Buchner funnel apparatus.

The standard Buchner Funnel test measures the vacuum filtration rates of sludge. The Buchner funnel apparatus used in this experiment is shown in Figure 3. A 9 cm diameter Whatman 40 filter pad is placed in the bottom of the funnel. The pad is then saturated with water and the vacuum pump turned on. This will pull the water through the pad and form as effective seal between the pad and funnel. This excess water is collected in the graduated cylinder and disposed of.

With the pad still sealed to the funnel the vacuum pump is restarted and 100 mL of sludge is then gently poured into the funnel at which time a stop watch was started. Minimizing turbulence at this point will help ensure data reliability by reducing the potential for floc shear. A pressure differential equivalent to approximately fifteen inches of mercury was applied across the sludge using the vacuum pump. Upon reaching 50 mL in

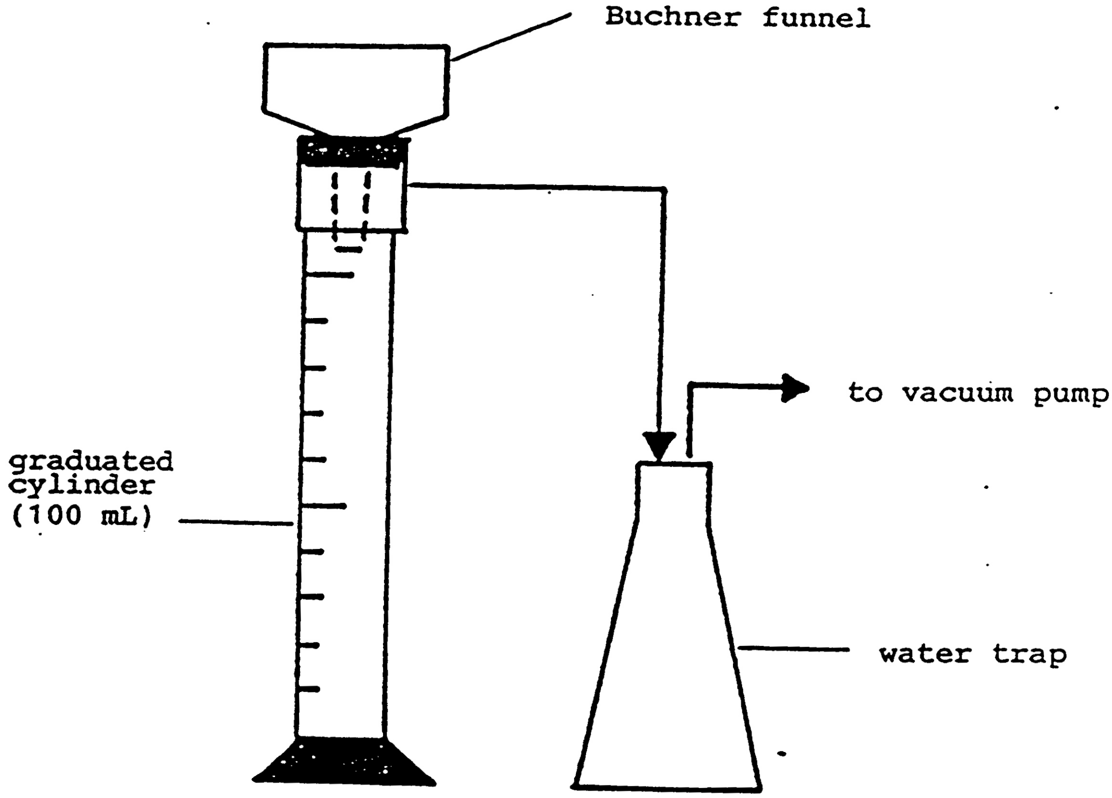


FIGURE 3. Buchner funnel apparatus.

the graduated cylinder, the stopwatch is stopped and the time recorded. Duplicate runs were performed throughout this research to check data reproducibility which remained very high.

Once the desired time to filter was obtained for a particular dosage and mixing speed, the conditioned sludge was discarded. This test was then performed for a different dosage, under the same conditions using another 1500 mL of sludge. Upon completion of a satisfactory number of experiments for one mixing speed, an optimum dosage would be obtained that would be used to condition a large volume of sludge to be fed to the filter press. Unconditioned sludge tests were also performed where sludge was mixed at the desired speed for one minute and introduced to the Buchner funnel apparatus without polymer addition. This information gave a general indication of the dewatering rate of the raw sludge. Typical data generated in this type of experiment is shwon in Figure 4.

Preparing sludge for the filter press involved the use of the large mixing chamber. Since the filter press typically used between 10 L and 40 L, large volumes of sludge needed to be mixed. As mentioned previously, 10 L at one time were mixed in this chamber under the same mixing conditions as for the small chamber. A check needed to be made, however, on the correlation between mixing intensities on both chambers. Thus, if a polymer

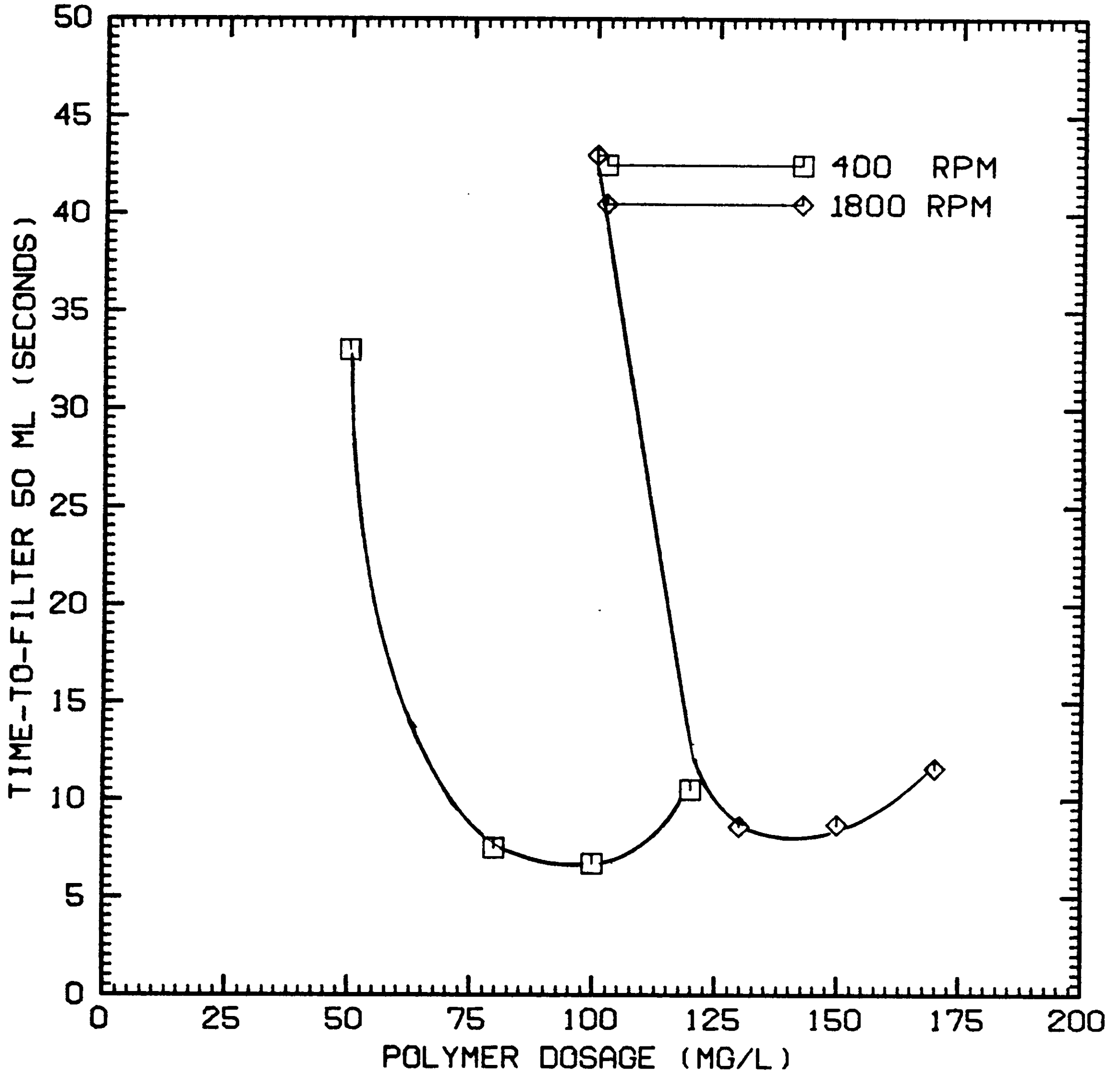


Figure 4. Typical data generated in the small mixing chamber experiments showing the relationship between time to obtain 50 ml of filtrate on a Buchner funnel apparatus and polymer dosage for one sludge and mixing speed.

dosage yielded a certain time to filter on the small mixing chamber, it was necessary to make sure that this same time to filter could be achieved with the large chamber for the same polymer dosage. Therefore, the Buchner funnel apparatus was used for this purpose and results indicated a very close correlation between both mixing chambers. If, in fact, a variation was observed that exceeded a three second difference, this newly mixed sludge was discarded to maintain data reliability. A new batch would then be prepared or the problem causing this difference would be determined and corrected.

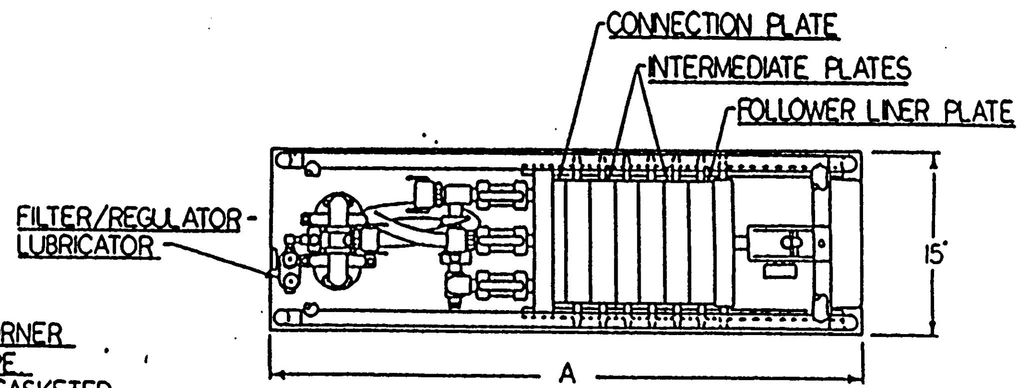
5. Filter Press Operation

The JWI* 250N30-5-.15MN pilot scale plate and frame "J" filter press was used in the sludge dewatering studies. This press is a manually closing unit that contains an air driven feed pump and six 250 mm squared non-gasketed plates that make up five chambers. Series 7100 filter cloths were used. A manufacturer's drawing is shown in Figure 5.

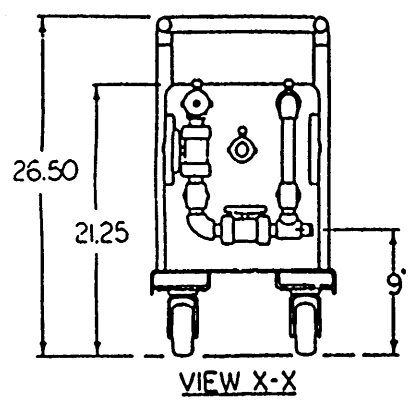
The following is a basic description of the operation of the filter press. A more detailed description of operating procedure can be found in the owners manual. Operating procedures were followed exactly as outlined in

*Holland, MI

ITEM NO	QTY.	DESCRIPTION
1	1	HEAD
2	2	SIDE BAR
3	1	FOLLOWER
4	1	CYLINDER BRACKET
5	1	FILTER CAKE TRAY
6	1	PLATFORM



PLATES TO BE CENTER FEED 4 CORNER DISCHARGE, WASHING/AIR BLOW TYPE PLATES OF POLYPROPYLENE NON-GASKETED CONSTRUCTION WITH 19/32" RECESSES FOR 1 3/16" THICK CAKES.



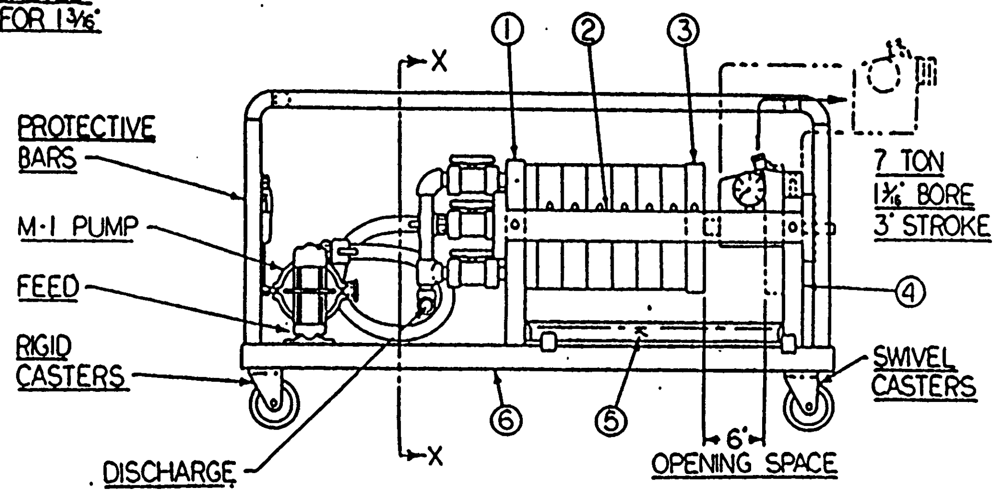


FIGURE 5. Manufacturer's schematic representation of the pilot scale filter press. (JWI, Holland, MI)

the owners manual except where noted in this text. Once sludge had been correctly prepared in the mixing device, it was gently placed in a larger holding vessel where it was continuously stirred with a double blade paddle to ensure a uniform solids distribution throughout the container. The rotational speed of this mixing unit was maintained below that of the mixing speed that was presently being used to condition the sludge and never exceeded 250 rpm. Maintaining a low mixing speed at this point not only allowed for complete particle suspension, but minimized the possibility of obtaining erroneous data caused by effects of additional high-intensity mixing.

Only two plates were used which accounted for one and one half chambers for sludge cake formation. This was necessary since large volumes of sludge would be needed to fill all five chambers. Once the plates were hydraulically closed to the recommended pressure, sludge from the holding vessel was poured into a feed tube connected to the feed pump. This allowed the sludge to fill the pump and feed line up to the inlet valve at the plate entrance. Once this tube was filled, it was inverted and placed into the holding vessel. Additional sludge was poured directly into this container during press operation.

Compressed air is used to drive the air pump. At start-up, the air is turned on, the inlet valve opened and a stopwatch is started. This starts the sludge flow and dewatering begins. The manufacturer suggests a gradual air pressure increase over the first half hour to increase press performance. Two start-up procedures were used in this study, however. First, as suggested by the manufacturer, a 20 psi initial pressure was used up to five minutes. Every five minutes thereafter, pressure was increased in 20 psi increments up to a maximum of 100 psi. The alternate start-up procedure involved an initial pressure increase to 100 psi at time, t=0, with no further increase. It was theorized that much higher initial shearing forces might be encountered with this procedure. If so, the high stress condition caused by high-intensity mixing during sludge conditioning may better simulate the large shearing forces encountered in this type of start-up procedure. This may improve filter press performance.

After start-up procedures were complete, further operation involved maintaining a constant supply of sludge and collecting filtrate. The filtrate volume was collected and recorded at desired time intervals throughout the press operation. This information was used to characterize the press performance. For instance, the greater the cumulative filtrate volume in a shorter period of time, typically the better the performance of the filter press.

Air was turned off to the feed pump when filtrate flow rate fell below 30 mL/min. Press runs of this type required two to three hours to complete and were only used when cake solids were to be analyzed. The press manufacturer suggested terminating operation when feed pump stroke time increased above sixty seconds at 100 psi; however, it was the experience of this writer that this led to a poorly dewatered sludge in that cake solids were very low. If cake solids were not to be analyzed, the press run was terminated at fifty minutes. This type of operation allowed for sufficient filtrate volume collection to characterize sludge dewatering capability in a shorter period of time.

Upon completion of either termination procedure, a "blowdown" time of two minutes was used to remove excess free water within the cake and press. This involved connecting the air supply to one of the filtrate discharge lines while maintaining a maximum pressure of 40 psi.

Upon completion of cake removal, the filter press was flushed with water to ensure all flow paths remained free of solids particles. Filter cloths were thoroughly washed and scrubbed with hot water to remove all sludge particles trapped on and within pore spaces. Proper cleaning helped maintain product reliability for the duration of the study.

6. Sludge Cake Analysis

Pressed sludge cake analysis consisted of determining percent total solids. Total solids data was taken on each plate at eight locations on the cake surface layer, middle layer and cloth layer looking at a cross section of the cake. For the full chamber of sludge cake, total solids data was typically taken on a surface layer and middle layer since both sides of the cakes were adjacent to the cloth surface. However, total solids was taken at the three aforementioned locations for the half chamber cake since surface and cloth layer data usually differed. Cake samples were taken at one inch and three inches, radially located from the center of the plate for each depth location. Also, cake samples were taken at 45, 135, 225, 315 degrees circumferentially located around the plate. This resulted in a total of twenty four total solids samples per cake.

IV. RESULTS AND DISCUSSION

Data collected in this research and in other studies indicated the importance of the total mixing energy input (Gt) in selecting an optimum polymer dose. Of equal importance, is the need to optimally select a mixing intensity (G) or mixing energy input (Gt) that simulates the type of shear environment to be experienced in the particular dewatering equipment to be used. The filter press data collected in this study indicates that a specific Gt value (or range of Gt values) is generated in the filter press and mixing intensities used in conditioning should be selected according to these values for optimal press performance. In this chapter, data will be presented and discussed which should provide a rationale for and guide to the proper conditioning for filter press operation.

To conduct this study it was first necessary to determine the optimum conditioning dosages for various mixing speeds using the mixing unit described in Chapter III. Since Gt values could not be measured directly on this mixing unit, it was then necessary to compare the results with a different mixing unit with known G values to characterize the mixing unit used in this research. Gt values corresponding to various mixing speeds (rpm) were, thus, established. Filter press experiments were then conducted to characterize this unit.

To determine the role of conditioning in filter press performance, experiments were then performed using various sludges optimally conditioned at various mixing speeds. A Gt value (or range of Gt values) could then be established for the filter press on the basis of optimal press performance by backing into the results of Gt obtained in the mixing experiments for various mixing speeds. Finally, to verify the Gt value established for the filter press, a different sludge was optimally conditioned at the mixing speed (or Gt) previously determined as optimum for the filter press, to see if comparable results could be obtained.

1. Selection of Conditioning Dose - Effects of Gt

The results of alum sludge conditioning tests are presented in Figures 6 - 11. As discussed earlier, a total volume of 1.5 L was used with a mixing time of one minute for all sludges. The only polymer used was Percol 727, a cationic polyelectrolyte, taken from a stock solution of 3000 mg/L. The five alum sludges studied all contained 2% total solids. While all five alum sludges were obtained from the same port on the same holding tank during each visit, these sludges are, obviously, characteristically different as can be observed from the data in Figures 6 - 11. These differences are attributed to the age of the sludge in the tank at the time of withdrawal.

In Figures 6 - 10, relationships between time-to-filter 50 mL on a Buchner funnel apparatus and polymer dosage are shown for each mixing speed used. It should be noted that the minimum time-to-filter 50 mL remained relatively constant (between five and seven seconds) for each of the alum sludges studied. While this holds true for most mixing speeds used, the data shows a minimum time-to-filter 50 mL of between eight and eleven seconds at the extreme ends of the mixing range used (i.e., 200, 300 and 1800 rpm) for each of the alum sludges tested at these speeds.

Optimum dosages used for filter press testing were selected on the basis of minimum time-to-filter 50 mL for a given mixing speed. For alum No. 1, a wide range of polymer dosages were used at mixing speeds of 400, 800, 1200, and 1800 rpm (Figure 6). Unconditioned alum No. 1 required between two and three minutes to filter 50 mL on the Buchner funnel apparatus. These points are not shown on Figure 6. This was done to produce a characteristic curve representing conditions of zero dosing, underdosing and overdosing. It is clear that polymer underdosing,

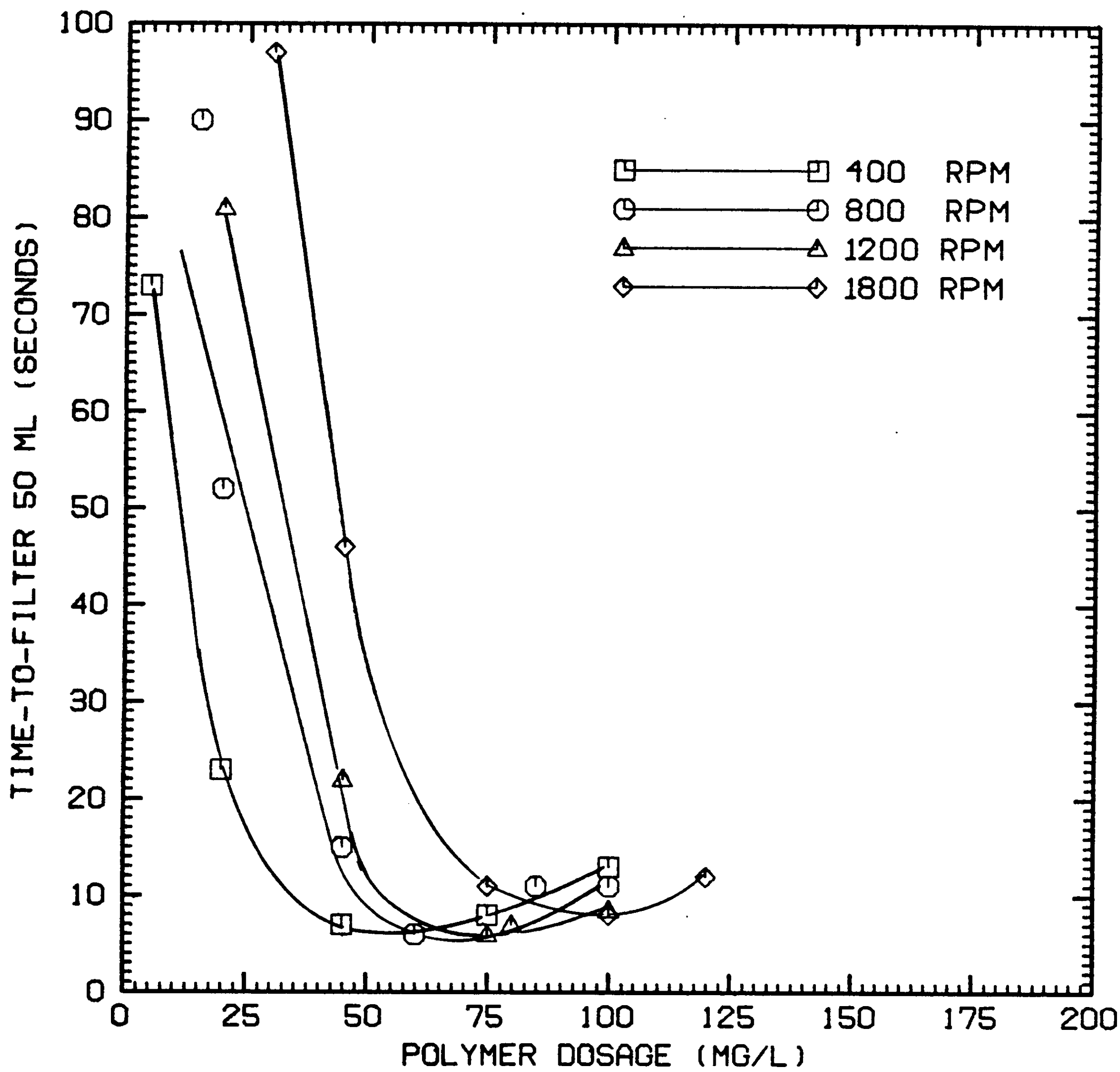


Figure 6. Relationship between time-to-filter 50 ml on a Buchner funnel apparatus and polymer dosage using various mixing speeds for alum sludge.

represented by the steep section of the curve before a minimum is reached, represents a critical condition in which sludge dewatering rates were adversely affected. This is seen by the large changes in time-to-filter 50 mL over a relatively small range of polymer dosages. Conversely, polymer overdosing, represented by the section of the curve after a minimum is reached, is a less critical condition since the time-to-filter 50 mL increased slightly over a relatively wide range of polymer dosages. Data in figure 6 indicate that mixing speeds of 400, 800, 1200 and 1800 rpm produce optimum dosages of 50, 60, 75 and 100 mg/L, respectively. This clearly shows that the optimum polymer dosage increased as the mixing intensity increased.

Figures 7 - 10 were constructed solely to determine the optimum dosage to be used for filter press testing and, therefore, do not cover as wide a range of polymer dosages as Figure 6. For alum No. 2, mixing speeds of 200, 300 and 400 rpm produced optimum polymer dosages of 115, 115 and 105 mg/L, respectively (Figure 7). It should be noted that those mixing speeds below 400 rpm produced the same optimum dosage.

Mixing speeds of 400 rpm and 1800 rpm for alum No. 3 yielded optimum dosages of 85 mg/L and 145 mg/L, respectively (Figure 8). For alum No. 4, mixing speeds of

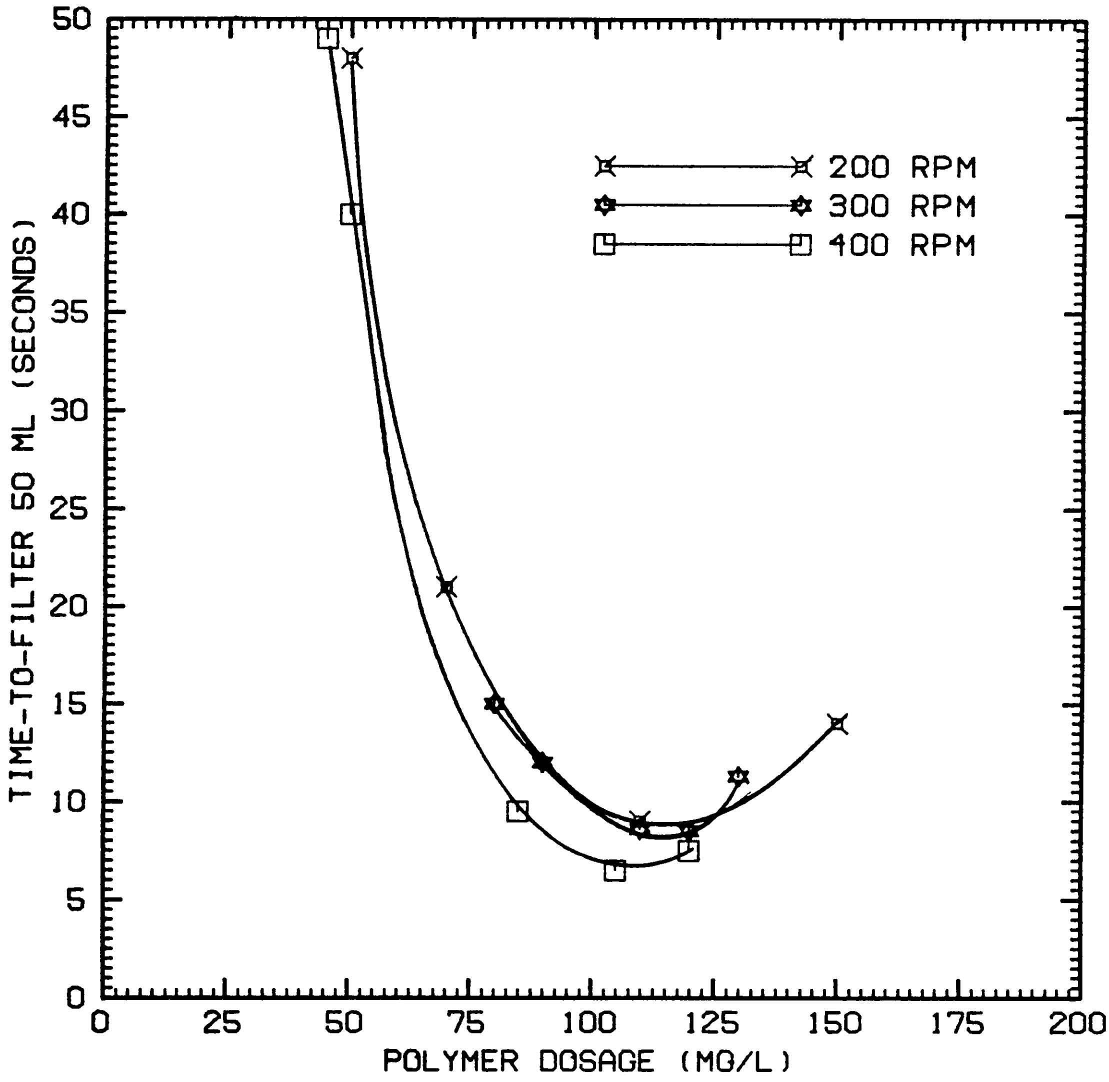


Figure 7. Relationship between time-to-filter 50 ml on a Buchner funnel apparatus and polymer dosage using various mixing speeds for alum sludge.

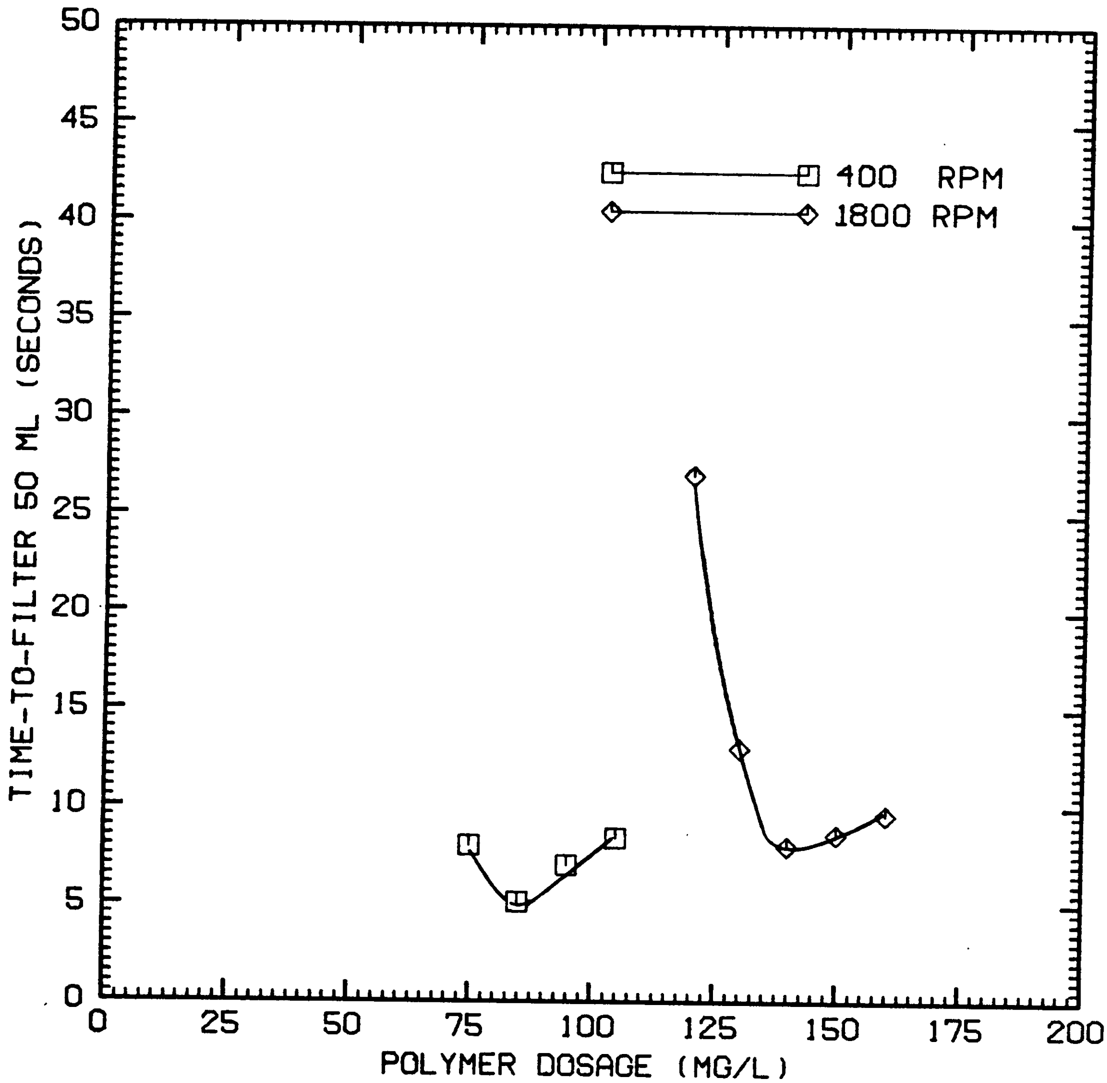


Figure 8. Relationship between time-to-filter 50 ml on a Buchner funnel apparatus and polymer dosage using various mixing speeds for alum sludge.

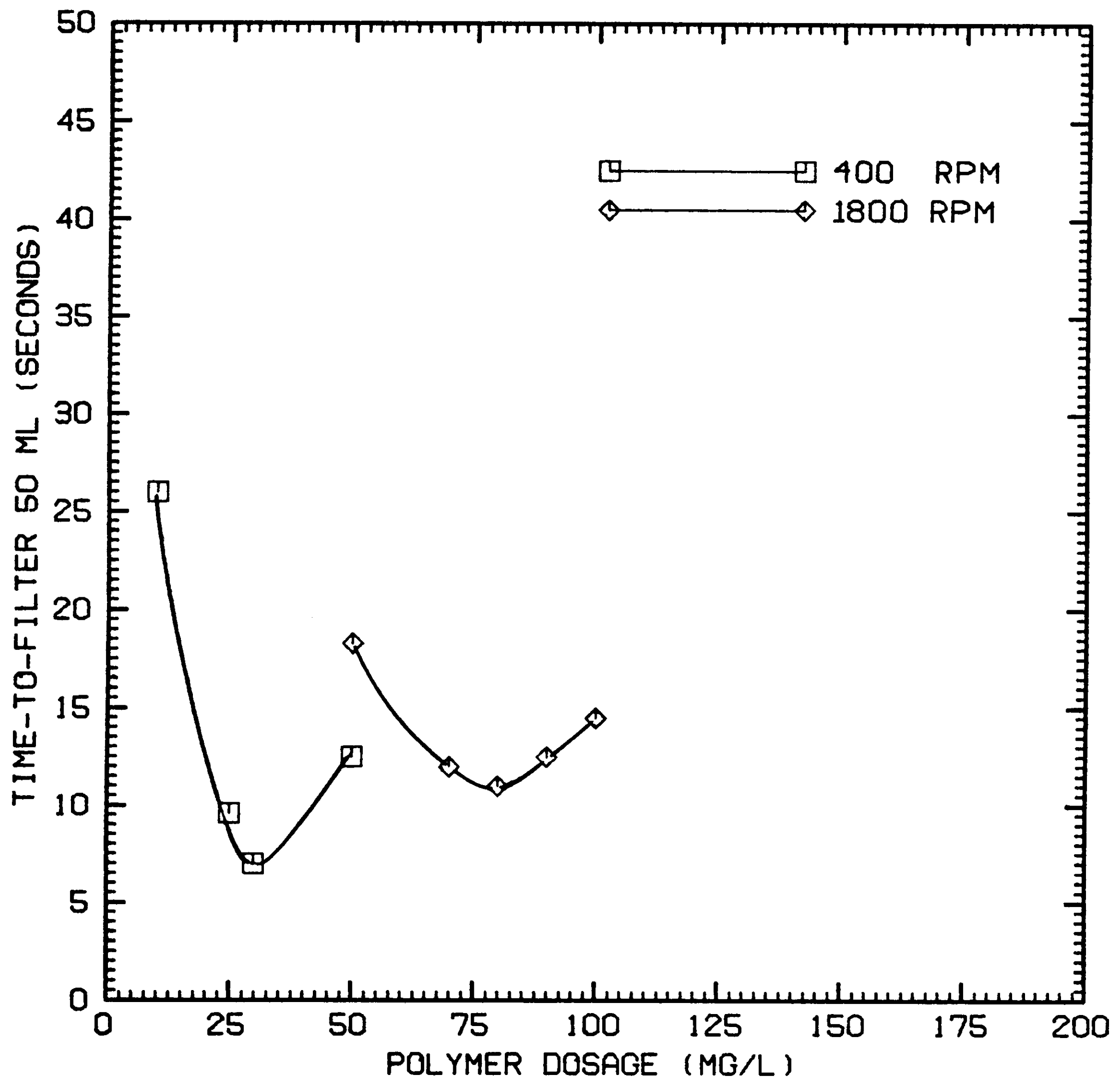


Figure 9. Relationship between time-to-filter 50 ml on a Buchner funnel apparatus and polymer dosage using various mixing speeds for alum sludge.

400 rpm and 1800 rpm yielded optimum dosages of 30 mg/L and 80 mg/L, respectively (Figure 9). These same mixing speeds used for alum No. 5, produced optimum dosages of 100 mg/L and 145 mg/L, respectively (Figure 10). These figures demonstrate that for each alum sludge sample, the optimum polymer dose requirements increase as a function of mixing speed in a similar manner.

In Figure 11, the relationship between optimum polymer dose and mixing speed is shown for the five alum sludges used. These curves were generated from the data presented in Figures 6 - 10 and more clearly demonstrates the increased required optimum dosage with subsequent increase in mixing speed. Note that in Figures 6 - 10, a "range" of optimum dosages could possibly be selected at each mixing speed in which the time-to-filter 50 mL varies slightly over approximately a two second range. In this case, Figure 11 would show a series of shaded regions representing this optimum range for each sludge. Figure 11 also provides a good representation of the variations that were observed among the five alum sludges all obtained from the same location.

The results of the anaerobically digested sludge conditioning tests are presented in Figures 12 and 13. In Figure 12, the relationship between time-to-filter 50 mL and polymer dosage is shown for selected mixing speeds.

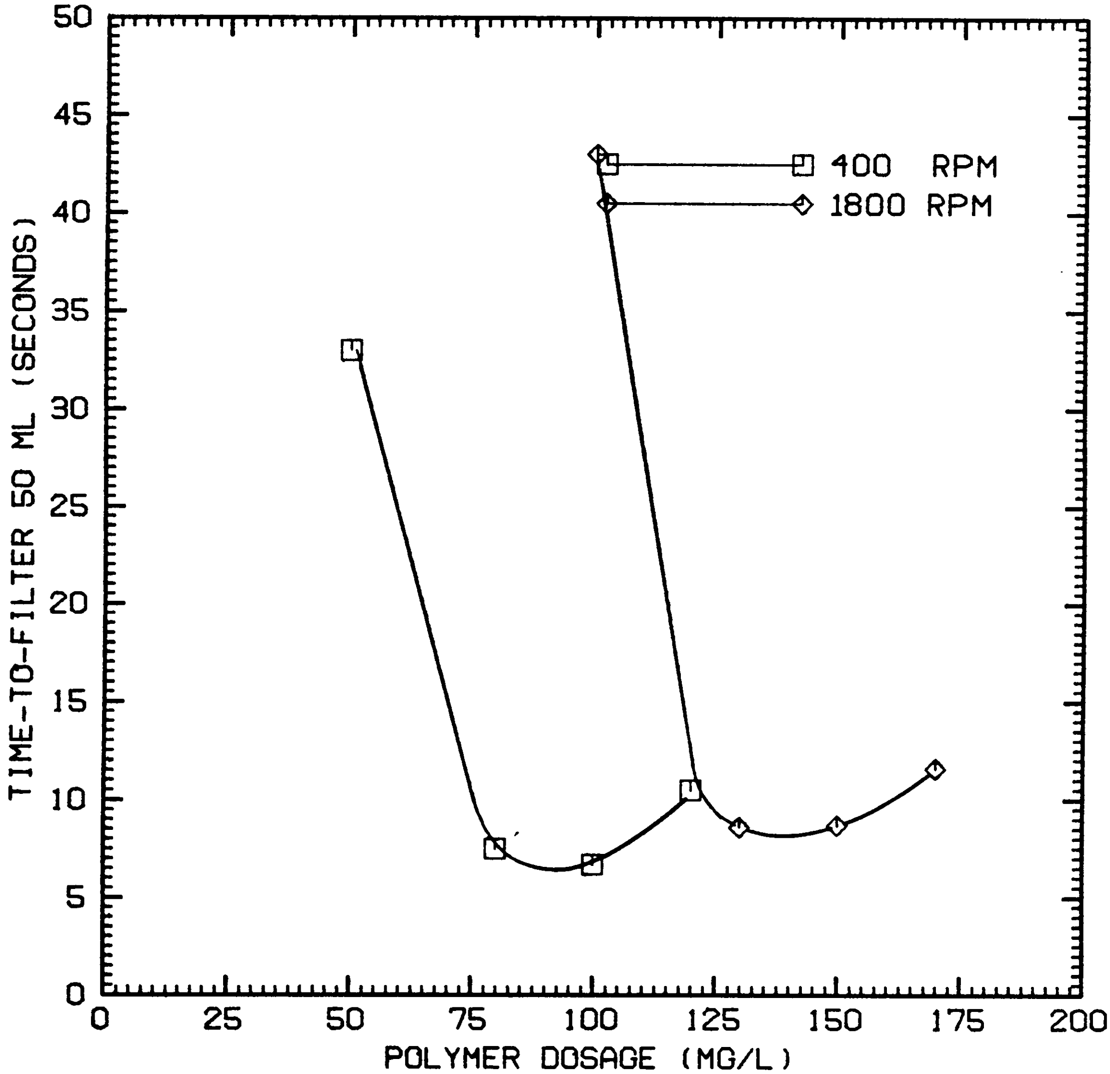


Figure 10. Relationship between time-to-filter 50 ml on a Buchner funnel apparatus and polymer dosage using various mixing speeds for alum sludge.

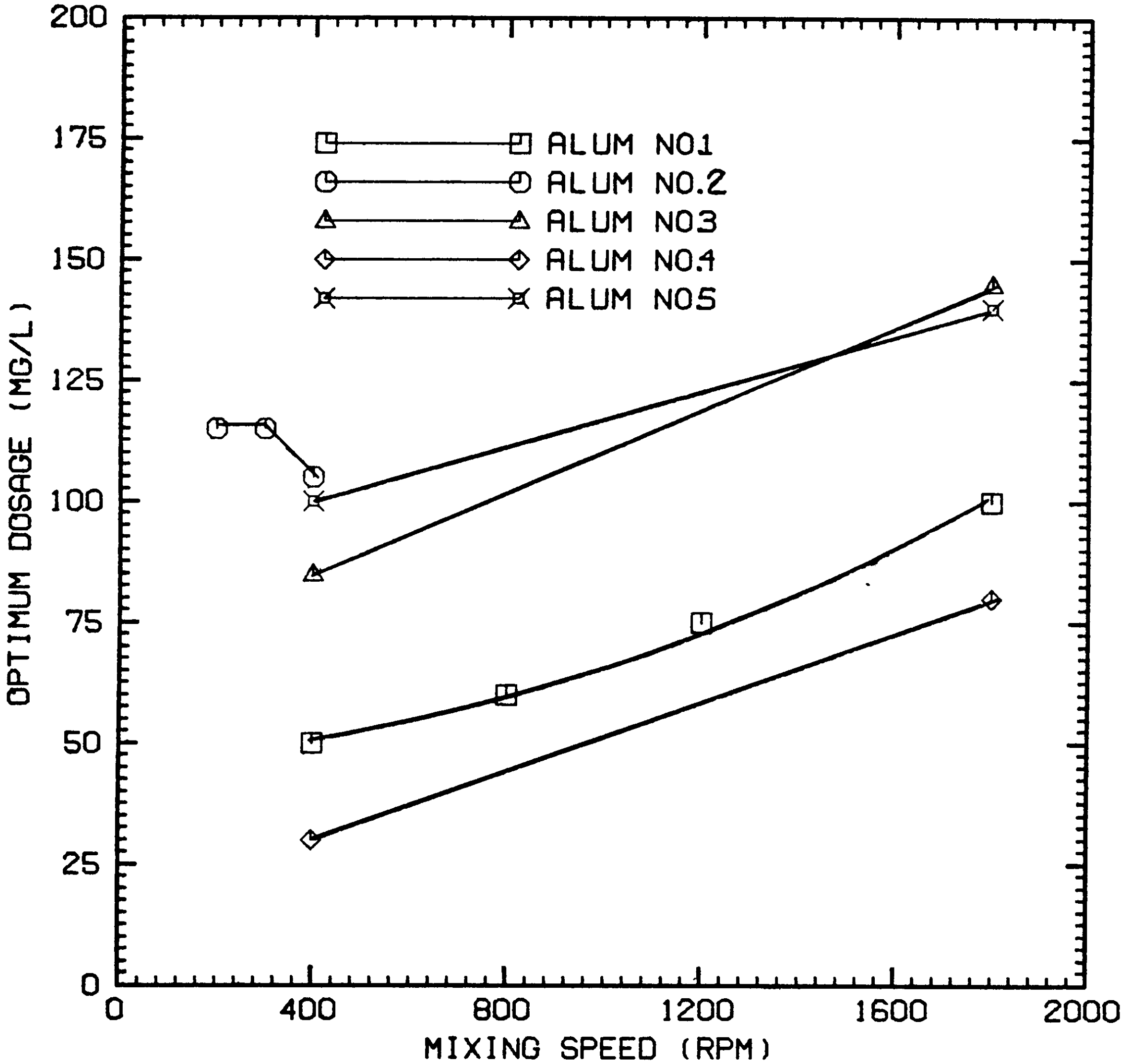


Figure 11. The effect of mixing speed on optimum polymer dosage for alum sludge.

This curve was constructed to determine optimum dose requirements at the desired mixing speeds for filter press testing. One can see that the minimum time-to-filter 50 mL, which represented the optimum dosage, remained relatively constant at approximately seven seconds for all mixing speeds. While the minimum at 1800 rpm is slightly higher than seven seconds, this becomes insignificant when one considers that the time-to-filter 50 mL of the unconditioned sludge exceeded fifteen minutes. This figure indicates that mixing speeds of 200, 400, 800, 1200 and 1800 rpm corresponds to optimum dosages of 60, 95, 155, 260 and 300 mg/L, respectively. As with the alum sludge, this sludge can be conditioned to resist floc deterioration due to mixing, but to do so required large polymer dosages.

While the preceding information provides some potentially useful concepts, direct G (or Gt) values corresponding to the mixing speeds used could not be obtained from the mixing apparatus. Gt values were, however, established for this mixing unit by comparing results obtained in experiments using a different mixing unit of known properties (of which Gt was known). Two separate tests were performed using the high mixing intensity apparatus described by Werle (1983) (42). The second test acted to verify the results obtained in the

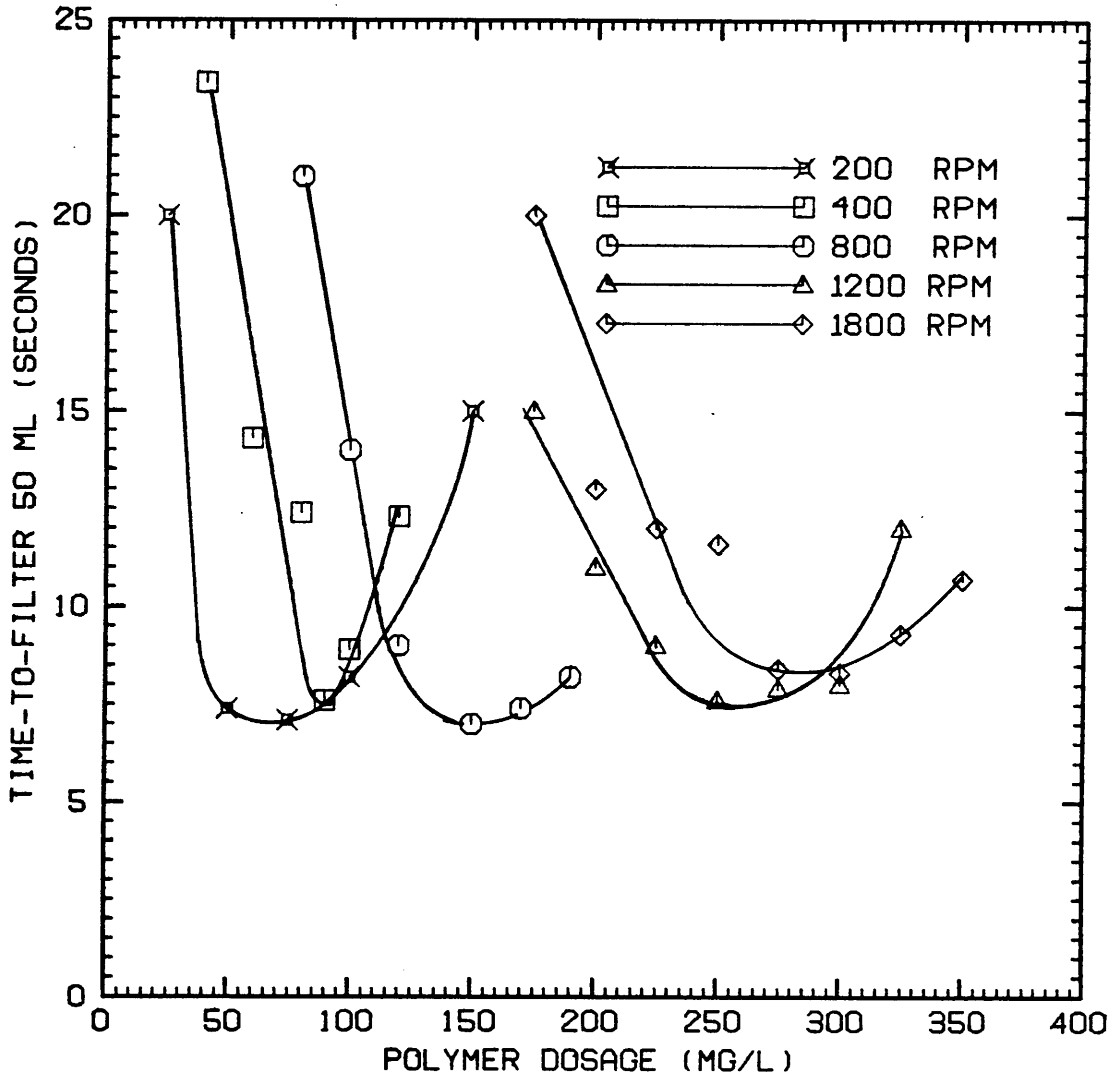


Figure 12. Relationship between time-to-filter 50 ml on a Buchner funnel apparatus and polymer dosage using various mixing speeds for anaerobically digested sludge.

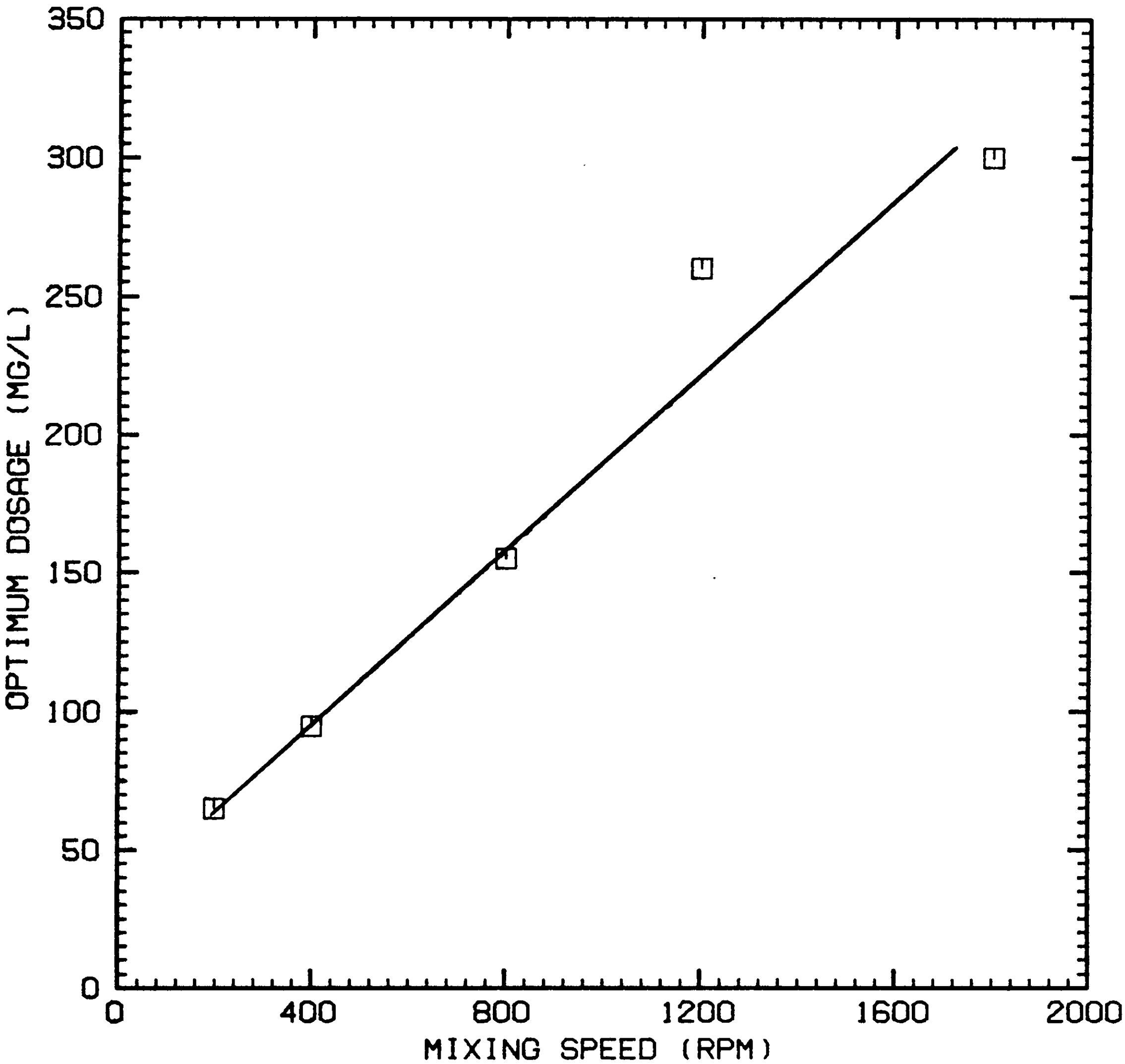


Figure 13. The effect of mixing speed on optimum polymer dosage for anaerobically digested sludge.

first test and both were used to establish Gt values for the mixing speeds used in this research.

Chelf (1988) provided the data for the first test that is presented in Figures 14 and 15 (9). The data presented in these figures were obtained using the same anaerobically digested sludge, percent total solids and polymer as used in the author's experiments. In Figure 14, the relationship between time-to-filter 50 mL and Gt is shown for one polymer dosage using various combinations of G and t. This data indicates that an optimum Gt, located at the minimum time-to-filter 50 mL, is obtained for a given polymer dose. By testing other polymer dosages, a series of curves can be obtained, from which optimum Gt values are determined for a given polymer dose. Figure 15 shows such a relationship between polymer dosage and Gt. It is proposed that the optimum dosages obtained for the given mixing speeds (as presented previously in Figures 12 and 13) can be plotted on Figure 15 to yield approximate values of Gt for the mixing speeds used in the author's research. This is shown graphically in Figure 16 which shows the curve generated in Figure 15 without data points from which Gt values of 15,000, 30,000, 70,000, 185,000 and 225,000 correspond to mixing speeds of 200, 400, 800, 1200 and 1800 rpm. Although some factors (such as mixing chamber volume) differ between the

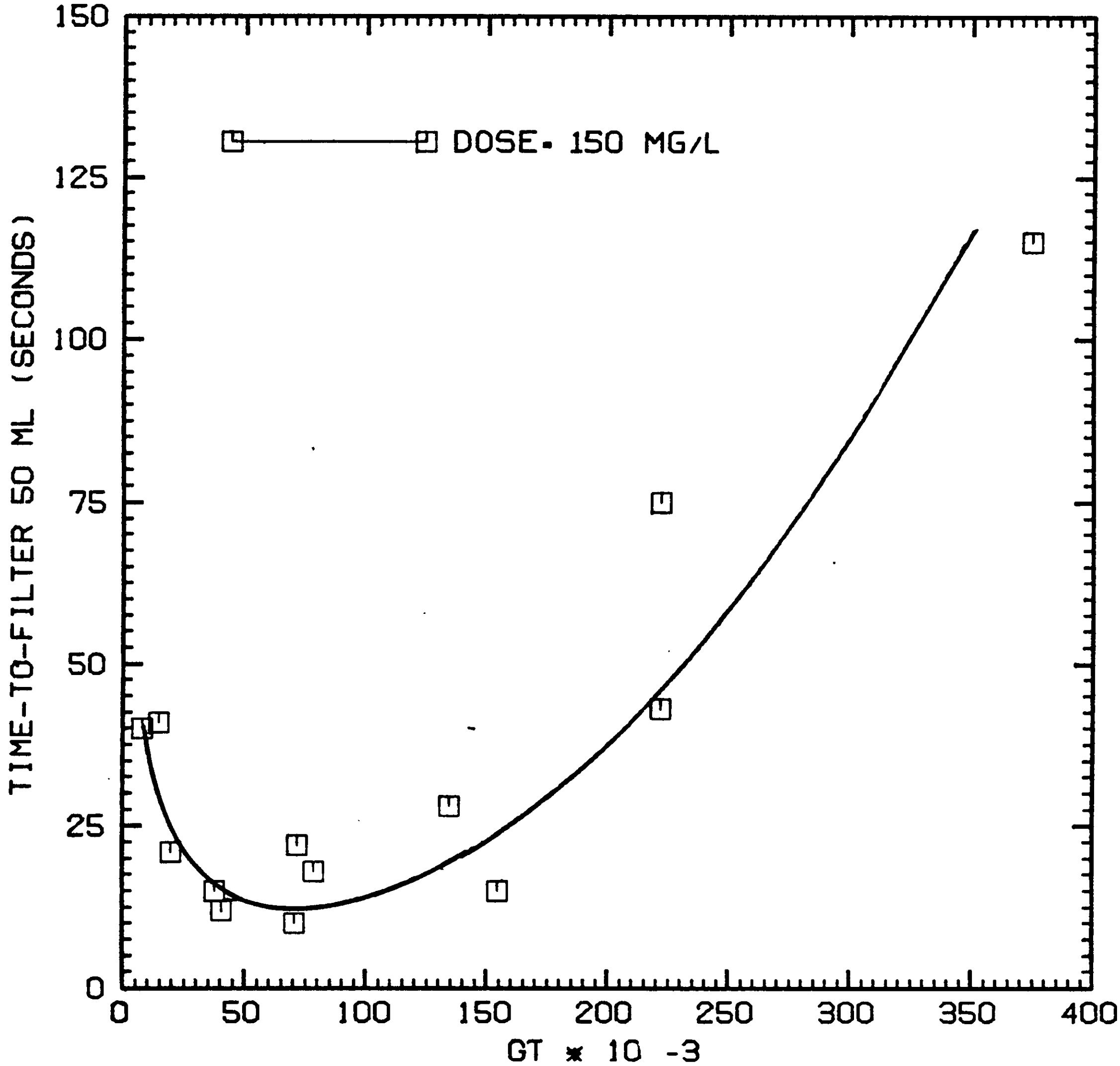


Figure 14. Relationship between time-to-filter 50 ml on a Buchner funnel apparatus and Gt for anaerobically digested sludge. (After Chelf, reference 9)

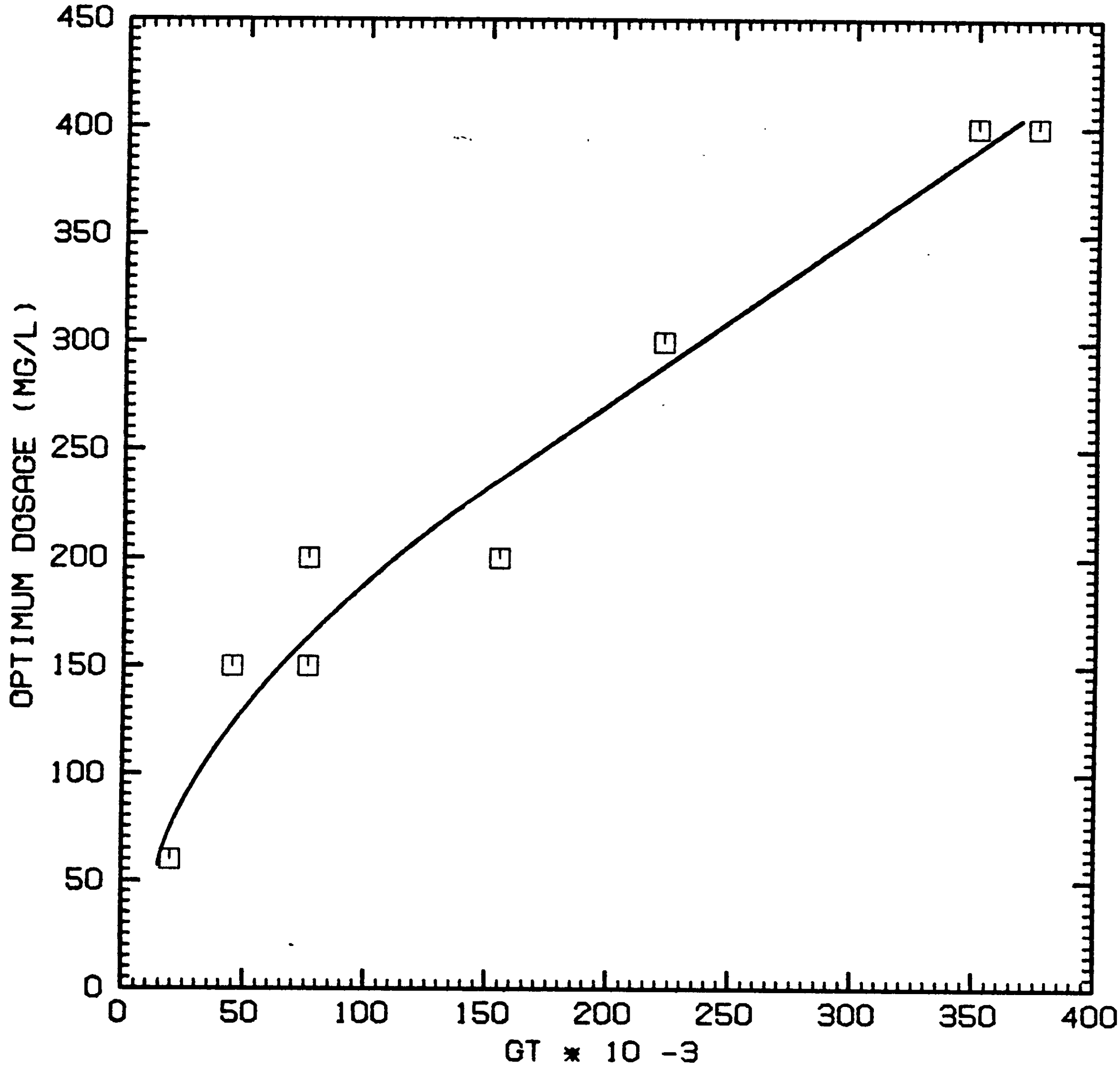


Figure 15. The effect of Gt on optimum polymer dosage for anaerobically digest sludge. (After Chelf, reference 9)

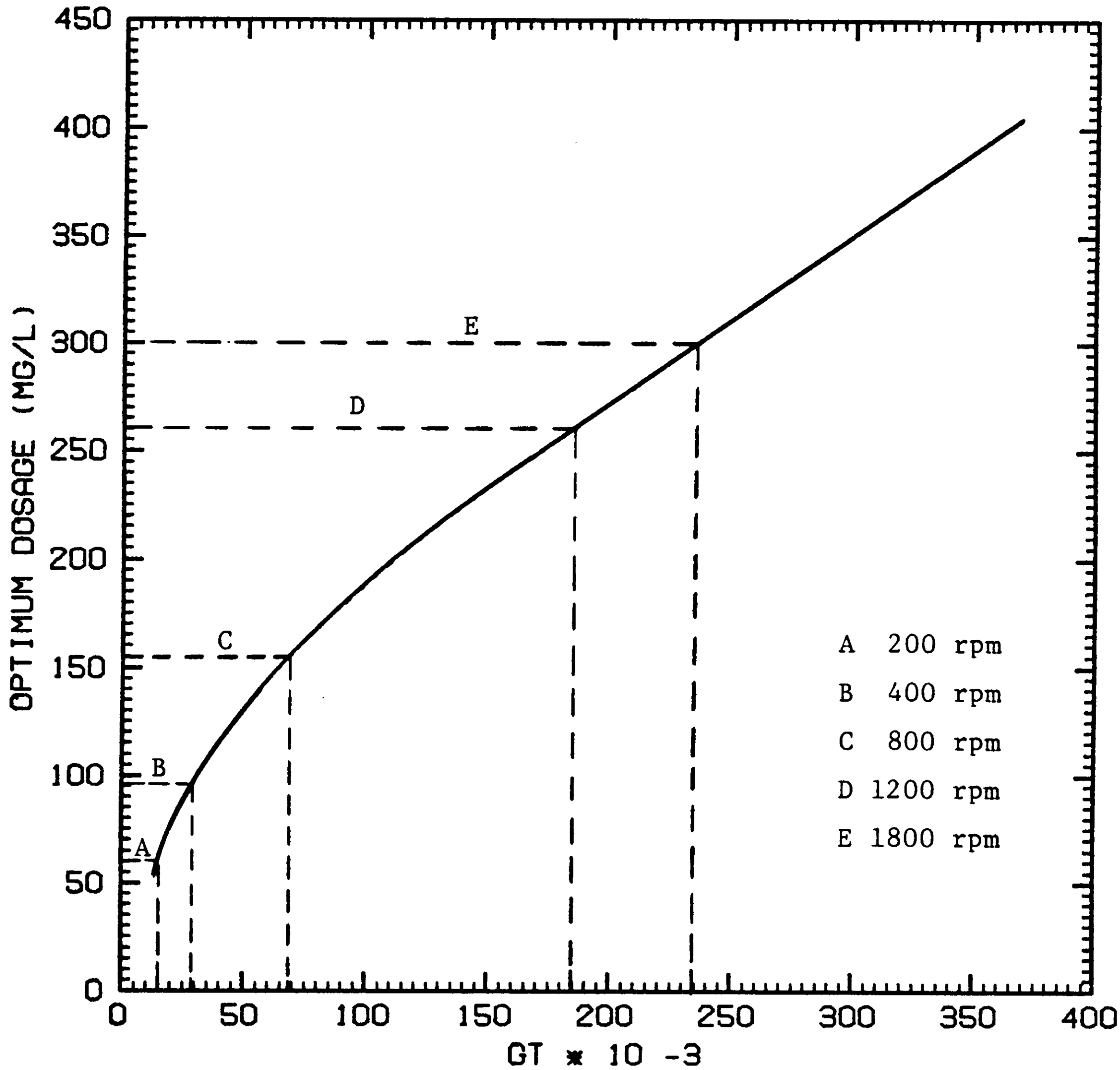


Figure 16. The relationship between time-to-filter 50 ml on a Buchner funnel apparatus and Gt for anaerobically digested sludge, showing the suggested correlation with mixing speed.

author's experiments and Chelf's experiments, the Gt values obtained from Figure 16 can be considered to be reasonable estimates since many factors were, in fact, consistent between both studies.

The second test was performed in order to verify the validity of obtaining Gt values as proposed to the previous test. This was done using a different sludge (alum No. 5), the same total solids (2%), and the same polymer. Reitz (1988) supplied the data presented in Figure 17 (34). This figure shows the relationship between Capillary Suction Time (CST) and Gt. A polymer dosage of 100 mg/L was used to generate data for one curve, while a dosage of 140 mg/L was used to generate data for the second curve. These dosages were selected based on the results presented in Figure 10 for alum sludge No. 5, in which these represented optimum dosages for 400 rpm and 1800 rpm, respectively, in the author's research. It was proposed in this test, that the optimum Gt for each curve (located at the minimum CST value) should correspond to the Gt values obtained in Figure 16 for 400 rpm and 1800 rpm. From Figure 17, optimum Gt values indicated are 35,000 and 240,000 corresponding to 100 mg/L (optimum dose at 400 rpm) and 140 mg/L (optimum dose at 1800 rpm), respectively. One can see that these Gt values very closely predict those obtained in Figure

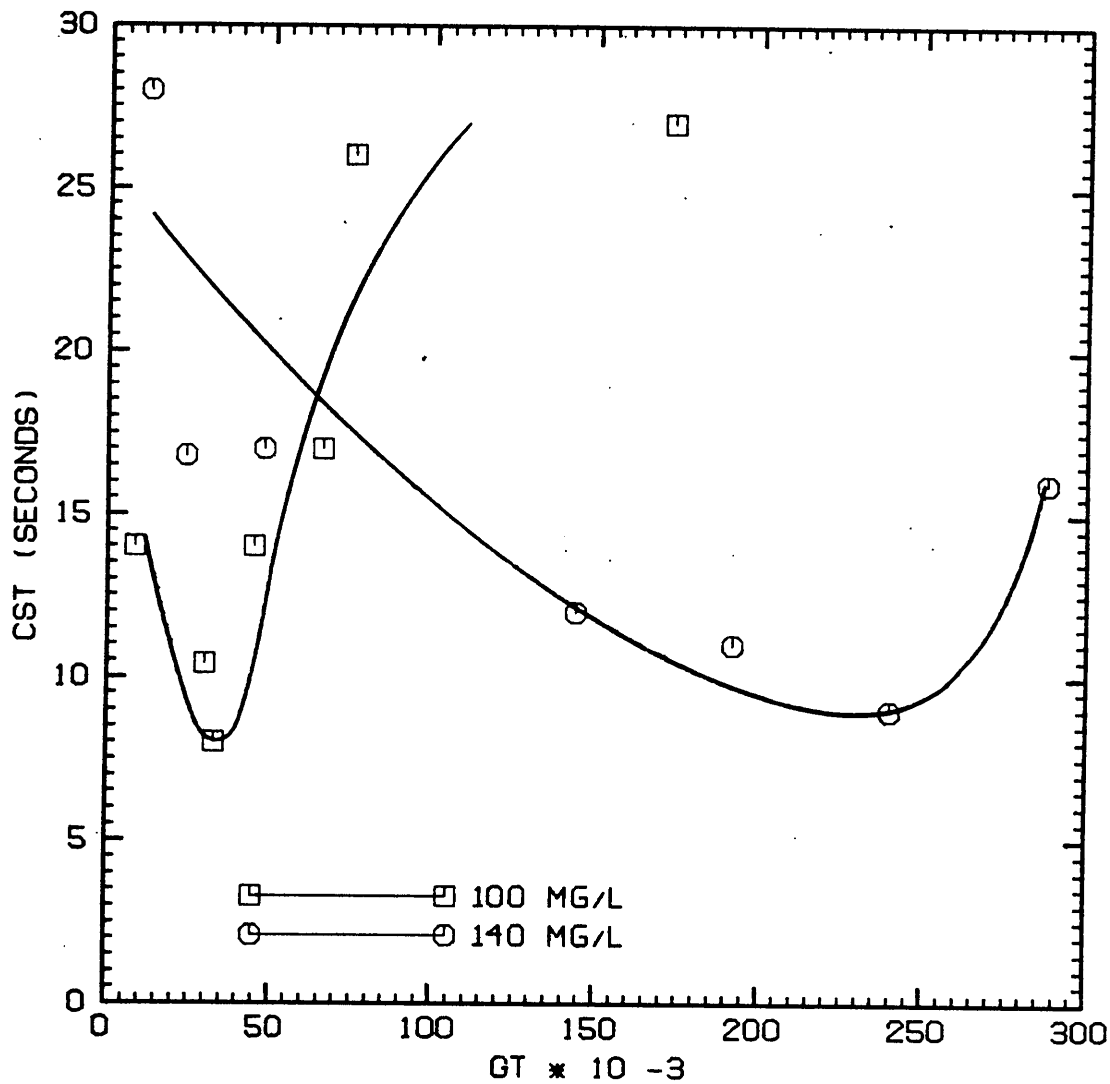


Figure 17. The relationship between CST and Gt using two optimum polymer dosages for alum sludge No. 5. (After Reitz, reference 33)

16. The data obtained in Figure 16 and Figure 17 is presented in Table 1 in which the suggested correlation between Gt obtained in the previously mentioned studies and mixing speed obtained in this study is shown. Table 1 indicates that although two different sludges requiring different polymer dosages were used, similar Gt values were obtained at mixing speeds of 400 rpm and 1800 rpm. Mixing devices are typically characterized by the mean velocity gradient, G. Since mixing times for all experiments conducted in this study remained constant at sixty seconds, G values were obtained by dividing the corresponding Gt values by sixty. G values are presented in the last column in Table 1. The information shown in Table 1 is graphically presented in Figure 18, in which mixing speed is plotted against both G and Gt. While G and Gt values have been established for the mixing apparatus, the difficulty of defining a Gt for the filter press still remains.

2. Reproducibility of Filter Press Results

Prior to performing filter press experiments it was necessary to determine the reproducibility of the results. Three separate trials were conducted, all using alum sludge No. 1, 2% total solids, a previously determined optimum polymer dosage of 50 mg/L and a mixing

TABLE 1. Correlation Between Measured Gt Values From Other Studies and Measured Mixing Speed (rpm) in this Study.

Sludge	Optimum Polymer Dosage (mg/L)	Gt Obtained in Designated Investigation	Mixing Speed Measured in This Study	G (sec^{-1}) Corresponding to Indicated Mixing Speeds
Alum	100	35,000	400	583
	140	240,000	1,800	4,000
Anaerobically Digested	60	15,000	200	250
	95	30,000	400	500
	155	70,000	800	1,167
	260	185,000	1,200	3,083
	300	225,000	1,800	3,750

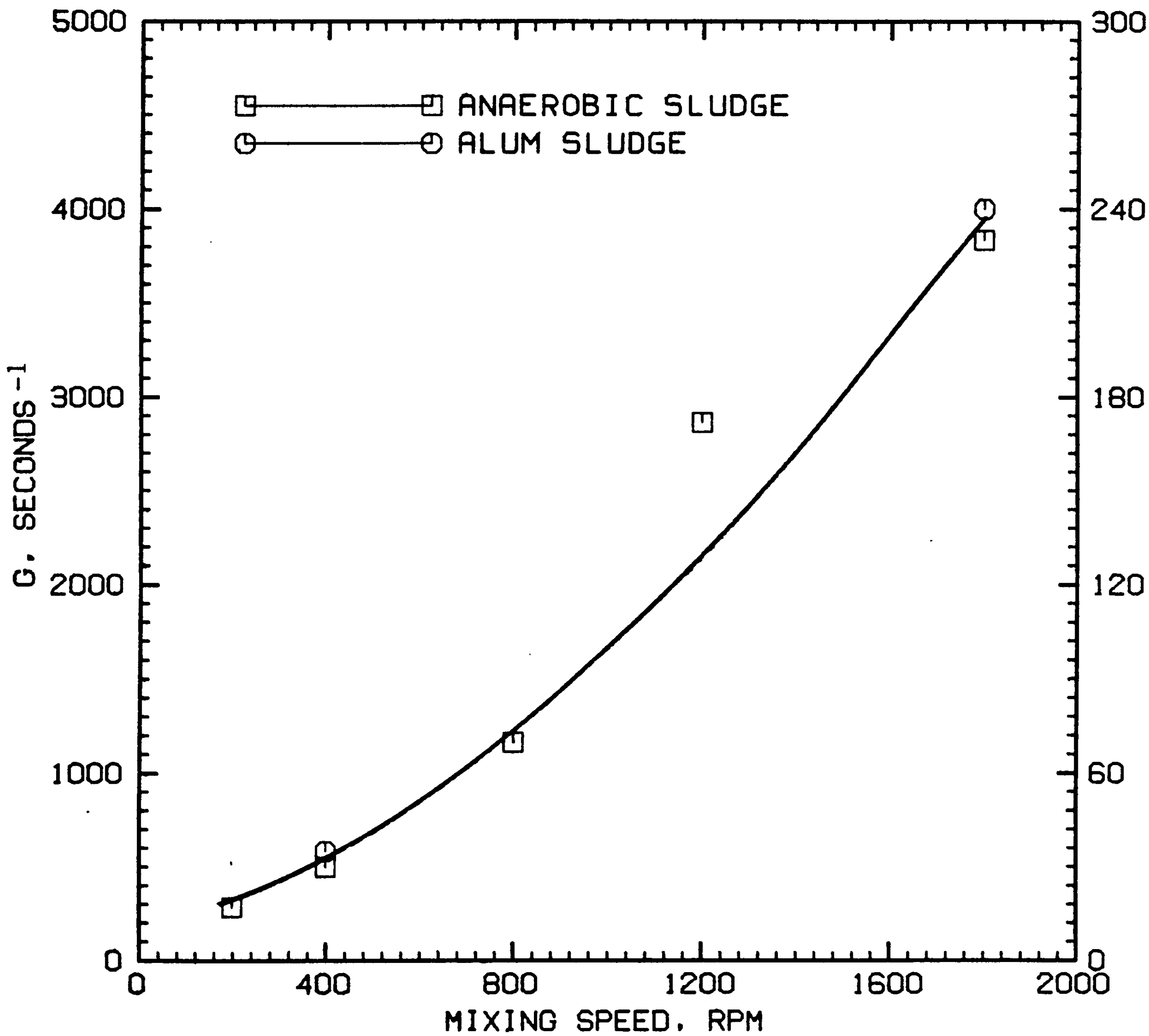


Figure 18. Mixing speed corresponding to optimum dosages at associated G and Gt values.

speed of 400 rpm. A gradual rate of feed pressure application (during start-up procedures) was used for the three trials. As discussed in Chapter II, ten liter volume batches of conditioned sludge were prepared for the filter press of which the time-to-filter 50 mL must correlate to the values obtained during the mixing experiments discussed in the previous section. These results are presented in Table 2, and indicate an acceptable correlation among all three trials.

Data collected to determine reproducibility included filtrate volume per unit time and final cake solids. Results of the three trials are presented in Figure 19 and Table 3. One should note that during Trial No. 1, the experiment was terminated at 105 minutes due to a lack of sludge. In Figure 19, the relationship between cumulative filtrate volume and time is shown for the three filter press trials. Sludge feed was terminated at approximately 230 minutes for Trials No. 2 and No. 3. It is evident that Trials No. 1 and No. 3 yield a very low percent error up to the termination of Trial No. 1. However, the data indicates that Trial 2 is within 10% error over the entire pressing time. This constitutes a reasonable error considering the possible variability not only in filter press operation (i.e., slight changes in the sludge, feed pressure application, and cleanliness of cloths and

Table 2. Correlation of Time-to-Fitler Results Between Conditioning Experiments (1.5 l) and Filter Press Experiments (10.0 l).

Conditioning Experiment	Filter Press Experiment			
Optimum dosage = 50 mg/l	Optimum dosage = 50 mg/l			
Minimum time-to-filter 50ml = 7 sec.	Minimum time-to-filter 50 ml			
	Trial No. 1	First	10 l	7.1
		Second	10 l	7.6
		Third	10 l	8.3
	Trial No. 2	First	10 l	6.5
		Second	10 l	6.0
		Third	10 l	6.0
		Final	10 l	6.5
	Trial No. 3	First	10 l	5.5
		Second	10 l	5.7
		Third	10 l	6.0
		Final	10 l	6.5

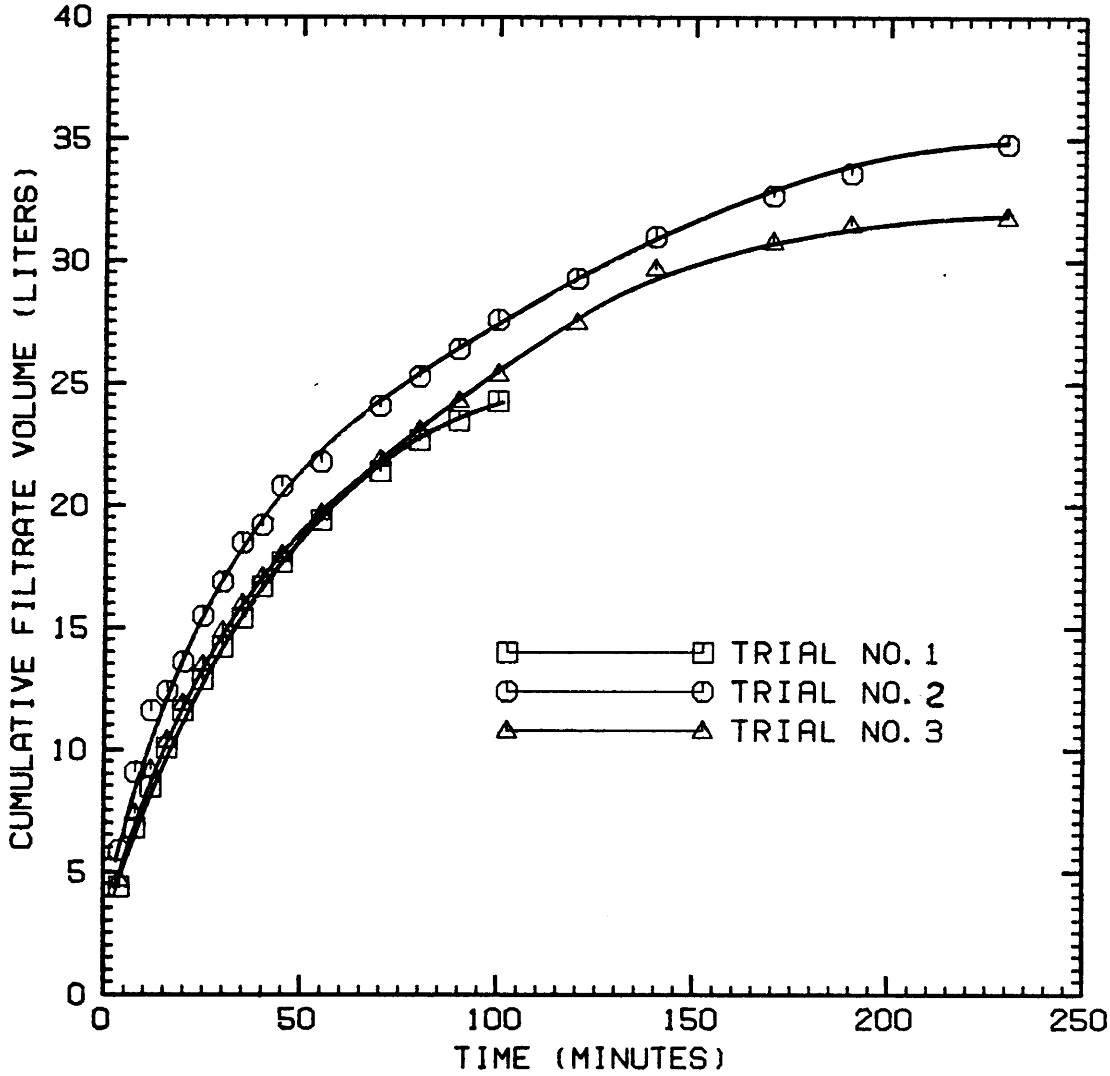


Figure 19. Reproducibility of filter press filtration curves for alum sludge No. 1 using a mixing speed of 400 rpm and a polymer dosage of 50 mg/L.

filtrate channels), but also in prior sludge conditioning.

In Table 3, the final cake solids as a function of location and depth in the filter cake is presented for the three trials. Only data for the full chamber (and not the half chamber) is shown since this is more applicable to full-scale plant concerns. A total composite solids value was not taken for each trial; however, the individual values and layer averages give a good indication of data reproducibility. While Trials No. 2 and No. 3 show very comparable results, the reason for the quite large difference in Trial No. 1 data may be attributed to the early termination of the filter press experiment and subsequent lack of a fully formed cake. Using these results along with the filtration curve results, one can conclude that filter press data can be reproduced within a reasonable error.

3. Effect of Rate of Feed Pressure Application on Filter Press Performance

The results of the rate of pressure application experiments are presented in Figures 20 - 25. As mentioned in Chapter III, filter press start-up procedures were varied in these test to include a slow, gradual increase in the feed air pressure application rate and a rapid instantaneous increase to the maximum design

TABLE 3. Final Cake Solids for Three Identical Filter Press Experiments.

		Percent Total Solids			
		Surface Layer		Middle Layer	
Trial No.	Circumferential Location (degrees)	1 in. Radial Location	3 in. Radial Location	1 in. Radial Location	3 in. Radial Location
1	45	26	31	16	21
	135	29	36	20	30
	225	-	-	-	23
	315	28	34	15	20
		Surface Layer Avg = 31		Middle Layer Avg = 21	
2	45	29	36	18	32
	135	36	39	25	35
	225	38	39	23	36
	315	30	35	21	29
		Surface Layer Avg = 35		Middle Layer Avg = 27	
3	45	28	34	19	29
	135	30	38	23	36
	225	34	39	22	34
	315	30	38	21	21
		Surface Layer Avg = 34		Middle Layer Avg = 26	

pressure. These tests were conducted using both alum and anaerobically digested sludge conditioned at mixing speeds of 400 rpm and 1800 rpm. Unconditioned sludges were also tested. All tests involving the rapid pressure application rate were terminated at fifty minutes. This was done for two reasons. First, at this time a marked difference could be observed in results if, in fact, one existed. This time was selected from experience, in which filter press experiments were run to completion (i.e., low filtrate flow rate). Representative filtration curves showed a constant difference between experiments that remained relatively unchanged starting at approximately fifty minutes and going to completion. This is clearly shown in Figure 19 between Trials No. 2 and No. 3. Secondly, sludge volumes were very limited and it was desired to complete as many studies as possible on a single sludge. The problems of using five separate alum sludge samples has already been established.

Figures 20 - 22 represent the alum sludge results, in which the relationship between cumulative filtrate volume per unit time is shown for both gradual and rapid pressure application rates. Results for the gradual application rate studies were conducted using alum No. 1, while those for the rapid application rate study were conducted using alum No. 4. Two sludges were necessary since sludge volumes were limited, as stated previously. These sludges were chosen since mixing experiments showed similar optimum polymer dosages at the desired mixing speeds, and thus, it was thought that they were similar (see Figure 11).

In Figure 20, results for the unconditioned sludge are presented, in which it appears that the gradual application rate produces better results. Figure 21 and Figure 22 show results for mixing speeds of 400 rpm and 1800 rpm, respectively. While it appears that the gradual application rate produces better results in both cases, one must consider that the difference shown indicates less than a 10% increase for both mixing speeds which is in the range of experimental error for tests of like conditions (described in the previous section).

Figures 23 - 25 represent the anaerobically digested sludge results, in which the relationship between cumulative filtrate volume and time is shown for both gradual and rapid application rates. In all three figures, it appears that the gradual application rate yields better results; however, the differences shown in Figure 23 and Figure 25 only indicate approximately a 10% increase. Figure 24, representing results using a mixing speed of 400 rpm, shows a marked increase in performance using a gradual application rate.

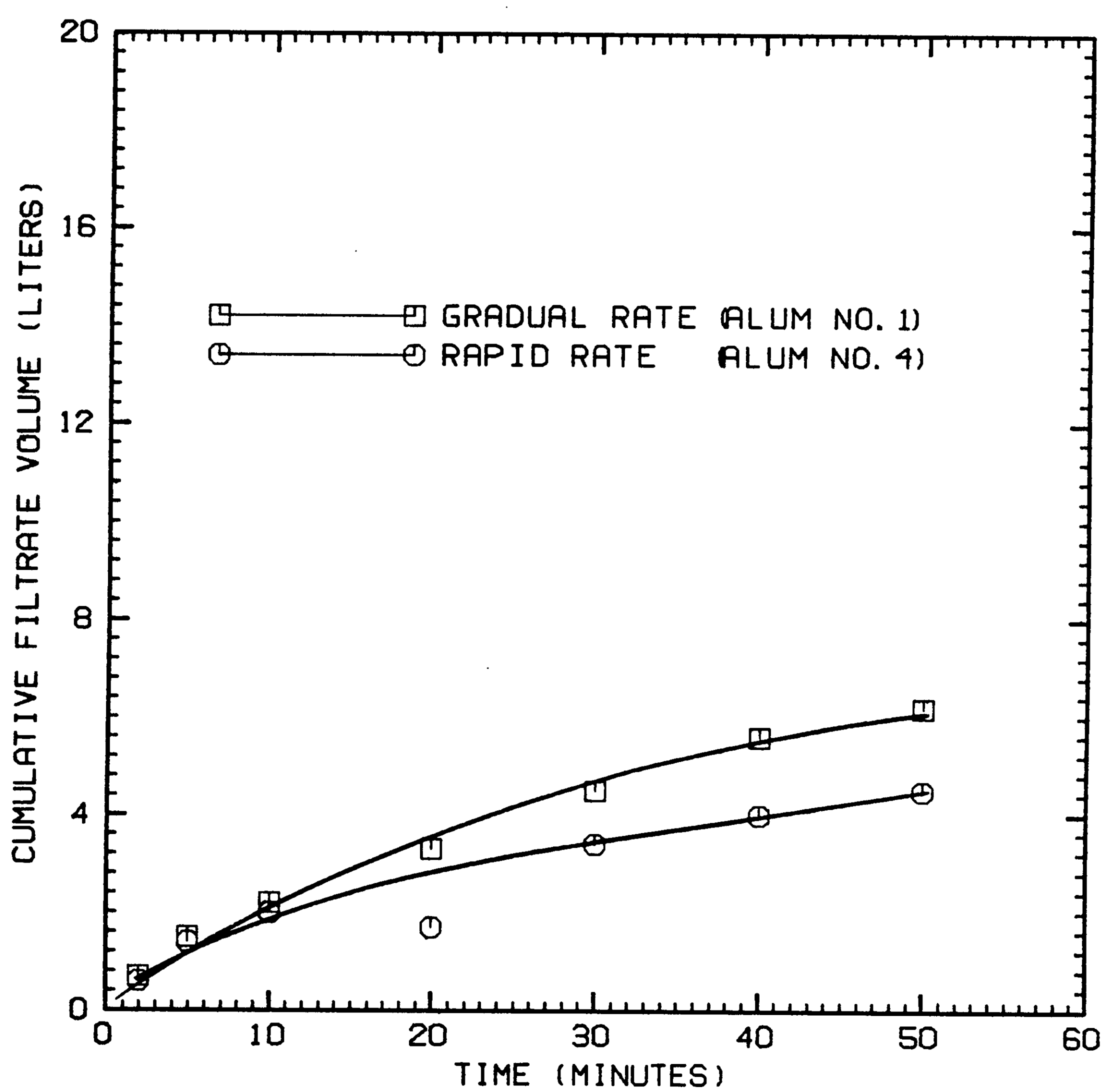


Figure 20. The effect of the changing rate of feed pressure application on filter volume for a filter press using unconditioned alum sludge.

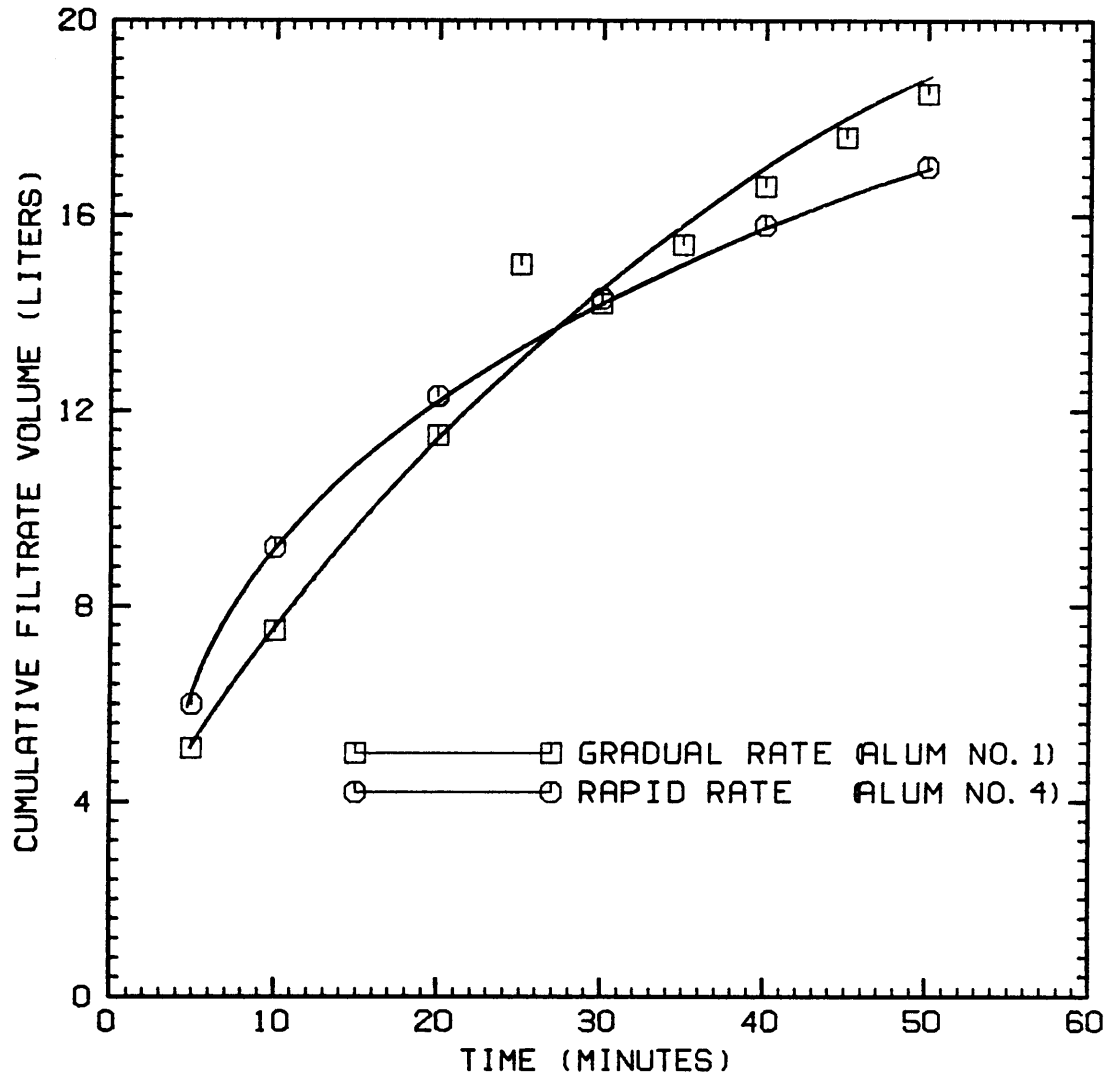


Figure 21. The effect of the changing rate of feed pressure application of filter volume for a filter press using conditioned alum sludge mixed at 400 rpm. The polymer dosages used are 50 mg/L for alum No. 1 and 30 mg/L for alum No. 4.

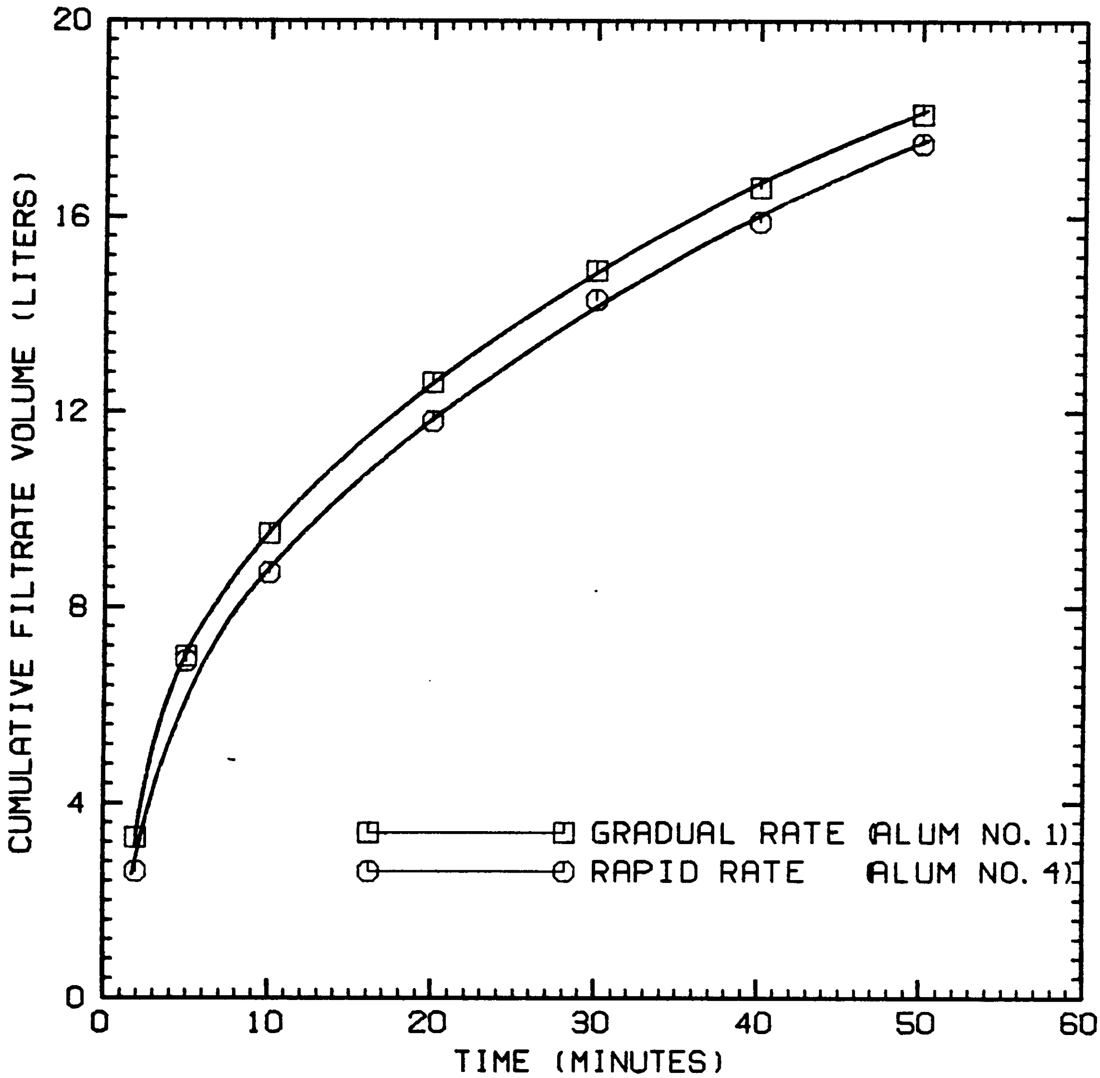


Figure 22. The effect of the changing rate of feed pressure application of filter volume for a filter press using conditioned alum sludge mixed at 1800 rpm. The polymer dosages used are 100 mg/L for alum No. 1 and 80 mg/L for alum No. 4.

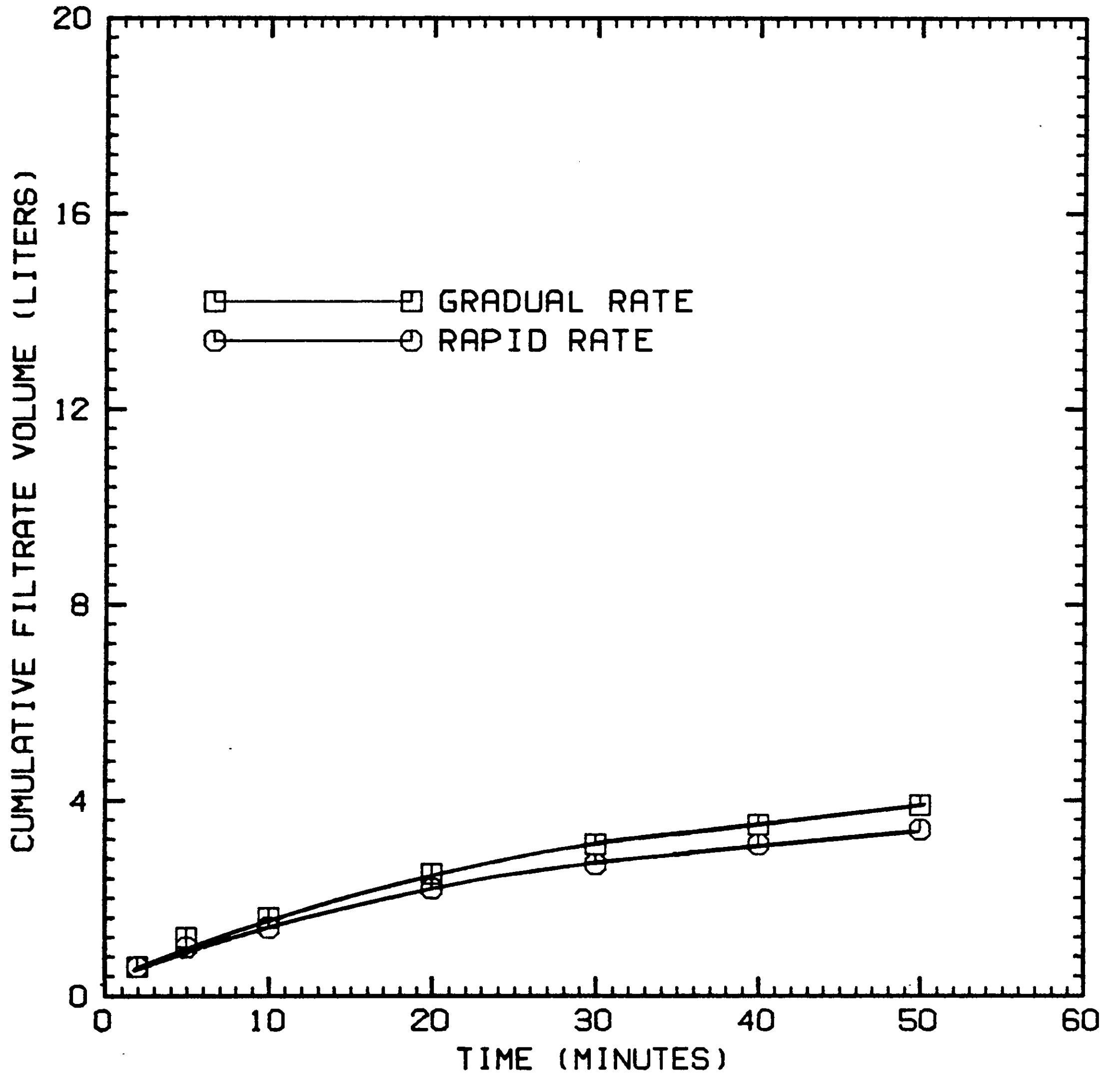


Figure 23. The effect of the changing rate of feed pressure application of filter volume for a filter press using unconditioned anaerobically digested sludge.

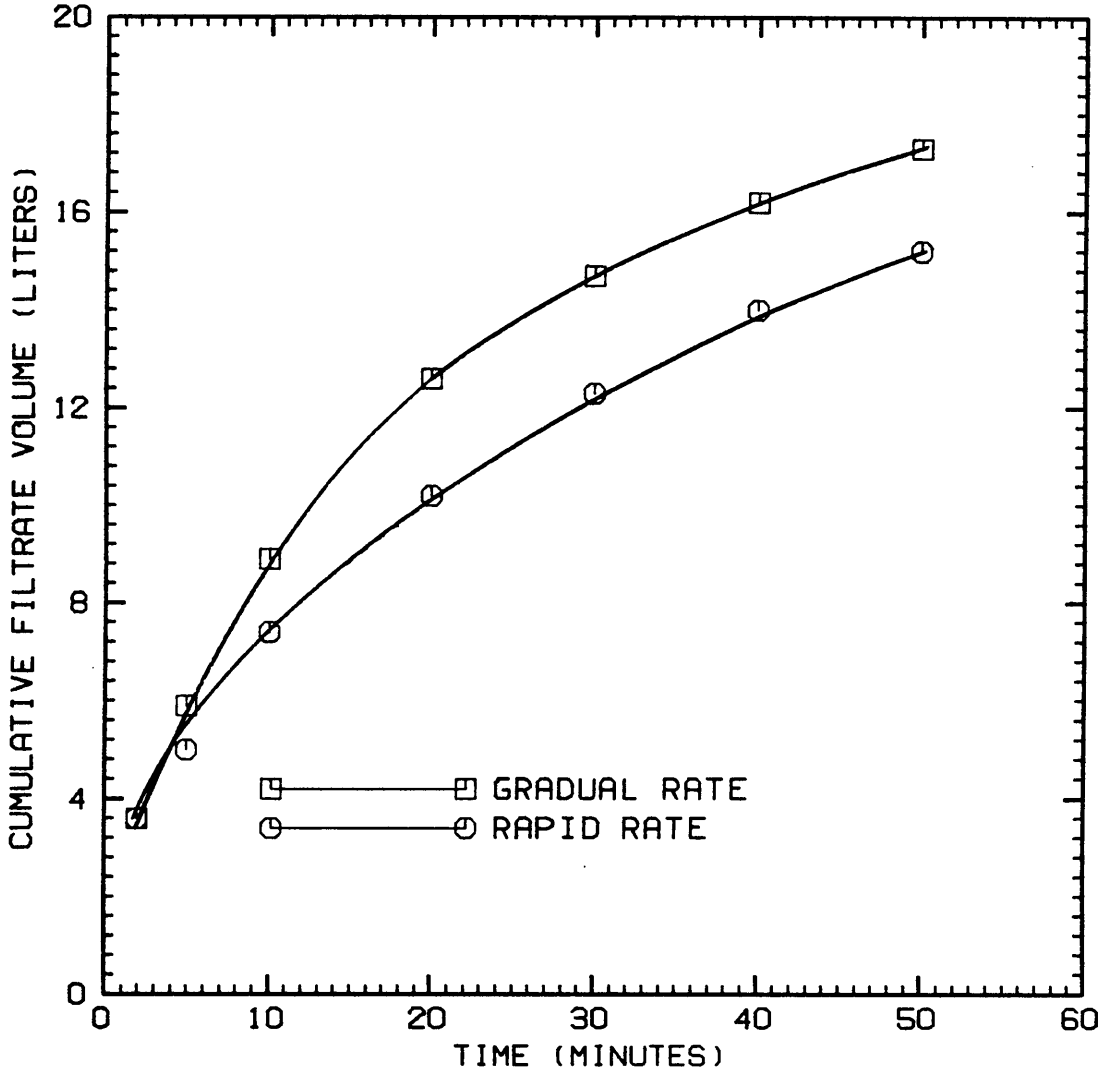


Figure 24. The effect of the changing rate of feed pressure application of filter volume for a filter press using conditioned anaerobically digested sludge mixed at 400 rpm. The polymer dosage used is 95 mg/L.

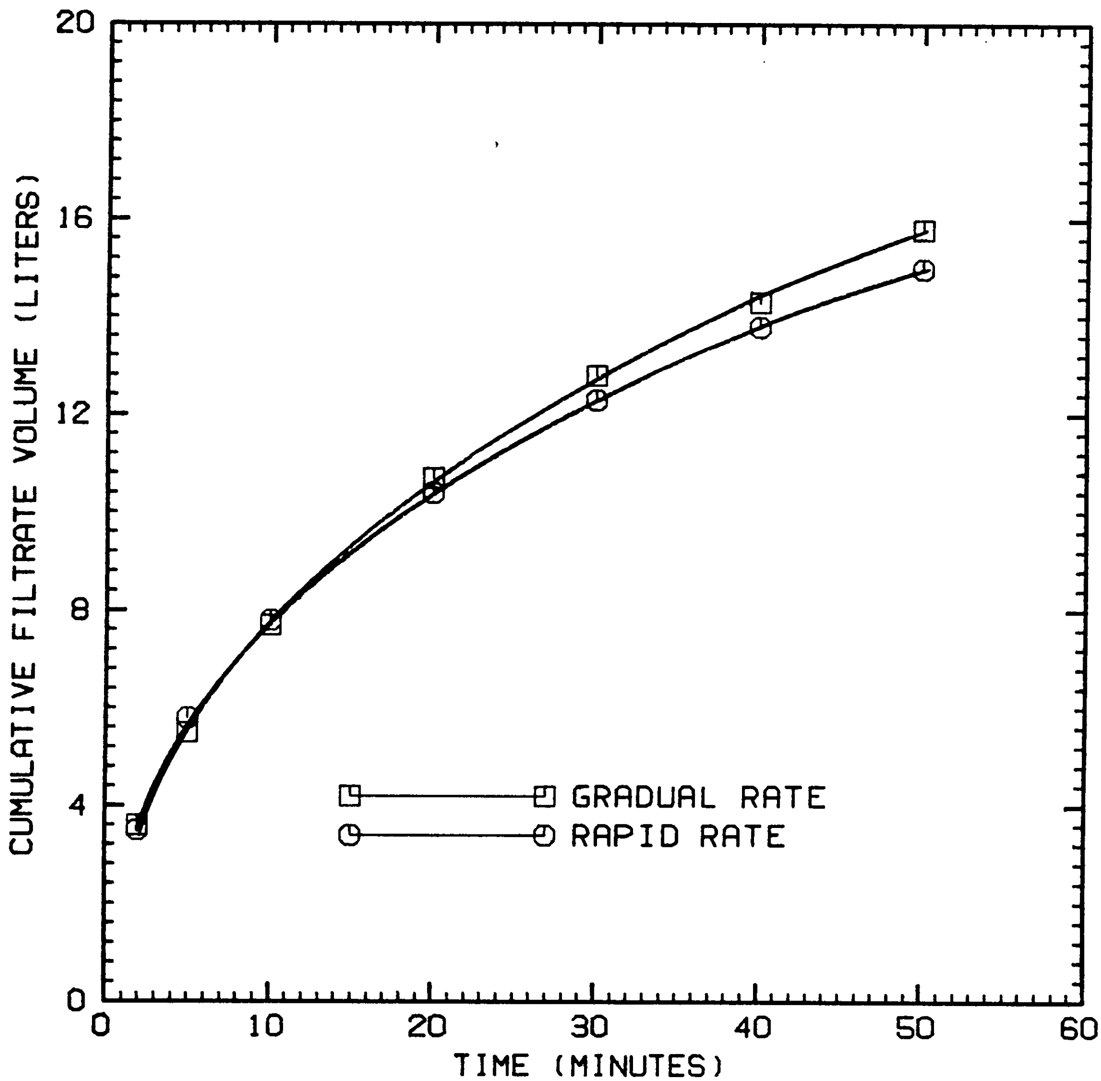


Figure 25. The effect of the changing rate of feed pressure application of filter volume for a filter press using conditioned anaerobically digested sludge mixed at 1800 rpm. The polymer dosage used is 300 mg/L.

Since a rapid feed application rate introduces the sludge more quickly into the filter press chambers, it was assumed that higher shear forces may be generated than in a gradual application rate condition. If so, higher G (or Gt) values would be generated. One may assume that sludge conditioned using a high Gt value may be relatively unaffected by feed application rate since the sludge particles may have been sheared adequately during conditioning to simulate either shear condition (i.e., rapid or gradual application rate). Figure 22 and Figure 25, both representing a high shear mixing condition (1800 rpm), indicated little difference between rapid and gradual rate filtration curves.

However, at a lower shear condition (during mixing), one may expect to find a larger difference in filtration curves, if the mixing speed used does not adequately simulate the shear conditions in the filter press at either application rate. From Figure 21 and Figure 24, one may conclude that sludge conditioned at 400 rpm better simulates the shear conditions generated in the filter press by a gradual application rate than at a rapid rate. The rapid application rate may reduce press performance by initially shearing large agglomerated flocs into smaller flocs.

In these two instances it can be said that with this particular combination of cloth, coagulant and sludge, better results are generally obtained using a gradual pressure application rate. As mentioned earlier, Baskerville et al. (1971), in a similar study noted that a gradual application rate yielded a filtrate lower in suspended solids, a more handleable sludge, and less cloth blinding (2). Data of this type were not collected in this research.

4. Determination of Filter Press Gt

Many of the studies relating to high-stress conditioning as presented in this author's review of the literature concluded that the mixing intensity (G) during sludge conditioning should simulate the shearing forces experienced in dewatering equipment. It has been suggested that substantial shearing forces exist in some mechanical equipment that can cause deterioration in sludge flocs having been conditioned using a low shear mixing regime. Dewatering equipment may produce a range of shear values depending upon the type of equipment and operation, however, assigning a G or Gt value to these conditions would be a useful endeavor. Doing so would allow for a comparison to those Gt values produced during conditioning, thus, facilitating the upgrading of the existing mixing equipment or even the selection of new equipment. In this section optimal filter press performance is shown to be achieved using a specific mixing intensity during sludge conditioning.

It was hypothesized that the filter press would perform optimally if a conditioned sludge was introduced that was mixed at an intensity that simulated the stress levels in the filter press. Knowing the Gt associated with this particular mixing regime, one can assume that this Gt value applies to the filter press, as well. This study used two different sludges optimally conditioned at various mixing intensities presented in the first section of this chapter. As previously mentioned, filter press filtration curves and final cake solids are used to characterize filter press performance for each optimally conditioned sludge. Mixing intensities in the data provided are expressed in terms of mixing speed (rpm) since Gt values were unknown at the time of experimentation. The Gt values previously obtained in this chapter will later be used to ultimately characterize the filter press. A gradual rate of feed pressure application was used for all testing, except where noted.

Results for the alum sludge testing are presented in Figure 26 and Table 4. Figure 26 shows the relationship between cumulative filtrate volume and time for sludges optimally conditioned at various mixing speeds. For alum

No. 1, mixing speeds of 400 rpm and 1800 rpm corresponded to optimum polymer dosages of 50 mg/L and 100 mg/L, respectively. Mixing speeds of 200 rpm and 400 rpm for alum No. 2 corresponded to optimum dosages of 115 mg/L and 105 mg/L, respectively. Data for a filter press trial using unconditioned sludge (alum No. 1) is presented as a reference for comparison with the conditioned sludge trials.

From the filtration curves for alum No. 2 presented in Figure 26, one can see that the sludge conditioned at 400 rpm produced a greater filtrate volume per unit time (over 16%) than that conditioned at 200 rpm. Results for alum No. 1 indicate that sludge conditioned at 400 rpm also produced a greater filtrate volume per unit time (approximately 10%) than that conditioned at 1800 rpm. The filtration curve representing the 400 rpm trial for alum No. 1 is that of Trial No. 3 as presented in Figure 8. While the differences in both sets of experiments presented in Figure 26 may not appear to be substantial, especially considering the previously discussed errors found in the reproducibility studies (less than 10%), one must consider other factors when determining which mixing speed is best suited for the filter press.

Table 4 presents the final cake solids data as a function of location and depth for the four filter press

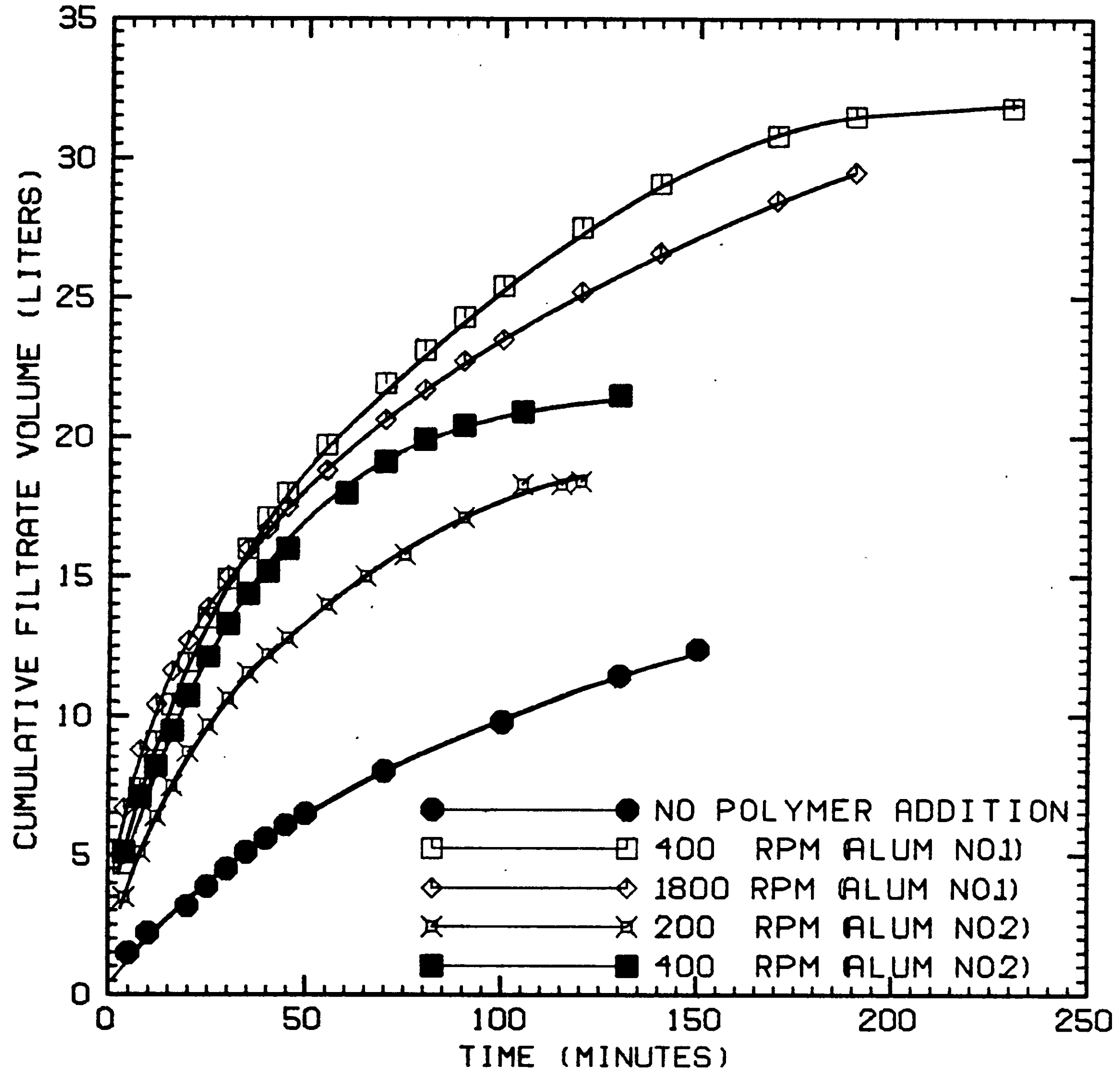


Figure 26. The effect of conditioning mixing speed on filtrate volume from a filter press for optimally conditioned alum sludge.

trials of conditioned alum sludge shown in Figure 26. Again, the data shown represents that of the full chamber of pressed sludge and not that of the half chamber. It should be noted that a composite solids sample for each chamber may have proven more applicable in this study; however, layer averages will be used for comparison purposes.

For alum No. 2, the surface layer averages indicate that the 400 rpm trial produced an average solids that was 15% greater than that of the 200 rpm trial, while the middle layer averages indicated over an 11% increase in solids averages. For alum No. 1, the 1800 rpm trial produced an average solids that was 3% and 8% greater than that of the 400 rpm trial for both the surface and middle layer averages, respectively. In summary, filter press performance, as indicated by both total filtrate volume per unit time and final cake solids, for the 400 rpm trial produced results greater than 15% over those for the 200 rpm trial. Filter press performance for the 400 rpm and 1800 rpm trials indicated results that were less than a 10% difference between the two trials.

From data presented in Figure 26 and Table 4 one can conclude that inferior filter press performance is observed when using the alum sludge (No. 2) optimally conditioned at a mixing speed of 200 rpm, as compared with

TABLE 4. Final Cake Solids for Filter Press Trials Using Alum Sludges Conditioned at Mixing Speeds of 200 rpm and 400 rpm (Alum No. 2) and 400 rpm and 1800 rpm (Alum No. 1).

Sludge	Mixing Speed (rpm)	Circumferential Location (degrees)	Percent Total Solids: Surface Layer, 1 in. Radial Location	Surface Layer, 3 in. Radial Location	Middle Layer, 1 in. Radial Location	Middle Layer, 3 in. Radial Location
Alum No. 2	200	45	13	21	11	21
		135	15	25	13	21
		225	16	26	26	22
		315	11	29	11	21
			Surface Layer Avg = 20		Middle Layer Avg = 18	
Alum No. 2	400	45	18	25	15	22
		135	23	26	17	25
		225	22	28	17	24
		315	17	27	18	24
			Surface Layer Avg = 23		Middle Layer Avg = 20	
Alum No. 1	400	45	28	34	19	29
		135	30	38	23	36
		225	34	39	22	34
		315	30	38	21	21
			Surface Layer Avg = 34		Middle Layer Avg = 26	
Alum No. 1	1800	45	31	39	24	34
		135	36	36	23	36
		225	36	36	19	36
		315	32	36	20	36
			Surface Layer Avg = 35		Middle Layer Avg = 28	

results obtained for optimally conditioned alum sludge (No. 2) at a mixing speed of 400 rpm. This can be explained in terms of floc deterioration with respect to internal shear forces developed in the filter press. It is possible that the G (or Gt) values generated during conditioning at 200 rpm are too low to simulate those encountered during dewatering. It appears that a mixing speed of 400 rpm during sludge conditioning may better simulate the conditions encountered during filter press operation. However, when considering the data for the 400 rpm and 1800 rpm trials (alum No. 1), it becomes difficult to conclude which condition better simulates that of the filter press since both sets of results are so similar. It may be possible that the shear forces generated during filter press operation can be adequately simulated within a range of mixing speeds, starting at 400 rpm. If so, optimum filter press performance can be observed when using any of the mixing regimes for conditioning in this range. One must note, however, that the mixing regime requiring the least polymer dosage would obviously be chosen for economic reasons. In this case, polymer requirements at 400 rpm were half of those at 1800 rpm, and thus a mixing apparatus using 400 rpm would obviously be selected to optimize press performance and minimize operational costs.

Differences in cake solids between the 400 rpm and 1800 rpm trials were observed even though the respective filtration curves yielded very similar results. It may be possible that the floc particles obtained by mixing at 1800 rpm were more compact and, therefore, more water was removed during pressing. This would yield a cake higher in percent solids than that formed with the larger size flocs produced in a lower shear environment during the 400 rpm trial.

Results for the anaerobically digested sludge are presented in Figure 27 and Table 5. Figure 27 shows the relationship between cumulative filtrate volume and time for sludges optimally conditioned at various mixing speeds. Data for a filter press trial using unconditioned sludge is, again, presented as a reference for comparison with the curves generated for the conditioned sludge trials. Mixing speeds of 200, 400 and 1800 rpm corresponded to optimum polymer dosages of 65, 90, and 300 mg/L, respectively. The similarities in filtration curves presented in Figure 27 indicates that filter press performance may not be effected by sludge conditioned at mixing speeds of 200, 400 or 1800 rpm.

It becomes necessary to evaluate cake solids data to determine if, in fact, filter press performance is affected by high-stress conditioning using mixing speeds

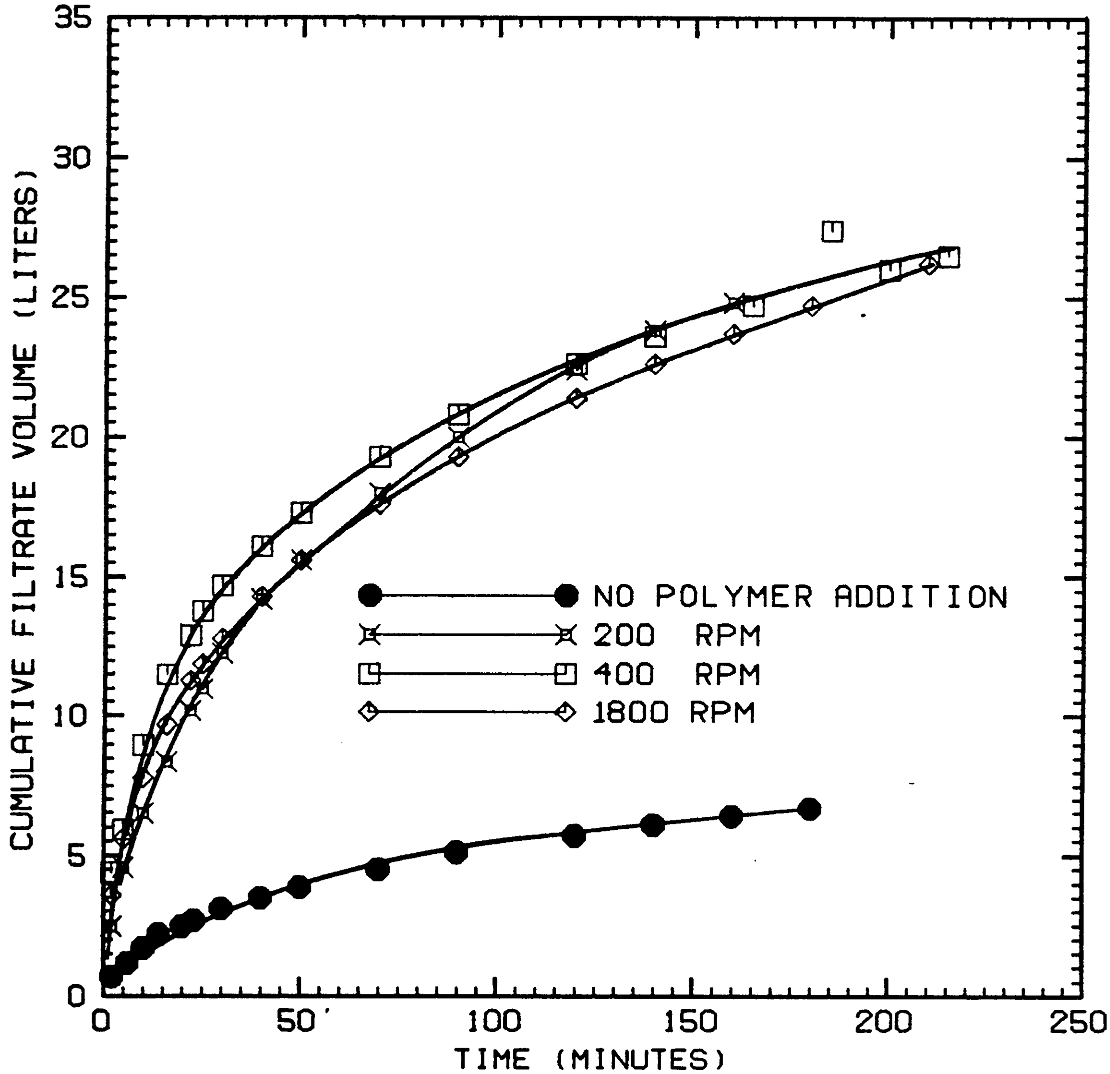


Figure 27. The effect of conditioning mixing speed on filtrate volume from a filter press for optimally conditioned anaerobically digest sludge.

of 200, 400 and 1800 rpm. Table 5 presents the final cake solids data as a function of location and depth for the three filter press trials of conditioned anaerobically digested sludge shown in Figure 27. Again, only full chamber solids data are presented. From the surface layer averages given one can see that the 1800 rpm trial produced an average solids that was 27% greater than that of the 200 rpm trial and 10% greater than that of the 400 rpm trial, while the 400 rpm trial produced an average solids that was 15% greater than the 200 rpm trial. From the middle layer averages given one can see that the 1800 rpm trial produced an average solids that was 23% greater than that of the 200 rpm trial and 17% greater than that of the 400 rpm trial while the 400 rpm trial produced an average solids that was 5% greater than that of the 200 rpm trial. In summary, little difference in filter press performance can be observed from the filtration curves of the three mixing speeds used in Figure 27, since less than a 10% difference in results was noted. However, from Table 5, one can see that the final cake solids content increased greater than 10% (except for the middle layer averages for the 200 and 400 rpm trials) as mixing speed increased from 200 rpm to 1800 rpm.

When comparing these results with those from the alum sludge testing, it appears that floc deterioration

TABLE 5. Final Cake Solids for Filter Press Trials Using Anaerobically Digested Sludge Conditioned at Mixing Speeds of 200, 400 and 1800 rpm.

		Percent Total Solids			
		Surface Layer		Middle Layer	
Mixing Speed (rpm)	Circumferential Location (degrees)	1 in. Radial Location	3 in. Radial Location	1 in. Radial Location	3 in. Radial Location
200	45	24	30	22	21
	135	24	27	23	21
	225	26	28	22	22
	315	-	-	22	21
		Surface Layer Avg = 26		Middle Layer Avg = 22	
400	45	26	38	22	23
	135	25	36	23	24
	225	24	29	23	24
	315	25	40	23	23
		Surface Layer Avg = 30		Middle Layer Avg = 23	
1800	45	22	36	19	28
	135	27	41	26	30
	225	32	39	27	31
	315	30	40	22	30
		Surface Layer Avg = 33		Middle Layer Avg = 27	

caused by the possible high shear condition in the filter press plays less of a role in filter press performance using anaerobically digested sludge conditioned at 200 rpm. However, better press performance is definitely observed at 400 rpm and 1800 rpm for both sludges. Differences in cake solids obtained in this study, again, may be explained by the discussions presented earlier for the alum sludge results. Although filtration curves remain very similar, floc particle size and resultant floc compaction within the filter press may account for the differences observed in cake solids data. From the solids data presented in Table 5, one may conclude that the 1800 rpm trial produced the highest cake solids and is, therefore, the optimum mixing speed. This may be true if one only considers these results. However, it is crucial to consider, once again, polymer requirements with respect to optimum filter press performance. For this sludge, using a 45% greater polymer dosage at a mixing speed of 400 rpm (over that at 200 rpm) will produce a greater filtrate volume while maintaining over a 10% increase in cake solids. However, three times the polymer requirements are needed at a mixing speed of 1800 rpm to produce similar results. Therefore, a mixing speed of 400 rpm may be chosen to produce good filter press results while minimizing operational costs.

5. Verification of Filter Press Gt

It was necessary to test one final sludge to determine if, in fact, a mixing speed of 400 rpm produced good results comparable with those of the other two sludges. This study used aerobically digested sludge (1% solids) at mixing speeds of 400 rpm and 1800 rpm. In Figure 28, results of the mixing experiments used to determine optimum dosages are presented, showing the relationship between time-to-filter 50 mL and polymer dosage. From the 400 rpm curve shown in this figure, three dosages were selected for filter press trials representing an optimum dosage (100 mg/L), a sub-optimum dosage (25 mg/L), and an overdose (350 mg/L). From the 1800 rpm curve shown, a sub-optimum dosage (40 mg/L) was chosen for a filter press trial. Filter press trials were terminated at fifty minutes for reasons previously described and therefore, only filtration curves are used to characterize press performance.

It was hypothesized that if a filter press trial using optimally conditioned sludge mixed at 400 rpm could produce good results similar to those of the other sludges than this condition would represent an optimum level of performance for the filter press as suggested by previous results. Also, the testing of underconditioned and

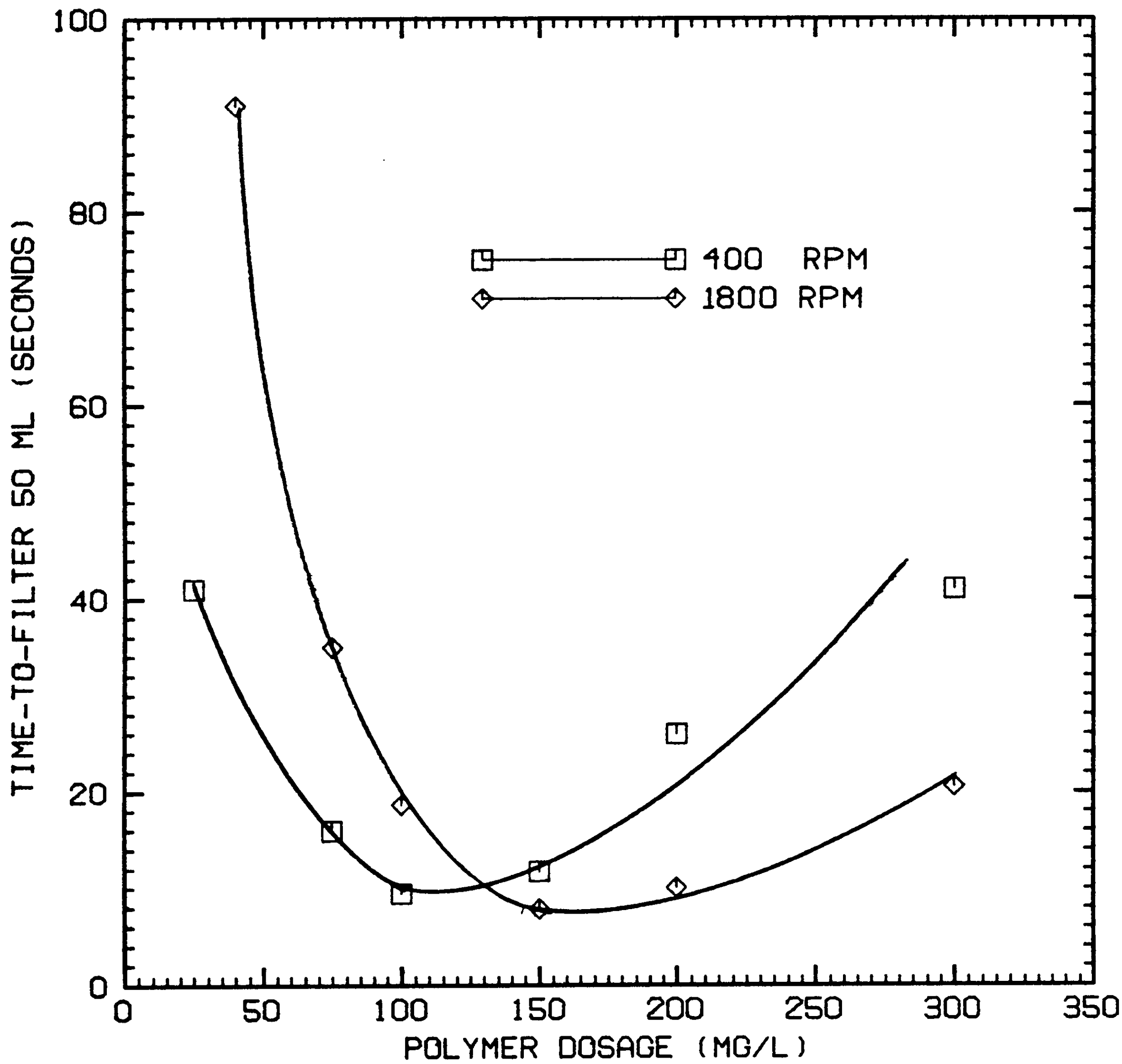


Figure 28. Relationship between time-to-filter 50 ml on a Buchner funnel apparatus and polymer dosage using various mixing speeds for aerobically digested sludge.

overconditioned sludges would provide information on filter press response to these conditions while serving a reference for the suggested optimally conditioned trial (at 400 rpm). A filter press trial using unconditioned sludge is also provided as a reference. Figure 29 shows the filtration curves obtained for the above mentioned filter press trials. As one can see the optimally conditioned 400 rpm trial produces far superior results, as expected, and the total filtrate volume obtained at fifty minutes is very similar to that obtained with the two other sludges (see Figure 26 and Figure 27). Also, not that the over conditioned sludge trial (at 400 rpm) produces better results than both of the underconditioned sludge trials (400 rpm and 1800 rpm). Although these results are inferior to those of the optimally conditioned sludge trial, this shows that using a sub-optimum dosage during conditioning is more detrimental than using an overdosed sludge in terms of filter press performance.

From the results presented for the three sludges using the indicated mixing intensities, one can conclude that filter press performance can be optimized using a mixing speed of 400 rpm. While a practical range of mixing speeds around 400 rpm would probably yield similar optimum results, a Gt value of around 32,000 rpm best characterizes this condition. Suggested Gt values

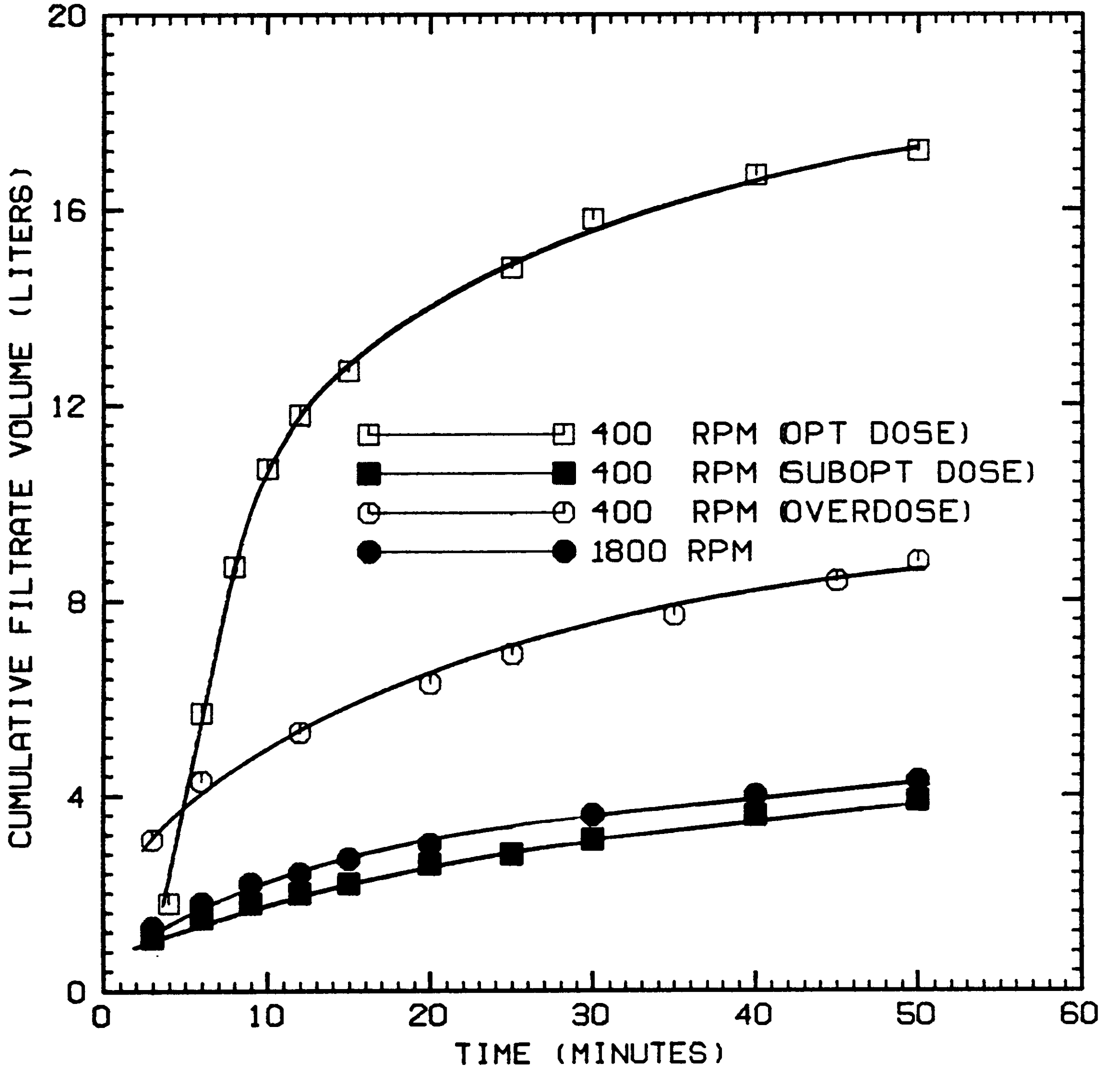


Figure 29. The effect of conditioning mixing speed and polymer dosage on filtrate volume from a filter press for aerobically digested sludge.

corresponding to mixing speeds used in this study were previously discussed and are found in Figure 18. However, due to the similarities in results for mixing speeds of 400 rpm and 1800 rpm, actual shearing forces produced in the filter press may possibly be represented by a larger range of Gt values. If so, total mixing energy inputs between 32,000 and 230,000 may best characterize those conditions produced in the filter press. This excludes any consideration of polymer requirement, which ultimately must be included in a full evaluation of filter press performance and operation.

V. SUMMARY AND CONCLUSIONS

The purpose of this study was to determine the proper method for conditioning sludges for dewatering by a plate and frame filter press. It is generally accepted that many mechanical dewatering systems, such as a filter press, generate a high-shear environment through various mechanisms inherent to the system which can deteriorate sludge flocs that have not been properly conditioned. This leads to poor filter press performance. Researchers have suggested that mixing intensities used during conditioning should simulate those experienced in the dewatering equipment in order to obtain better equipment performance. Conditioning involving mixing intensities characterized by the mean velocity gradient, (G), or mixing energy input (Gt), may simulate these conditions. In this study optimum polymer dosages were selected for three sludges using mixing speeds of 200, 400 and 1800 rpm. These "optimally" conditioned sludges were introduced into the filter press and filter press performance was evaluated according to cumulative filtrate volume per unit time and final sludge cake percent solids. Before these experiments were conducted, other studies were needed to determine the reproducibility of filter press data and how operational procedures affected filter press performance.

Based on the results of this study, the following conclusions were made:

1. Alum, anaerobically digested and aerobically digested sludges can be conditioned to dewater efficiently during filter press dewatering processes.

2. For alum, anaerobically and aerobically digested sludges; as the mixing intensity increases during conditioning so does polymer dose requirements (except for alum sludge conditioned at mixing speeds less than 400 rpm).

3. A gradual rate of feed pressure application rate generally yields better filter press performance with respect to cumulative filtrate volume per unit time than does a rapid rate of application.

4. Filter press performance, characterized by filtration curves and final cake solids, can be optimized using sludge optimally conditioned within a range of mixing speeds between 400 rpm and 1,800 rpm (corresponding to Gt values between 32,000 and 230,000). Filter press performance is substantially decreased when using sludge conditioned at a mixing speed of 200 rpm (corresponding to a Gt value of 17,000). This may be caused by a poor simulation in shear values between mixing apparatus and filter press.

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