Predicting Dewatering Equipment Performance From Laboratory Tests

by

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(ABSTRACT)

This study was undertaken to evaluate the dewatering characteristics of a bench-scale belt filter press and a full-scale screw press, and to develop a suitable bench-scale test to simulate dewatering in a full-scale screw press. Tests were conducted to determine the effect of pressure and shear on dewatering of anaerobically digested, alum, waste activated, and pulp and paper sludges. The first part of the study involved tests conducted on a bench-scale belt filter press. Pressure was varied to develop performance characteristics with respect to cake and filtrate solids, and polymer demand. The second part of the study consisted of mixing intensity tests conducted to evaluate the effect of shear on dewatering in sludges. The third part of the study involved field evaluation of dewatering performance using a full-scale screw press. Tests were conducted to determine the shear produced in the dewatering process and to assess its effect on polymer conditioning requirements.

The tests indicated that the polymer demand produced by the belt filter press simulator and the screw device was minimal. Rather, a substantial polymer demand was observed as a result of shear in the pipes and pumps during full-scale screw press dewatering operations. A combination of a high
speed mixing device and a free drainage tester was capable of predicting polymer conditioning requirements for a full-scale screw press. Individual sludge performance characteristics varied with pressure producing changes in cake solids and filtrate quality.
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INTRODUCTION

The purpose of dewatering is to reduce the sludge volume and improve handling properties, by removing water. The source of the sludge and type of prior treatment and storage influence its dewatering properties. The mechanical dewatering equipment used will depend in part on the sludge characteristics and the ultimate disposal technique.

Laboratory testing is helpful in selecting the conditioning chemical and dosages required for the dewatering system employed. Polymers are frequently used for conditioning prior to dewatering. Selecting the correct polymer dose is an economic necessity and is useful in increasing the efficiency of the dewatering process.

Belt filter presses and screw presses are dewatering devices originally used in the pulp and paper industry. They are devices that are operated as a continuous system to dewater sludges. The belt filter press is one of the devices most commonly used for dewatering wastewater sludges. The sludge is dewatered initially under gravity and subsequently using pressure. The screw press is a recently developed method for dewatering sludges. The sludge receives a gradually increasing pressure as it moves through the unit. This process of expression resembles to some degree high pressure dewatering in the belt filter press. The screw press can dewater over a wider range of pressures, and can attain pressures much higher than that achievable by a belt filter press. A screw press preceded by a gravity filtration device could dewater
sludges much like a belt filter press. For both devices, optimum conditioning is required to suitably dewater sludge.

The study was undertaken to evaluate the effect of pressure on polymer conditioning requirements on a belt filter press and a screw press. The study was also conducted to evaluate the shear produced while dewatering sludge in a screw press. For this study, a laboratory belt filter press simulator and a full-scale screw press were used to evaluate these processes. Several sludges were utilized to investigate the effect of pressure and mixing on their dewatering characteristics. This study was conducted by performing bench-scale dewatering tests and mixing intensity tests. The study was conducted with three proposed objectives:

1. To develop a suitable bench-scale procedure to simulate dewatering in a full-scale screw press.

2. To determine the dewatering characteristics of a bench-scale belt filter press simulator and a full-scale screw press.

3. To evaluate the effect of pressure and shear on dewatering of several sludges.
LITERATURE REVIEW

Literature from three areas related to dewatering of water and wastewater sludges will be reviewed. The polymer conditioning requirements and the effect of mixing intensity on polymer dose will be initially discussed. Filtration and expression processes and their influence on sludge dewatering characteristics will be discussed later.

Polymer Conditioning of Sludge

The dewatering process depends in part on the characteristics of the sludge. These characteristics can be altered by suitably conditioning the sludge. The conditioners that have been most successful in improving the sludge characteristics have been organic polyelectrolytes or polymers. The use of polymers as conditioners has several advantages. They do not create high sludge volumes. Compared to inorganic conditioners, low dosages are required. Further, polymer are easy to handle and they do not reduce the fuel value of the sludge if it is to be incinerated. Polymers are available in liquid and powder forms (1).

The polymers used in dewatering are usually long chain water soluble molecules of molecular weight greater than one million (2,3). Polymers can be classified according to structure, charge, charge intensity and molecular weight (4). Polymers are available in cationic, anionic and nonionic forms. They
function as coagulants in the dewatering process. Coagulation is achieved through charge neutralization and/or interparticular bridging (1 - 5). Charge neutralization is achieved by reducing the electrostatic forces between sludge particles. Interparticular bridging occurs when a polymer chain links across sludge particles. Biological sludges have been indicated to require cationic polymers (2,4). These sludges are anionic in nature and achieve charge neutralization using cationic polymers (4). Chemical sludges responded well with nonionic to slightly anionic polymers (5). Charge neutralization was, however, not considered a prerequisite for effective sludge conditioning (2).

Several researchers have indicated the importance of polymer molecular weight for dewatering sludges (2-5). Polymers come in a large range of molecular weights depending on the application. Low molecular weight polymers are usually more soluble and less viscous than high molecular weight polymers. These polymers are generally used as primary coagulants in a dewatering scheme or in water treatment, and have molecular weights ranging from 20,000 to 100,000 daltons. They have low viscosities, are usually cationic, and can be easily diluted and mixed with water at the application point.

High molecular weight polymers (up to $2 \times 10^7$ daltons) are available in cationic, anionic and nonionic forms. They come as viscous liquids, latex emulsions or in dry powder form. They are usually mixed in water at concentrations of 0.5 to 2% and are very effective in super flocculating the sludge particles (6). For high molecular weight polymers, dose requirements generally decreased with increase in polymer molecular weight (5). High molecular weight polymers were found effective for both chemical (5) and biological sludges (4).
Effects of Mixing Intensity and Polymer Dose on Dewatering

Sludge properties have been shown to change with mixing. Polymer dose, mixing intensity, \((G)\) and mixing time, \((t)\) were parameters shown to affect dewatering rates (7). Mixing intensity was found to be a function of the speed of mixing and the torque imparted while mixing (8). The product of mixing intensity and mixing time or mixing energy input, \(Gt\), was found to be an important parameter governing shear in sludge conditioning (7). Mixing intensity and mixing time acted together to shear sludge during conditioning. For a particular sludge, an optimum polymer dose value, producing best dewatering rates could be found for a particular \(Gt\) range. Polymer demand produced as a result of high shear mixing conditions was compared with dose requirements encountered in high shear dewatering equipment (9).

Novak and O'Brien (5) found that polymer dose requirement was minimum under low mixing conditions. Polymer dose was found to be almost independent of sludge solids concentration. Polymer demand was seen to increase with increase in mixing intensity (4). Also, sludges conditioned under high intensity mixing were shown to resist break up or deterioration into smaller particles.

Novak and Haugan (4) found that polymer application would improve filter press performance. However, they indicated that improved performance would be realized only at the correct polymer dose and mixing. They also found that the jar test under predicted polymer dose requirement when used for predicting dose needed for a dewatering device. They stated that a laboratory test used to investigate polymer dosing requirements for a dewatering device should incorporate the same mixing intensity as the dewatering device. In such a
situation, a jar test would not be suitable for mixing. A high mixing intensity device would have to be used in such a case.

Several researchers conducted mixing intensity tests using a high speed mixer and a capillary suction time (CST) device (7, 10, 11, 12). The mixer was utilized to impart mixing energy while the CST device was utilized to measure the sludge dewatering rate. The variables used were the polymer dose, the mixing intensity and the mixing time. Each study extended the work of the previous researcher. Polymer dose and mixing energy input were found be the most important parameters.

Werle et al. (7) indicated that optimal polymer requirements increased with increase in mixing energy input. They further indicated that for an optimal Gt, any combination of G and t within a range of G and t ratios would provide optimal dewatering results.

Novak et al. (13) found excess polymer application resulted in overdosing. This was attributed to excessive surface coverage and, therefore, charge reversal by the polymer. They concluded that sludges could be conditioned to resist deterioration due to high Gt, and could be effectively dewatered using high shear mechanical dewatering process. They also concluded that polymer selection was important for high mixing energy inputs.

Novak and Bandak (10) found that some sludges were more sensitive to mixing intensity than to mixing time. An exponent of G was considered an appropriate measure of the stability of sludge particles. The mixing requirements to optimally condition sludge were represented by the equation:

\[ G^Xt = K \] (1)
A value of 2.8 was found for this exponent for unconditioned sludge. The value of the exponent decreased to a value of 1.0 with an increase in polymer dose. This indicated that a decrease in the value of the exponent resulted in an increased resistance of the sludge to shear.

Novak and Lynch (11) investigated the effect of shear occurring in a filter cake during mechanical dewatering. They conducted a series of filtration tests using a Buchner funnel apparatus. Results from tests indicated that filtrate moving through a sludge cake created shear in the cake. This shear exerted a polymer demand. They found that polymer requirements increased with an increase in vacuum pressure. They saw a similar response with a high speed mixing device. As seen with previous researchers, they found an increase in polymer demand with increase in mixing energy input. They tried to correlate these two effects together. These results are indicated in Figure 1.

An attempt was made by several investigators to develop a suitable bench-scale method to predict polymer dose for full-scale operation of mechanical dewatering devices. Results from previous investigators indicated a unique optimum dose for a particular range of mixing energy input. These investigators tried to define a mixing energy input for a particular dewatering device. The optimum polymer dose found for that mixing energy input in lab-scale mixing tests could then be used in correlation as the dose required for that dewatering device. This would eliminate expensive testing on a full-scale basis (14).

Zocolla (14) and Lynch (15) tried to find a relation between results from mixing intensity tests and a pilot-scale filter press performance. Zocolla (14) found an increase in polymer dose requirement for the pilot-scale filter press for
Figure 1. Correlation of effect of applied vacuum pressure and Gt on optimal polymer dose of activated sludge. From Novak and Lynch (11).
an increase in mixing intensity during the conditioning step of the test. However, he was unable to find a Gt value specific to the press. Lynch (15) minimized the mixing intensity for conditioning the sludge. He used a mixing energy input of 5,000 during conditioning. For this value of mixing he obtained a Gt value in the range of 15,000 to 40,000 for the pilot-frame filter press. He was also able to find an optimum dose for the pilot-scale filter press using mixing intensity test results. An optimum polymer dose for a mixing energy input of 30,000 was used for dewatering in the pilot-scale filter press.

Reitz (16), Burgos (12) and Schuler (17) similarly investigated conditioning requirements for a belt filter press. Reitz (16) tested for conditioning requirement in the three zones of the belt filter press. He used a wedge zone simulator to test in the gravity zone and the wedge zone of the belt filter press. He utilized a pilot-scale belt filter press to test for polymer dose requirement in the expression zone of the belt filter press. He found that the polymer dose requirement for the three zones of belt filter press operation were essentially the same. This was regardless of the gradual increase in pressure and shear from the gravity zone to the expression zone. He indicated that the polymer requirements for a belt filter press was more a function of superflocculation (large curd-like flocs) rather than energy applied in the dewatering process. He also found the Gt of the belt filter press simulator to be 45,000. This result was found using a Buchner funnel to measure sludge dewatering properties. He indicated that a wedge zone simulator could be adequately used for predicting optimum polymer dose requirements for the belt press simulator.

Schuler (17) found the belt filter press to be a low shear device. He found the Gt for the press to be approximately in the range of 10,000. Result were
obtained using a CST device as a measure of sludge dewatering properties. He also found that mixing energy required to obtain good dewatering rates was a minimum. Mixing intensity value of lower than 500 s\(^{-1}\) was found to be sufficient while conditioning for dewatering. He also indicated that the extent of water removal depended on the type of sludge particles rather than the residence time of the sludge in the pressure zone. He also correlated lab-scale test to full-scale operations and found that the lab-scale study adequately predicted the polymer dose requirement for a full-scale belt filter press.

Similar results were observed by Burgos (12). He found the wedge zone tester was suitable in predicting polymer conditioning requirements for full-scale belt filter presses. He found that the polymer dose requirements for a bench-scale device imparting a Gt between 8,000 and 12,000 could optimize requirements for a full-scale belt filter press. An important conclusion Burgos (12) arrived at was that mixing during conditioning could exert more polymer demand than the expression stage of the belt filter press.

Burgos (12) used a pressure range of between 5 psi and 20 psi. He did not detect a significant polymer demand in the pressure range used. He indicated that the polymer requirement for the gravity zone was similar to the polymer requirement for a belt filter press.

Burgos (12) conducted tests on alum sludge, anaerobically digested sludge and waste activated sludge. For the sludges he used, he did not find any significant increase in polymer demand with an increase in pressure. He found an increase in cake solids with increase in pressure. He also indicated that the cake solids reached a maximum and the filtrate solids reached a minimum for optimum dosing conditions.
Filtration and Expression

Sludge dewatering usually occurs in two stages. These stages can be broadly defined as filtration and expression. These two stages can occur simultaneously or as two separate distinct steps. Filtration and expression occur concurrently when the conditioned sludge is discharged into the dewatering device and the process forces are applied immediately. They occur separately when free liquid is allowed to drain off initially. The removal of free liquid from superflocculated sludge can take place in the dewatering device itself, as usually happens in a belt filter press, or in two independent processes, as can happen with most other dewatering devices.

Gravity filtration in a belt filter press occurs when the conditioned sludge is fed onto the belt, and before it enters the wedge zone of the press (18). It essentially occurs in the form of gravity drainage. The water is allowed to filter through the pores in the filter cloth, as the sludge is conveyed to the next stage of the dewatering process. Filtration occurs as a distinct step when separated from the main dewatering device. A common device used for this purpose is a rotating screen thickener (19). Here the sludge is gently rolled in the body of the thickener to release the interstitial water in the sludge slurry.

Expression occurs when pressure is applied to release water. Expression has become an important method in the dewatering process, as it is usually cheaper than any thermal method of dewatering (20). During expression water is squeezed out from the sludge floc to form a cake. The dewatering process used
in expression depends on the dewatering device. The cake solids concentration achievable during expression also depends on the dewatering device used. Filtration and expression occurring in a belt filter press and screw press is indicated in Figure 2 and Figure 3. Filtration in a belt filter press is a part of the dewatering process. However, in a screw press the filtration step is not necessarily part of the dewatering process.

Expression in a belt filter press occurs in the wedge zone and the compression dewatering stage. In the wedge zone, the belts of the press come together, with the sludge in between forming a firm sludge cake (18). In the compression dewatering stage, the upper and lower belts move relative to each other, exerting a force on the sludge. The pressure can be varied by adjusting the strain on the belt (21).

Expression in a screw press occurs in a continuously fed system of polymer conditioned sludge (20). Pressure is gradually increased as it progresses through the unit. The sludge is forced between a channel formed between a perforated barrel and a rotating screw. The pressure in a screw press can exceed 150 psi before the sludge is discharged from the press (18).

The belt filter press and the screw press dewater using a continuous process. Both use pressure as a dewatering mechanism. The pressure is gradually increased as the polymer conditioned sludge moves along the dewatering equipment. The pressures used can be varied depending on the sludge used and the dewatering required. Although the belt filter press and screw press are two different dewatering processes, they essentially work on a similar concept of gradually increasing pressure along the length of the process in a continuous feed system. The function of applied pressure in a belt filter
Figure 2. Schematic of a belt filter press. From USEPA (1).
Figure 3. Schematic of a screw press. From HIW Company Brochure (22).
press has been evaluated by several researchers (12, 16, 17, 21). These studies generally indicated a minimal effect of pressure on polymer dose required. Information obtained from a screw press process in North Carolina indicated an increased polymer requirement compared to a belt filter press. The common factor promoting dewatering in both these devices was applied pressure. The screw press had the ability to use much higher pressures than achievable in a belt filter press.

Information regarding effects of increased pressure on polymer conditioning requirements is necessary in order to understand the process variables better. A bench-scale mixer and a dewatering device have been used in several studies to investigate polymer conditioning requirements for belt filter press systems (12, 14, 15). The same could also be used for the screw press. Use of increased pressure in the bench-scale tests could help in investigating the effect of pressures on dewatering in belt filter presses and screw presses.

The screw press is a relatively new device used for dewatering sludges. Like the belt filter press, the screw press has been primarily used in dewatering pulp and paper sludge. The use of belt filter press has been expanded for dewatering various different kinds of sludges. Considerable work has been done to understand the process mechanism of the belt filter press. However due to its recent development much research has not been conducted on the screw press. Due to similarities in the dewatering process between the screw press and belt filter press, research carried out on belt filter presses could be used in screw presses. However, independent study is also required to evaluate the screw press. This study is important if the use of the screw press is to be expanded to dewater various types of sludge.
The screw press has been described as a process which could dewater high volumes of sludge. It can dewater sludge of low solids content and is found to be economical in operating and maintenance costs. It can produce solids concentration equal to or higher than belt filter press (18). The advantages of the screw press can be favorably used over other dewatering systems if a detailed study is conducted to characterize the process.
METHODS AND MATERIALS

This chapter outlines the procedures and materials used to conduct this research. Items included are a study of bench-scale and full-scale testing methods. Mixing intensity tests and laboratory-scale dewatering tests are included in the bench-scale study. Testing conducted at a pulp and paper plant is included in the full-scale study.

Experimental Design

Three sets of tests were conducted in this study. The first and second sets of tests were conducted on several sludges to evaluate the effect of pressure and shear on each sludge. The first set of tests was performed on a bench-scale belt filter press to assess the effect of pressure on cake and filtrate solids, and on polymer demand. The second set of tests was conducted using a mixing apparatus and a capillary suction time (CST) device. These tests were conducted to evaluate the effect of shear on dewatering of sludges. The third set of tests were conducted both in the field and in the laboratory to characterize sludge dewatering in a screw press.
Sludge Samples

Sludge samples from three facilities were investigated in this study. The samples were obtained from a water treatment facility, a wastewater treatment facility and an industrial wastewater treatment facility. Two batches of sludge were obtained from Peppers Ferry Regional Wastewater Treatment Plant in Radford, Virginia. One batch of sludge was collected from the Blacksburg Water Treatment Plant. Three batches of sludge were obtained from a pulp and paper plant in Plymouth, North Carolina. The solids content for each sludge sample was determined using the 16th edition of Standard Materials for the Examination of Water and Wastewater (23).

Anaerobically digested sludge from Peppers Ferry Regional Wastewater Treatment Plant was obtained from a sampling valve of a pipe in the sludge storage building that carried the sludge from the anaerobic digester to the belt filter press. The sludge was collected in two five-gallon carboys. The dry solids content of the sludge averaged 3.3%. The tests were completed over a four day period to minimize change in sludge characteristics.

Very thick alum sludge was collected from a storage lagoon at the water treatment plant. The sludge was collected in one five-gallon carboy and diluted to a solids concentration of 4.3% using tap water. The tests on the sludge were carried out over a period of ten days. Due to the chemical nature of the sludge, it was presumed to be stable over the study period.

Waste activated sludge was collected from a sampling valve at the outlet of the secondary settling tank of the Peppers Ferry Regional Wastewater Treatment Plant. The sludge was collected in two five-gallon carboys and
concentrated to obtain a solids concentration of 1.2%. The sludge was tested within two days of collection to prevent the sludge from becoming anaerobic and changing characteristics.

Pulp and paper sludge was collected from a paper manufacturing facility in Plymouth, North Carolina. One batch of sludge was collected from an outlet valve connected to a pipe that transported sludge from lagoon to the mixing tank. Three batches of sludge were collected from an outlet valve of a pipe connected to a mixing tank that supplied sludge to the screw press. A polymer coagulant was added between these two sampling points.

**Polymer Preparation**

Several polymer were used in the study. The polymers were high molecular weight compounds. Nalco 2879-521 polymer was used to condition anaerobically digested sludge. The polymer was supplied in liquid form and was a high molecular weight cationic product. Betz 1120 polymer was used for conditioning alum sludge. The polymer was supplied in dry powder form and was anionic in nature. Nalco N7199 polymer was used to condition waste activated sludge. This polymer was a cationic liquid product. AmCy 1555C was used to condition one batch of pulp and paper sludge. The product was also liquid and cationic. Another batch of pulp and paper sludge was conditioned with Nalco N7199 polymer. The third batch of sludge was conditioned with Rhone-Poulenc Clarifloc C9715 polymer. This polymer was liquid and cationic. The pulp and paper sludge was initially conditioned with Nalco 8799 polymer coagulant. The
polymer coagulant was liquid, less viscous and had a lower molecular weight than the other polymers used.

The cationic liquid polymers were prepared as 1% solutions and the anionic dry powder polymer was prepared as a 0.1% solution. The stock polymer solutions were prepared the day they were to be used for sludge conditioning and were refrigerated for up to four days. Tap water was used to prepare these polymer solutions. The liquid polymers were collected using a three mL syringe. The syringe was initially coated on the insides with the polymer and the tare of the syringe was then obtained. Three grams of polymer was then drawn into the syringe. The polymer was assumed to have density of water. 297 grams of water was collected in a plastic jar. The 3 grams of polymer was then added to this water simultaneously as the solution was mixed. The solution was mixed using with a Nalco caged impeller mixing paddle powered by a Cole-Palmer variable speed motor mounted on a ring stand. A variac was used for added speed control. The polymer was mixed at 750 rpm until a homogeneous solution was formed. The liquid polymers were mixed for one hour.

The anionic polymer was supplied in a dry powder form. The polymer was weighed and mixed with an appropriate volume of water. The same mixing procedure utilized to prepare liquid polymer stock solution was used to prepare 0.1% dry powder polymer solution. The polymer was mixed for twelve hours to ensure dissolution of the powder.
Bench-Scale Mixing Equipment

A high speed mixer was used in the bench-scale mixing experiments. The polymer and sludge were mixed to specific mixing intensity (G) values. The G value was calibrated to the rotational frequency (rpm) of the mixer. The mixing was performed using a Cole-Palmer variable speed motor mounted on a ring stand. The speed was controlled by a Fischer Scientific Variable Auto transformer connected through a Cole-Palmer speed controller. The motor rotated a two inch by half inch metal paddle. The mixing chamber was a cylindrical Plexiglas container. The chamber was 3.7 inches in diameter and 8.5 inches high. Four, half inch baffles placed 90 degrees apart were located lengthwise in the cylinder.

The mixer was calibrated by Werle et al. (7) and Lynch (15). It was calibrated such that the paddle rpm could be converted to mixing intensity or mean velocity gradient, G, using the equation given by Stump and Novak (3). Torque was measured by Lynch (15) using a Power Instrument Model 783 torque meter mounted between the motor and paddle. A General Radio Strobotac strobe light was utilized to read the torque meter. The volume of the sample was 500 mL. From Werle et al. (7), the value of kinematic viscosity was assumed to be $5.68 \times 10^{-3}$ in$^2$/sec, and the density of water at 20 degrees C was assumed to be 0.576 oz/in$^3$. Substituting these values, the equation for mean velocity gradient was reduced to:

$$G = 20.14(NT)^{0.5} \quad [2]$$
The calibration results are presented in Table 1. The setting for the variable auto transformer was fixed for the required rotational frequency using the strobe light. A plot of log (G) versus log (rpm) obtained from the calibration results by Lynch (15) was utilized to determine the mixing intensity applied to the sludge at the rpm desired.

**Bench-Scale Mixing Intensity Tests**

Mixing intensity experiments were conducted using the bench-scale mixing equipment and a Triton Type 1165 Capillary Suction Time (CST) device. These tests were conducted to determine the effect of mixing intensity and polymer conditioning on the dewatering properties of sludge.

The CST device, as shown in Figure 4, was used to measure the dewatering properties of the sludge. It measures the time taken for the sludge sample to travel a fixed distance through a filter paper. The movement of the sludge sample occurs in a radial manner due to capillary forces induced by the filter paper. Whatman #17 chromatography paper and a 10 mm diameter container were used in the test. The device consisted of two plates. The upper plate contained electrodes that would set off a timing device to activate or deactivate, depending on the electrode excited. The sample was withdrawn from the mixing device using 10 mL cutoff tip pipettes.

The sludge samples for the laboratory study were mixed at G values of 250 s⁻¹, 600 s⁻¹, and 1200 s⁻¹. A G value of 550 s⁻¹ was used for the field study. These values were chosen to develop a wide range of Gt values. For
Table 1. Calibration of Bench-Scale Mixing Device. From Lynch (15).

<table>
<thead>
<tr>
<th>RPM</th>
<th>Torque in Air (in-oz)</th>
<th>Torque in Sludge (in-oz)</th>
<th>Net Torque</th>
<th>G (s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>420</td>
<td>0.8</td>
<td>1.8</td>
<td>1.0</td>
<td>410</td>
</tr>
<tr>
<td>600</td>
<td>1.2</td>
<td>2.8</td>
<td>1.7</td>
<td>640</td>
</tr>
<tr>
<td>1200</td>
<td>2.3</td>
<td>6.2</td>
<td>3.5</td>
<td>1380</td>
</tr>
<tr>
<td>1500</td>
<td>2.8</td>
<td>7.1</td>
<td>4.3</td>
<td>1620</td>
</tr>
</tbody>
</table>
Figure 4. Schematic of a capillary suction time device.
each test run, an appropriate volume of polymer was used and combined with sludge to form a 500 mL sample. The volume used corresponded with that required to achieve the correlation between G and rpm obtained by Lynch (15). 420 mL of sludge was used in the test. Polymer was measured in a graduated cylinder and then filled to the 80 mL mark with tap water to obtain a constant volume of polymer solution. The polymer volume was chosen such that it did not exceed 20% of the sludge volume and the 500 mL mark for the slurry. In this way the sample volume was kept fixed to prevent an increase or decrease in G caused by volume fluctuations. The mixer was set to a specific mixing speed. The sludge sample was then mixed for specific time intervals. The mixing time was used to yield a desired G_t product. Samples were drawn at these interval using the cutoff tip pipette and released into the container in the CST device. The mixing was temporarily stopped during the operation of the CST device. The mixing time was calculated on a cumulative basis.

Bench-Scale Dewatering Device

Filtration and expression tests were conducted in the laboratory using a bench-scale dewatering device. The belt filter press simulator was developed for field testing of sludge by the Arus-Andritz Company (12). A schematic of the device is shown in Figure 4. The device contained a box type dewatering chamber arranged on a double level wooden frame. An Ashcroft A38 pneumatic cylinder was mounted on the frame. The wooden frame was raised to fit a 250 mL measuring cylinder underneath. A filtrate funnel was used to collect the liquid
Figure 5. Schematic of Belt Filter Press Simulator.
produced during dewatering in the measuring cylinder. The pneumatic cylinder was controlled using an air pressure regulator. A dual action Atlas-Copoco pneumatic switch was used as an on-off mechanism for the pneumatic cylinder.

The dewatering chamber was made of Plexiglas. It was a box, 3 inches square and 3 and 3/8 inches high. The box was sealed at the bottom with a rubber gasket. The box and the gasket were drilled with a matrix of 1/8 inch holes to drain the filtrate. This box was open at the top. A square piece of belt filter fabric was placed at the bottom of the box. On top of the fabric was placed a 1/4 inch wide square perimeter rubber gasket. The second gasket was used to prevent any leakage of the sludge around the sides of the filter fabric.

A concentric box was used to squeeze the sludge sample in the dewatering chamber. This box was smaller and fit tightly into the outer box. This box had similar perforations as the outer box. A sample of conditioned sludge was first poured into the outer box containing a filter fabric at the bottom. After 30 seconds another piece of filter fabric was placed on the dewatering sludge. On this was placed the inner box. A sandwich was formed between the outer and inner boxes. A piston was used to impart pressure on the inner box using compressed air in the pneumatic cylinder. Pressure was applied for one minute after one minute of gravity drainage.

The pressure applied on the sludge cake was a factor of the pressure in the pneumatic cylinder. A weighing scale was used to measure the force imparted by the piston connected to the pneumatic cylinder. The force was measured at several pressure values of the pneumatic cylinder. A linear correlation was obtained between the force imparted and the pressure applied. The conversion factor obtained was 0.56 and this factor was applied to the
pressure in the pneumatic cylinder. Pressures used in the bench-scale
dewatering tests varied from 11 psi to 49.5 psi. These pressures were higher
than used by Burgos (12) for a similar apparatus setup so as to evaluate the
effect of pressure on sludge dewatering properties. A wide range of pressures
were selected to develop a good correlation of its effect on dewatering properties.
The highest pressure was the maximum achievable in the dewatering device.
The pressure was used to suitably develop expression in the bench-scale
dewatering device to simulate dewatering in a belt filter press or screw press.

Bench-Scale Dewatering Tests

The belt filter press simulator was used to determine the polymer
conditioning requirement for the test. These tests were conducted to assess the
effects of pressure on polymer conditioning requirements. The test was also
conducted to determine if it could adequately predict the dewatering trends and
mechanisms of full-scale belt filter presses and screw presses.

The sludge dewatering performance was measured by determining the
cake solids and filtrate solids obtained during dewatering. The volume at free
drainage and during expression was also measured as a check on the cake and
filtrate solids concentrations obtained.

140 mL of sludge was used in the test. The required volume of polymer
was initially measured and then tap water was added such that the volume of
sample used in the dewatering device was constant at 170 mL. The sludge
volume was chosen to prevent overtopping of the sludge during pressure
application. The polymer volume was chosen so as not to exceed 20% of the sludge volume to avoid an unreasonable amount of dilution.

The sludge and polymer solution were added simultaneously into the baffled mixing chamber. This ensured distribution of the polymer within the sludge. The mixer was set to the lowest G value achievable, at 100 s\(^{-1}\). A low G value was chosen to minimize shear during the conditioning stage of the experiment. This G value was maintained throughout for all the sludges used. The sludge slurry was mixed for 5 seconds to obtain a Gt of 500 in the conditioning step of the test.

After mixing, the sludge was immediately poured into the dewatering chamber. The sludge was allowed to filter by free drainage for one minute. Filtrate volumes were measured using the 250 mL graduating cylinder at 10 s, 30 s, and one minute cumulative time intervals. The second filter fabric and the inner box were placed on the sludge between the 30 s and one minute time intervals. Pressure was applied after one minute of free drainage. The sludge was expressed using the piston connected to the pneumatic cylinder. Pressure was applied on the inner box for a period of two minutes. Filtrate volumes were measured every 30s. The total time utilized by the dewatering procedure was two minutes. The pressure was then switched off and the volume of any liquid retained in the inner box was measured to obtain the final dewatered volume of filtrate. Duplicates were performed whenever required to reflect representative results.

Cake solids and filtrate solids were measured according to procedure described in Standard Method for the Examination of Water and Wastewater (23). Cake solids were measured as total solids, while filtrate solids were
measured as total suspended solids. The same procedure was used throughout in the laboratory study.

Field Study

Experiments were conducted with a full-scale screw press. The screw press was located at a pulp and paper production facility in Plymouth, North Carolina. Mixing intensity tests were conducted at the location. Bench-scale dewatering tests were conducted subsequently in the laboratory with the same sludge and polymer.

The tests were conducted on February 12, 1992 at the operating conditions maintained by the facility. Two polymers were used in the field study. The first polymer was a Nalco 8799 polymer coagulant. The coagulant was applied after the sludge was sent to the mixing basin as indicated in the flow diagram shown in Figure 6. The coagulant was mixed at a rate of 3 lb polymer/ton dry sludge. The sludge was temporarily stored and mixed in the mixing basin. Potassium permanganate was used as an oxidizing agent to prevent odors caused by H₂S production. The sludge was slowly mixed in the mixing basin to retain its consistency. Rhone-Poulenc Clarifloc C9715 polymer was used as a flocculating agent. The polymer was manufactured by Polypure, Inc. It was a high molecular weight latex polymer. The polymer concentrate contained petroleum distillate, cationic polyacrylamide, water and nonionic surfactant. It was supplied in a liquid form and mixed with water to form a 0.9% polymer solution. The sludge was pumped at 500 mL/min. The polymer at
Figure 6. Schematic of sludge in the field dewatering process.
optimum dose was fed at 18 mL/min. The sludge contained 3.1% dry solids. This formed a feed of 21 lb polymer/ton dry sludge. The building containing the screw press consisted of three levels. The polymer solution was prepared at the lowest level.

The sludge and the polymer were pumped to the top level where they were mixed by an in-line mixing device. There were three rotating screen thickeners (RST) at this level. The RSTs were manufactured by Andritz-Ruthner, Inc. and each rotated at a rotational frequency range between 7.3 rpm and 35 rpm. The RSTs were operated by a Sew-Eurodrive, Inc. motor. There was a system of pipes that split the flow to these thickeners. Only two RSTs were on-line at the time of the study. Venturimeters were installed in-line to quantify the flow of the sludge to the RST. The sludge-polymer slurry was gravity filtered in the RST to obtain a partially dewatered sludge cake. The sludge from the RST was then sent to the screw press.

There were three screw presses located at the mid-level of the building. Two screw presses were on-line at the time of the study. The screw press contained an enclosed gear drive. The filtrate was collected through perforations along the length of the screw press. The screw was rotated at 2.27 rpm. A steadily increasing pressure was applied by the screw along the length of the press during expression. The cake solids at the output of the press had a solids content ranging from 40% to 48%, as indicated by the plant operators. The cakes from the screw press were sent for incineration.

The plant operators were requested to cut back on the polymer feed to test for underdosing in the screw press. The polymer dose was reduced twice
from 21 lb polymer / ton dry sludge to 17 lb polymer /ton dry sludge and 14 lb polymer / ton dry sludge.

The sludge samples were collected from the RSTs and screw presses. Filtrate and cake solids were collected separately from the two devices. Samples were collected from both the operating RSTs and screw presses. The samples were sealed tight and analyzed in the laboratory. The samples were refrigerated and analyzed the next morning for cake and filtrate solids.

The solids were measured according to Standard Methods for the Examination of Water and Wastewater (23). Cake solids were measured as total solids and filtrate solids were measured as total suspended solids.

Mixing intensity tests were conducted on the coagulated sludge and partially dewatered samples at optimum dose from the RST to study their dewatering properties. The results obtained are discussed in the Results and Discussion.

Two five-gallon carboys, one each of coagulated and raw sludge, were also obtained from the plant for laboratory analysis of field data. The samples from the RSTs were tested in the laboratory using both the bench-scale dewatering equipment and the mixing intensity equipment. The sludge samples obtained in the carboys were also tested using the mixing intensity set-up. The coagulated sludge was tested on the bench-scale dewatering device.

The results of the laboratory analysis and the field data collected is described in the field study of the Results and Discussion chapter.
RESULTS AND DISCUSSION

Results from both the laboratory and field study will be presented in this section. Items to be considered are the effect of applied pressure on cake and filtrate solids and polymer dose requirements in bench-scale dewatering tests and mixing intensity tests. Field studies conducted on sludge from a pulp and paper plant will also be discussed.

Laboratory Study

Several sludges were used to evaluate the effect of polymer dose and applied pressure on dewatering characteristics. Mixing intensity tests were conducted to assess the effects of shear on sludge dewatering and polymer dose requirement. Sludges and polymers used in these tests were described in the Methods and Materials.

Bench-Scale Dewatering Tests

The bench-scale dewatering tests were conducted using a laboratory belt filter press simulator, as described in the Methods and Materials chapter. The belt press simulator had two stages; the first stage consisted of gravity drainage, followed by an expression stage. In the gravity drainage stage, the sludge was allowed to drain under gravity to obtain a partially dewatered cake. This cake
was then squeezed in the expression stage under pressure. The pressing time and the applied pressure could be varied. A substantial volume of water (approximately 60%) was removed in the gravity drainage portion of the test. The expression stage consisted of simultaneous cake formation and water removal. Most of the water removed during expression occurred in the first few seconds of this stage.

The sludges were considered to be optimally dosed when the cake solids was maximum and filtrate solids were minimum. There were instances when only one of these parameters was used to determine optimum dose due to the lack of a well defined optimal for the other parameter.

### Anaerobically Digested Sludge

The anaerobically digested sludge was conditioned with Nalco 2879-521 polymer at doses varying from 43 lb polymer / ton dry sludge to 130 lb polymer / ton dry sludge. The main factor considered in selecting the dose range was the ability of the dewatering device to form a cake without the sludge floc mass squirting from the sides of the box under pressure. The initial solids content of the anaerobically digested sludge averaged 3.3%. As mentioned in the Methods and Materials section, the mixing device was set to impart an approximate mixing intensity, $G$ of $100 \text{ s}^{-1}$ and mixed for 5 seconds to transmit a mixing energy, $Gt$ of 500, during polymer addition. Pressures of 11 psi, 22 psi, 33 psi and 44 psi were applied in the expression step of the test.
As shown in Figure 7 and Figure 8, there was an initial increase in the cake solids with an increase in polymer dose. This was followed by a decrease in cake solids with further addition of polymer. The region of highest cake solids was considered to be the optimal dose. Lower doses were considered to be characteristic of an underdosed situation and higher doses an overdosed situation.

As shown in Figure 8, an increase in pressure produced variations in optimum dose, but did not produce a significant increase in polymer demand. These results were also observed by Burgos (12), although his tests were conducted at lower pressures.

There was a very limited effect of pressure on the cake solids. Over the pressure range used, a slight increase in cake solids with pressure was found. Burgos (12) found a somewhat greater increase in cake solids with pressure for the same sludge on tests conducted two years earlier. In the optimum dose region, there was an increase in filtrate solids with pressure. The increase in filtrate solids was possibly due to the rupturing of floc particles in the cake, under pressure, which then passed through the filter fabric into the filtrate. This however did not translate into an increase in polymer demand as indicated in Figure 7.

**Alum Sludge**

The alum sludge was conditioned with Betz 1120 polymer at a polymer dose which varied from 3.3 lb polymer / ton dry sludge to 10 lb polymer / ton dry
Figure 7. Cake solids and filtrate solids versus polymer dose for anaerobically digested sludge with Nalco 2879-521 polymer under four applied pressures.
Figure 8. Optimum dose and corresponding cake solids and filtrate solids versus applied pressure for anaerobically digested sludge using NaIco 2879-52I polymer.
sludge. The main factor considered in selecting the dose range was filtrate breakthrough in the underdosed and overdosed stages of testing. The initial solids content of the sludge averaged 4.3%. Pressures of 11, 33 and 44 psi were applied in the expression step of the test.

As indicated in Figure 9, over the polymer dose range used for the sludge, there was an increase in cake solids with an increase in polymer dose, followed by a decrease in cake solids beyond the optimum.

Alum floc particles were considerably more sensitive to application of pressure than anaerobically digested sludge. There was a noticeable breakthrough of sludge floc into the filtrate region during application of 44 psi pressure. This is shown in Figure 9 and Figure 10. Similar results were observed by Burgos (12) at lower pressures. Also, an increase in pressure did not increase cake solids. Further, a comparison between the final cakes obtained between anaerobically digested sludge and alum sludge indicated a lower percent cake solids obtained for alum sludge for corresponding pressures suggesting that there was a greater ability of alum floc particles to hold water. The alum sludge consisted of nonfibrous homogeneous particles. The floc particles appeared to fracture under increasing pressure rather than allow the additional release of water. An increase in pressure only resulted in significant deterioration in filtrate quality. Optimum dose values were developed for maximum cake solids and minimum filtrate solids. An increase in pressure did not result in an increase in polymer demand as shown in Figure 10.
Figure 9. Cake solids and filtrate solids versus polymer dose for alum sludge with Betz 1120 polymer under three applied pressures.
Figure 10. Optimum dose and corresponding cake solids and filtrate solids versus applied pressure for alum sludge using Betz 1120 polymer.
Waste Activated Sludge

The waste activated sludge was conditioned with Nalco N7199 polymer at a polymer dose which varied between 31 lb polymer / ton dry sludge and 112 lb polymer / ton dry sludge. The main factor considered for selecting the dose range was the ability of the dewatering device to form a cake without the sludge floc mass squirting from the sides of the box under pressure. The initial solid content of the sludge averaged 1.4%. Pressures of 16.5 psi and 33 psi were applied in the expression step of the test.

As shown in Figure 11 and Figure 12, there was an increase in cake solids with increase in pressure. This increase was substantial as compared to the anaerobically digested sludge. However, at similar pressures, the cake solids obtained for the waste activated sludge was much lower than that obtained for the anaerobically digested sludge. This may be attributed to a lower potential for waste activated sludge flocs to release water. An increase in cake solids was also seen with increase in polymer dose. These results corresponded with results from anaerobically digested sludge and alum sludge. Data for an overdosed situation could not be collected, since the sludge would not dewater under gravity drainage conditions when overdosed. This was attributed to excess polymer in the liquid phase and not to the sludge. As seen with anaerobically digested sludge and alum sludge, and indicated in Figure 12, the waste activated sludge did not seem to display any increase in polymer demand with an increase in pressure at the optimum dose for the sludge.
Figure 11. Cake solids and filtrate solids versus polymer dose for waste activated sludge with Nalco N7199 polymer under two applied pressures.
Figure 12. Optimum dose and corresponding cake solids and filtrate solids versus applied pressure for waste activated sludge using Nalco N7199 polymer.
Pulp and Paper Sludge

Two batches of sludge were obtained from the pulp and paper plant in Plymouth, North Carolina. The sludge was conditioned with AmCy 1555C and Nalco N7199 polymers. These polymers displayed varying characteristics due to the differences in their molecular weights. Nalco N7199 had a higher molecular weight and correspondingly displayed sharper optimum dose peaks than AmCy 1555C.

AmCy 1555C polymer

As mentioned earlier, one of the batches of pulp and paper sludge was conditioned with AmCy 1555C polymer. The polymer dose was varied between 17 lb polymer / ton dry sludge and 71 lb polymer / ton dry sludge. The lower polymer dose limit was set by significantly high filtrate breakthrough. The upper limit was set by increased filtrate concentration with polymer dose. The initial solid content of the sludge averaged 2.6%. Pressures of 11 psi, 22 psi, 33 psi and 44 psi were applied in the expression step of the test.

As shown in Figure 13 and Figure 14, at pressures of 11 and 44 psi, there was an increase in cake solids with increase in polymer dose. Underdosing and overdosing patterns were observed in the filtrate quality. Filtrate solids initially decreased with an increase in polymer dose. This was followed by an increase in filtrate solids with further increase in polymer dose. These results were similar to results obtained for anaerobically digested sludge.
Figure 13. Cake solids and filtrate solids versus polymer dose for pulp and paper sludge with AmCy 1555C polymer under four applied pressures.
Figure 14. Optimum dose and corresponding cake solids and filtrate solids versus applied pressure for pulp and paper sludge using AmCy 1555C polymer.
The pulp and paper sludge could withstand very high pressures under optimum polymer dosing conditions. The flocs in the sludge cake would form a tight interlocking mesh preventing breakup or rupture. This resulted in very low filtrate and high cake solids. Optimum dose was at maximum cake solids and minimum filtrate solids. An increase in polymer demand was not observed for increase in pressure, as shown in Figure 14. Trends indicated an increase in percent cake solids with applied pressure at the optimum dose values. This increase indicated that the pulp and paper sludge could be expressed at higher pressures to provide increased dewatering performance. This result was not observed for alum and anaerobically digested sludge.

**Nalco N7199 polymer**

Another batch of pulp and paper sludge was conditioned with Nalco N7199 polymer. The polymer dose was varied between 16 lb polymer / ton dry sludge and 90 lb polymer / ton dry sludge. Filtrate quality was the consideration when setting the limits for the polymer. The initial solid content of the sludge averaged 2.7%. Pressures of 16.5 psi and 49.5 psi were applied in the expression step of the test.

The polymer had a very high molecular weight. It overdosed very easily. Also a lower polymer dose was required to achieve optimal dosing compared to AmCy 1555C polymer. Underdose and overdose regions were well outlined. As indicated in Figure 15, the cake solids in both sets of the test displayed very sharp peaks, clearly defining the optimum dose values shown in Figure 16. As
Figure 15. Cake Solids and filtrate solids versus polymer dose for pulp and paper sludge with Nalco N7199 polymer under two applied pressures.
Figure 16. Optimum dose and corresponding cake solids and filtrate solids versus applied pressure for pulp and paper sludge using Nalco N7199 polymer.
seen earlier, and indicated in Figure 16, there was an increase in percent cake solids with applied pressure. An increase in polymer demand was not observed with an increase in pressure.

Several observations can be made for the sludges tested. First, the characteristics of the sludge is very important in defining dewatering performance. Second, the type of dewatering devices which would be applicable would depend on the sludge characteristics.

Alum sludge dewatered very poorly when a pressures of 44 psi was applied. There was also a considerable breakthrough of sludge solids into the filtrate. This breakthrough suggests that high pressure dewatering may not be suitable for alum sludge, however, a more gradual application of pressure may reduce or eliminate breakthrough making high pressure dewatering possible.

Anaerobically digested sludge produced minimal increase in cake solids for increase in pressure, when using the bench-scale dewatering device. This suggests that application of high pressures would not greatly increase the cake solids. The sludge produced stable sludge cakes and low filtrate solids concentrations at the optimal dose range for all pressures. A range of dewatering devices may be applicable to this sludge although at would be desirable to conduct tests at higher pressures to insure that the sludge would not fracture when dewatered by a recessed plate and frame or screw press.

The pulp and paper sludge was highly fibrous. The sludge responded well to pressure application. An increase in cake solids resulted from an increase in applied pressure. The cakes were very stable at high pressures, giving low filtrate concentrations in the optimum dose region. These results indicated that
the sludge could probably accept a lot more pressure and provide increasingly higher percent cake solids at increased pressures.

The pulp and paper sludge would dewater virtually with any dewatering device as verified by screw press results in the field. The cake solids obtainable would depend on the scale of expression or pressure used. The pulp and paper sludge can be expressed to produce very dry sludge cakes. Belt filter press or a screw press applying high pressures are very good candidates for this sludge if high cake solids are desired.

The waste activated sludge produced lower cake solids than any of the other sludges. This was probably due to its high amount of retained water within the flocs. The sludge produced an increase in percent cake solids with increased pressure. Combining data obtained from Burgos (12) and those in Figure 11, waste activated sludge responds similar to anaerobically digested sludge upon pressure application but produces lower cake solids. Depending on the sludge source, the applicable pressures for the waste activated sludge, would have to be determined. For the municipal waste activated sludge obtained from Peppers Ferry, there was an increase in cake solids with pressure. However, the cake solids concentration (16%) was still low as compared to the other wastewater sludges. This will probably be the trend for most other waste activated sludges. Increased pressures could result in significant deterioration in filtrate quality.

From the tests performed on a variety of sludges, it appears that underdose and overdose conditions exist for most sludges. Depending on the polymer and sludge used, there may be a broad or a very narrow optimal dose region. In the case of pulp and paper sludge, the higher molecular weight polymer produced optimal dewatering at lower doses than lower molecular
weight polymer. But the polymer was overdosed easily. Usually overdosing is observed in the filtrate quality and a substantial rate of increase in filtrate solids was seen with increase in polymer dose beyond the optimal dose range for the higher molecular weight polymer. For sludges which vary considerably in their properties with time, a polymer which has a larger optimum dose region would be preferred. This would usually be obtained in lower molecular weight polymers although substantial savings in polymer costs may be attainable with higher molecular weight polymers.

The filtrate quality obtained is a function of the applied pressure and the type of sludge used. Higher pressure usually results in higher cake solids which in some cases results in a worsening of filtrate quality. Depending on the sludge and the dewatering equipment, a balance would have to be reached between these parameters.

The dewatering device used in these studies utilized gravity drainage stage as the first dewatering step. Most dewatering devices could use gravity filtration as a first step in the water removal process. The dewatering attained by gravity drainage, removed most of the water in the conditioned sludge. The presence of the filtration stage appears to result in the reduction in the shear caused by water moving through a sludge cake (11). This stage allows for removal of a large volume of water which would otherwise move through to the expression stage. The expression stage did not appear to produce any polymer demand. The water removal during expression occurred very quickly, simultaneous with the cake formation process. The gravity filtration component proves to be important in minimizing the shear produced in a dewatering system. For sludges sensitive to shear, filtration could be used with advantage in
maintaining the integrity of the superflocculated sludge. The use of filtration with other dewatering devices would have to be compared in order to estimate its effectiveness in reducing polymer demand.
Mixing Intensity Tests

Alum Sludge

The alum sludge conditioned with Betz 1120 polymer was tested for dewatering characteristics when mixed over a range of mixing intensities. The polymer dose was varied between 3.3 lb polymer / ton dry sludge and 6.6 lb polymer / ton dry sludge and the capillary suction time device (CST) was used to determine the dewatering performance at each specific mixing intensity and mixing time. Approximate mixing intensities of 250 s⁻¹, 600 s⁻¹, and 1200 s⁻¹, were used in the test. The relationship between CST and Gt was used to characterize the effect of Gt on dewatering. A minimum CST value or range was taken to be the optimum dewatering condition. Figure 17 indicates the results at several selected doses and at the three mixing intensities used. As mixing energy input (Gt) increased, the polymer dose needed to optimize dewatering also increased. These results correspond with that of several researchers (12,14,15,16,17) and are summarized in Figure 26. The polymer dose below the optimum dose region is underdosed, and that above is overdosed.

In the bench-scale dewatering tests, alum sludge was found to be extremely sensitive to pressure. Floc break up and cake disintegration occurred at high pressures. The mixing intensity tests were conducted under a wide dosing condition to include the dose range to be used in the bench-scale dewatering test. As indicated in Figure 17, there was a significant deterioration of the sludge at high Gt values. This was especially the case under high G
Figure 17. Effect of Gt and polymer dose on dewatering rate of alum sludge with Betz 1120 polymer at selected mixing intensities.
Figure 18. Effect of Gt and polymer dose on dewatering rate of alum sludge with Betz 1120 polymer, at selected polymer doses.
conditions. At a G of 1200 s\(^{-1}\) and a Gt of \(10^5\), the optimum dose range determined by the bench-scale dewatering tests resulted in a CST of 60 seconds. Although the Gt may be much higher than that found in any dewatering equipment, it gives an indication of the sensitivity of the sludge to shear.

Higher G values resulted in an increased deterioration of the sludge for the same Gt values. As indicated in Figure 18, a G of 1200 s\(^{-1}\) produced higher CST values than a G of 600 s\(^{-1}\), at the same Gt values, and at a higher Gt range. Sludges which are more sensitive to G are more sensitive to high shear equipment, and would deteriorate with increases in shear. This would result in a greater sensitivity of the sludge to any changes or variations in dewatering conditions. Alum sludge was characterized by all these conditions.

**Waste Activated Sludge**

Mixing intensity tests were performed between waste activated sludge and Nalco N7199 polymer. The polymer dose was varied between 35 lb polymer / ton dry sludge and 105 lb polymer / ton dry sludge. The mixing device was set to mixing intensities of 250 s\(^{-1}\), 600 s\(^{-1}\) and 1200 s\(^{-1}\). The mixing time was varied to obtain a range of mixing energy inputs. For each dose and mixing intensity CST versus Gt curves were generated and are presented in Figure 19. The results obtained were similar to alum sludge response. As the mixing energy input increased, polymer dose requirements increased.

Sources in literature suggest that waste activated sludge flocs are fragile and bench-scale dewatering tests support this. The sludge did not dewater as
Figure 19. Effect of Gt and polymer dose on dewatering rate of waste activated sludge with Nalco N7199 polymer at selected mixing intensities.
Figure 20. Effect of Gt and polymer dose on dewatering rate of waste activated sludge with Nalco N7199 polymer at selected polymer doses.
well as anaerobically digested sludge and pulp and paper sludge. In mixing intensity tests conducted for the sludge, at G of 1200 s\(^{-1}\) and Gt of 10\(^5\), the sludge produced a CST of 30 seconds at optimum bench-scale dewatering dose values. Although the CST value was not as high as that of alum, it was large enough to indicate the sensitivity of the sludge to shear.

The effect of increased G on dewatering was not as pronounced for waste activated sludge, as it was for alum sludge. However, the differences in CST between G of 1200\(^{-1}\) and G of 600\(^{-1}\), at same Gt values, and at a higher range, indicated its sensitivity to high shear, although to a lesser extent than alum sludge. This is shown in Figure 20.

**Pulp and Paper Sludge**

Mixing intensity tests were performed using pulp and paper sludge and two polymers, AmCy 1555C and Nalco N7199. The polymer dose was varied between 15 lb polymer / ton dry sludge and 111 lb polymer / ton dry sludge and between 14 lb polymer / ton dry sludge and 89 lb polymer / ton dry sludge respectively. The mixing device was set to mixing intensities of 250 s\(^{-1}\), 600 s\(^{-1}\) and 1200 s\(^{-1}\) and the mixing time was varied. For each dose and mixing intensity CST versus Gt curves were generated. These curves are presented in Figure 21 and Figure 23. The results obtained were similar to the alum and waste activated sludge. As the mixing energy input increased, polymer dose requirements increased.
Figure 21. Effect of Gt and polymer dose on dewatering rate of pulp and paper sludge with AmCy 1555C polymer at selected mixing intensities.
Figure 22. Effect of Gt and polymer dose on dewatering rate of pulp and paper sludge with AmCy1555C polymer at selected polymer doses.
Figure 23. Effect of Gt and polymer dose on dewatering rate of pulp and paper sludge with Nalco N7199 polymer at selected mixing intensities.
Figure 24. Effect of Gt and polymer dose on dewatering rate of pulp and paper sludge with Nalco N7199 polymer at selected polymer doses.
The pulp and paper sludge was found to be very resistant to pressure in bench-scale dewatering tests. As mentioned earlier, this sludge was very fibrous. The flocs that formed did not destabilize easily. Similar results were found in the mixing intensity tests.

The pulp and paper sludge when mixed with AmCy 1555C polymer produced low CST values at high G values. As indicated in Figure 21, for a G of \(1200 \text{s}^{-1}\) and \(Gt\) of \(10^5\), and under optimum bench-scale dewatering dose conditions, the CST value was 10 seconds. The CST value was low, indicating a physically stable sludge capable of resisting high shear conditions. The CST value produced was much lower than corresponding values produced for both alum and waste activated sludge, indicating its stability when exposed to shear forces. As indicated in Figure 22, under optimum bench-scale dewatering dose conditions, the \(Gt\) at high and low shears produced similar CST values. This indicated that the sludge could resist high G values, with minimum shear effects, and yet produce good dewatering rates.

The pulp and paper sludge when mixed with Nalco N7199 polymer produced comparable results. For G of \(1200 \text{s}^{-1}\) and \(Gt\) of \(10^5\), and under optimum bench-scale dewatering dose condition the sludge produced a similar CST value of 10 seconds. As shown in Figure 24, this was similar to the results obtained using AmCy 1555C polymer and further indicated that the sludge was less sensitive to shear than the alum sludge and waste activated sludge.
Anaerobically Digested Sludge

Mixing intensity tests were conducted for anaerobically digested sludge by Lynch (15), with sludge from the Peppers Ferry wastewater treatment plant. Figure 25 shows the results of these tests. At $G$ of $1380 \text{ s}^{-1}$ and $G_t$ of $10^5$, and for a polymer dose of $900 \text{ mg/l}$, the CST was found to be 20 seconds. Further, a comparison of low and high $G$ values indicated some variation in CST values. This indicated that the anaerobically digested sludge was somewhat more sensitive to shear than pulp and paper sludge, but much more stable than the waste activated sludge. This corresponded with results obtained in the bench-scale dewatering tests.

Anaerobically digested sludge and pulp and paper sludge produced stable cakes in bench-scale dewatering tests, when subjected to pressures, as compared to waste activated sludge and alum sludge. They produced lower CST values in mixing intensity tests when subjected to high shear. The CST value corresponding to anaerobically digested sludge is 20 seconds, and could be considered a maximum for the use of high shear equipment on sludges.
Figure 25. Effect of Gt and polymer dose on dewatering rate of anaerobically digested sludge with polymer 52 # 1 at polymer dose of 900 mg/l. From Lynch (15).
Correlation of Bench-Scale Dewatering Tests and Mixing Intensity Tests

Optimal dose regions were developed for alum, waste activated and pulp and paper sludges. These dose regions were developed from CST versus Gt data obtained for the sludges. These regions were developed in a similar manner as used by Novak and Lynch (11). The Gt range at minimum CST values for a polymer dose was plotted in a graph of Gt versus polymer dose. The Gt at minimum CST value was the optimum mixing condition for the sludge at that dose. In other words, the sludge was optimally dosed for mixing conditions producing low CST values. Gt values were obtained for several polymer doses resulting in an optimal dose range. From these graphs, at any value of optimum dose, a Gt range could be obtained, and the mixing condition determined.

Alum Sludge

Optimum polymer dose requirement predicted by the bench-scale expression device and the conditioning requirements expected for mixing energy inputs are compared in Figure 26. The vertical line represents the polymer dose that would result in good dewatering for the applied pressures used in the bench-scale dewatering device. The intersection of the vertical line with the shaded region represents the range in which the polymer will produce good dewatering conditions, and the Gt of the dewatering device in that range. This dose is dependent on the sludge and polymer characteristics. The Gt value associated with the optimum polymer dose predicted by bench-scale dewatering tests is in
Figure 26. Effect of Gt on dewatering of alum sludge with Betz 1120 polymer under optimal dosing conditions.
the range of 8,000 and 12,000. This is the dose required by the dewatering device to yield both satisfactory and economical dewatering.

**Waste Activated Sludge**

Waste activated sludge results from expression tests and mixing intensity tests were correlated. Results obtained were similar to those obtained using alum sludge. Polymer dose requirements as predicted by bench-scale dewatering tests and mixing intensity tests are indicated in Figure 27. The $G_t$ value associated with the optimum polymer dose predicted by bench-scale dewatering tests is in the range of 7,000 and 15,000. These results were similar to that obtained for alum sludge.

**Pulp and Paper Sludge**

Optimum polymer dose requirement, for pulp and paper sludge mixed with AmCy 1555C, predicted by bench-scale dewatering test and the conditioning requirements predicted by mixing energy test is shown in Figure 28. The $G_t$ value associated with the optimum polymer dose predicted by the bench-scale dewatering test is in the range of 9,000 and 18,000. These results were similar to results obtained earlier.

For pulp and paper sludge mixed with Nalco N7199 polymer, the optimum polymer dose predicted from expression tests was correlated with mixing
Figure 27. Effect of Gt on dewatering of waste activated sludge with Nalco N7199 polymer under optimal dosing conditions.
Figure 28. Effect of Gt on dewatering of pulp and paper sludge with AmCy 1555C polymer under optimal dosing conditions.
intensity test results. These results as shown in Figure 29, suggested that, for the optimum dose, the Gt imparted by the bench-scale dewatering test was in the range of 7,000 and 18,000. These results corresponded with those determined earlier.

Summarizing the above results, the optimum dose found at any pressure in the expression device, was the same as the optimum dose for gravity drainage for all the sludges tested. Dewatering devices using gravity filtration as an initial water removal step experience a minimum Gt in the dewatering device. A Gt range of 8,000 to 15,000 was found to predict optimum polymer dose. The polymer demand represented the minimum dose required to separate the water from the flocs. This dose would prevent the breakup of flocs by providing a resistance to shear. This is characterized by the superflocculating condition observed when polymer conditioned.

The Gt developed in the filtration step was produced using an almost negligible mixing intensity in the conditioning step. Any increase in the mixing intensity, or the overall mixing energy input in the conditioning step would increase the polymer demand. Shear caused by any step before or during the filtration step would result in an increase in the Gt at the end of the filtration step. Results from previous work by several researchers indicated that mixing during polymer addition greatly influenced ultimate dewatering and polymer dose requirements (12,15). Combining these results, it can be concluded that mixing energy input during conditioning, and handling of the sludge immediately prior to and subsequent to mixing greatly influenced the ultimate polymer dose required.

An overview of the dewatering properties of the selected sludges indicate that the mixing intensity test is a suitable procedure to predict the effect of shear
Optimum dose determined from the bench-scale belt filter press simulator

Optimum dose for laboratory mixing unit

Figure 29. Effect of $G_t$ on dewatering of pulp and paper sludge with Nalco N7199 polymer under optimal dosing conditions.
on the dewatering of sludges. Figure 30 summarizes the effect of shear on
dewatering of these sludge in mixing intensity tests. The figure indicates the
dewatering options for a particular type of sludge. Pulp and paper sludges can
be dewatered using any dewatering equipment. The sludge has a very high
resistance to pressure and shear. Also, the sludge can be subjected to very high
pressures to produce very dry cakes. This makes the sludge ideal for high
pressure dewatering equipment, like high pressure belt presses and screw
presses.

On the other extreme, for alum sludge and waste activated sludges the
right dewatering equipment will have to be considered with care. These sludges
form very sensitive flocs with polymers. The flocs break up under application of
pressure. This is especially so for alum sludge. Their hydrous properties and
their inability to resist high pressure limits their dewatering. Any equipment that
could be used would have to use a low applied pressure, to prevent solids
breakthrough or the sludge would have to be altered considerably perhaps by
substantial lime addition.

Anaerobically digested sludge produced intermediate dewatering
performance as compared to waste activated sludge, and pulp and paper sludge.
The sludge displayed reasonably good dewatering rates in bench-scale
dewatering tests. Also, the sludge had some resistance to shear in mixing
intensity tests. The type of dewatering device used for anaerobically digested
sludge will depend on the extent it can withstand high pressures and produce
high percent cake solids, and low filtrate concentrations.
Figure 30. Effect of Gt on dewatering of selected sludges under a mixing intensity of 1200 /second (polymer dose lb /ton dry sludge).
Field Study

Field Studies were conducted at a pulp and paper plant located at Plymouth, North Carolina to determine the polymer demand exerted by the screw press and to compare laboratory predictions with full-scale performance. Specific items of interest were polymer dose requirements, cake solids and filtrate quality. The flow scheme for the screw press is presented in Figure 31. The sludge was pumped from lagoons and initially mixed with Nalco 8799 polymer coagulant. The sludge was then pumped into the screw press building and mixed with the polymer flocculant using an in-line mixing device. This conditioned sludge was transferred to a rotating screen thickener (RST). The RST was a gravity filtration device used to separate water from the sludge flocs to obtain a partially dewatered sludge mass. The sludge finally entered the screw press where it was expressed to obtain the final cake product.

The conditioning chemical was Rhone-Poulenc Clarifloc C9715 polymer flocculant. The polymer flocculant concentrate was mixed with water to form a 0.9% polymer solution. The plant operators had previously determined that the optimum polymer dose for the screw press was 21 lb polymer / ton dry sludge for the sludge and polymer being treated on the day of the trials. Due to the long detention time in the screw press, the range of tests were limited. Three doses were used, optimum (21 lb polymer / ton dry sludge) and two others which were expected to be underdoses (14 lb polymer / ton dry sludge and 17 lb polymer / ton dry sludge).
Figure 31. Schematic of dewatering process.
Samples were obtained from four sampling points (A, B, C & D) in the process, as shown in Figure 31. Table 2 indicates the sampling program, the corresponding tests conducted and plots of the data which was obtained.

RST Sludge Sample

Tests were performed on samples obtained from the RST (C). Samples could not be obtained prior to dewatering by the RST because of the equipment configuration. The samples from the RST were analyzed for their dewatering characteristics using a CST device. The sludge floc mass obtained from the RST at optimum polymer dose was in the range of 7% solids. The initial solids of the sludge was 3.3%. This indicated a more than 50% volume reduction in the RST. The RST was quite effective in draining water prior to the passage of the sludge into the screw press. As shown in Figure 32, there was an increase in cake solids and a reduction in filtrate solids with an increase in polymer dose. This suggested that the polymer dose ranged from underdosed to near optimum.

The sludge from the RST was also tested on the bench-scale dewatering device. An applied pressure of 44 psi was used in the test. The results are presented in Figure 33. As observed earlier, there was an increase in cake solids with increase in polymer dose. There was also a reduction in filtrate solids with an increase in polymer dose. As indicated earlier, the sludge ranged from being underdosed to optimally dosed.

Conditioning tests were performed on the sludge collected from the two operating rotating screen thickeners. The sludge was tested under 14, 17 and 21
Table 2. Index of tests conducted and plots of data obtained for sludge samples.

<table>
<thead>
<tr>
<th>Sludge</th>
<th>Figure</th>
<th>Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Sludge (A)</td>
<td>Figure 38</td>
<td>Gt tests</td>
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<tr>
<td></td>
<td>Figure 39</td>
<td>Optimal dose</td>
</tr>
<tr>
<td>Coagulated Sludge (B)</td>
<td>Figure 37 &amp; 38</td>
<td>Gt tests</td>
</tr>
<tr>
<td></td>
<td>Figure 39</td>
<td>Optimal dose</td>
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<tr>
<td></td>
<td>Figure 36 &amp; 40</td>
<td>Bench-scale dewatering tests</td>
</tr>
<tr>
<td>RST Sludge (C)</td>
<td>Figure 34 &amp; 35</td>
<td>Gt tests</td>
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<tr>
<td></td>
<td>Figure 33 &amp; 40</td>
<td>Bench-Scale dewatering tests</td>
</tr>
<tr>
<td></td>
<td>Figure 32</td>
<td>Cake Solids &amp; Filtrate Quality</td>
</tr>
<tr>
<td>Screw Press Sludge (D)</td>
<td>Figure 40</td>
<td>Cake Solids</td>
</tr>
</tbody>
</table>
Figure 32. Cake solids and filtrate solids versus polymer dose for pulp and paper sludge, mixed with Nalco 8799 polymer coagulant and Rhone-Poulenc Clarifloc C9715 polymer flocculant, collected from rotating screen thickeners.
Applied Pressure = 44 psi from RST\#2

Applied Pressure = 44 psi from RST\#3

Figure 33. Cake solids and filtrate solids versus polymer dose for pulp and paper sludge, mixed with Nalco 8799 polymer coagulant and Rhone-Poulenc Clarifloc C9715 polymer flocculant, collected from rotating screen thickeners, under 44 psi pressure.
lb polymer /ton dry sludge dosing conditions. Mixing intensity of 550 s$^{-1}$ was applied.

The sludge deteriorated with application of mixing intensity for all the three polymer doses. This is indicated in Figure 34. If the sludge were overdosed in the RST, as a result of additional polymer dose requirement in the screw press, it would have improved in its dewatering before deteriorating. The application of mixing energy did not enhance the dewatering properties of the sludge at these doses. This was particularly relevant for the dose of 21 lb polymer / ton dry sludge as this was the optimum dose for the screw press set by the plant operators. This indicated that the sludge at the output of the RST was not overdosed at 21 lb polymer / ton dry sludge. This further indicated that the screw press did not exert any additional polymer demand. Although the screw press used in the pulp and paper plant was a high pressure device, it did not increase the polymer dose requirement.

As shown in Figure 31, there was a change in the polymer flocculant application point prior to the sludge entering RST2 and RST3. In the case of RST2 configuration, the polymer flocculant was applied subsequent to in-line mixing, while for RST3, the polymer flocculant was applied prior to in-line mixing. Mixing during conditioning can increase polymer demand substantially. As shown in Figure 35, RST2 displayed better dewatering than RST3 at 17 lb polymer / ton dry sludge. The application of polymer subsequent to the in-line mixing device seems to have helped the dewatering property of sludge to a small extent. This was probably due to a reduced shear at the point of polymer input, which avoided disaggregation of flocculated sludge. However, no significant
Figure 34. Effect of Gt and polymer dose on dewatering rate of pulp and paper sludge, mixed with Nalco 8799 polymer coagulant and Rhone-Poulenc Clarifloc C9715 polymer flocculant, collected from rotating screen thickeners, for the two RSTs sampled.
Figure 35. Effect of Gt and polymer dose on dewatering rate of pulp and paper sludge, mixed with Nalco 8799 polymer coagulant and Rhone-Poulenc Clarifloc C9715 polymer flocculant, collected from rotating screen thickeners, at selected polymer doses.
change in sludge dewatering properties was observed at 21 lb polymer / ton dry sludge between the two RSTs

**Screw Press Sludge Sample**

The sludge from the RST was transferred to the screw press. Water was expressed from the sludge flocs under high pressure. The samples obtained from the screw press were analyzed for cake solids (D). Due to the absence of a sampling port, filtrate solids could not be measured. Cake solids of approximately 40% were obtained from the screw press as shown in Figure 40. Also in the case of screw press #2, an increase in cake solids was observed from 17 lb polymer / ton dry sludge to 21 lb polymer / ton dry sludge. These results were however not reproduced for screw press #3.

**Raw and Coagulated Sludge Samples**

Tests were also conducted on the raw sludge treated with coagulant Nalco 8799 polymer (B). The Nalco coagulant was already previously mixed in the field and collected from the screw press building off an outlet point, using a carboy, and brought to the lab. The coagulated sludge (B) was tested using the CST device and also the bench-scale dewatering device with Rhone-Poulenc Clarifloc C9715 polymer flocculant.

An applied pressure of 44 psi was used for the bench-scale test conducted on the coagulated sludge with Nalco 8799 polymer coagulant and Rhone-
Poulenc Clarifloc C9715 polymer flocculant. The sludge was also tested under gravity drainage conditions. This is shown in Figure 36. For the pressure test, the polymer dose was varied between 8 lb polymer / ton dry sludge and 42 lb polymer / ton dry sludge. For the gravity drainage test, the polymer dose was varied between 4 lb polymer / ton dry sludge and 17 lb polymer / ton dry sludge.

The initial solids content of the coagulated sludge averaged 3.1%. The mixing device was set to impart an approximate mixing intensity, $G = 100 \text{ s}^{-1}$ and mixed for 5 seconds to transmit a mixing energy, $G_t = 500$, in the conditioning step of the test. The bench-scale test suggested an optimum dose of 12-14 lb polymer / ton dry sludge. There did not exist an additional polymer demand with pressure beyond that required for free drainage. This can be compared to 21 lb polymer / ton dry sludge found optimum for the screw press.

For mixing intensity tests on coagulated sludge (B) using the flocculant, the polymer dose was varied between 14 and 24 lb polymer / ton dry sludge. The mixing intensity was maintained at 550 s$^{-1}$. This test was previously conducted in the field, under similar conditions with polymer doses of 14, 17, and 21 lb polymer / ton dry sludge. A good correlation was found between the field and lab tests. The difference in field and laboratory tests were that the laboratory tests were conducted on sludge which had been transported and stored, so a delay of 12 hours existed between collection and testing. The data are shown in Figure 37. Although there were variations in the dewatering rates in the curves for the field and the laboratory tests, the minimum mixing energy input for similar polymer doses was essentially the same. As shown in Figure 39, the $G_t$ associated with 21 lb polymer / ton dry sludge was found to be in the range of 25,000 and 30,000. This suggests that considerable shear exists in the
Figure 36. Cake solids and filtrate solids versus polymer dose for pulp and paper sludge with Nalco 8799 polymer coagulant and Rhone-Poulenc Clarifloc C9715 polymer flocculant under gravity drainage and 44 psi applied pressure.
Figure 37. Comparison of Gt curves obtained in the field and in the laboratory with Naico 8799 polymer coagulant and Rhone-Poulenc Clarifloc C9715 polymer flocculant.
dewatering system, although not in the screw press itself, that increases polymer requirements from 12 to 21 lb polymer / ton dry sludge.

Tests were conducted in the lab on the raw sludge (A) without using Nalco 8799 polymer coagulant. The test was conducted to estimate the shearing on the sludge during transportation from point (A) to point (B) in the system as shown in Figure 31. The raw sludge (A) without the coagulant was obtained at a point upstream to point (B), from an outlet point near the lagoons. The sludge had yet to be transported to the screw press building and had not undergone the shearing in the piping system. As mentioned earlier, the coagulated sludge (B) was obtained from the screw press building, by which time it was suspected that the sludge had undergone some shearing in the pipes and pumps during transport into the building.

Rhone-Poulenc Clarifloc C9715 polymer flocculant was used in the tests. The polymer dose was varied in the same range used previously for the coagulated sludge. The use of a low molecular weight polymer coagulant helps in considerably reducing the overall dose of the high molecular weight polymer flocculant. As shown in Figure 38 and Figure 39, the raw sludge (A) without the coagulant performs better than the coagulated sludge (B). This is characterized by a lower dose requirement for the sludge without the coagulant as compared to that with the coagulant at same Gt values. The sludge at point (B) had undergone some degree of physical shear caused by transport in the piping system. This shearing would be expected to increase polymer demand. This resulted in a lowering of the polymer demand, to an extent that a smaller dose of only the polymer flocculant was required to achieve the same dewatering for raw
Figure 38. Effect of Gt and polymer dose on dewatering rate of raw and coagulated pulp and paper sludge with Rhone-Poulenc Clarifloc C9715 polymer flocculant.
Figure 39. Effect of Gt on dewatering of pulp and paper sludge with Rhone-Poulenc Clarifloc C9715 polymer flocculant, for raw and coagulated sludge, under optimal dosing conditions.
sludge (A) as that required by a larger dose of the combined coagulant and flocculant for sludge from (B).

Several conclusions can be made from the field tests. The cake and filtrate solids obtained at the optimum dose in the RST (C), closely corresponded with the solids obtained at the optimum dose for the coagulated sludge (B) during gravity drainage in bench-scale dewatering tests. This is indicated in Figure 32 and Figure 36 and data shown in Table 3. A pressure of 44 psi was applied to both the coagulated sludge (B) and the sludge obtained from the RST (C). As indicated in Figure 40 and Table 3, the cake solids obtained for both these sludges were also nearly identical. This near correlation of the cake and filtrate solids during and after gravity filtration indicate that 21 lb polymer / ton dry sludge was the optimum dose or nearly optimal for the RST.

The cake solids obtained from the screw press were analyzed. As indicated in Figure 40, the cake solids obtained in the screw press (D), was substantially higher than that obtained using 44 psi pressure in the bench-scale tests for both raw sludge (B) and sludge from RST (C). This is because the pressures that can be applied in the screw press are substantially higher than those achievable in the laboratory device.

A major objective for conducting the field test was to estimate the shear developed in the system during the dewatering operations. To characterize this shear an attempt was made to obtain sludge samples from every possible point in the system. However, due to the equipment configuration, the number of sampling points were limited to the four already discussed. From the results obtained, it can be concluded that shearing exists at almost every point in the system, as the sludge is transported from point (A) near the lagoons to point (C)
Table 3. Comparison of cake solids and filtrate solids at optimum dose.

<table>
<thead>
<tr>
<th>Total Solids</th>
<th>RST # 2</th>
<th>RST #3</th>
<th>Gravity Drainage in Laboratory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filtrate</td>
<td>100</td>
<td>300</td>
<td>100</td>
</tr>
<tr>
<td>Cake</td>
<td>7</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>Cake at 44 psi*</td>
<td>29</td>
<td>30</td>
<td>27</td>
</tr>
</tbody>
</table>

Note: Optimum dose for sludge from RST was 21 lb polymer / ton dry sludge and for coagulated sludge from bench-scale dewatering tests was 12 lb polymer / ton dry sludge.

* Pressure of 44 psi applied on sludge obtained from the RSTs. Same pressure applied on coagulated sludge sample tested in the laboratory using belt filter press simulator.
Figure 40. Cake solids versus polymer dose for pulp and paper sludge, mixed with Nalco 8799 polymer coagulant and Rhone-Poulenc Clarifloc C9715 polymer flocculant, collected from screw press, rotating screen thickener under 44 psi applied pressure, and from belt filter press simulator under 44 psi applied pressure.
in the RST. Some shear can be avoided or reduced and some shear will persist as part of the system. As mentioned earlier, the field polymer dose was found to be optimum at 21 lb polymer / ton dry sludge and this dose corresponded with a Gt of between 25000 and 30000. This is indicated in Figure 39. The bench-scale dewatering test suggested an optimum polymer dose of 12-14 lb polymer / ton dry sludge and a corresponding Gt of 8000. The field polymer dose was found to be almost double the laboratory polymer dose and the Gt was almost three times the laboratory mixing energy input.

If used properly, the laboratory test adequately predicted field conditions. There is a high Gt in the screw press used at the pulp and paper plant. As shown in results, no additional polymer demand was encountered between point (C) and point (D) in the system. This indicates that the shear in the screw press was not important with regard to polymer demand. Rather, it appeared that the shear was developed prior to the sludge entering the screw press. It was suspected that the Gt was developed during pumping, mixing and flow measuring operations conducted during the transport of sludge from the sludge holding tank into the press. This Gt was approximately 30000 and resulted in an increase in polymer demand beyond what was needed for the dewatering equipment to function effectively. Sludge handling prior to dewatering appears to be extremely important in reducing the ultimate polymer dose.
CONCLUSIONS

This research was undertaken to evaluate the effect of pressure on dewatering of several sludges with a specific goal of using this information to evaluate the performance of a full-scale screw press. This study was conducted on several sludges. The sludges were tested using a belt filter press simulator to determine the polymer conditioning requirement under pressure and full-scale tests were performed to determine how shear influences conditioning requirements in a screw press. The basis for conducting the bench-scale test was to reproduce the conditions of the full-scale process and thereby predict the polymer demand.

The cake solids and the filtrate quality were investigated under several pressure and polymer dosing conditions. Mixing intensity tests were conducted to evaluate the shear in the dewatering device and to determine the Gt at the optimal dose range.

The polymer conditioning requirement in the belt filter press simulator was the same regardless of the pressure applied. This was true for all the sludges tested. Each sludge, however, reacted differently under the influence of pressure and shear. The pulp and paper sludge was found to be very stable, while alum sludge dewatered poorly under higher pressure and shear. Anaerobically digested sludge and waste activated sludge were intermediate in their dewatering performance.

The dewatering in the belt filter press simulator was somewhat similar to the dewatering scheme in the full-scale screw press process. In the actual screw
press, a rotating screen thickener filtered the sludge which was later expressed in the screw device. The shear produced in the screw press in this treatment scheme was found to be minimum. The screw press did not produce an increase in polymer demand. However, there was a substantial polymer demand exerted by the pipes and pumps in the dewatering process. The polymer demand produced was as much as twice the dose predicted in the laboratory. A mixing device combined with a free drainage testing device would help in predicting polymer dose for a screw press. It would also facilitate in selecting the polymer for the full-scale device. If the mixing device can simulate the shear in the full-scale process, the polymer demand would be the dose producing optimum cake and filtrate solids during gravity drainage.

Further investigation is required to estimate the merits of using a filtration device prior to a high pressure expression device. The reduction in polymer demand and improved dewatering produced by filtering before expressing has to be further investigated.

The following conclusions can be made from the results presented:

1. The polymer demand exerted by the belt filter press simulator was same regardless of the pressure applied during the expression phase.

2. Polymer demand was not exerted by expression in the screw press. Rather, the demand occurred prior to entering this device as a result of shear in pipes and pumps. A free drainage tester coupled with a mixing device is capable of predicting polymer conditioning requirements for a full-scale screw press.
3. Each sludge reacted differently under the influence of shear and pressure. Alum sludge was found to be sensitive to shear and pressure. On the other extreme, pulp and paper sludge was found to resist shear and pressure.
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22. HIW Screw Press Company Brochure.

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