Municipal Sludge Dewatering Using a Belt Filter Press

by

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(ABSTRACT)

Experiments were performed on alum, anaerobically digested and aerobically digested sludges to determine the optimum polymer conditioning for a belt filter press The optimum polymer dosages for all three zones of a belt filter press were compared with each other to determine the best overall conditioning. The requirements of all three zones of a belt filter press were the same. However, the gravity rate of drainage seems to under predict the dosages for optimum belt filter press performance. In addition the total mixing energy, G (the shear) and t (the mixing time), that represents the laboratory belt filter press was found to be approximately 45,000. Using a mixing energy input of 45,000 and a standard Buchner funnel apparatus the correct polymer dose for the belt filter press can be predicted.

ACKNOWLEDGEMENTS

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Finally, my wife is to be thanked for putting up with all the trials and tribulations of leaving a perfectly good job and moving across the country, so that I could attend school. Without her support this research would not have been possible.

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INTRODUCTION

In the modern society in which we live, a substantial quantity of waste in the form of sludge is produced by various water and wastewater treatment processes. Sludges produced as a by-product of municipal water and waste water treatment are typically high in water content which is often difficult to remove. Dewatering of sludges prior to disposal is required for several reasons. Dewatering reduces the land area necessary for ultimate disposal, reduces transportation costs and makes the sludge easier to handle. If incineration is employed for final sludge disposal, dewatering will significantly reduce associated fuel costs.

One of the more recent developments in the area of sludge dewatering equipment has been the development of the belt filter press (BFP). The belt filter press makes use of gravity, pressure, and shear to dewater sludges. In light of the importance of optimizing performance of the belt filter press to reduce operating costs associated with sludge disposal, this study was under taken.

This study was designed to determine polymer conditioning requirements for different zones of the belt filter press. Requirements for each of the zones were compared to determine the best overall conditioning.

Presently, BFP performance for specific sludges is evaluated using a laboratory belt filter press. This laboratory machine is not only very expensive, but bulky, heavy and expensive to transport. This research sought to characterize the laboratory belt filter press by relating its optimum performance to simple laboratory tests to see if proper polymer dosing could be determined using these simple laboratory techniques. The advantage being that these characterizations might reduce the need to test a sludge on a laboratory belt filter press, thereby saving much money and effort.

LITERATURE REVIEW

Only a modest amount of literature exists which describes the characteristics and performance of belt filter presses for the dewatering of municipal sludges. Laboratory parameters CST and specific resistance will be discussed to understand how these parameters may be related to the belt filter press. This chapter will briefly review how sludges are characterized and how belt presses operate so that an understanding of how these parameters might be applied to the belt filter press characterization. This review will also include a general discussion of polyelectrolytes as they applied to this study, a discussion of general features of belt filter presses and a section about the work that has been done to predict belt filter press performance using laboratory tests.

CHARACTERIZING SLUDGE DEWATERING IN THE LAB

The test parameter, specific resistance to filtration (SRF), is a commonly used test for measuring the dewatering rate of sludges. In 1968, Gates and Mcdermott (1) concluded that specific resistance measurements were a valid characterization for the analysis of sludge dewatering. The SFR test measures the rate at which a sludge will dewater by vacuum filtration, but it has not been found useful for predicting the actual performance of belt filter presses or plate and frame filters (2).

Christianson and Dick (3) attempted to refine the SRF so that it could be used universally with different sludges. Novak and Knocke (4) disputed their results, pointing out the time consuming nature of the SRF test. They felt that the SRF test was an appropriate index for sludge dewatering characteristics but should be used in the same way that BOD is used as an index for waste water strength.

Baskerville and Gale (5) developed the capillary suction time (CST) apparatus as an alternative to the specific resistance test about 20 years ago. The capillary suction time test has gained wide spread acceptance for sludge testing mainly due to its ease of operation compared to the SRF test (4). Test results from the CST apparatus are influenced primarily by the settleable solids fraction of a sludge (2). It is limited in its ability to test all the properties of sludge dewaterability (2).

In 1988, Vesilind (5) studied the CST test and concluded that it is a rapid, simple and inexpensive test of sludge dewaterability, but that it is unique to specific sludge solids. Vesilind stated that the CST test should be used to compare a single sludge to itself, (evaluating conditioners for example) but should not be considered a fundamental sludge dewatering rate measure and is not appropriate for comparing different sludges. Vesilind did conclude that a mathematical relationship that describes CST is valid for describing the sludge dewatering rate.

POLYELECTROLYTE CONDITIONING OF SLUDGES

Polyelectrolytes are long chain, water soluble chemicals used for coagulation and flocculation of colloids in water treatment and sludge (6). Organic polyelectrolytes increase the rate of sludge dewatering, while having little effect on the cake solids concentration (7).

During the past 10, years many advances have been made in the manufacture of polymers for use in sludge conditioning. Organic polyelectrolytes are now widely used in sludge conditioning (6). They vary greatly in composition and effectiveness (6), and are characterized using three primary parameters. These characteristics of polyelectrolytes are: relative charge density, molecular weight, and charge type (8). Anionic polymers carry a negative electrical charge in aqueous solution, whereas cationic polymers carry a positive charge. Cationic polymers are the most widely used in sludge conditioning since most sludge solids carry a net negative surface charge (6). The required charge density of the polymer is affected by the sludge particles. For example, as the particle becomes smaller in size, a higher degree of charge is required (6). As the molecular weight of a polymer is increased, the solubility decreases and the polymer becomes more sensitive to shear forces (8). Low molecular weight polymers require higher dosages to obtain the minimum dewatering rate than do longer chained medium to high weight polymers (8). Novak and Piroozfard (9) found that the mechanism through which a polymer functions is by increasing the particle size. The average particle size is maximized at the optimum polymer dose. Overdosing causes a reduction in this average particle size.

Polyelectrolytes come in basically two forms, dry powdered and liquid, although emulsified forms are gaining in popularity. Dry polymers must be given adequate mixing time for the polymer to dissolve completely (6). Mixing time also allows for aging, and for the polymer molecule to uncoil and take the form that promotes flocculation (6). Liquid polymer must also be adequately mixed to insure a homogenous solution. Once mixed, the polymer solution is usually stable for about 24 hours(6); however, it is desirable to avoid prolonged stirring or storage of a polymer solution as this can cause a reduction in effectiveness (10).

Typical dosages for a belt filter press were published by the EPA according to sludge type (6). For primary sludge, polymer dosages range from five to ten pounds of dry polymer per ton of dry solids. For aerobically digested the typical dose would be approximately ten pounds per ton of dry solids. For anaerobically digested sludge, the typical value ranged from three to six pounds of dry polymer per ton of dry solids in the sludge.

EFFECT OF MIXING INTENSITY ON DEWATERING

In 1969, Birkner and Morgan (11) found that an optimum polymer dose exists for maximum flocculation efficiency at a given mixing intensity, G. They found that an increase in G values tended to break up the floc. Similarly, for sludges it has been found that increased mixing time tended to deteriorate the dewatering rate of sludges (12).

Werle et al (14) studied the effect of mixing intensity and polymer dose on the dewatering of sludges. A CST apparatus was used for determining optimum polymer requirements over a range of G and time (t) values. They found that polymer dose and total mixing energy input (Gt) are the two most important parameters governing high stress sludge conditioning. For all the sludges tested, it was found that within "ideal" ranges, the product of Gt was important as opposed to either parameter G or t since there was a corresponding product of mix time and intensity that would minimize the filtering time for that dose. An increased Gt beyond the optimum resulted in deterioration of dewaterability. As Gt was increased, higher polymer doses were required to maintain the optimum dewatering properties.

Prendiville (13) also concluded that polymer dose and Gt were important for sludge conditioning. For a given sludge, it was possible to determine an optimum polymer dose and Gt value that produced the best filtering rate (13). Like Werle et al, Prendiville also found that the product of Gt is important and any combination may be used within practical limits to obtain the same results. Prendiville suggested that dewatering equipment such as belt filter presses are thought to produce G values in the range of 500 to 2500 sec^{-1}, so standard jar testing will not necessarly correctly predict the polymer performance for these machines. In the case of alum sludge, Prendiville found that an optimum polymer dose may be selected for the Gt to be encountered with the equipment being used. Prendiville's final conclusions stated that alum and activated sludges can be conditioned to resist deterioration and dewater well under high stress; for alum and activated sludge, as mixing energy increases, polymer dose also increases.

Novak and O'Brien (7) showed that under low mixing energy conditions, polymer requirements are minimized and almost are independent of solids concentration; additional mixing will lower the dewatering rate of a sludge. High mixing energy increased the polymer dose required, but produced a more stable sludge (7). Polymer dose predictions using a jar testing apparatus will underpredict polymer dose. They also observed that an optimal dose exists for each process, depending upon the shear encountered. Therefore to predict performance, the dose, mixing and dewatering conditions should match those encountered in actual dewatering process.

Recently, Chelf (15) showed the effect of under and overdosing of polymer on the response of sludges to the shear (G) during mixing. Using CST and SRF tests to measure dewatering rate, she found that at extreme doses (usually thought of as under or overdoses) an exponent of G may exist. Therefor $G^x t$ may be a better description for the dewatering response to polymer dose. Under most normal dosing ranges, x would be equal to one. The exponent x would also be indicative of the relative stability of the sludge. If x is greater then one, the sludge is less stable (more delicate flocs) and if x is less than one, the floc is more stable.

BELT FILTER PRESSES, PROCESS FUNDAMENTALS

Belt filter presses, of German origin, consist of a pair of continuous belts running between rollers which dewater sludges by squeezing sludge between the belts (16). The machines are designed to dewater sludges that have been "super flocculated" with polyelectrolytes. These super flocs are very fragile and susceptible to degradation by shearing forces (16). If super flocculation cannot be achieved, dewatering of sludge by belt filter presses if not feasible (10).

The super flocculated sludge is introduced to the belt where the free water drains under the influence of gravity. This is known as the gravity zone of the belt filter press. The solids concentration in this zone should increase from an initial value of approximately one to three percent to five to ten percent at the end of this zone, depending on many operating variables (6).

The semi-dewatered sludge then travels through the wedge formed where the two belts come together (Wedge Zone). Here the sludge is subject to gradually increasing pressure and more water is forced out (16). If free drainage is still occurring when the sludge enters this compression stage the excess water tends to act as a lubricant, and promotes the movement of sludge solids both laterally out of the side and through the belt fabric (10).

In the last zone, the high pressure zone (HPZ), the forces exerted are due to high pressure created by the decreasing diameter of the roller, the relative movement of the belts to each other, and the drive torque of the machine (6). The sludge cake is then discharged continuously (16). Solids retention is normally 99 percent or better in this stage, with a majority of the solids coming from the filter wash at the end of the cake discharge (16). Figure 1 shows a simple schematic of a belt filter press diagraming these different zones.

The EPA (6) describes three forces exerted by the high pressure zone on the sludge. The first (F1) is the force exerted due to the drive torque of the machine. The second (F2) is the force of the sludge cake due to belt tension. The third (F3) is the force on the sludge due to belt elasticity causing the shear action. The total pressure on the cake at any one roller is related to the sum of the pressures and roller diameter by the equation:

$$\text{psi} = 2(F1 + F2 + F3)/D$$

where D is the diameter of the roller.

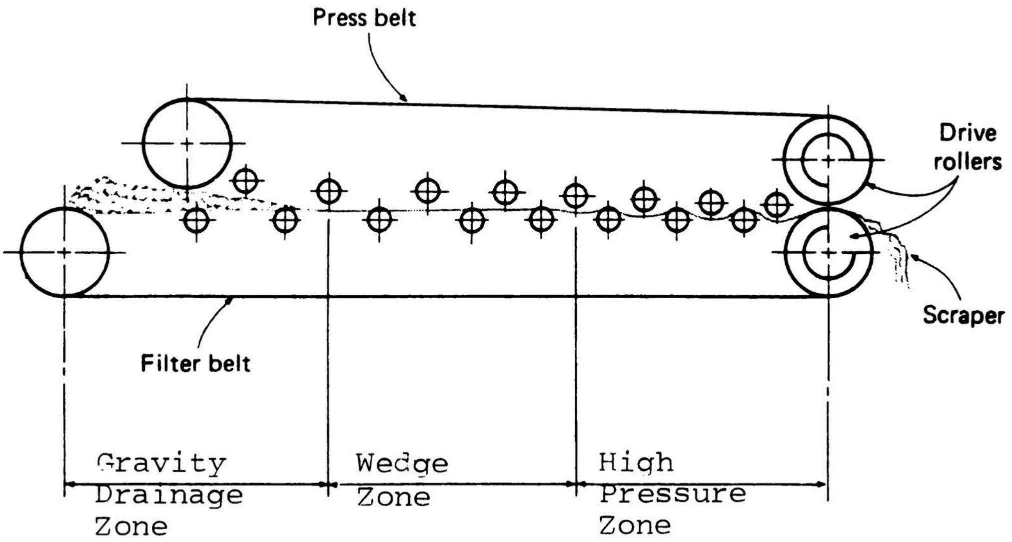

Figure 1. Belt Filter Press Schematic

Several variables influence the performance of the filter belt press. Pressure exerted, number of rollers, belt speed, belt type, sludge type, sludge conditioning are just a few (18).

LABORATORY ATTEMPTS TO PREDICT BELT PRESS PERFORMANCE

Baskerville et al (10) described several laboratory tests that could be used to predict performance of the belt filter press. The first evaluation that can be performed is a visual inspection of the "super floc". "Super floc" is a term used to describe a condition where the water visibly separates from the sludge. This type of evaluation is difficult to quantify, and does not give any indication about the completeness of adsorption of the polymer by the sludge solids (10).

Another evaluation recommended was one using a CST apparatus in conjunction with a standard laboratory stirrer to make a prediction of polymer dose. In making this recommendation, the CST of each sample were measured at various polymer doses and stirring times. The change in the CST of each sample over different stirring periods gave an indication of the strength of the sludge flocs and the presence or absence of unabsorbed polyelectrolyte. A sharp rise in CST with stirring is an indication of weak flocs with no surplus polymer present. If the CST remains constant or decreases with stirring time, then excess polymer in the sludge is indicated.

Baskerville et al (10) also suggested a test method for determining rate of drainage under gravity. The super flocculated sludge was put into a 70mm Hartley funnel fitted with filter media identical to the belt press. A range of sludge loadings were applied and the volume filtered through was measured versus time. The times required for each respective sludge loading gave an indication of the maximum belt speed that should be used in the full scale press and the output which might be obtained.

Baskerville et al (10) then characterized the pressure zones with a piston type press. The sludge was gradually pressurized to simulate the wedge zone. Pressure was maintained on the cake until filtrate flow had ceased. Good correlation was found for solids obtainable by this method and actual belt presses using the same sludge and polymer doses.

Halde (17) also simulated the belt filter press by pressing sludge in a piston arrangement while simultaneously simulating shearing action by rotating the piston. For these tests separate pressing cycles had no significant increase in filter cake solids over one continuous pressing of equal duration, assuming no cake disruption between cycles. If cake disruption did occur between cycles of applied pressure, more filtrate could be withdrawn. Squeezing several thin layers of sludge produced drier cakes then squeezing one large layer and the application of pressure had to be applied gradually or sludge dewatering was unsatisfactory. He also discovered that measured specific resistance to filtration did not necessarily predict the dewatering by the filter belt press.

In summary, the belt filter press uses gravity, pressure and shear to dewater sludge. Characterizing conditioned sludges as to shear and dewatering properities in a labratory and comparing these to performance of a belt filter press may yield valuable information as to what shear may actually exist in the belt filter press. If a shear value or Gt could be determined for a belt filter press, a simple stirring mechanism (with a known G) could be used to simulate shear of a belt press, to determine the dewatering properties of a sludge for a belt filter press.

METHODS AND MATERIALS

This research was performed to characterize the labratory belt filter press and to find a method to determine the conditioning chemical and dose that will optimize BFP performance. Many variables effect the actual performance of the belt filter press including sludge type, polymer, mixing energy, applied pressures, and belt type. The equipment and materials used in this study as well as the methods employed are described in this section.

COLLECTION AND PREPARATION OF THE SLUDGE SAMPLES

Sludges used in these experiments were obtained from water and waste water facilities in the Blacksburg, VA area. Alum sludge was obtained from the Radford Arsenal in Radford, VA . Anaerobically digested sludge came from the Roanoke, VA municipal wastewater treatment plant. Aerobically digested sludge was collected from the Christiansburg, VA wastewater treatment plant.

Alum sludge was collected from a sludge holding tank at the Radford Arsenal and was stored in five and ten gallon carboys. The sludge solids content was determined in the lab using the method described in the 16th Edition of Standard Methods for the Examination of Water and Waste Water (18). The solids content was adjusted to two percent by decanting the supernatant liquor after allowing the sludge to settle. This sludge was used within a one month period after it was collected.

The anaerobically digested sludge was collected from a lagoon at the Roanoke treatment plant. The sludge was obtained by throwing a bucket with a rope into the lagoon and pulling in the filled bucket. This sludge was also stored in five and ten gallon carboys with loose fitting caps. The sludge solids varied but were approximately 12 percent as collected in the field. This sludge was thinned and standardized to two percent solids with tap water prior to testing, and was used within a 2 week period after collection.

The aerobically digested sludge was obtained from a sampling valve directly on the digester at the Christiansburg plant. This sludge was also stored in five and ten gallon carboys. Since this sludge was susceptible to daily changes, it was kept aerated with compressed air and a diffuser stone, and was tested the day after it was collected. The solids concentration of this sludge was adjusted to two percent before use. Prior to testing all sludges were well mixed to assure good suspension of all particulate matter. All the sludges used were stored at 20 degrees centigrade in the laboratory.

POLYMER PREPARATION

Several different polymers (both cationic and anionic) were used in the experiments. Betz 1120 was the only anionic polymer used for the testing. Betz 1120 (dry powder form) is a high molecular weight, moderate charge density polymer. Percol 757 (dry powder form), and Betz 1167L, were the cationic polymers used. Polymers E and F were experimental cationic liquid polymers supplied by the Nalco company.

Solutions of both the Percol 757 and Betz 1120 (both dry powders) were mixed in the following manner. A 2500 mg/L stock solution of these polymers was prepared by weighing out 1.25 grams of the dry polymers and mixing them with 0.5 liters of tap water. The polymers were mixed by measuring out the water and putting it in a 1.0 liter beaker which was then placed on a magnetic stirrer turned to high speed. Dry polymer was then gradually poured into the water. The speed was reduced and the polymers were allowed to solubilize for 24 hours, after which they were used. This procedure was used each time one of these polymers was used in conditioning tests to insure the polymers to be fresh, and eliminate storage requirements.

Liquid polymers were mixed immediately before use each time. Liquid polymer was measured with a syringe, introduced to the water and mixed as previously described. For the purpose of determining dry weight of polymer in the stock solution, the polymer manufacturer indicated that a one percent solution by volume equals 10,000 mg/L concentration. From this conversion, dry polymer solids were determined for liquid polymer doses. The polymers were allowed to mix vigorously for at least 30 minutes before use.

SLUDGE CONDITIONING

Traditionally sludges had to be superflocculated using polymers for the belt filter press to operate properly. This was to keep the sludges from squeezing through the filter fabric. The sludges used in this reasearch proved to be no different. Early attempts in this reasearch to use highly mixed sludge/polymer combinations and unconditioned sludges were made, but these sludges were characterized by minimal solids retention on the belt filter.

Sludges were superflocculated with the polymers prior to their testing in the belt filter press simulators. To dose with polymer, 500 mL of the sludge was measured in a graduated cylinder and poured into a one liter beaker. The sludge was then placed onto a jar tester and mixed at 100 rpm for ten seconds. Polymer was introduced into the sludge over a period of about the first one to two seconds of the mixing to distribute it evenly. The mixing speed was then reduced to 30 rpm for an additional 50 seconds to coagulate and flocculate the sludge solids. This conditioning was assumed to provide a negligible mixing energy Gt.

WEDGE PRESS APPARATUS

The wedge zone of the belt filter press was simulated using an Astro Standard Wedge Zone Simulator provided by the Arus Andritz company, as seen in Figure 2.

The simulator consisted of a pneumatic cylinder fitted over a box type dewatering chamber. The pneumatic cylinder (Atlas Copoco C4-63-20-300) pressure was regulated with a standard air pressure regulator. The on-off operation of the pneumatic cylinder was accomplished with a dual action pneumatic switch (Atlas Copoco VA 15 HB2-5).

The box type dewatering chamber (Figure 3) was a square metal box, 4 inches square by 3 3/8 inch deep, open at the top, with several 1/8 inch holes in the bottom. The box bottom was fitted with a piece of the belt fabric placed over the holes. The top "ram"

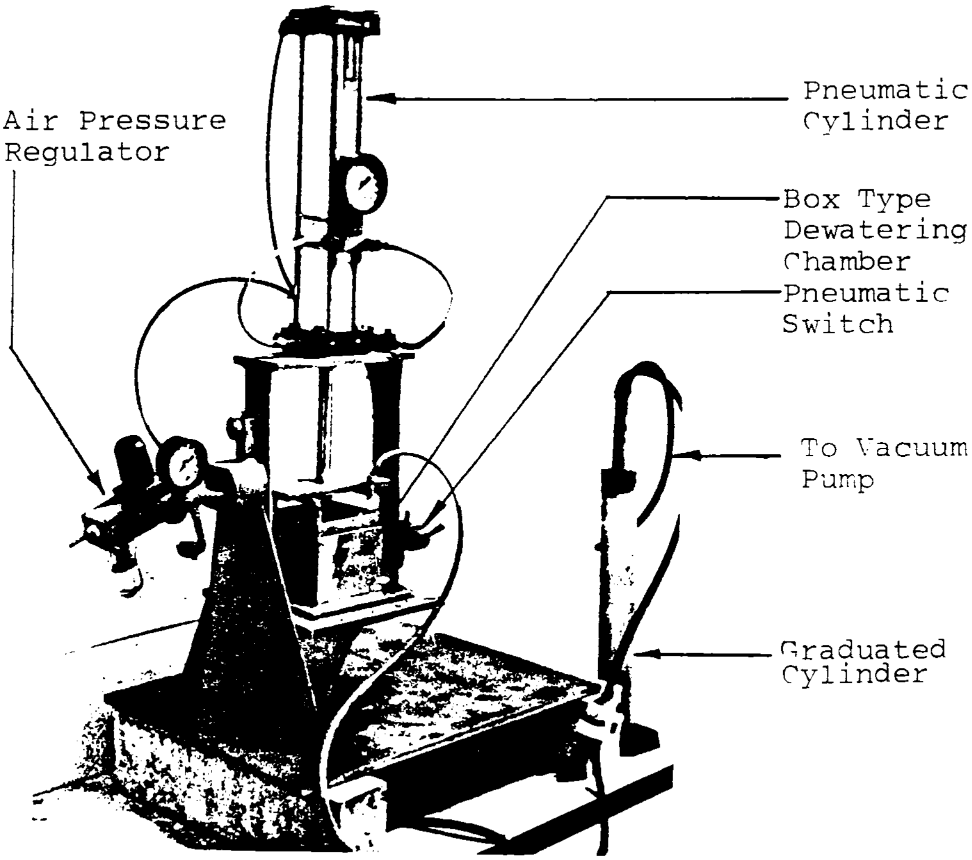

Figure 2. Astro standard wedge zone simulater used in experiments

component of the dewatering chamber was similar to the bottom, but was smaller so it would fit snugly into the first box. This effectively sandwiched the conditioned sludge in between the two filter cloths.

The conditioned sludge was quickly poured into the bottom box, and the free water was allowed to drain under the influence of gravity for one minute to simulate the gravity zone of the BFP. Another piece of the filter fabric was then placed on top of the sludge. The top "ram" portion of the dewatering chamber was inserted into the bottom box on top of the sludge. Pressure was then applied to the sludge to simulate the wedge zone of the belt press. Filtrate was allowed to drain both from the top and the bottom of the box. Filtrate from the bottom was caught in a funnel arrangement below the box. The filtrate was pumped by vacuum from both the top and bottom of the box to a graduated cylinder so that a record could be made of the volume of filtrate expelled. The sludge remained under this simulated wedge zone pressure for one minute (recommended by Arus Andritz personnel) to approximate a typical time sludge might be in this zone. The pressure was released and solids content samples were taken. The sludge cake was then placed in the belt filter press simulator for testing.

The pressure applied to the sludge in the wedge zone simulator was a function of the pressure (psig) applied to the cylinder. The manufacturer gave a conversion factor of 0.31 psi applied to the sludge per psi gauge applied to the cylinder. This was confirmed by setting a scale under the pneumatic ram and measuring the force applied. This force was related to the 4 inch square surface area of the dewatering chamber and the gauge pressure applied. The same conversion factor of 0.31 was obtained. The pressure chosen to use in the wedge zone simulator (4.65 psi) was based on the good results obtained

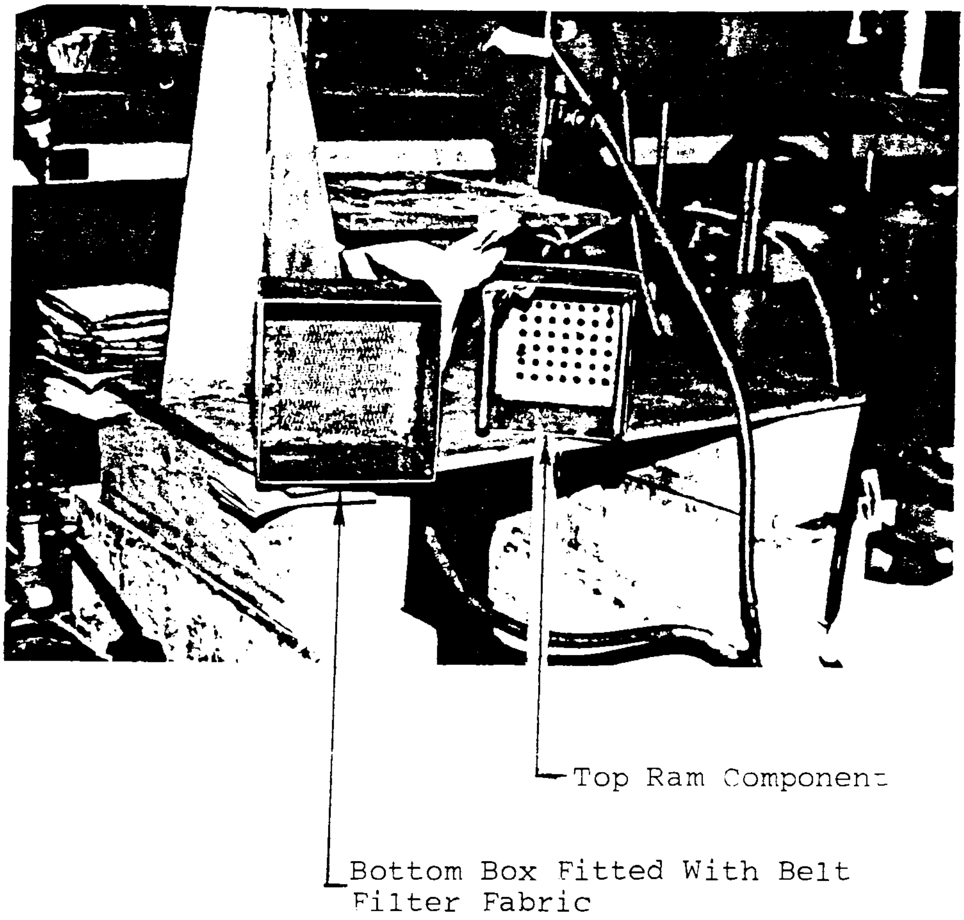

Figure 3. Dewatering chamber for the wedge zone simulator

at this pressure, the even gauge pressure (15 psig) to monitor, and the range of 3 to 10 psi suggested by Arus Andritz (19).

The volume of water expelled during the gravity portion of the test as well as final volume of water expelled was used with the final solids content of the sludge to calculate the gravity zone solids content. The calculation was as follows:

$$Sg = Si + (Sw - Si)(Vg/Vt)$$

where Sg = solids content, gravity zone (% by wt),

Si = initial solids content,

Sw = solids wedge zone,

Vg = volume water expelled by gravity,

Vt = volume water expelled total.

The optimum polymer dose for each respective zone was the dose that corresponded to the highest solids content in the cake.

BELT FILTER PRESS SIMULATOR

The high pressure zones (HPZ) of the belt filter press was simulated using an Astro Laboratory Belt Press. A picture of this press is shown in Figure 4, and a schematic of the simulator is shown in Figure 5. Technical data on the machine are presented in Table 1.

The machine allowed for adjustment of the belt speed as well as the belt tension. The belt speed could be controlled to the nearest one foot per minute, and monitored with a digital read-out. The belt tension was monitored with a pressure gauge that indicated

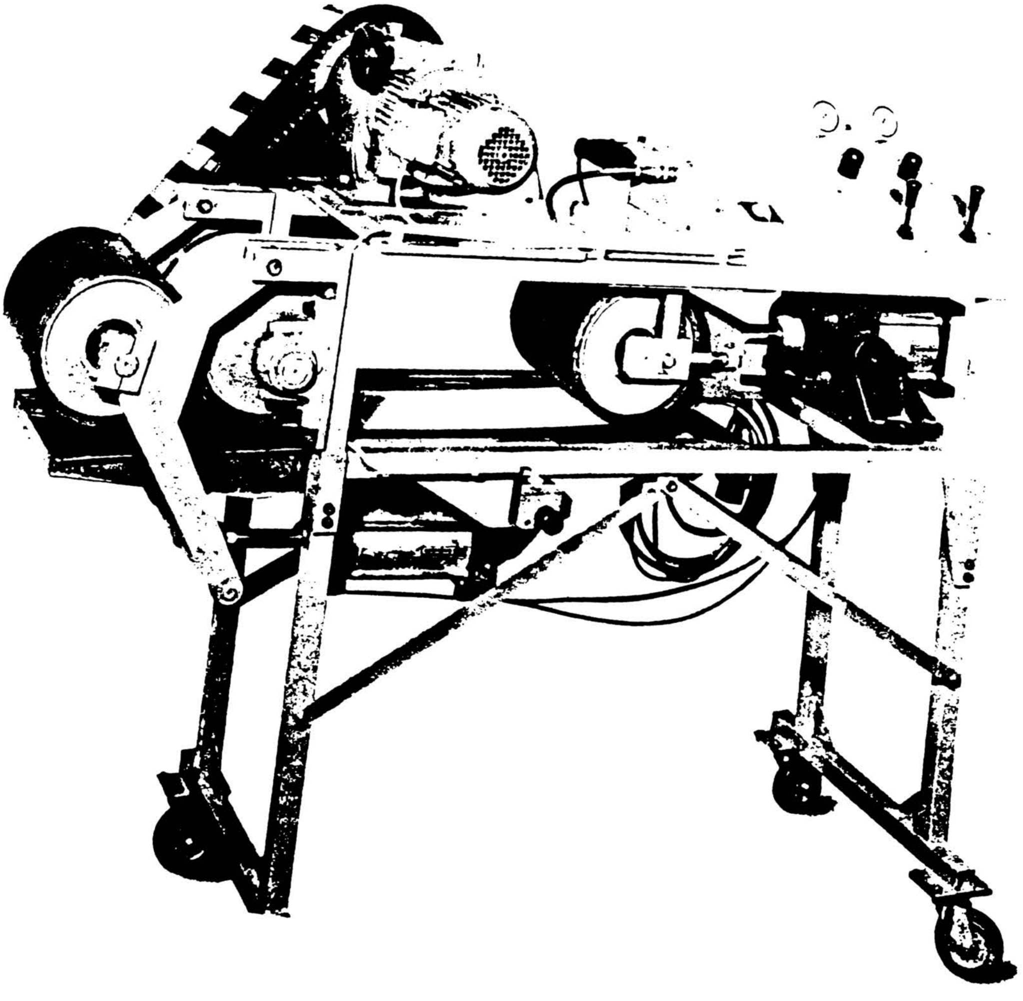

Figure 4. Astro laboratory belt filter press simulator (19)

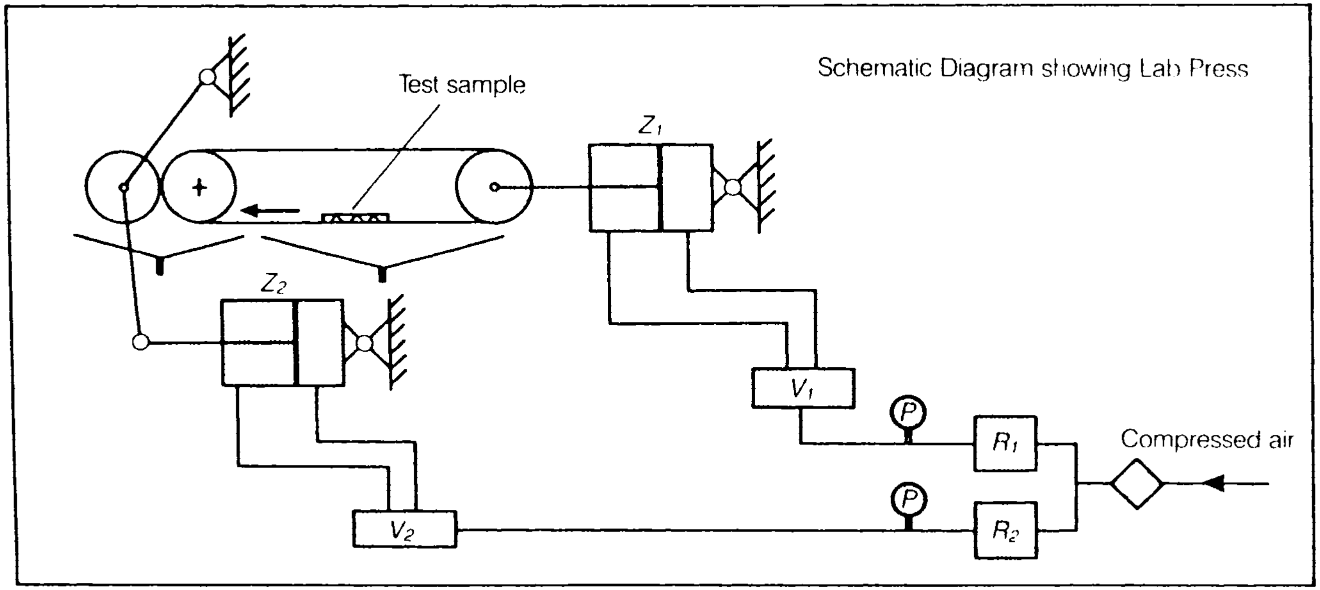

Figure 5. Schematic diagram of the belt filter press simulator (19)

Table 1. Labratory Belt Filter Press Technical Data (19)

Technical Data

Dimensions Length x Width x Height	1800 x 700 x 1600 mm	71x28x63 in
Machine speed	1 - 17 m/min.	3.3-55 fpm
Roll diameter	250 mm	9.84 in.
Length of roll	250 mm	9.84 in.
Maximum surface pressure	12.5 N/cm^2	18.1 psi
Maximum line pressure	2000 N/cm	11400 pli
Length of clothing x width	2000 x 200 mm	80x8 in.
Drive	Electric motor 0.7 kW, 380 or 440 V, 50 or 60 Hertz	
Compressed air connection	6 - 10 bars	87 - 145 psi
Weight	180 kgs	400 lbs

pressure applied to the pneumatic cylinder (Z2, Figure 5) and could be adjusted using a standard air regulator (R1, Figure 5).

The partially dewatered sludge (from the wedge zone simulator) was placed on the belt of the simulator. A second piece of filter fabric the width of the belt and two feet long, was then placed over the top of the sludge and held in place with paper clips. This sandwiched the sludge between the continuous belt and the piece of fabric.

The number of times the sludge cake was passed through the rollers was dependant upon which test was being performed. Initially, the sludge was passed many times through the rollers at various pressures. In later tests, two passes at a slow speed and constant pressure were chosen to simulate a typical dewatering cycle for municipal sludge. The dewatered cake was then scraped from the continuous belt and the dry solids concentration determined. The nip roller apparatus of the simulator (roller, cylinder Z2 and regulator R2) was not used in these tests.

The pressures encountered in this machine are similar to those that occur in the high pressure zone of a belt filter press according to Arus Andritz company literature (19). To convert applied gauge pressure to surface pressure on the sludge, the manufacturer of the belt press simulator recommended a conversion factor of 3.11. That is, the gauge pressure is divided by 3.11 to obtain the pressure applied to the sludge in psi. The variables involved in this pressure conversion factor supplied by the manufacturer are related by the formula:

$$Pa = T / RR$$

where Pa = pressure applied to the sludge (psi)

T = tension of the belt (lb/in)

RR = roller radius (inches)

This formula is simplistic in nature and does not take into account all the forces described by the EPA (6) concerning elasticity, drive torque and take up tension. This simulator has only one continuous belt so force F1 (EPA) would be minimized. Other parameters necessary to determine force F2 (EPA) and F3 (EPA) were not measured. Formula 3 does take into account the resultant force P as described by the EPA. Since the absolute actual pressures applied were not important to this study compared to the relative pressures and durations, the manufacturers conversion was used to convert pressure read on the gauge to pressure exerted by the machine.

MIXING DEVICE

Bench type sludge dewatering tests were conducted using a high energy mixer and CST apparatus. Mixing tests were not performed as a preliminary conditioning step for the belt filter press but to attempt to relate mixing intensity of a laboratory mixer (with a known G) to the results of tests using the belt filter press. It was desired to find a Gt of the mixing device that would minimize the CST of the optimum sludge-polymer combinations (as determined in previous tests).

The mixing device (Figure 6) consisted of a baffled mixing chamber with a stirring mechanism that fits over the top. The stirring component of the device consisted of a Eastman Model 3-1800 RPM variable speed motor and stirring paddle. The stirrer was self supported on the baffled mixing chamber. The coupling between the motor and the paddle was fitted with a magnet which was used to send a signal to a Hewlett Packard Model 3734A electronic counter. The gate time of the counter was set at one second, which allowed for the rotational speed of the paddle to be read in revolutions per second.

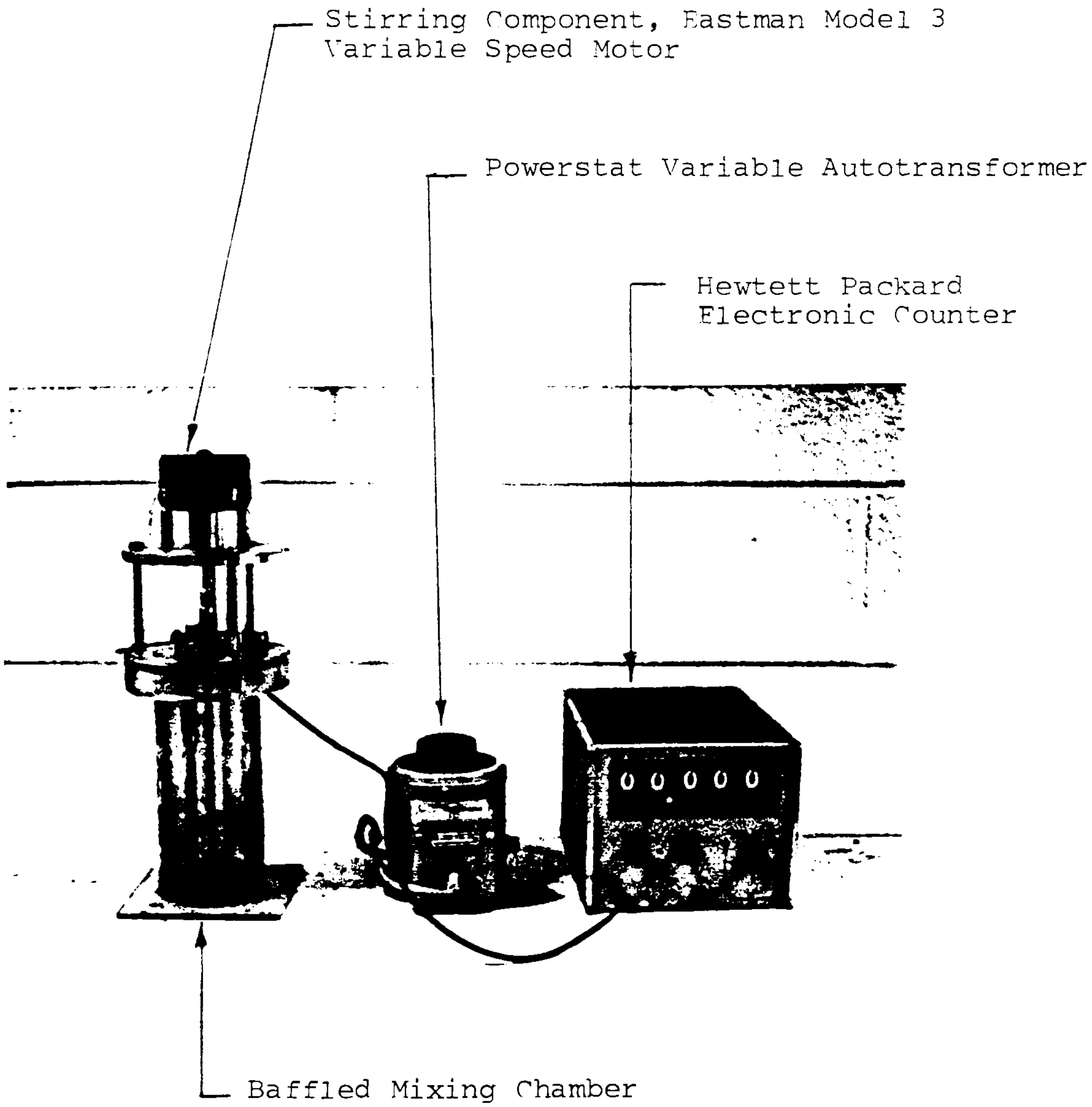

Figure 6. Mixing apparatus used for determination of Gt values

The speed of the motor was controlled by a type 116B Powerstat variable Autotransformer connected directly to the motor.

The cylindrical plexiglass mixing chamber measured 9.4 cm in diameter and 21.7 cm high. Four 1.2 cm baffles set 90 degrees apart were installed lengthwise in the cylinder.

The paddle measured 2 inches by .5 inches and was situated 0.6 cm from the bottom of the mixing chamber. The mixer was previously calibrated by Chelf (15) so that paddle rotational speed could be directly converted to velocity gradient G. The basic equation for the velocity gradient that was given by Stump and Novak (19) is:

$$G = \{2[3.143]g\ NT/60\ Vvp\}^{.5} \qquad [1]$$

where G = mean velocity gradient, $\sec^{-1}$

g = acceleration of gravity, in/sec,

N = paddle rotational speed, RPM,

T = net torque on paddle, oz-in,

V = sample volume, in^3

v = kinematic viscosity, in^2/sec, and

p = density of water, oz/in^3

Chelf (15) measured the torque on the paddle produced by stirring with a Power Instruments Model 783 torque meter fitted in between the motor and the stirring paddle. A Strobotach Strobe light unit was used to read the torque meter. Readings were taken in air and in two percent anaerobically digested sludge for calibration purposes.

Werle et al (14) found the viscosity of alum and primary sludges to be $5.68 \times 10^{-3} in^2/sec$ and this value was used for the calibration. The value of 0.576 oz/in^3 was used for the density of water at 20 degees C. The volume of sludge used was 0.5 liters.

Using these values reduces equation (1) to:

$$G = 20.14(NT)^{.5} \qquad [2]$$

Results of the calibration are presented in Table 2. These data were plotted for use during the testing to determine the G values applied to the sludges in the mixing apparatus.

DEWATERING TESTING AND APPARATUS

Dewatering characteristics of the sludges were measured with a Triton Type 1165 Capillary Suction Time (CST) apparatus. Whatman # 17 chromatography paper was used as the filter paper. The theory of CST operation is that the filtrate flows through the paper at a rate that is dependent on the relative dewatering properties of the sludge. The apparatus measures the time it takes for the filtrate to travel a fixed distance.

The impact of varying mixing energy input (Gt) on sludge dewatering rates was quantitified using the CST device. The polymer doses used for these tests were the doses that were determined as optimum for the belt filter press. One half liter samples of sludge were placed into the mixing apparatus along with the polymer. The mixer was then turned to a preset speed and samples were withdrawn from the mixing chamber at the desired times without turning off the mixer. This was accomplished by withdrawing the sludge through a hole in the top of the mixing chamber using a pipette fitted with a suction bulb. The withdrawn sludge was then transferred to the CST apparatus and the corresponding CST value determined. The amount of sludge withdrawn from the mixing chamber each time was assumed to be negligible in comparison to the total sludge vol-

Table 2. Calibration of the mixing apparatus as performed by Chelf (15)

RPM	Torque in air (oz-in)	Torque in sludge (oz-in)	net Torque (oz-in)	G (sec^{-1})	log RPM	log G
420	2.3	3.5	1.2	452	2.62	2.66
600	2.8	5.2	2.4	764	2.78	2.88
720	3.0	6.3	3.3	982	2.86	2.99
900	3.0	7.3	4.3	1253	2.95	3.10

ume of 0.5 L. Enough samples were taken so that a good relationship between mixing time and CST could be established.

The Gt vs CST curves were determined using G values of 250 sec^{-1} and 750 sec^{-1}. This was to check how the dewatering responded to changing the mixing energy, Gt.

BUCHNER FUNNEL APPARATUS

The Buchner funnel apparatus (Figure 7) is most commonly used to determine the specific resistance of a sludge sample. However, for this series of tests it was used in a much more simplistic manner. The Buchner Funnel was fitted with Whatman No. 40, 7 cm diameter ashless filter paper and a vacuum of 20 psi was applied to the sludge samples. The time to obtain 50 mL of filtrate was used as an indication of relative dewatering rate. This test was performed using the values for G and t that had been defined for the belt press machine. The test was used to try to predict the dose of polymer required to optimize the belt filter press. It was also used to evaluate the validity of defining a Gt value for the BFP, and how this value might be applied in the lab for predicting belt press performance. The predicted dose was then checked to see that it corresponded to the actual polymer dose determined to be optimal for the belt filter press.

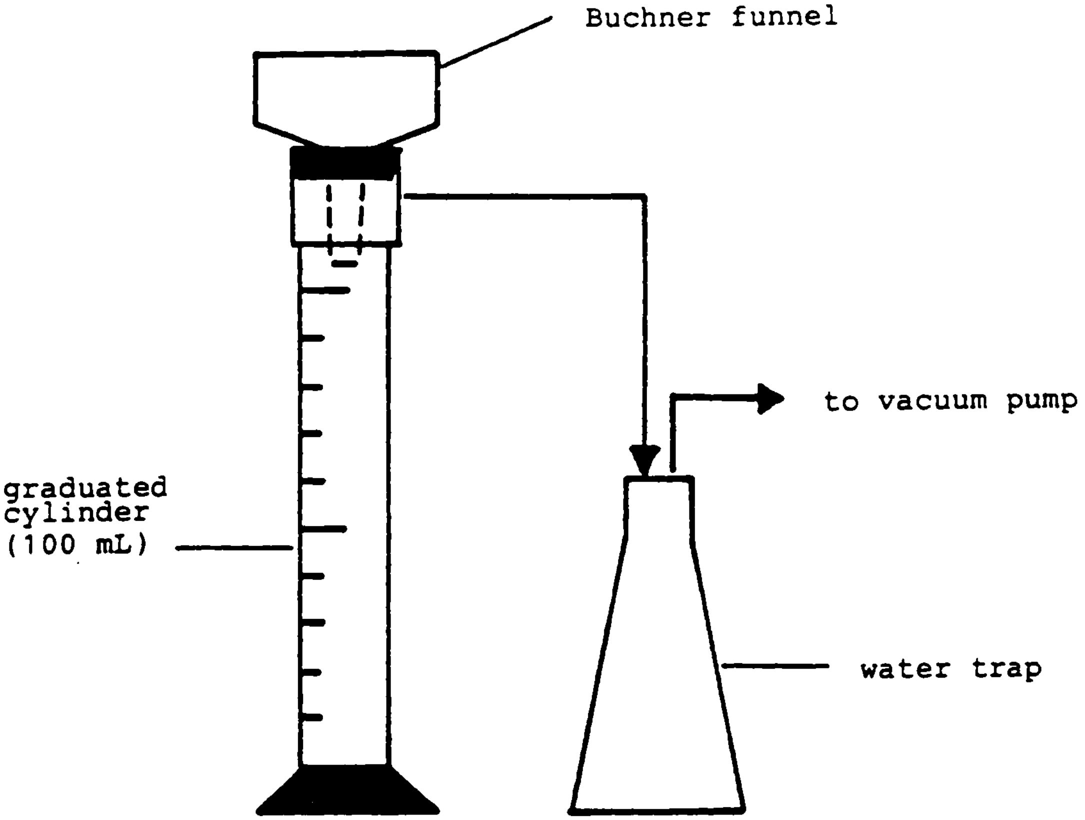

Figure 7. Buchner Funnel apparatus

RESULTS AND DISCUSSION

Data were collected in the initial part of this research to determine the polymer dose required to optimize the different zones of the BFP. The doses to optimize gravity drainage, the wedge zone and the high pressure zone were compared to each other. Using the optimum polymer doses, shear values were found using a bench top mixing apparatus to attempt to determine the G and t of the belt filter press. This section will present the results of the research to support the observations noted.

EFFECTS OF POLYMER DOSE ON OPTIMUM SOLIDS CONTENT

Different zones of the BFP were tested to determine the polymer dose required to optimize dewatering performance for the each zone. These tests were conducted to:

1. Determine if the required polymer dose increases from the gravity to the wedge zone, and from the wedge zone to the high pressure zone.

2. Determine if polymer requirements increased as the sludge passed through one roller, four rollers and seven rollers.

3. Determine a dose that might adequately optimize the overall BFP performance.

4. Determine how the gravity rate of drainage compares to the belt press performance.

ALUM SLUDGE

The first set of experiments on alum sludge were conducted not only to determine required doses for a given sludge but also to determine the effects of varying the belt pressing parameters on the optimum polymer dose. This was accomplished by comparing the optimum dose (as determined by the maximum solids content) of the gravity, wedge and belt press cycle to determine if a shift towards a higher dose occured at higher pressures. The number of rollers the sludge was passed through as well as the speed of the belt and the pressure were also varied. The Appendix contains tables showing pressures and speed settings for a two roller, four roller and seven roller press cycle.

Data obtained by passing the Alum sludge conditioned with Percol 757 through the belt press with a seven roller cycle are shown in Figure 8. Data presented in Figures 9 and 11 are the results of tests for the same sludge and polymer using four roller press cycle. Figure 10 shows the results for the same polymer and sludge arrangement passed through the belt press rollers four times with a sample taken after the first roller and last roller. Figure 12 shows the results of all the 4 roller tests conducted on alum sludge using Percol 757 polymer. Similar studies using a different polymer (Betz 1120) and a four roller press cycle are presented in Figure 13. This figure contains data showing the results of two tests conducted in exactly the same manner.

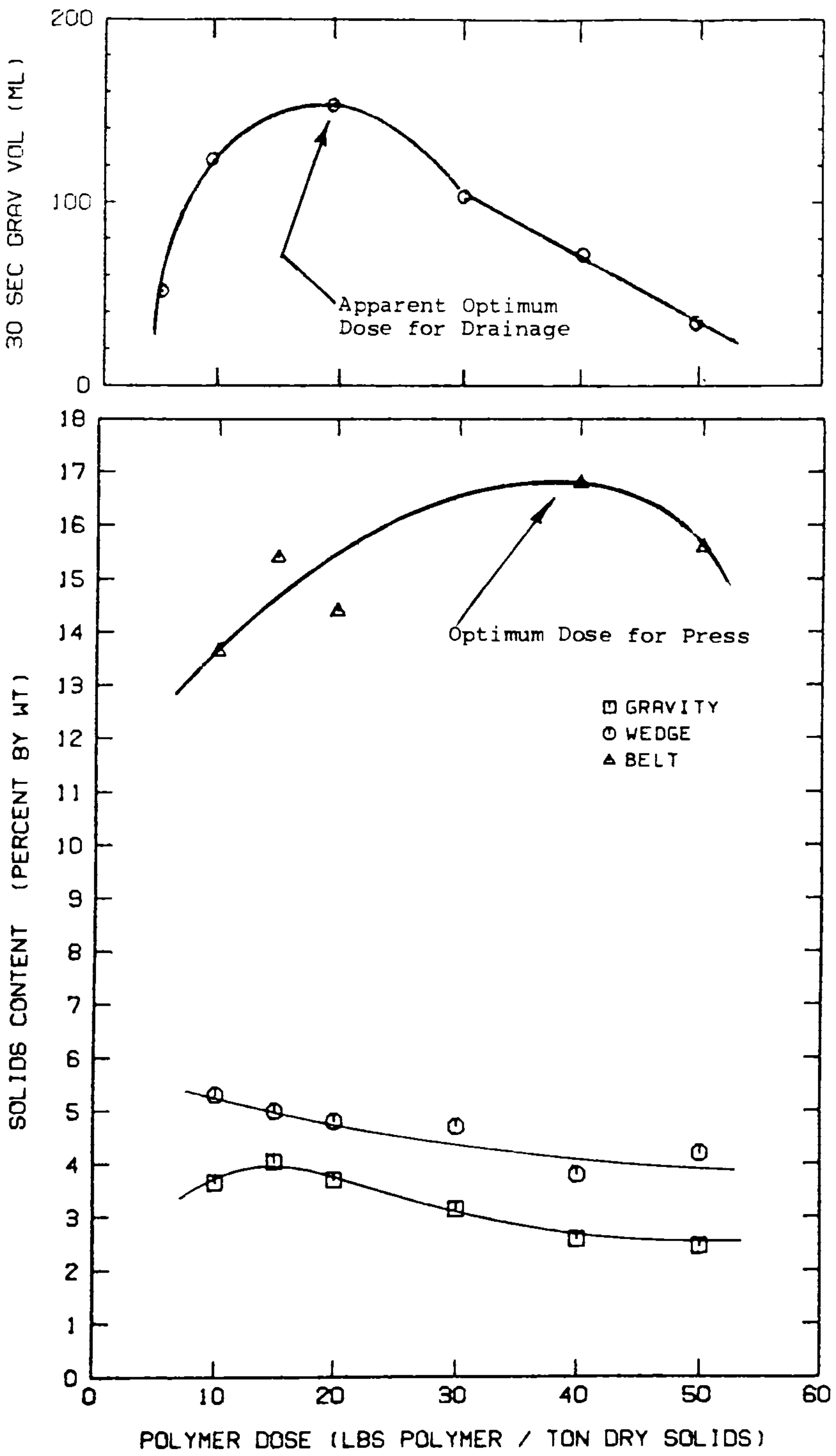

Figure 8. Cake solids of a seven roller belt press cycle versus Percol 757 polymer dose using alum sludge

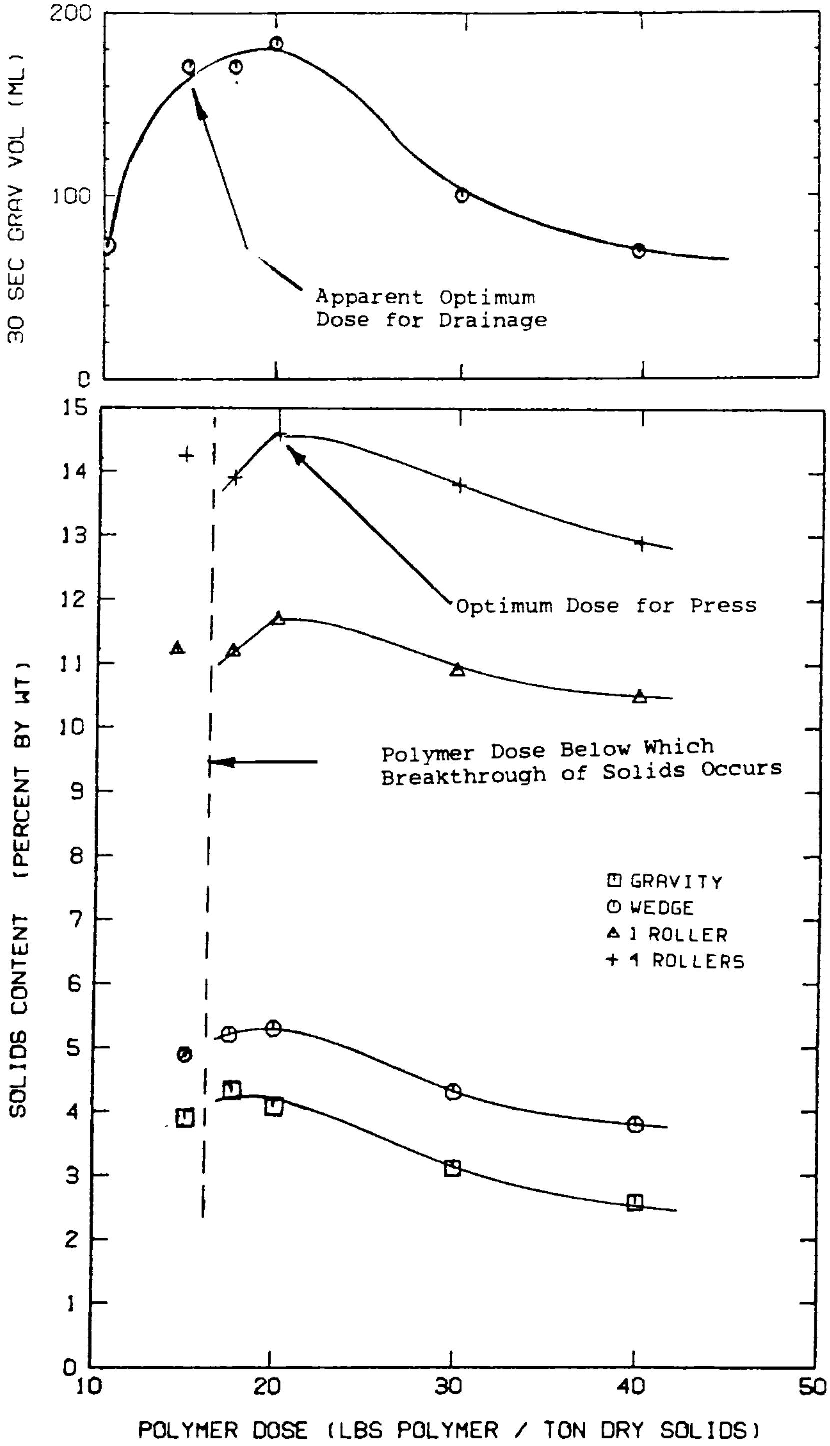

Figure 9. Cake solids of a one and 4 roller belt press cycle versus Percol 757 polymer dose using alum sludge

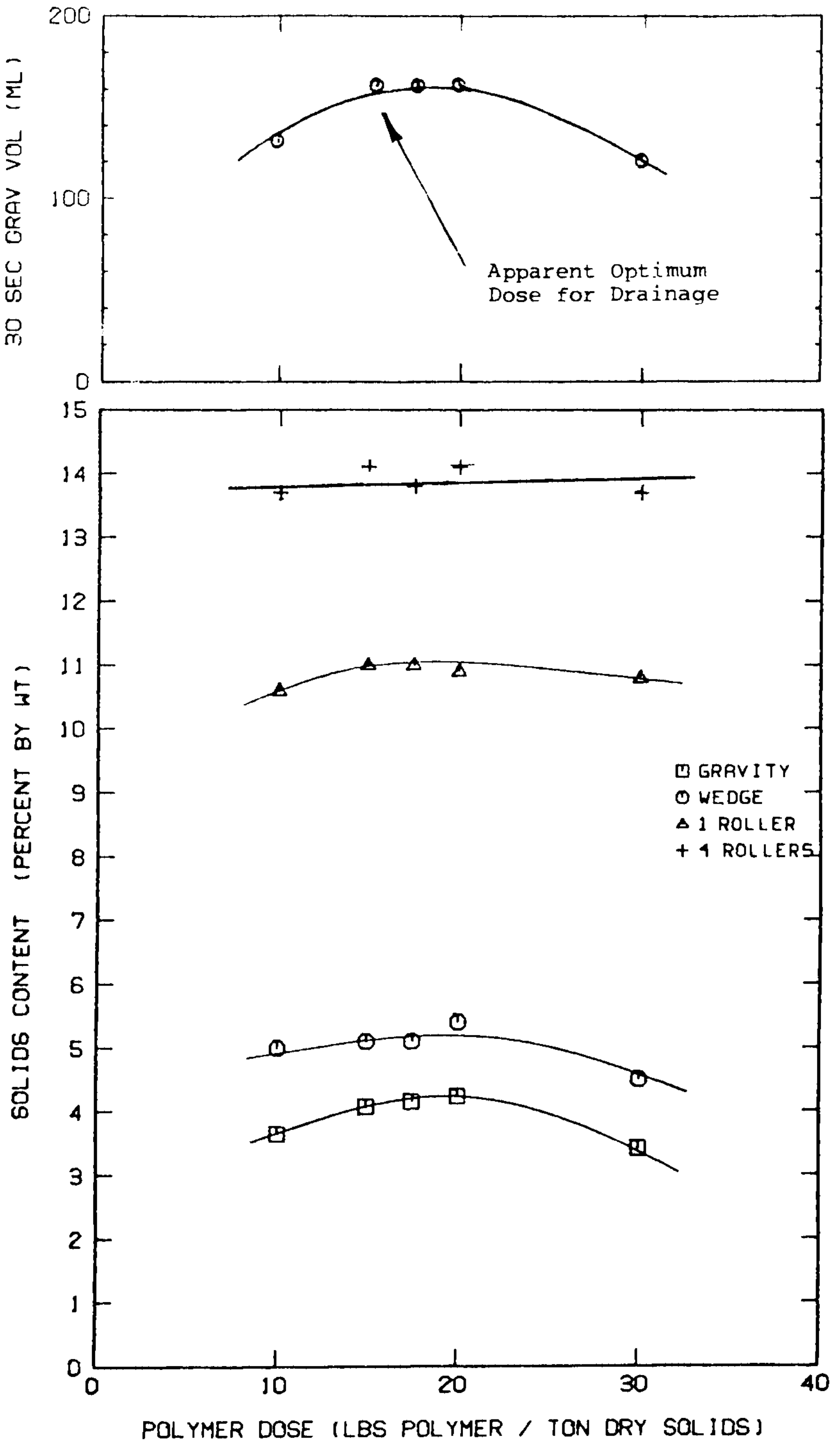

Figure 10. Cake solids of a one and 4 roller belt press cycle versus Percol 757 polymer dose using alum sludge

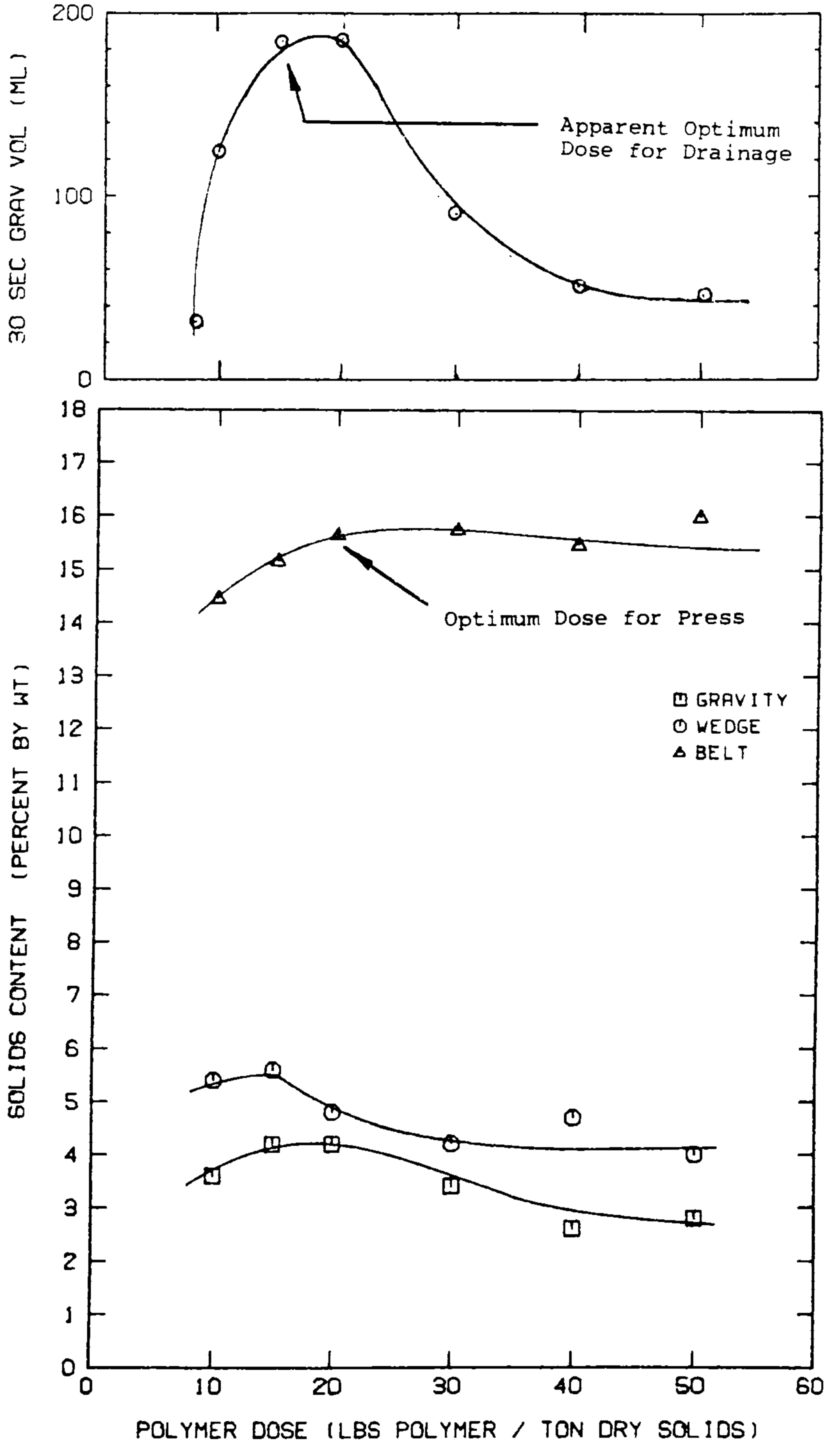

Figure 11. Cake solids of a 4 roller belt press cycle versus Percol 757 polymer dose using alum sludge

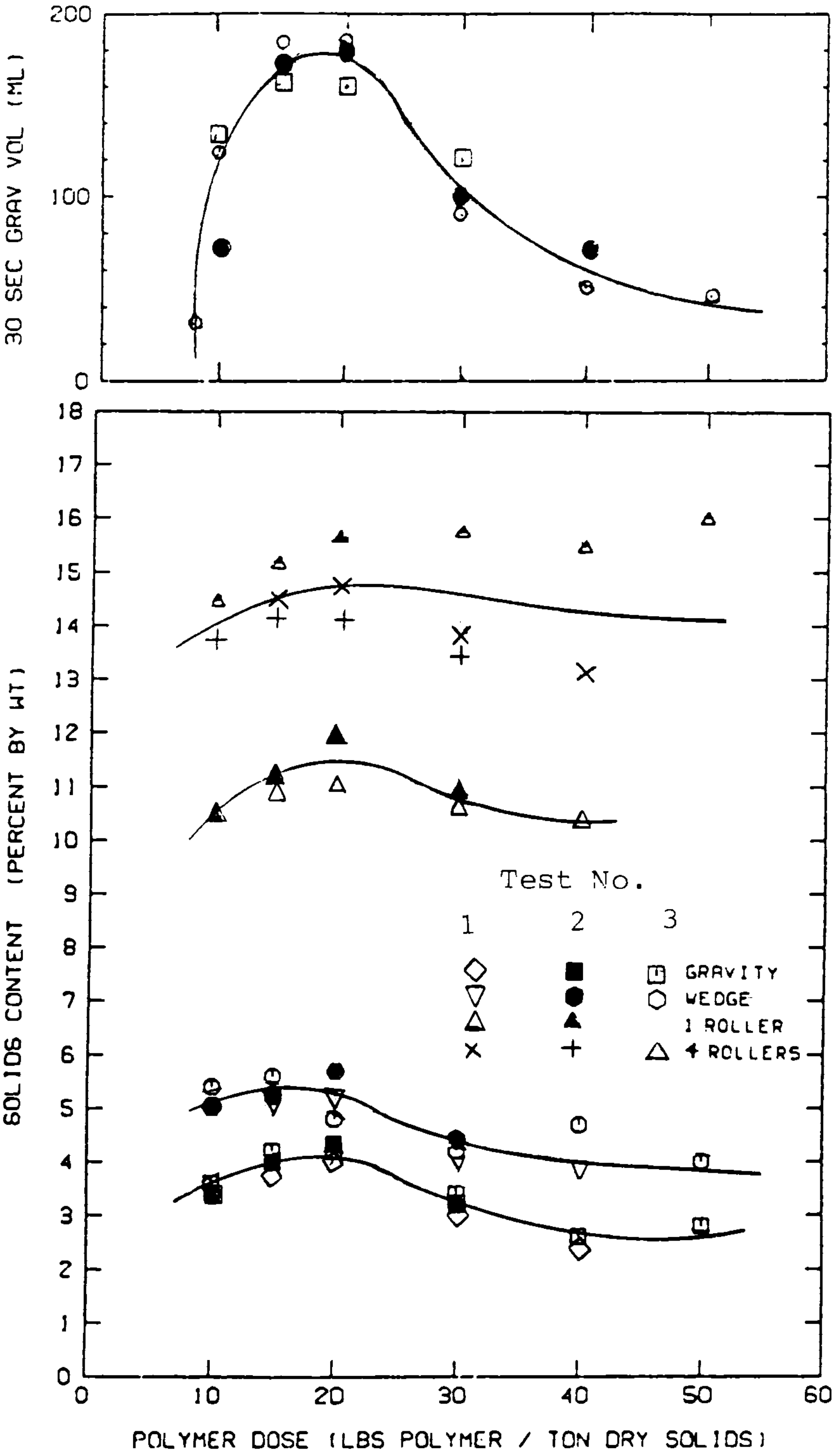

Figure 12. Cake solids of all the 4 roller belt press cycles using Percol 757 polymer and alum sludge

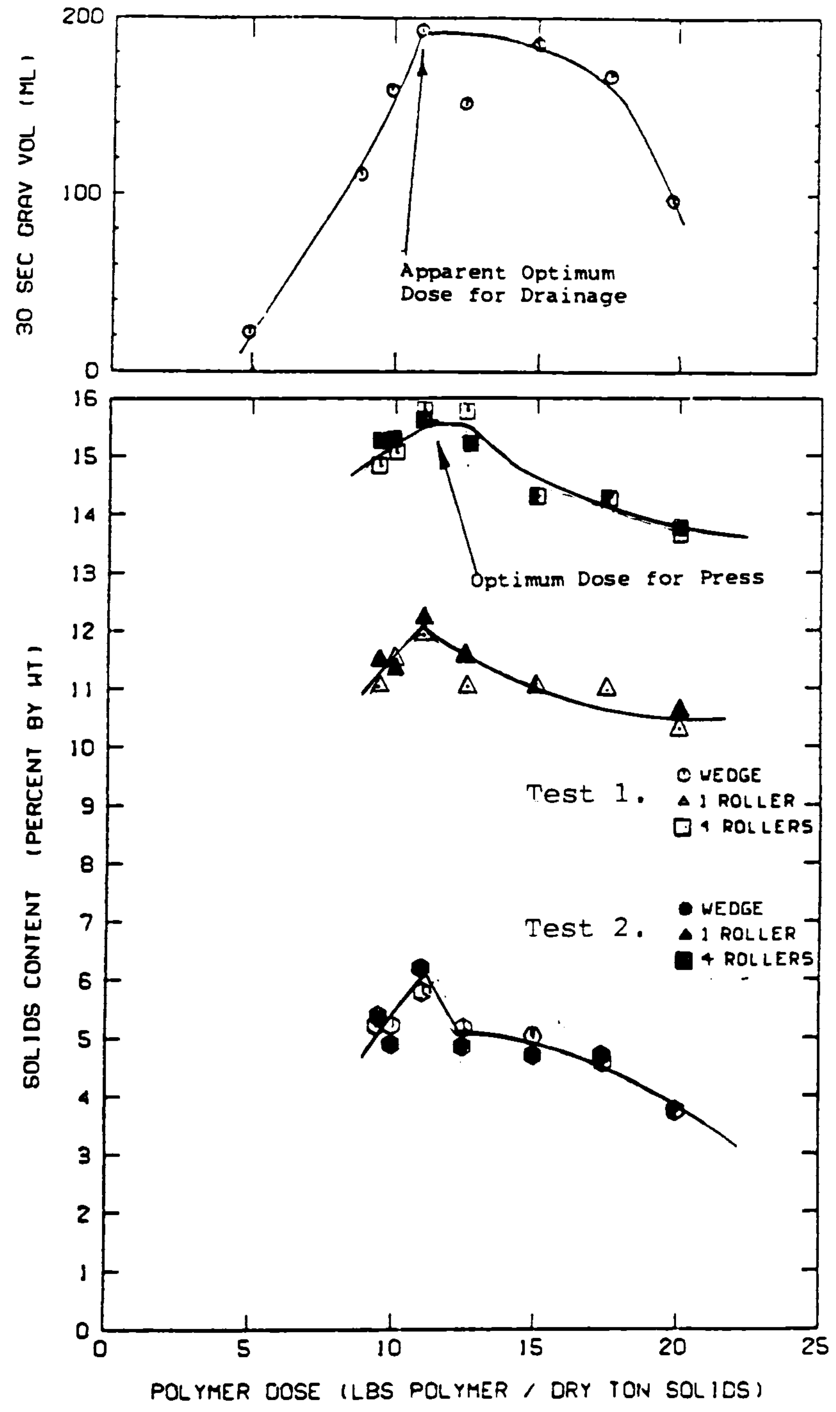

Figure 13. Cake solids of a one and 4 roller belt press cycle verses Betz 1120 polymer dose using alum sludge

For most of the tests the filtrate quality of the wedge cycle was monitored by visual inspection. If under or overdosed with polymer, the conditioned sludge would tend to "break through" in the wedge cycle which was visually apparent. For alum sludge conditioned with both Percol 757 and Betz 1120 a single test for each polymer was conducted in which the suspended solids was measured as a function of polymer dose. These tests gave an indication of the total suspended solids concentration in both clean filtrate and under "breakthrough" conditions. Results of these tests are shown in Figures 14 and 15 and are compared to the 30 second volume of water expelled in the gravity cycle and the wedge solids content. When "breakthrough" visually occurred the suspended solids were in the range of 500 to 2000 mg/L. Clean filtrate was considered to contain total suspended solids less than 100 mg/L. It is interesting to note that when breakthrough occured, it was during the wedge cycle rather than during the belt pressing. The 30 second gravity volume was not affected as drastically by breakthrough conditions. These figures also indicate that the polymer dose that gives the highest 30 second gravity volume may also be the best dose for the wedge cycle.

Based on the data in Figures 8, 9, 10 and 11 as well as the filtrate quality, it appeared that the optimum Percol 757 dose for alum sludge was 20 lbs/ton. Although a range of optimum doses of 10 to 20 lbs/ton may actually exist, the one chosen represented that with the best solids content most of the time and the best filtrate quality all of the time.

Based on the results shown in Figures 13 and 15 the optimum dose for the alum sludge conditioned with Betz 1120 was determined to be 11 lb/ton.

The results of this series of tests demonstrated that the optimum dose for all the cycles appeared to be approximately equal. The expected shift toward a higher optimum dose under high pressure belt pressing cycles was not apparent. Likewise, the optimum dose

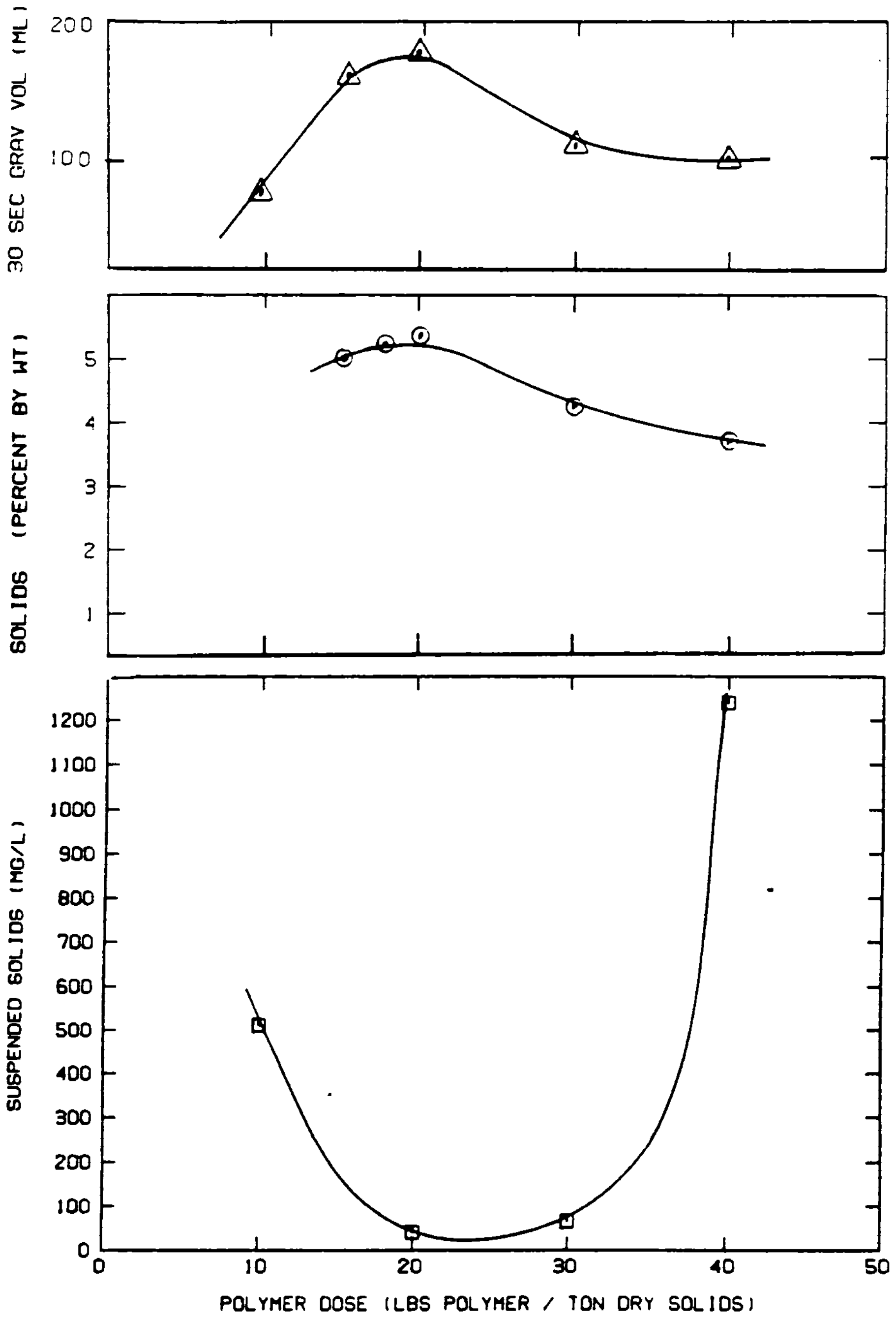

Figure 14. Comparison of filtrate quality, wedge zone solids, and the 30 second filtrate volume of the gravity zone using Percol polymer and alum sludge

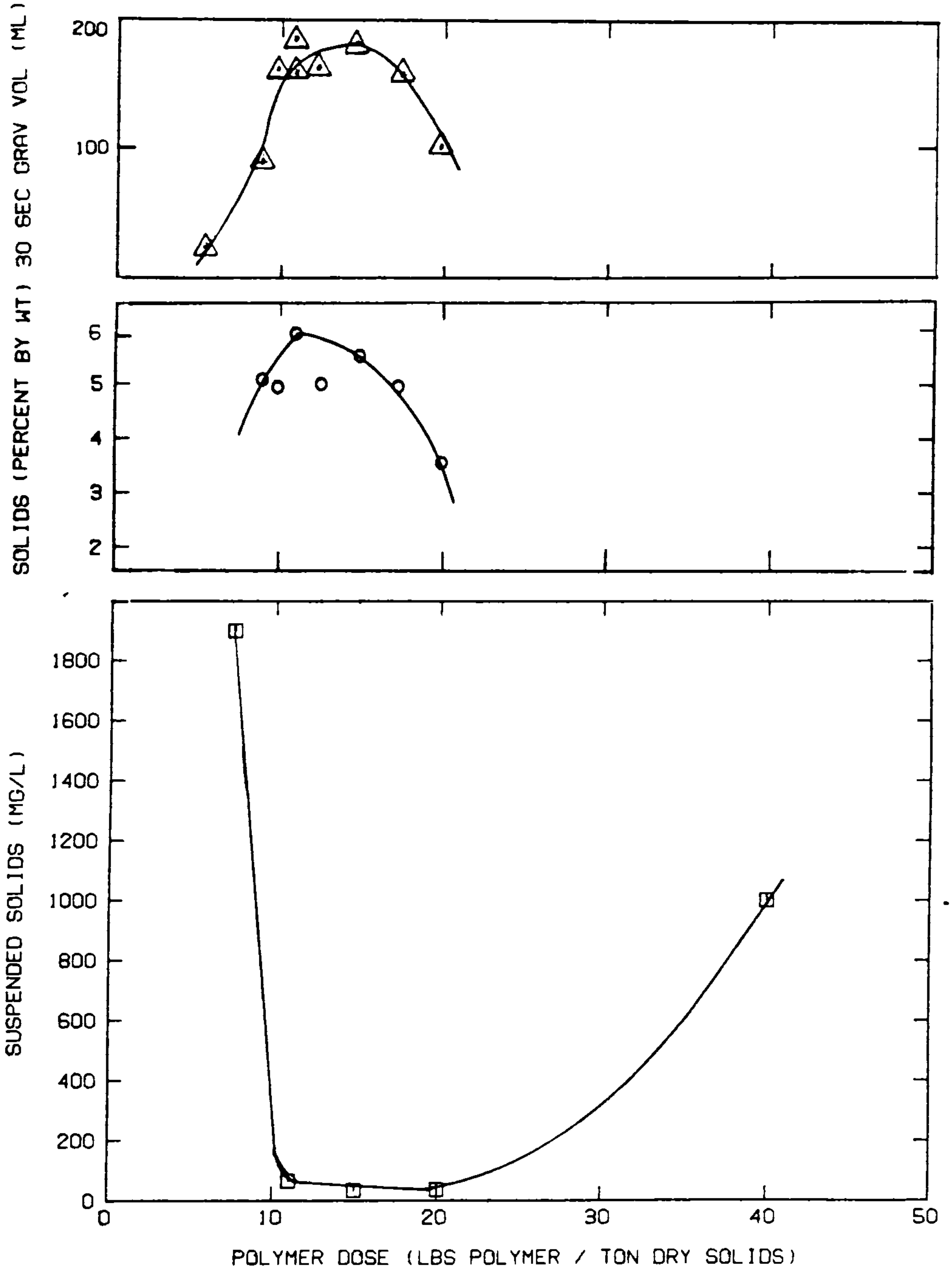

Figure 15. Comparison of filtrate quality, wedge zone solids, and the 30 second filtrate volume of the gravity zone using Betz 1120 polymer and alum sludge

did not seem to be affected by varying the number of belt cycles or the speed and intensity of the cycles. The number of cycles did effect the absolute value of the optimum solids content, but this was of no real value to this study. Also, based on these same figures, the optimum dose could be accurately predicted by the 30 second gravity drainage volume, since the dose that gave the maximum volume drained under gravity was the same dose that optimized performance of the belt press cycle.

Since a shift towards a higher dose at higher applied stresses was not seen in any of these tests, it was decided to use a 2 roller press test configuration to determine optimum polymer doses for the duration of the study. The speed of the belt was fairly slow and the pressure was increased on the second roller for this 2 roller configuration. Since the time the sludge is under pressure is important as compared to the number of rollers, this relatively slow speed was chosen to simulate a multi roller condition during the remander of the study.

ANAEROBICALLY DIGESTED SLUDGE

Three polymers were used to aid in dewatering the anaerobically digested sludge. Percol 757, Betz 1167L and Nalco Polymer E were all used. All tests were performed using the two roller configuration for the belt cycles previously described.

Results of testing with the Percol 757 are shown in Figure 16 and 17. Betz 1167 L results are shown in Figure 18. Tests results using Polymer E are found in Figure 19.

Based on the data presented in Figures 16 and 17 the optimum Percol 757 dose for the anaerobically digested sludge was 10 lbs per ton. A dose of 35 lbs/ton was selected as

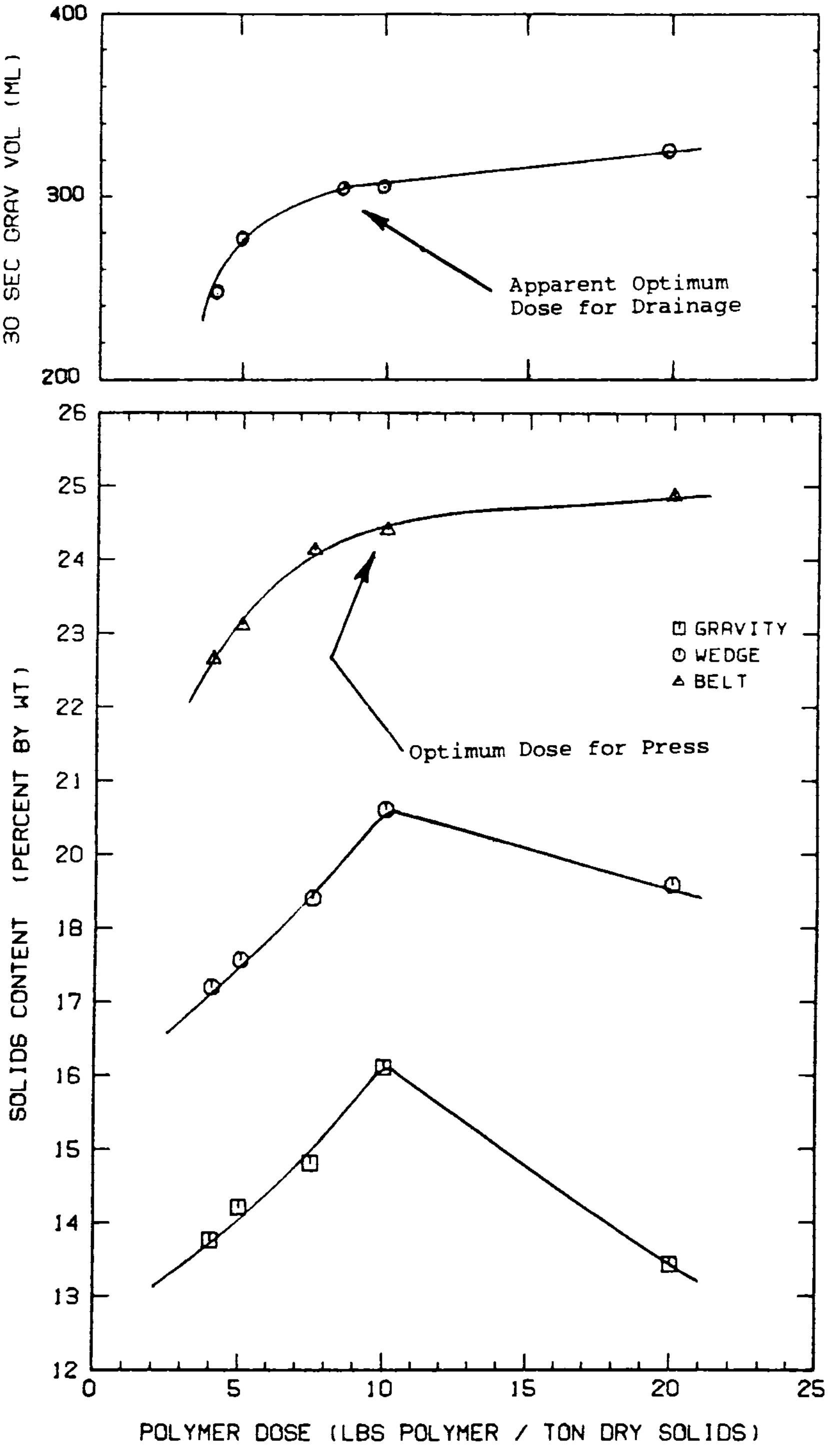

Figure 16. Cake solids of a 2 roller belt press cycle verses Percol 757 polymer dose using anaerobically digested sludge

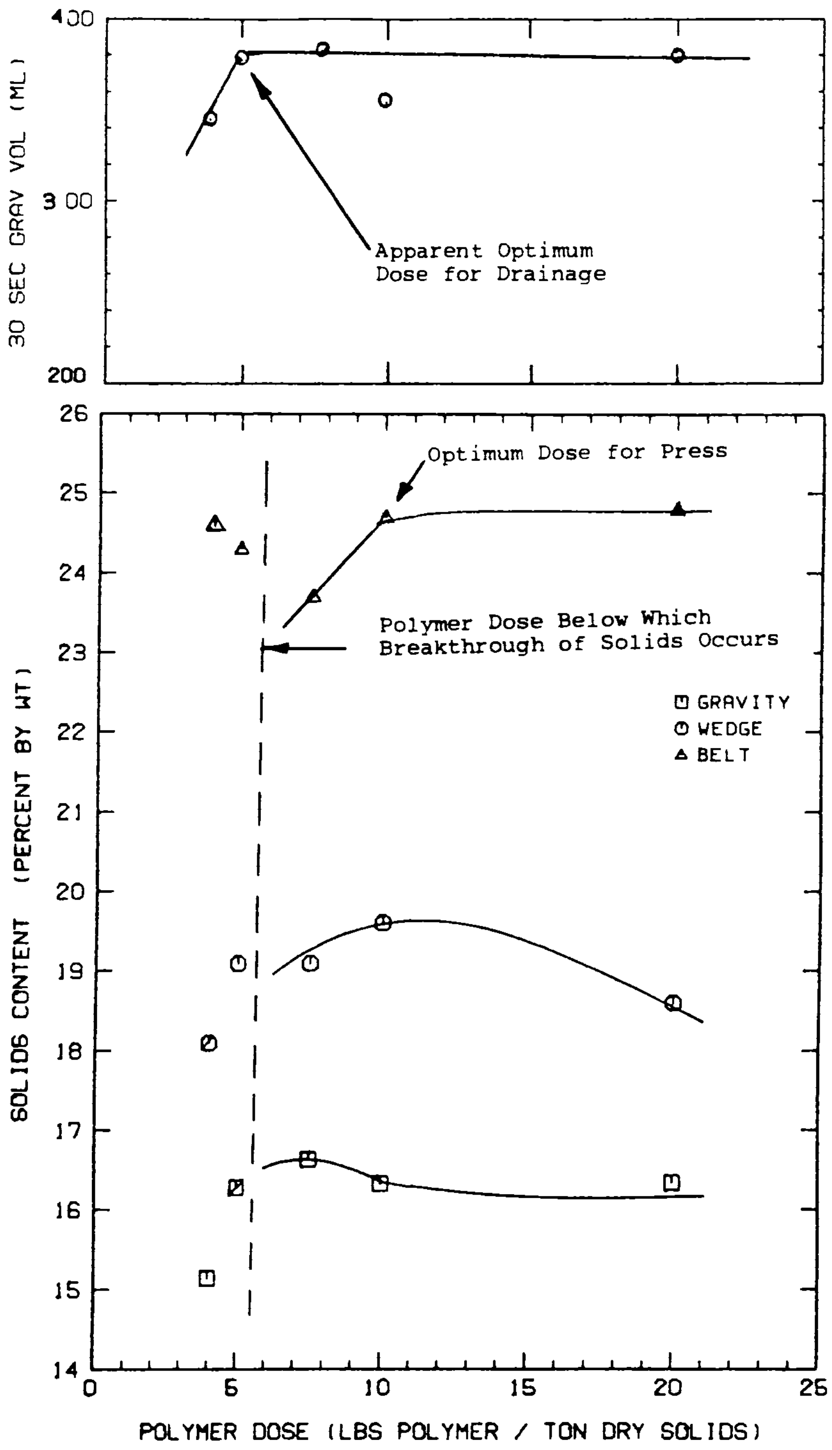

Figure 17. Cake solids of a 2 roller belt press cycle verses Percol 757 polymer dose using anaerobically digested sludge

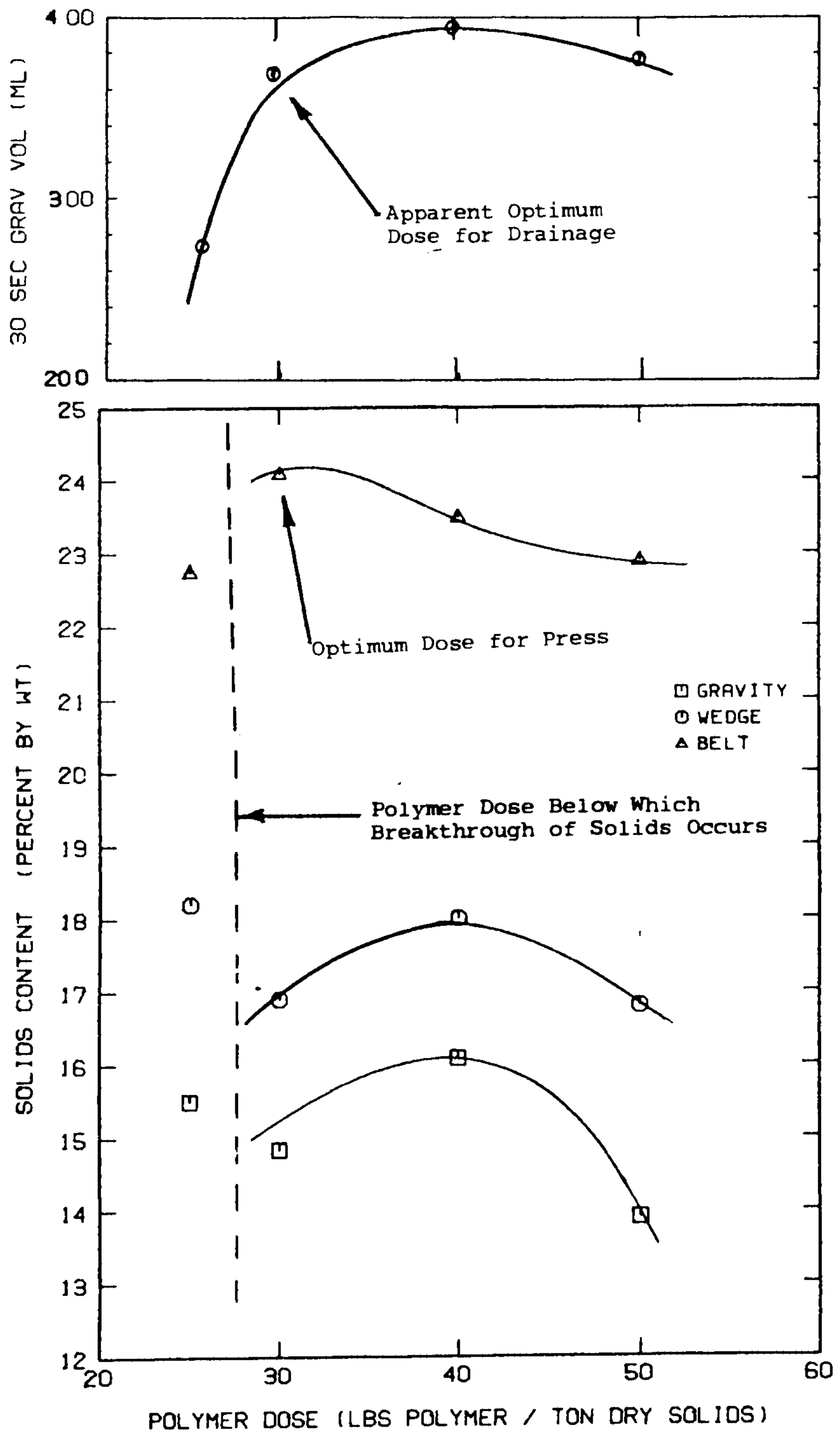

Figure 18. Cake solids of a 2 roller belt press cycle verses Betz 1167L polymer dose using anaerobically digested sludge

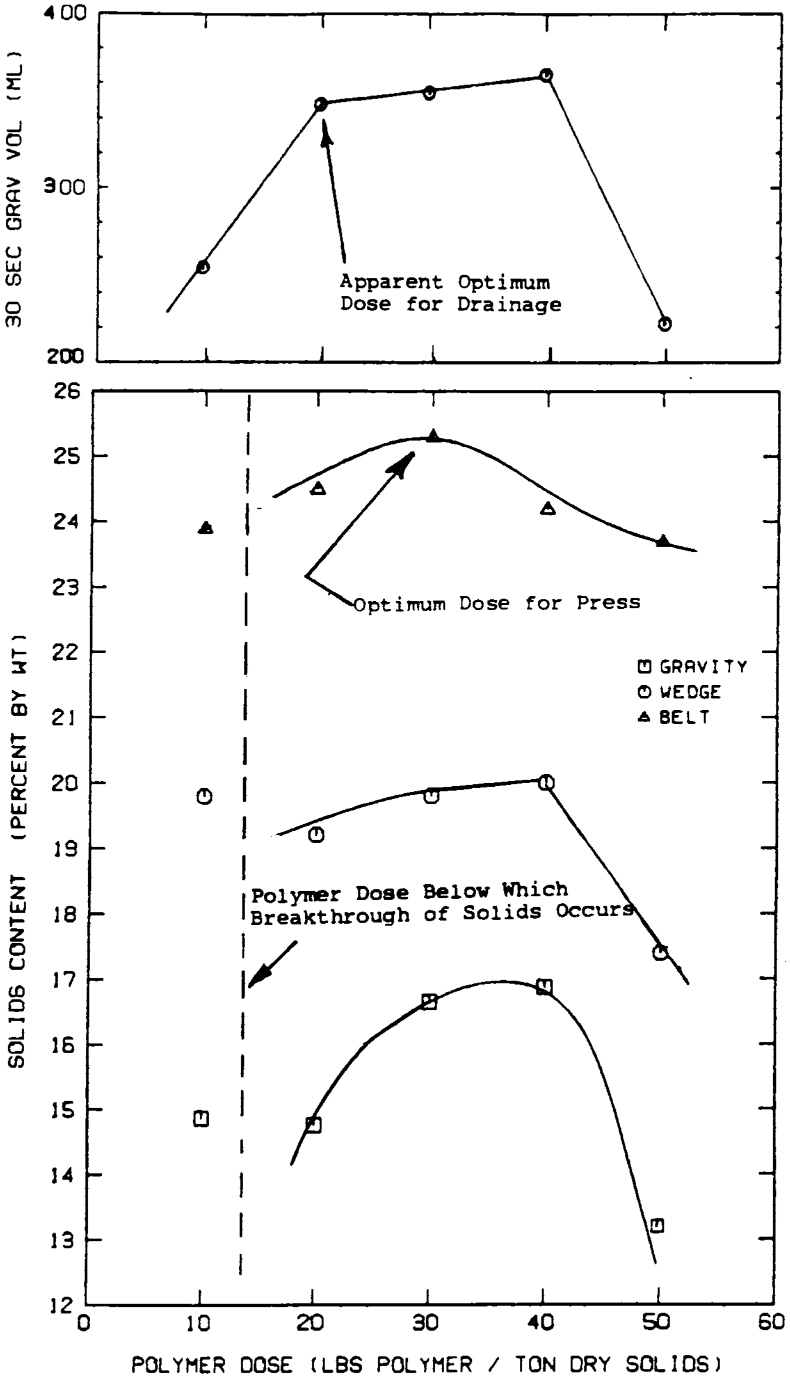

Figure 19. Cake solids of a 2 roller belt press cycle verses polymer E dose using anaerobically digested sludge

the optimum dose of the Betz 1167L polymer; however, a range of doses provided acceptable results. The high solids content of the sludge conditioned with Betz 1167L at low doses (25 lbs/ton) was because breakthrough was occurring at this low dose, resulting in formation of a very thin cake which attained a high solids content. From data in Figure 19 a dose of 30 lbs/ton was chosen as the optimum dose using Polymer E.

The results of these tests demonstrate no increase in polymer conditioning requirements as the number of pressing cycles was increased. The 30 second gravity drainage volume seemed to under predict the Percol dose required to optimize the BFP performance. It did a fair job in determining the correct range of Betz 1167L doses and accurately predicted the correct dose for the wedge cycle. The drainage test also seemed to under predict the optimum dose for polymer E.

AEROBICALLY DIGESTED SLUDGE

A two roller press cycle was again used to determine the optimum belt press doses of the aerobically digested sludge. Polymer E and Polymer D were used to dewater the aerobically digested sludge. Figure 20 shows the results obtained using polymer E, and Figure 21 provides the results obtained using Polymer D.

Based on the data in Figure 20, the optimum dose using Polymer E was selected to be 15 lbs/ton. The optimum dose of Polymer D was 25 lbs/ton based on data in Figure 21. Both figures indicate no disernable difference in polymer conditioning requirements for the different zones.

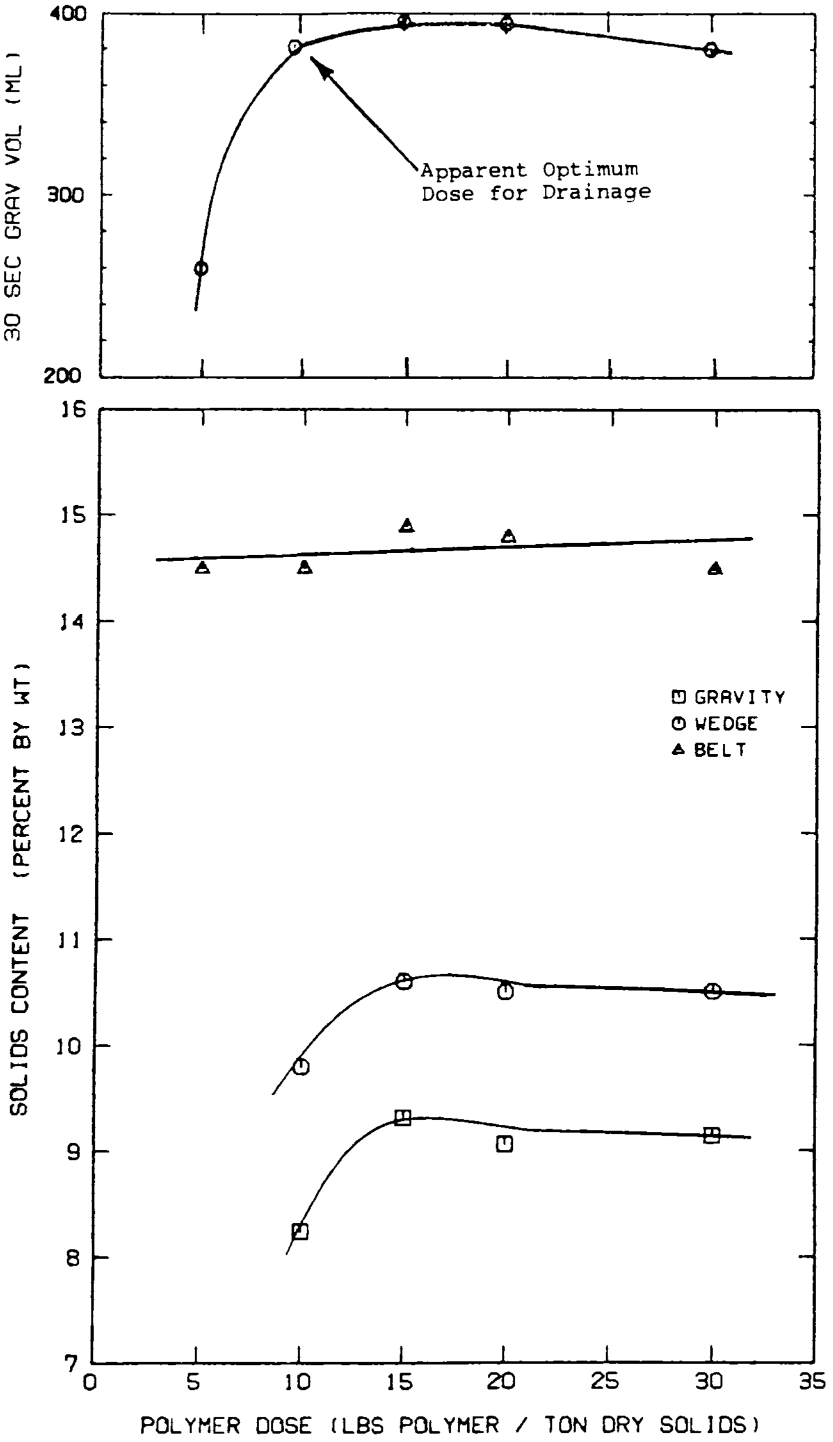

Figure 20. Cake solids of a 2 roller belt press cycle verses polymer E dose using aerobically digested sludge

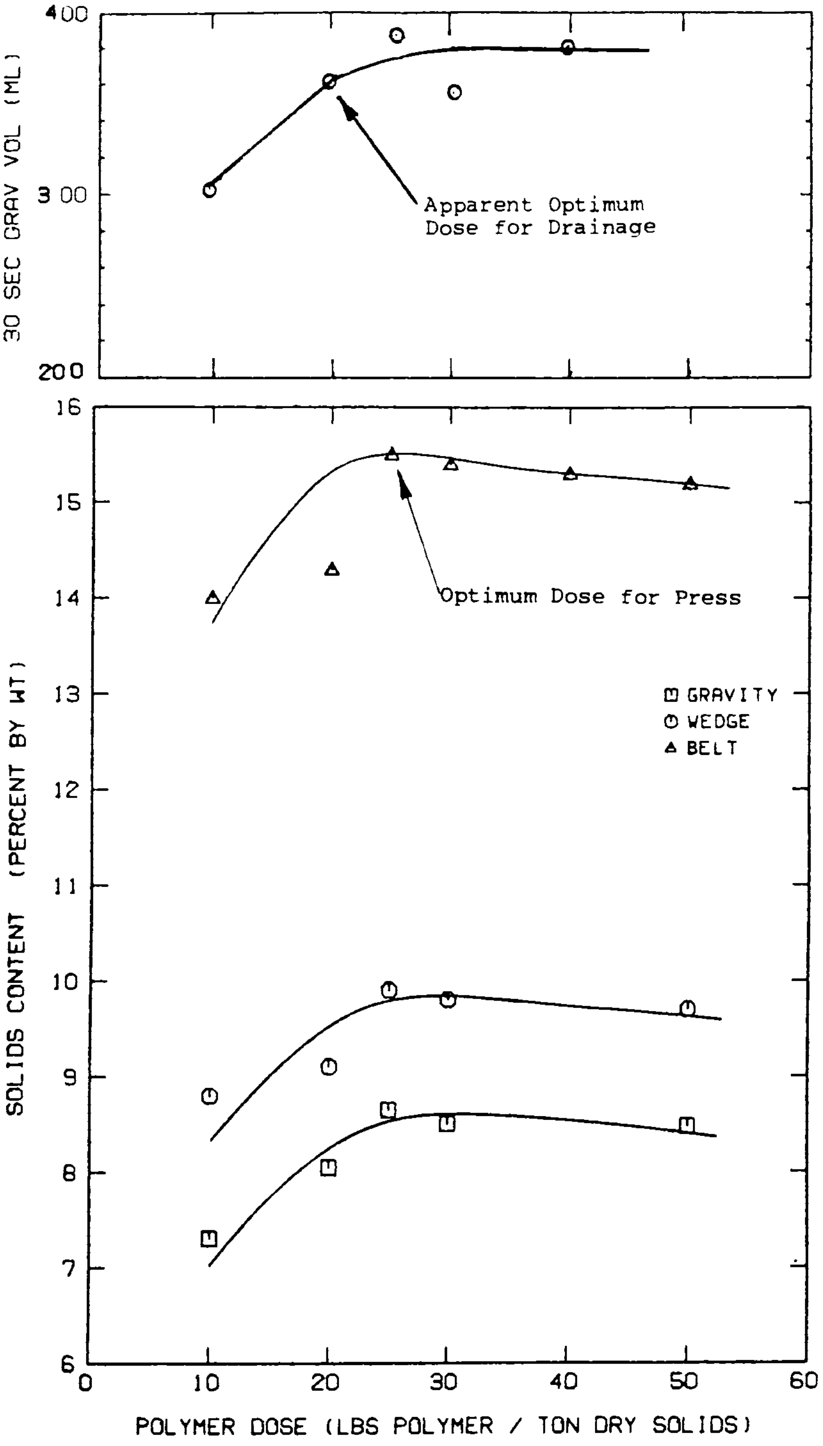

Figure 21. Cake solids of a 2 roller belt press cycle verses polymer D dose using aerobically digested sludge

The 30 second gravity volumes tended to underpredict Polymer E dose but accurately predicted polymer D doses.

Table 3 presents a summary of results of these optimum polymer dosage tests performed on all the sludges.

DETERMINING Gt OF THE BELT PRESS

Since the Gt of the belt press cannot be measured directly an attempt was made to measure the Gt of the belt pressindirectly. This was accomplished by comparing the polymer dose requirement for the belt press to the dewatering response using the labratory mixer over a range of mixing times and intensities. The Gt that gave the best dewatering rate was assumed to be the Gt that would characterize this laboratory BFP set up as tested.

Results of the Gt vs CST test conducted on Betz 1120 polymer at the optimum dose of 11 lbs/ton are shown in Figure 22. Figure 23 presents the dewatering results of Alum sludge conditioned with 20 lbs/ton Percol 757 polymer. The data indicated that one optimum CST did not exist. The data were then replotted and by trial and error an exponent of of G of 0.7 was found to best describe the response to CST. (shown in Figure 24)

Figure 25 shows the relationship between CST and Gt for anaerobically digested sludge using a Percol polymer dose of 10 lbs/ton. Figures 26 and 27 show similar data for Betz 1167L polymer and Polymer E. Each of these doses was chosen as the optimum for belt press performance.

Table 3. Comparison of Optimum Polymer Dosages as determined by the 30 Second Drainage Voulme Compared to the Labratory BFP Simulator

		Optimal Polymer Dose(lb/ton) Based on:			
Sludge	Polymer	30 Second Volume	Wedge Zone Cake Solids	HPZ Cake Solids	Reference Figures
Alum	Percol 757	15	15-20	20	9,10,11,12
	Betz 1120	11	11	11	13
Anaerobically Digested	Percol 757	5-8	10	10	16,17
	Betz 1167L	30	40	30	18
	Polymer E	20	40	30	19
Aerobically Digested	Polymer E	10	15	15	20
	Polymer D	20	25	25	21

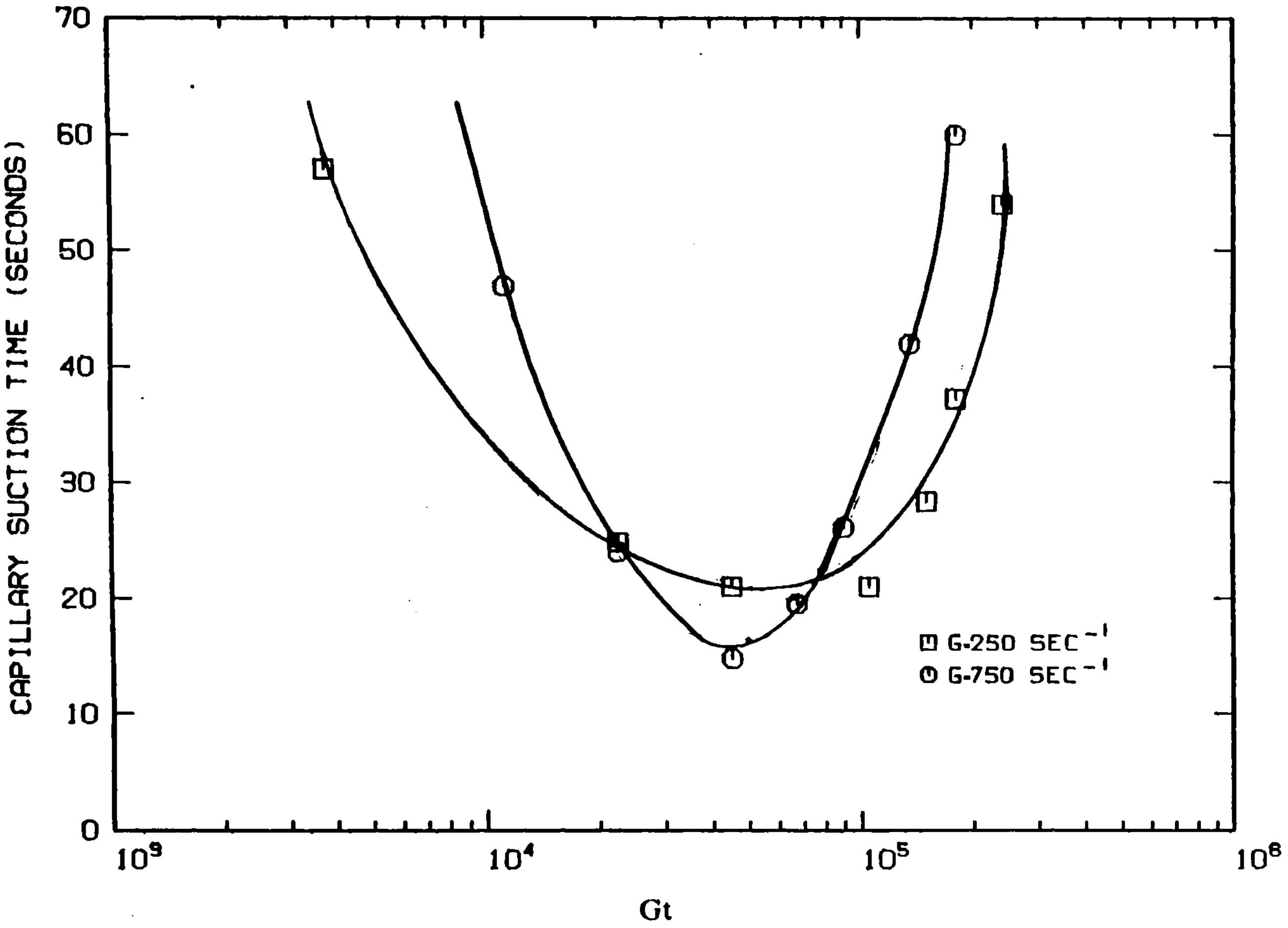

Figure 22. Capillary suction time verses Gt using alum sludge and Betz 1120 polymer

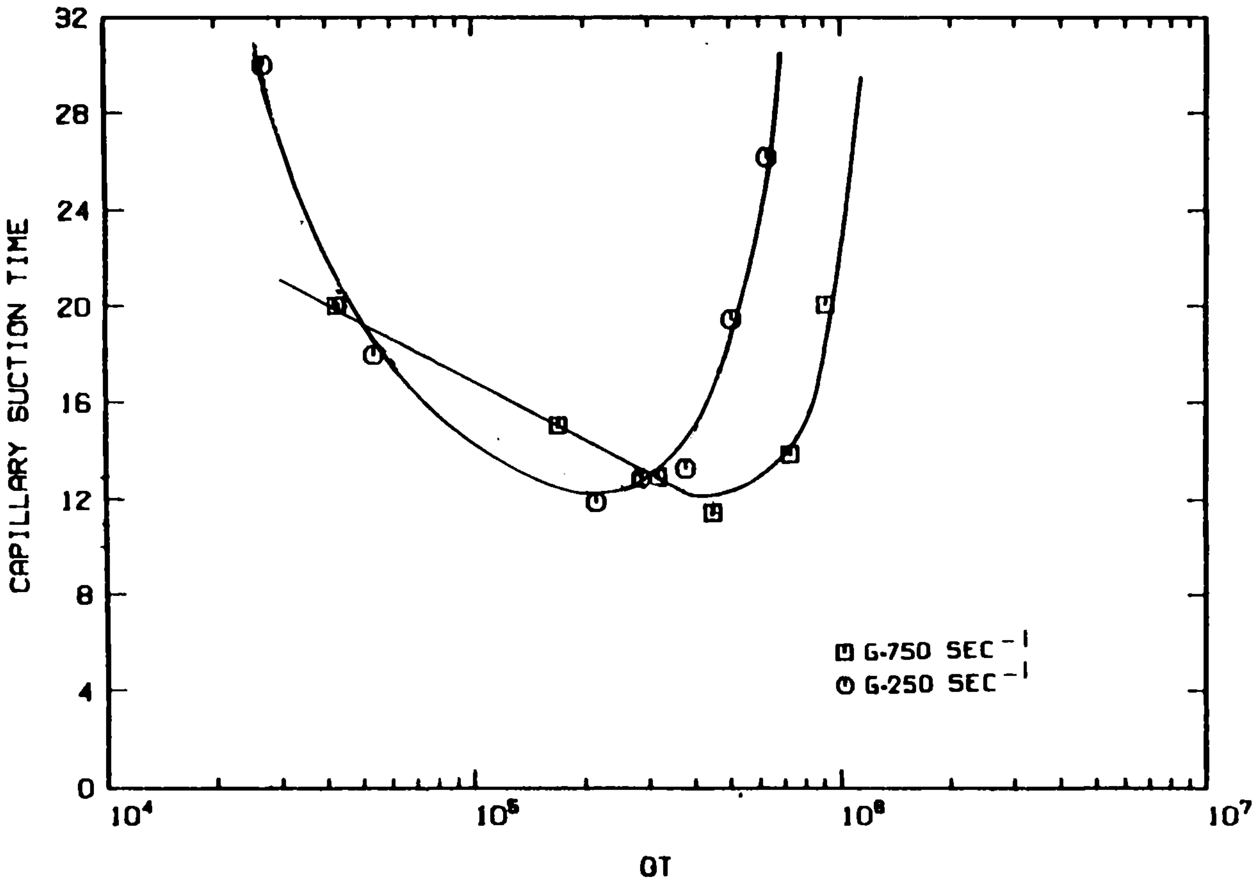

Figure 23. Capillary suction time verses Gt using alum sludge and Percol 757 polymer

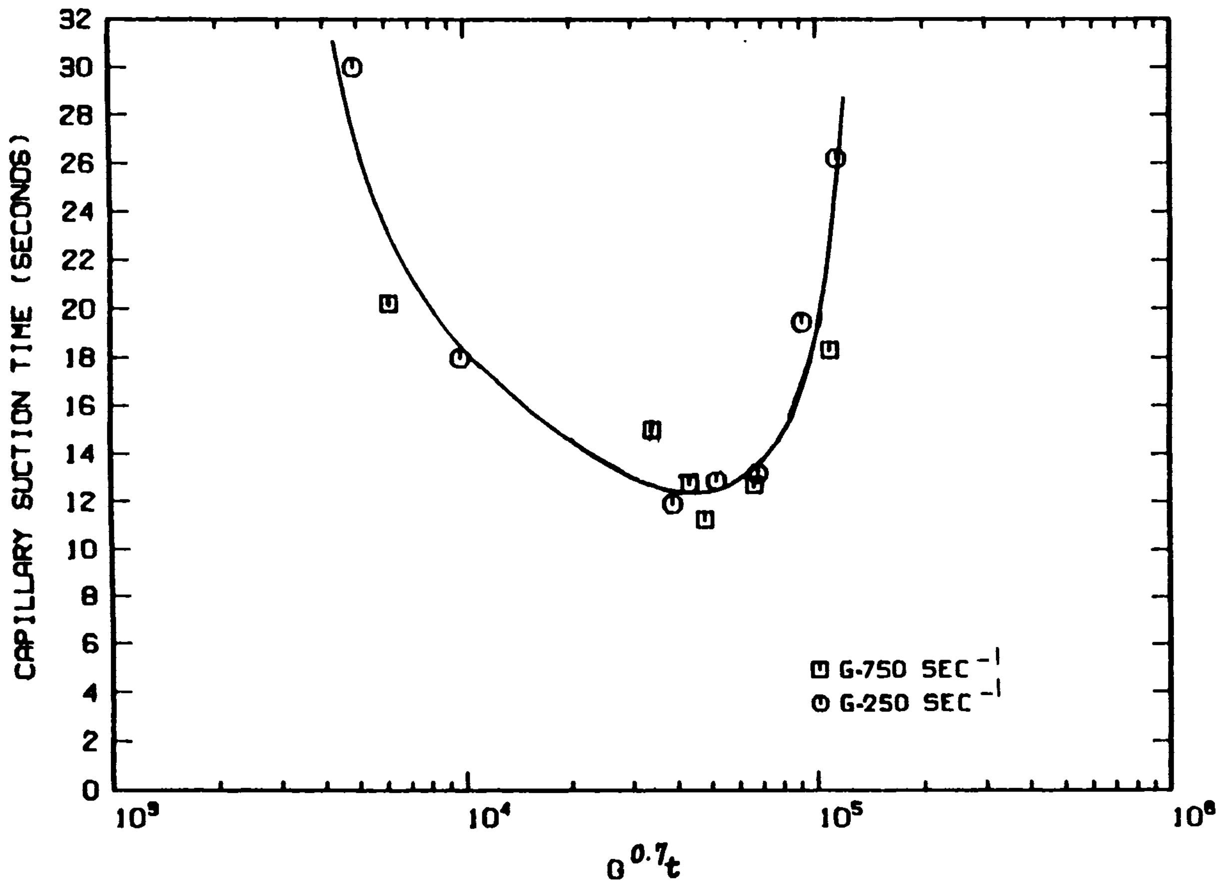

Figure 24. Capillary suction time versus $G^{0.7}t$ using alum sludge and Percol 757 polymer

Figure 28 and 29 present the results of the aerobically digested sludge tested with Polymer E and D, tested at the optimal dose for belt press operation.

All of these results with the exception of the data in Figures 23 and 24 show that a Gt in the range of 30,000 to 90,000 is the mixing condition where the CST is minimized. A range of 30,000 to 80,000 for $G^{0.7}t$ was also found from Figure 24. These data indicate that $G^{x}t$ for the machine is in the range of 30,000 to 90,000. This also suggests that if an exponent does exist for any sludge / polymer combination, the exponent could be determined and used to help find the optimum polymer dose required for the belt press.

USING Gt TO PREDICT POLYMER DOSE

Since the Gt of the machine was determined to be in the range of 30,000 to 90,000 a value of 45,000 (assuming $x = 1$) was used to see if this mixing condition combined with Buchner funnel testing would predict the same polymer dose as the belt press. Using the Gt of 45,000 ($G = 750$, $t = 60$) the time to filter 50 mL (TTF 50) using the Buchner funnel was checked versus the polymer dose. The theory was that the dose determined as optimum on the belt press should also give the lowest TTF 50.

Results for the alum sludge tests conditioned with Percol 757 are found in Figure 30. Figure 31 shows data for the alum sludge conditioned with the Betz 1120. Using this method to predict an optimum polymer dose, it can be seen that it predicted the Betz polymer dose, but under predicted the Percol polymer. This may be because an exponent of G other than one existed for the percol polymer and alum sludge.

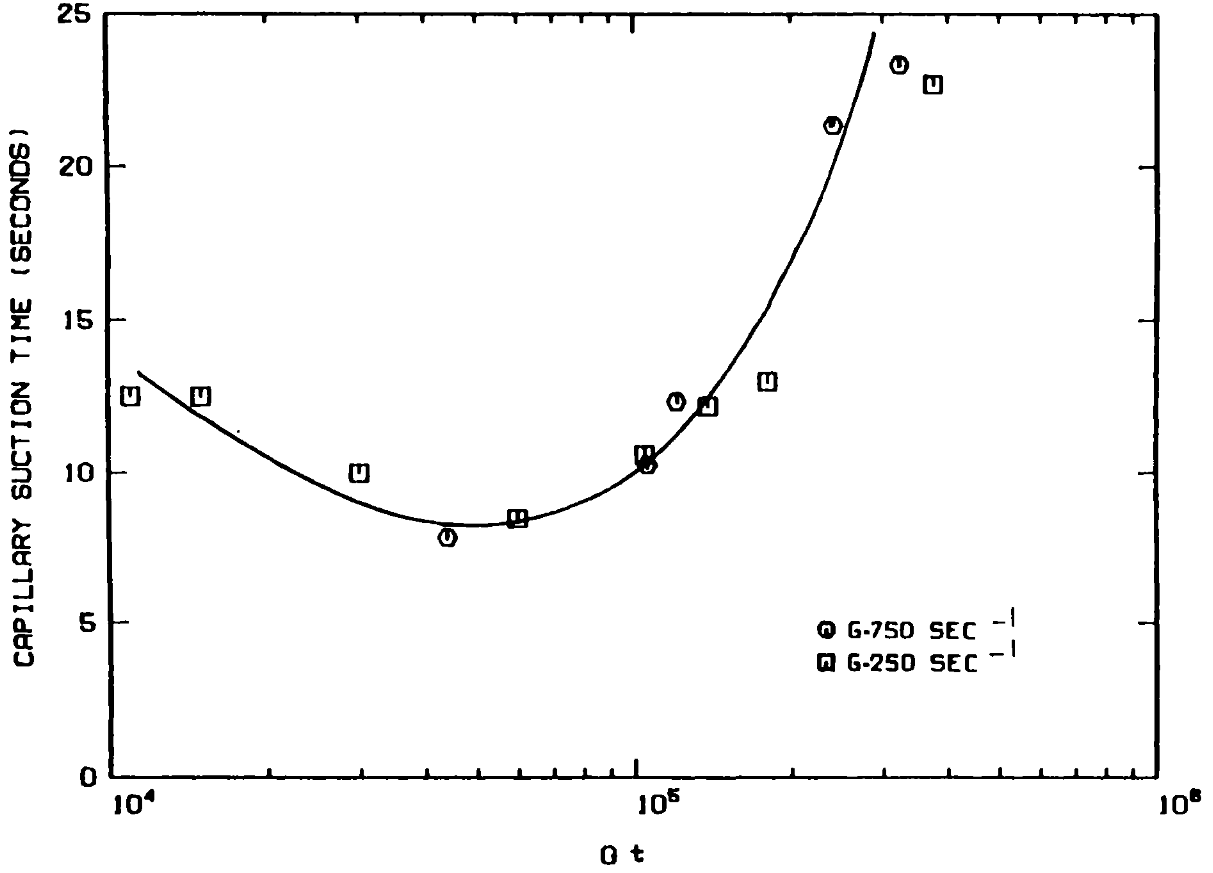

Figure 25. Capillary suction time verses Gt using anaerobically digested sludge and Pèrcol 757 polymer

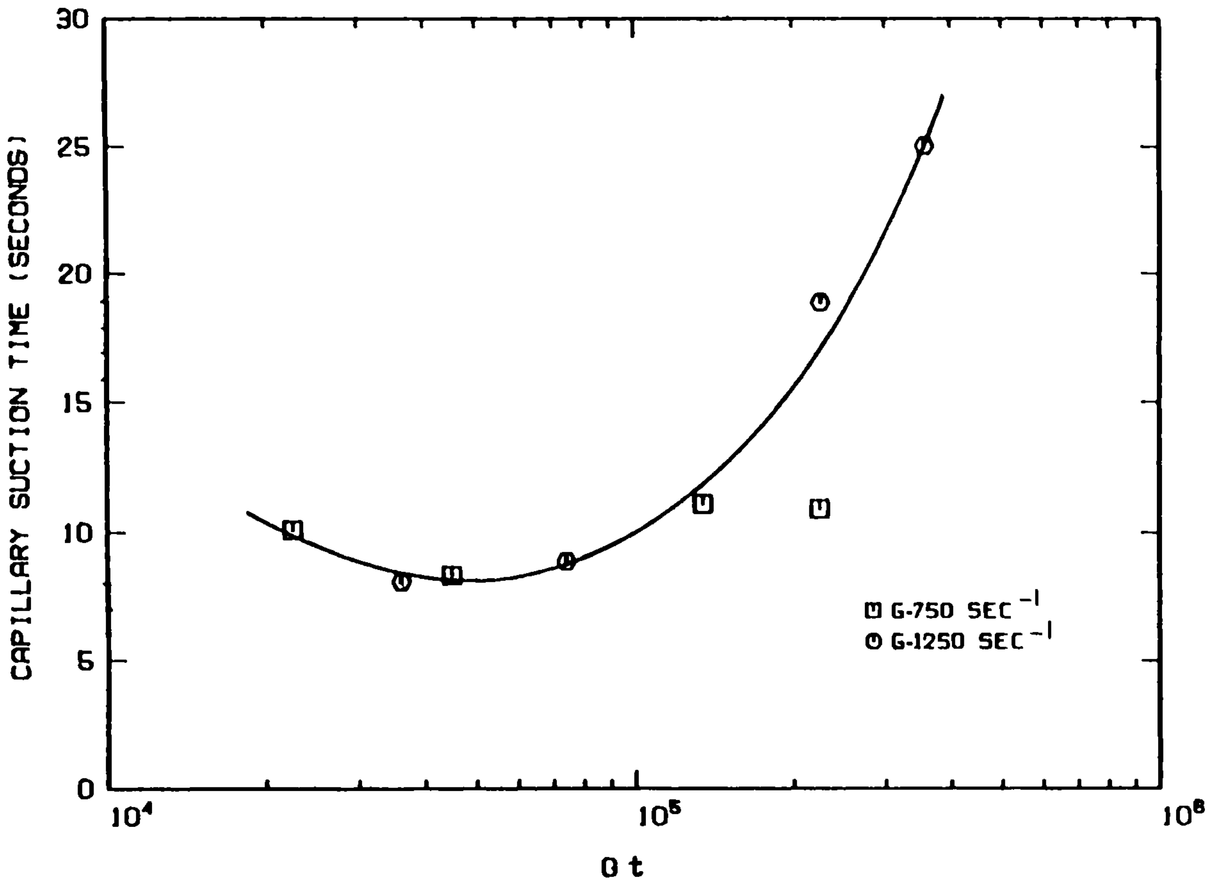

Figure 26. Capillary suction time verses Gt using anaerobically digested sludge and Betz 1167L polymer (by Chelf, 15)

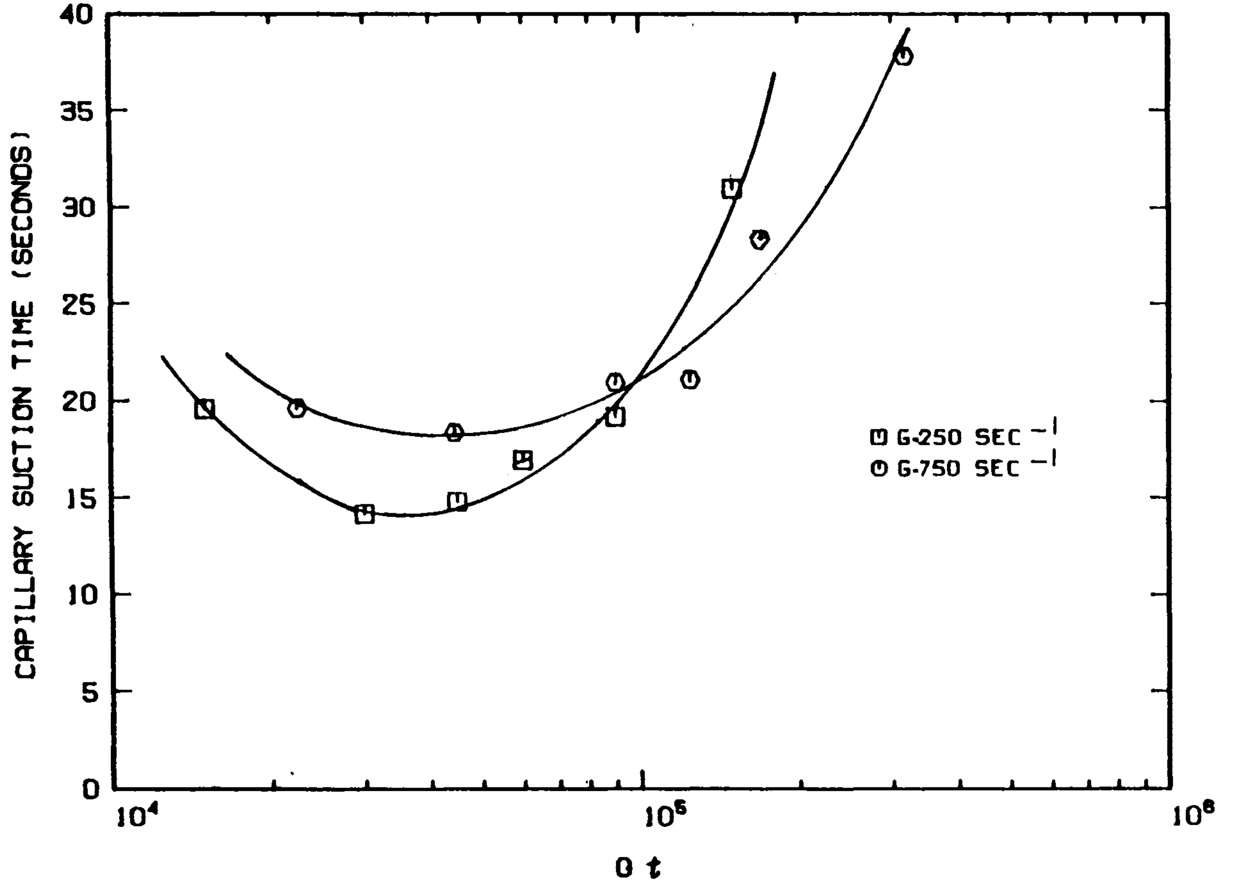

Figure 27. Capillary suction time verses Gt using aerobically digested sludge and polymer E'

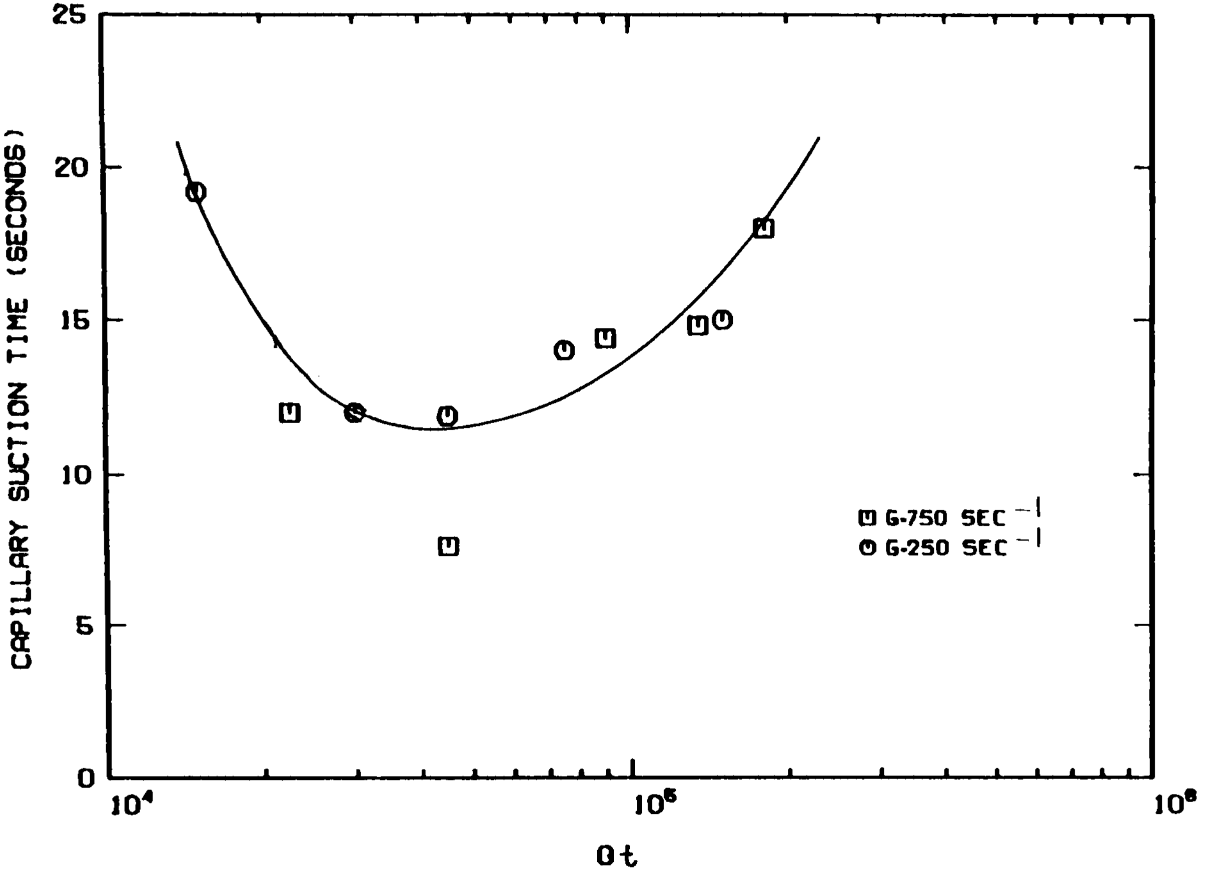

Figure 28. Capillary suction time verses Gt using aerobically digested sludge and polymer D

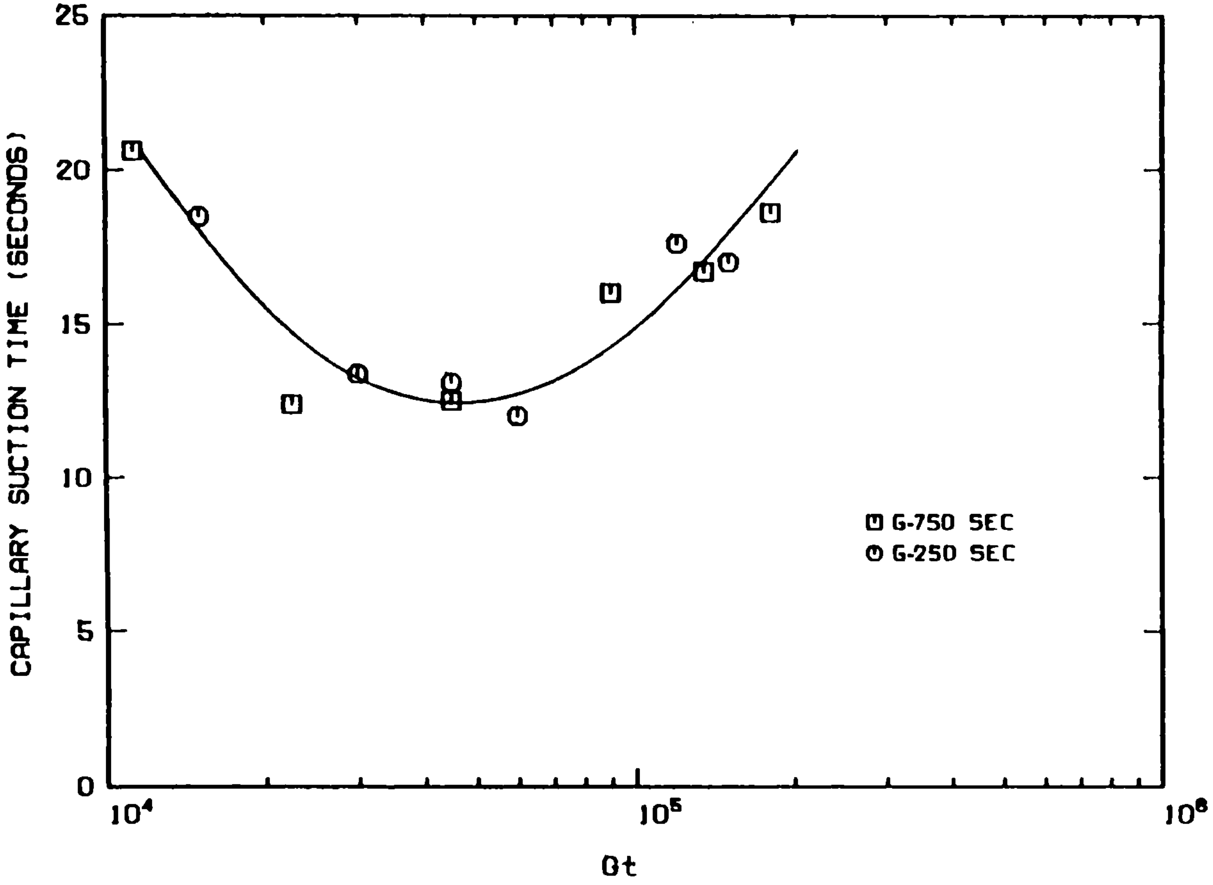

Figure 29. Capillary suction time verses Gt using aerobically digested sludge and Polymer E

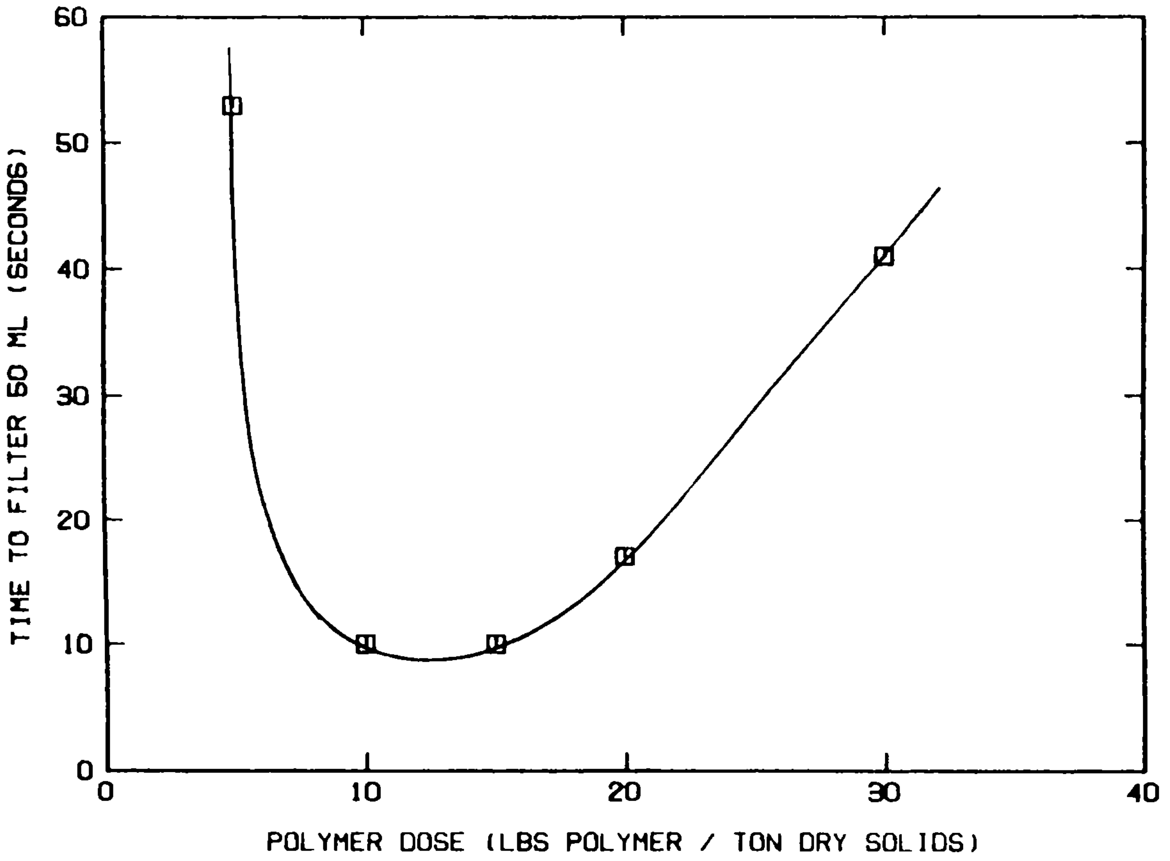

Figure 30. Time to filter 50 mL through a Buchner Funnel using Alum sludge conditioned with Percol 757 polymer at a Gt = 45,000

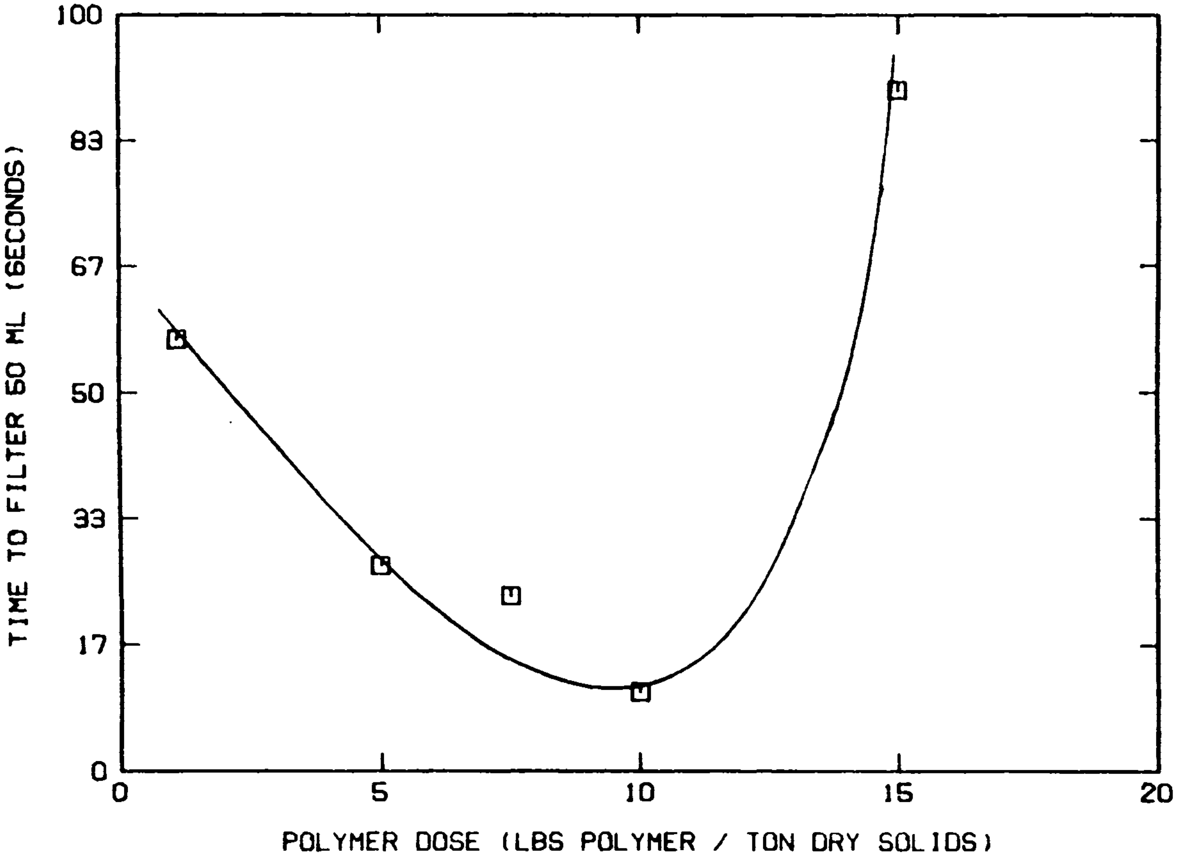

Figure 31. Time to filter 50 mL through a Buchner Funnel using Alum sludge conditioned with Betz 1120 polymer at a Gt = 45,000

Figure 32 presents the results of studies using anaerobically digested sludge conditioned with the Percol 757 polymer. Figure 33 is the results of the anaerobically digested sludge conditioned with the Betz 1167L polymer, whereas Figure 34 contains the results using Polymer E. The test method did a good job in predicting optimum doses for the anaerobically digested sludge for all three polymers. A very narrow optimum range was predicted for the Betz 1167L curve but did not occur for the belt press.

Figure 35 shows the results of aerobically digested sludge conditioned with Polymer E. Figure 36 is the results of the aerobically digested sludge conditioned with Polymer D. This test method did a fine job in determining the optimum dose required for the aerobically digested sludge using these polymers.

From the results presented it appears that using a Gt of 45,000 in conjunction with a TTF 50 ml vs polymer dose will give a good indication of the range of acceptable polymer doses, and will predict the optimum dose for the labratory BFP if the exponent of G is 1. Table 4 presents a summary of the optimum doses as found by the belt filter press verses the optimum doses found by the Buchner funnel-Gt tests.

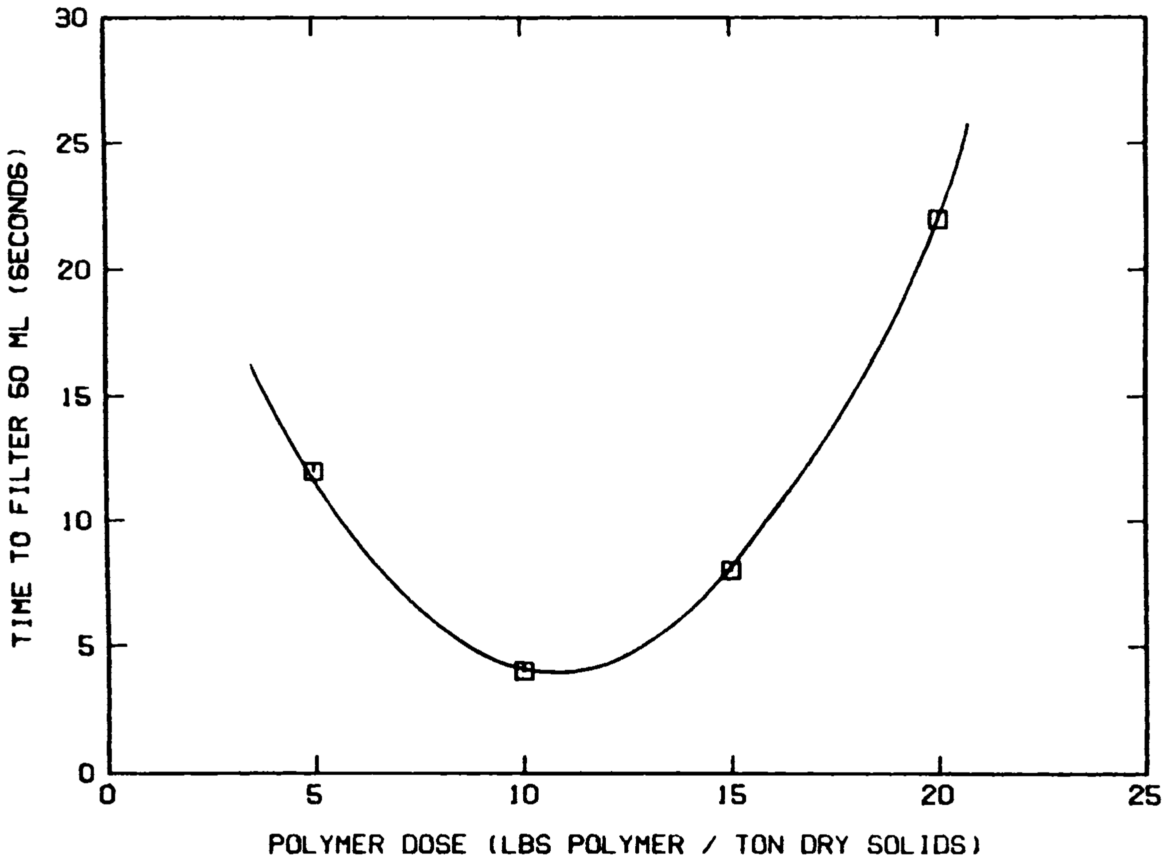

Figure 32. Time to filter 50 mL through a Buchner Funnel using anaerobically digested sludge conditioned with Percol 757 polymer at a Gt = 45,000

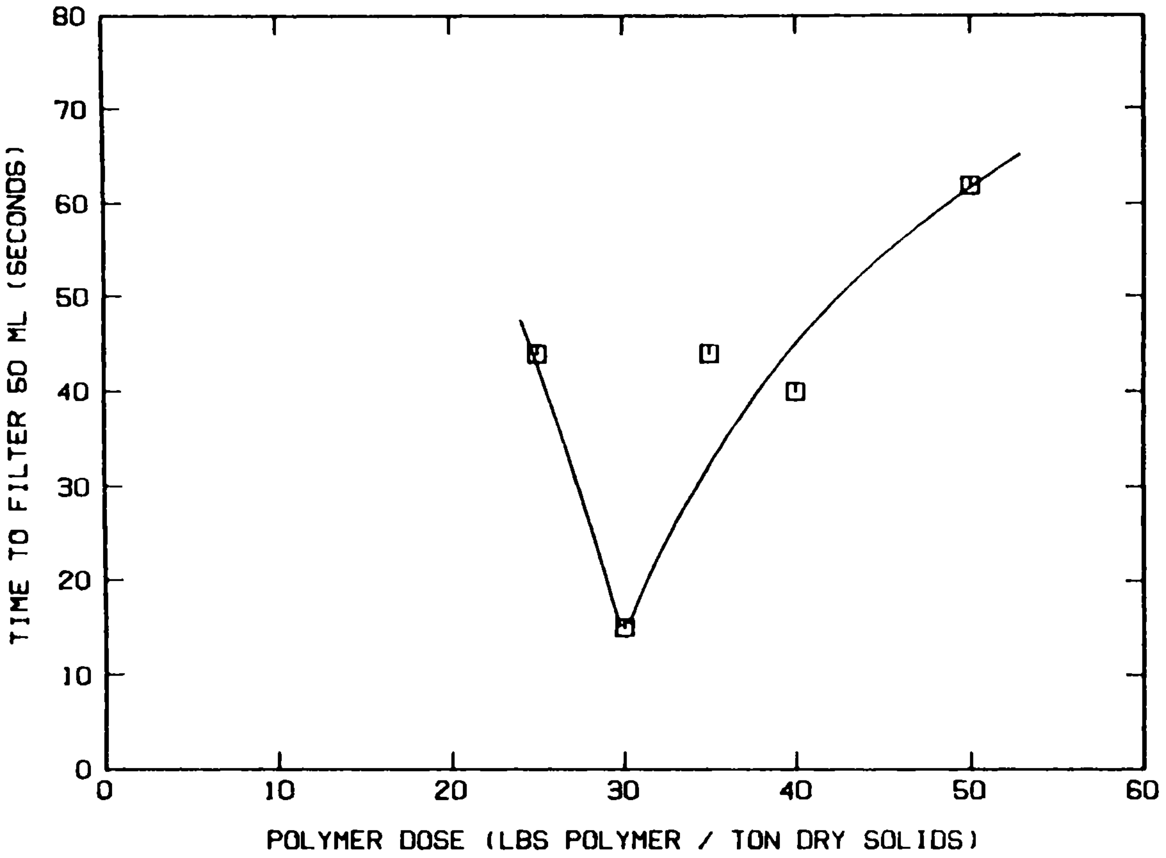

Figure 33. Time to filter 50 mL through a Buchner Funnel using anaerobically digested sludge conditioned with Betz 1167L polymer at a Gt=45,000

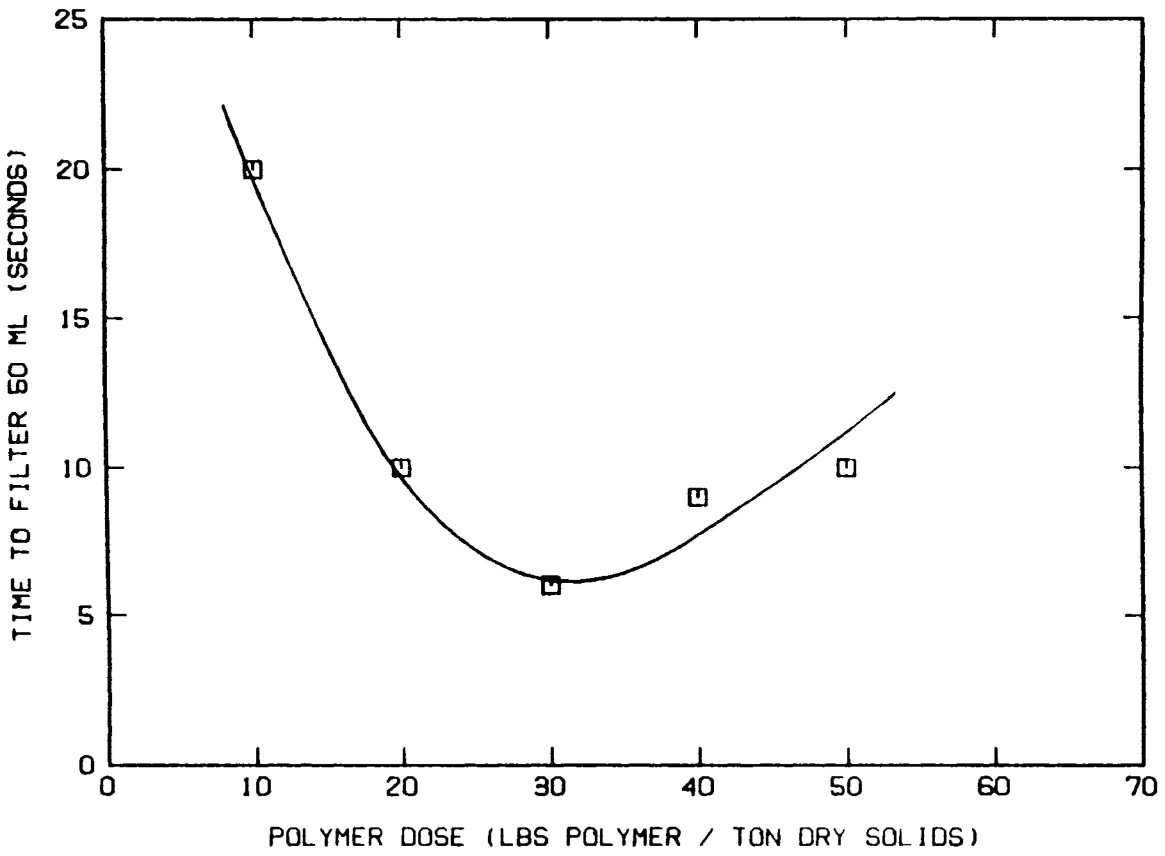

Figure 34. Time to filter 50 mL through a Buchner Funnel using anaerobically digested sludge conditioned with polymer E at a Gt=45,000

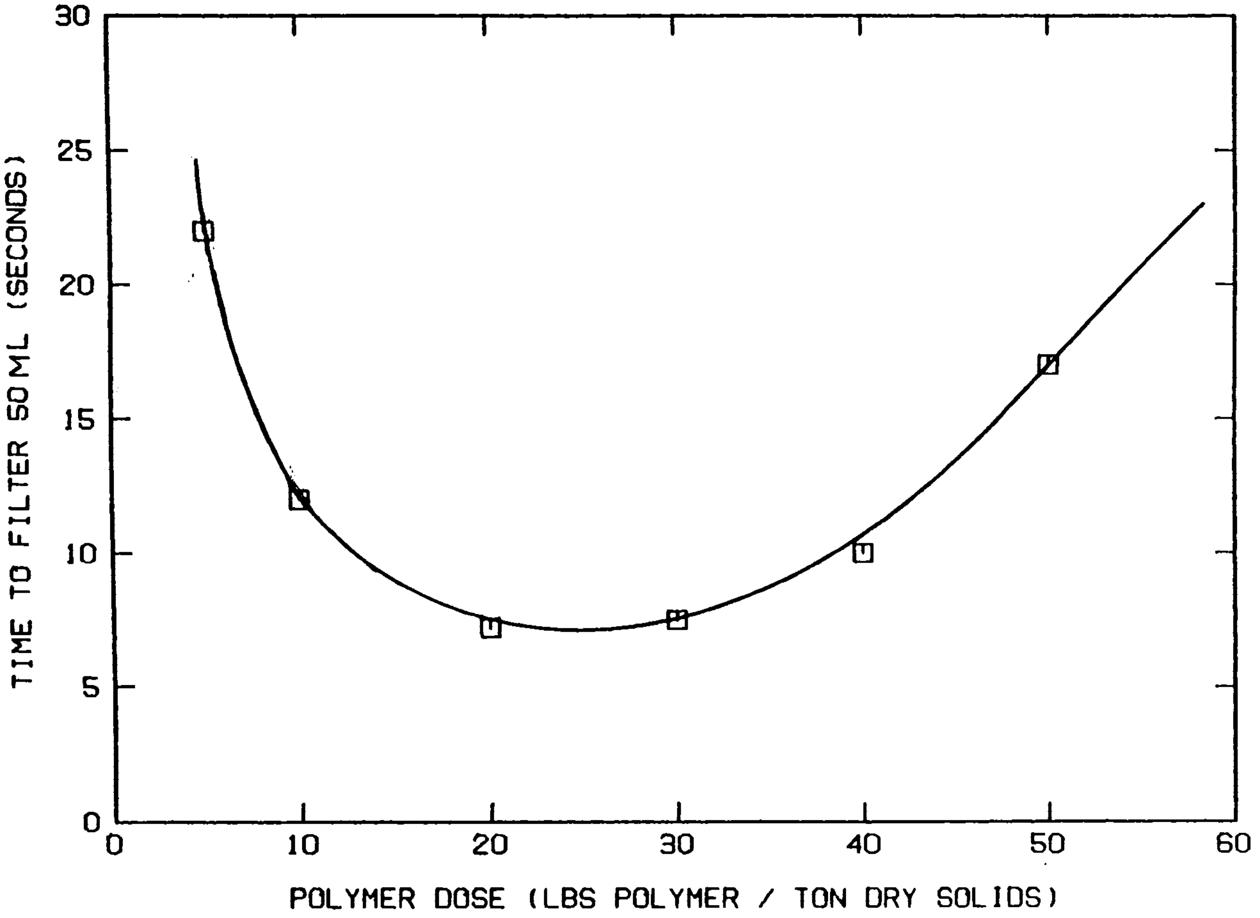

Figure 35. Time to filter 50 mL through a Buchner Funnel using aerobically digested sludge conditioned with polymer E at a Gt = 45,000

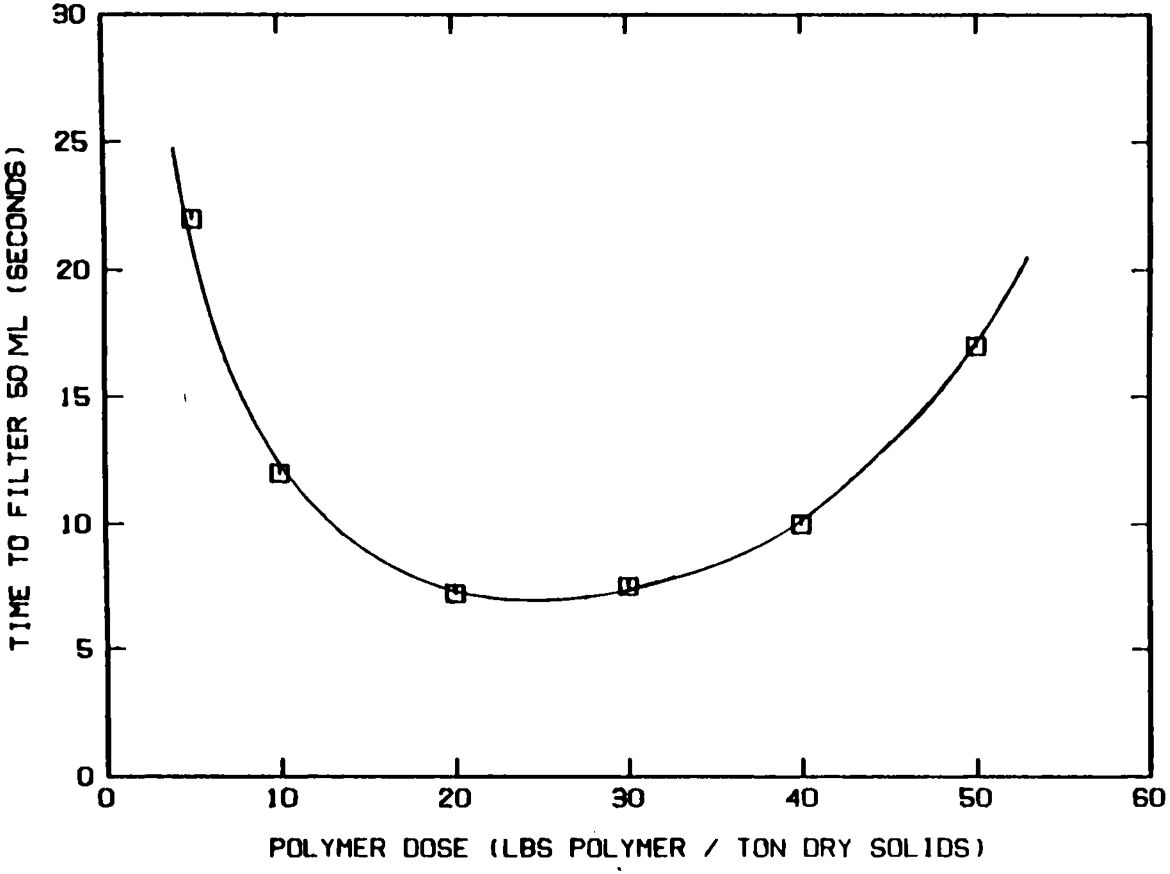

Figure 36. Time to filter 50 mL through a Buchner Funnel using aerobically digested sludge conditioned with polymer D at a Gt = 45,000

Table 4. Predicted Polymer Dosages Verses Actual BFP Optimum Polymer Dosages

		Optimum Dose (lb/ton)	
Sludge	Polymer	Lab BFP	Buchner Funnel
Alum	Percol 757	20	10-15
	Betz 1120	11	10
Anaerobically Digested	Percol 757	10	10
	Betz 1167L	30	30
	Polymer E	30	30
Aerobically Digested	Polymer E	15	20
	Polymer D	25	20

SUMMARY AND CONCLUSIONS

The belt filter press has three distinct zones that can be characterized. The first step in dewatering, gravity drainage, requires super flocculation of the sludge using organic polyelectrolytes. The gravity zone of the BFP makes use of the super flocculated condition of the sludge and gravity to initially drain off the free water. The transition zone known as the wedge zone further dewaters the sludge by applying pressure and forms a sludge cake. The high pressure zone uses high pressure and shearing action to complete the dewatering process.

The first aspect of the study was to test each zone to find how conditioning requirements would change. Polymer requirements for one, four and seven belt cycles in the HPZ were also studied. Each zone in the belt filter press was tested to determine the polymer dose required to optimize the respective zone tested. The optimal polymer dose for the gravity drainage rate as compared to BFP performance was also studied in this phase.

The next important task of this study was to assign a Gt value to the lab belt filter press. The importance of such a characterization is that a simple mixing apparatus used in conjunction with capillary suction time or a specific resistance test could yield much information about how a sludge will dewater in a belt filter press, without having to test a field unit, or a laboratory belt press.

The third aspect of the research was to use the Gt value found in the previous experments to predict an optimum polymer dose for the lab belt filter press. It was decided to use the polymers and sludges previously tested for this set of experiments, but to use a different tool, the Buchner funnel to test the dewatering rate of the sludge. It is assumed that the results would have been similar if a CST device was used instead of a Buchner funnel.

From the experiments performed and the results obtained, the following important conclusions were made:

1. Optimum dosages of organic polyelectrolyte required to dewater municipal sludges are essentially the same for all three zones in the belt filter press. Furthermore, no increase in dose requirements occured as the sludge was subjected to added belts. In some cases, however, the optimal dose for 30 second gravity drainage underpredicted the dose for the wedge zone. These results may indicate that for a BFP, polymer requirements may be more a function of the super flocculation conditioning than the energy applied to the sludge to dewater it.

2. The $G^{x}t$ of the laboratory belt filter press as it was tested appeared to be in the range of 30,000 to 90,000.

3. Using a Gt of 45,000 in conjunction with a time to filter 50 mL through a Buchner funnel will predict a polymer dose that would adequately condition sludge for dewatering in the belt filter press simulator. (where the exponent of G equals one)

4. The wedge zone simulator does well in predicting optimum doses for the belt filter press simulator.

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Appendix A. BELT SETTINGS

Table 5. Labratory Belt Filter Press Settings for a Two Roller Configuration

	Roller Number	
	1	2
Gauge Pressure (psi)	17	25
Sludge Pressure (psi)	5.5	8.0
Belt Speed (fpm)	5	5

Table 6. Labratory Belt Filter Press Settings for a Four Roller Configuration

	Roller Number			
	1	2	3	4
Gauge Pressure (psi)	17	25	37	50
Sludge Pressure (psi)	5.5	8.0	11.9	16.0
Belt Speed (fpm)	5	5	8	8

Table 7. Labratory Belt Filter Press Settings for a Seven Roller Configuration

	Roller Number						
	1	2	3	4	5	6	7
Gauge Pressure (psi)	17	17	25	25	35	40	50
Sludge Pressure (psi)	5.5	5.5	8.0	8.0	11.3	12.9	16.0
Belt Speed (fpm)	15	8	8	8	15	20	30