DEWATERING A SWINE MANURE SLURRY BY EXPRESSION

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ABSTRACT

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By

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Expression is a special case of filtration in which a two phase liquid--solid mixture is placed under compression by the movement of retaining walls. The liquid is allowed to escape through perforations in the retaining wall while the solids are held back.

Basic information concerning the expression of a swine manure slurry is presented. Swine feces are found to consist of large fibrous solids and fine solids. The fine material may be separated from the fibrous solids by the addition of a dilutant (such as water) and subsequent mixing. Final removal is accomplished by allowing the fibrous solids to settle and conveying the excess liquid (with fines in suspension) away from the settled material. Liquid is easily expressed from the fibrous solids once the fine material has been removed. Expression is a viable method of dewatering swine manure if the fine solids are properly managed.

James Freeman Steffe

A pilot scale model expression device was constructed to test a design concept for use in a full scale waste system. Model construction was based on the initial expression data and the experience gained in that phase of the work. The pilot scale device received an influent slurry from which the fine solids had been previously removed. Performance of the pilot expression model was promising and the design concept could be used for a full scale expression device. If such a device were added to an existing flush--lagoon system a 58.8% reduction in the quantity of volatile solids going to the lagoon could reasonably be expected.

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DEWATERING A SWINE MANURE SLURRY BY EXPRESSION

By

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DEFINITIONS

Expression: The separation of liquid from a two phase solid-liquid system by compression under conditions that permit the liquid to escape while the solid is retained between the compressing surfaces. Expression is distinguished from filtration in that pressure is applied by movement of retaining walls instead of by pumping the material into a fixed space (Perry and Chilton, 1973).

Raw Manure: Feces plus urine with no bedding. The feces would be the raw manure less urine.

Units:
1 Pascal (pa) = 1 Newton per square meter N/m^2
1 Newton (N) = 1 Kg • m/s^2
1 pound force (lbf) = 4.44 Newtons
1 pound force/$inch^2$ (psi) = 6.894×10^3 Pascals (pa)
1 pound mass (lbm) = .453 Kg

I. INTRODUCTION

People are becoming more and more aware of soil, air and water pollution problems. Increasing demands will be placed on swine producers to properly manage the waste generated from their businesses. The United States Department of Agriculture (1975) reports an average U.S. market hog inventory of 40.7 million for the June 1, 1974 to June 1, 1975 period. This is down 19 percent from the preceeding year, but is currently rising back to a higher level. On the average, a market hog will have a mass of 67 Kg. Assuming a hog produces a quantity of manure equal to 6.5% of its weight per day, then 40.7 million market hogs produce 177 million Kg of manure per day. This figure does not include the waste produced from breeding stock.

The physical characteristics of manure are strongly influenced by the diet of the particular animal in question. Miller (1975) estimates that 80% of U.S. hogs produced are fed a corn - soy diet, 10% are fed a milo - soy diet and 10% are raised on barley and other assorted grains. The waste used in the research presented here was taken from hogs on a corn - soy diet. Therefore, the results are applicable to a large percentage of the hogs produced in the United States. Very few hogs raised for foreign markets are fed corn - soy diets.

Slotted floor confinement housing with flush type manure handling systems are becoming increasingly popular in the swine industry because of the low labor input required for operation. In these systems manure is hydraulically transported from the animal building to a temporary storage facility, where it is held for land application, or the waste is sent to an anaerobic lagoon for biological treatment. The partially treated wastewater is often recycled for flushing.

Efficient liquid-solid separation of swine waste slurries offers a significant improvement to the flush-lagoon system mentioned above. A few of the possibilities include:

1. Improving the treatment kinetics of the anaerobic lagoon. Sixty to seventy percent of the total solids in swine manure are slowly biodegradable and their presence will reduce the effectiveness of any biological treatment process (Ngoddy et al., 1971). The absence of solids would reduce lagoon loading and thus reduce the size requirement of the treatment pond.

2. The removal of large solid particles would avoid plugging problems sometimes found in irrigation equipment during lagoon pump - out.

In addition to the above, there may be valuable uses for the separated manure fractions. These would include refeeding the solid material to livestock and digesting the liquid effluent for methane gas production. Also, liquid - solid separation may aid in controlling odor problems associated with anaerobic lagoons. Reduced lagoon loading, due to solids removal, would decrease the total quantity of odorous gas produced from such facilities.

II. THE THESIS PROBLEM

Formulation of Objectives

The motivating force behind the research presented here was the desire to develop a practical method of separating the liquid and solid parts of a swine manure slurry. Many farmers are adopting hydraulic waste transport because of the low labor input required to operate such systems. With the future in mind, the most desirable type of liquid - solid separation device to develop would be one which could be integrated into a flushing system. This basic thought was incorporated into the thesis objectives and it strongly influenced the experimental methods.

A significant portion of the solid material in a swine manure slurry can be retained behind a perforated plate. The quantity of liquid which flows through the plate will depend on the amount of pressure applied to the slurry, the size of the perforations and the pretreatment given to the slurry. This process of liquid - solid separation is a special case of filtration called expression.

Preliminary studies showed that expression had excellent potential as a swine waste liquid - solid separation concept. Based on these findings the following objectives were formulated:

1. Identify the variables which significantly affect the expression of a swine manure slurry.
2. Evaluate the liquid - solid separation potential of expression when used in conjunction with a swine barn flushing system.
3. Design and evaluate an expression system for swine farm use.

Approach to the Problem

Initially, a literature search was conducted which produced no published information dealing with the expression of liquid from a swine manure slurry. Other swine slurry liquid - solid separation schemes which have been investigated are presented in the literature review.

With no guidelines to follow it was necessary to start the study by collecting basic expression data. A solid vertical cylinder, sealed at one end, was constructed and a porous piston was used to express water from a slurry contained by the cylinder walls. The slurry was made from fresh swine feces and tap water. A number of parameters such as quantity of water and degree of mixing were considered during sample preparation. The amount of pressure required to express liquid from the slurry and the piston pore size were also considered as variables.

Design criteria for a pilot model expression device were generated from the basic expression data collected during the first phase of the research. This design incorporated a number of unique and unproven ideas. These ideas included (1) the use of an influent slurry which had undergone prior physical treatment to remove fine material and (2) the formation of solid cakes utilizing previously dewatered solids for partial slurry containment. The pilot model expression device was constructed and tested to determine the usefulness of these concepts.

From the identification of swine manure expression variables and the operation of a pilot expression device, sufficient information was made available to permit construction of a full scale expression system. Speculations on the testing and development of an on farm expression system are presented for the benefit of anyone who may accept the task. The study concludes with a hypothetical example of a swine manure handling system which includes flushing, an anerobic lagoon, and an expression type liquid - solid separation device. The potential reduction in total and volatile solids due to liquid - solid separation are discussed and dimensions for a large expression chamber (scaled-up version of the pilot scale model) are suggested.

III. LITERATURE REVIEW

When dealing with animal manure the following factors, which affect the physical characteristics of the waste, are important:

1. Livestock species.
2. Diet fed to a particular specie.
3. Animal environment.
4. Manure collection and handling practices.

Most existing literature fails to consider all the above parameters (see Table 1). Without this information it is difficult to compare the results obtained from different researchers. The salient aspects of the studies presented in Table 1 are discussed in the remaining part of this literature review.

Verley and Miner (1975) used a rotating flighted cylinder to concentrate the solids in a swine waste slurry. This device is described as "an inclined tube fitted with a helically wound fin attached to the inner surface". As the tube is rotated the solids are concentrated between the fins and finally discharged from the upper end of the device. The cylinder is capable of removing all settlable particles which would be retained by a screen with 1.19 mm openings. A solids stream of 4.3% was obtained from a feed

TABLE 1. Basic information on studies dealing with the liquid - solid separation of swine manure slurries.

Authors	Hog Diet	Source of Waste	Liquid-Solid Separation Devices Tested
Verley & Miner (1975)	Not Specified	Pit under slotted floors	Rotated flighted cylinder
Shutt et al. (1975)	Not Specified	Flushed from gutters	Stationary Screen Liquid Cyclone Vibrating Screen
Homes, Day & Pfeffer (1971)	Not Specified	Oxidation Ditch Mixture	Centrifuge
Ngoddy et al. (1971)	79.0 to 85.5% Ground shelled corn + 18.0 to 11.5% Soybean Meal + 3% additives	Individual hogs isolated in metabolism pens	Vibrating Screen
Glerum, Klump Podma (1971)	Not Specified	Not Specified	Vibrating Screen Centriseive Decanter Centrifuge Vacuum Filter
Taiganides & White (1972)	Not Specified	Flushed from gutters	Stationary Screen

slurry of .04% solids. This apparatus will not produce a product which can be handled as a solid material.

Shutt et al. (1975) were able to obtain a total solids concentration of 10.9% from a 3.0% total solids slurry using a stationary screen with .15 cm openings. The screen loading rate for this test was 352 l/min per m^2. The researchers found that screen plugging was a major problem which required daily attention. Slime buildup and plugging problems were also mentioned by Taiganides and White (1972) in their efforts to separate solids from a swine manure slurry prior to treatment in an aerobic digester.

Shutt et al. (1975) and Glerum et al. (1971) have reported swine manure liquid - solid separation studies with a vibrating screen. The most extensive information on this subject has been collected by Ngoddy et al. (1971). This research group performed a complete engineering analysis on the vibrating screen separator. Using this type of device a 17 -20% total solids material was produced from a dilute swine waste slurry.

Due to high cost or poor performance the centrisieve, liquid cyclone and vacuum filter are inapplicable for practical farm use and will not be discussed in this study.

Expression is the separation of a liquid from a two phase solid - liquid system by compression under conditions that permit the liquid to escape while the solid is retained between the compressing surfaces (Perry and Chilton, 1973). The expression process is a special case of filtration: it deals with mixtures usually considered to be nonpumpable and the pressure is generated by the movement of the retaining walls.

Empirical equations have been developed for the expression of cotton seed oil by Baskerville et al. (1947) and Carter (1952). Koo (1942) presented an equation which describes the expression of oil from seven different kinds of seeds (soybean, cottonseed, grapeseed, peanut, sesame seed, tung nut and castor bean).

Gurnham and Masson (1946) hypothesized the following equation:

$$P = a \exp (b/v) \tag{1}$$

where a = constant

b = constant

P = Pressure drop across the porous retaining wall

v = specific volume, based on the quantity of dry matter being compressed.

Experimental work done by pressing dry and rewetting (with water and various mineral oils) materials such as paper pulp, sawdust, woolen yarn, wool felt and asbestos fiber verified the hypothesis in pressure ranges from 1.72×10^6 to 137×10^6 pascals (250-2000 psi).* The authors, Gurnham

*1 pascal (pa) = 1 N/m^2.

and Masson (1946), found that the equation was invalid for pressures below 3.44 X 10^5 pa (50 psi) and for small diameter cylinders (less than .65 cm).

Deerr (1912) presented the following equation to describe the expression of juice from sugarcane and bagasse:

$$V_c = CP^{-n} \tag{2}$$

where V_c = volume of the solid material and unexpressed liquid

P = pressure drop across the porous retaining wall

C = constant for a particular experiment

n = constant or a function of pressure depending on the pressing conditions

I consider the Deerr equation to be the most representative of the expression of liquid from swine manure. This type of expression is accomplished at pressures where the Gurnham and Masson (1946) equation is invalid, and the materials Deerr (1912) used in his experiments are more representative of feces than the products considered by the other researchers.

IV. SWINE MANURE EXPRESSION VARIABLES

Experimental Equipment

To construct an expression chamber (Figure 1) I used a 7.62 cm (3 inch) inside diameter plexiglass cylinder. The cylinder was placed between two pieces of plywood which were held together with four threaded steel rods. A rubber gasket placed between the lower piece of plywood and the cylinder formed a water tight seal at the bottom of the chamber. The upper piece of plywood was cut to permit the piston to move freely in and out of the chamber. A removable piston rod guide fit between the bolts on the upper surface of the expression chamber.

a sheet of plexiglass 1 cm thick. Each piston plate was 7.5 cm in diameter and was uniformly perforated with 18 identically sized holes. The hole diameters were 2.38 mm, 4.76 mm and 6.35 mm in each of the three plates.

I used two methods to apply a force to the piston rod: constant rate of displacement and constant force. An Instron Universal Testing machine applied a variable force while keeping the rate of descent of the piston constant. The constant force loading device was a dead weight on the piston rod. Knowing the magnitude of the

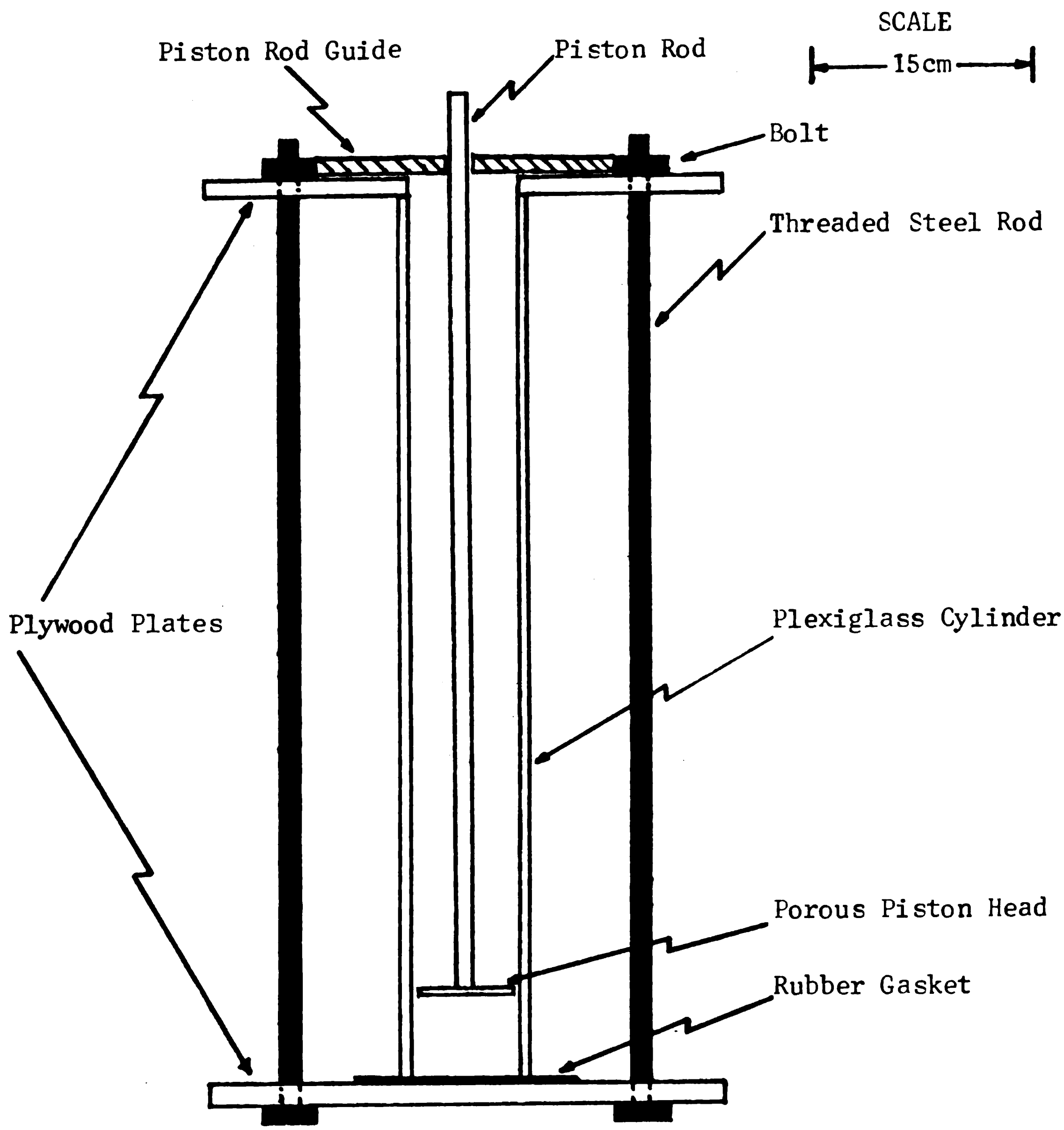


Figure 1. EXPRESSION CHAMBER

force and the area of the plate in contact with the contained material, it was easy to calculate pressure inside the expression chamber.

Sample Preparation

Sampling is one of the biggest problems faced by people working in pollution research. The nature of the subject material makes it difficult to regularly obtain similar samples. The following questions are considered in this section of the study:

1. Where should the samples be collected?
2. What type of liquid should be used to form the manure slurry?

In the preliminary expression studies waste was collected from hogs isolated in metabolism cages. The floor of each cage is a steel grate through which the feces are punched to a collection surface. The collection surface is a piece of sheet metal sloped to allow the urine to drain to a central location. Overflow from the watering hoses drained to a separate point.

Feces taken from isolated hogs was compared with feces taken from above slats in a swine growing and finishing barn. The two samples were found to be significantly different. The feces deposited on the metal collection sheet under the metabolism cages were much drier than the barn sample. The drier sample had turned from a light brown to a black color (this may have been due, in part, to the age of the material) and formed a surface crust. I diluted each sample with tap water and stirred with a glass rod. The barn sample mixed easily--the lumps were quickly broken into their particle constituents. The lumps from the drier sample floated and were very difficult to disperse.

In considering the above differences, it was obvious that the sample most representative of what would be found in a practical situation was the feces collected from above slats. It is possible, however, to obtain very dry feces from above slats. In various locations around a hog pen (corners, under railings) feces may accumulate. This material is blacker and drier than the fresher feces, and constitutes a small portion of the total feces produced. I obtained the data presented in this study from feces samples collected above slats.

Assuming that a practical liquid - solid separation device would be incorporated into a hydraulic waste transport system, it was necessary to dilute the feces with an appropriate fluid. Fresh water (tap water) and recycled lagoon water are commonly used for flushing.

I performed an experiment to determine if there were any major differences between using lagoon water or tap water as the sample mixing medium. Two 100g feces samples were each placed in two 1 l. beakers. One sample was mixed with 1000 ml of tap water and the other sample was mixed with 1000 ml of lagoon water. The slurries were immediately poured into 3.7 cm I.D. plexiglass cylinders which were vertically supported and sealed at one end. After thirty minutes an 8.9 cm layer of large non-flocculating solids had settled to the bottom of each cylinder. A 5 cm layer of fluffy flocculated material had fallen on top of the large solids in the fresh water mixture. The comparable fluffy layer was 4.5 cm in the sample mixed with lagoon water. These differences are minor, so I concluded that tap water, due to its easy availability, would be used as the mixing fluid for subsequent experiments.

Experimental Procedure

Feces were collected from above slats in the M.S.U. swine finishing and growing barn. No attempt was made to obtain samples from the same group of hogs each time. The animals were fed a standard diet which consisted of 68.5 to 79% ground corn, 16 to 26.5% soy meal and 5% M.S.U. mineral - vitamin supplement. Watering hoses provided an unlimited supply of drinking water.

For each test a 300 g sample was placed in a large beaker and a measured amount of tap water was added. The mixture was then stirred until the large pieces were broken up. Thirty seconds of mild stirring usually accomplished this task. The samples were then poured into the compression chamber for the expression step. Unmixed samples were used for two of the four tests run on the Instron and for one constant pressure test.

There were nine experiments conducted under constant force conditions. Forces ranging up to 296 N (66 lbf) were applied to the top of the piston rod to push the porous pressure plate down into the chamber. This resulted in chamber pressures up to 7.05 X 10^4 pa (10.2 psi). At each force level, I measured the distance from the bottom of the compression chamber to the lower face of the piston when the system had come to equilibrium. This measurement was taken when no fluid movement through the porous piston could be detected by visual observation. Other variables (besides pressure) in these tests included piston hole size, sample mixing and quantity of dilution water.

Four tests were run on the Instron Universal Testing machine. This instrument was used to evaluate the effect of mixing at different rates of expression. I recorded the variable force required to move the piston face downward at .508 and 1.270 cm/min through mixed and unmixed samples (fixed amount of dilution water). The pressure plate with the 2.38 mm holes was used in each case.

At the end of an expression test the cake (material below the piston) and the effluent (material above the piston) were separated. The effluent was removed using a trapped vacuum pump or by holding the piston in place and inverting the chamber to pour out the fluid. The cake was removed by disassembling the compression chamber and pushing (with the piston) the solid material out the bottom of the cylinder. Total solids tests were made on the cake and effluent by weighing the samples before and after oven drying at 104° C for approximately 24 hours. Information on the chemical composition of the cake and effluent total solid material is presented in the appendix.

Testing Results

I tested the three different piston plates under identical conditions to determine the plate hole size best suited for containing the solid material. It is desirable to have holes which are large enough to avoid serious plugging and yet small enough to restrict passage of solid particles. Figure 2 shows volume plotted against pressure for the various hole sizes. A solid cake was formed in each test but the quality of the effluent was different for the various plates. The effluent moisture content for the 2.38 mm hole size was 98% while the moisture content for the 4.76 mm hole size was 95.6% (Table 2). As would be expected, the larger holes retained

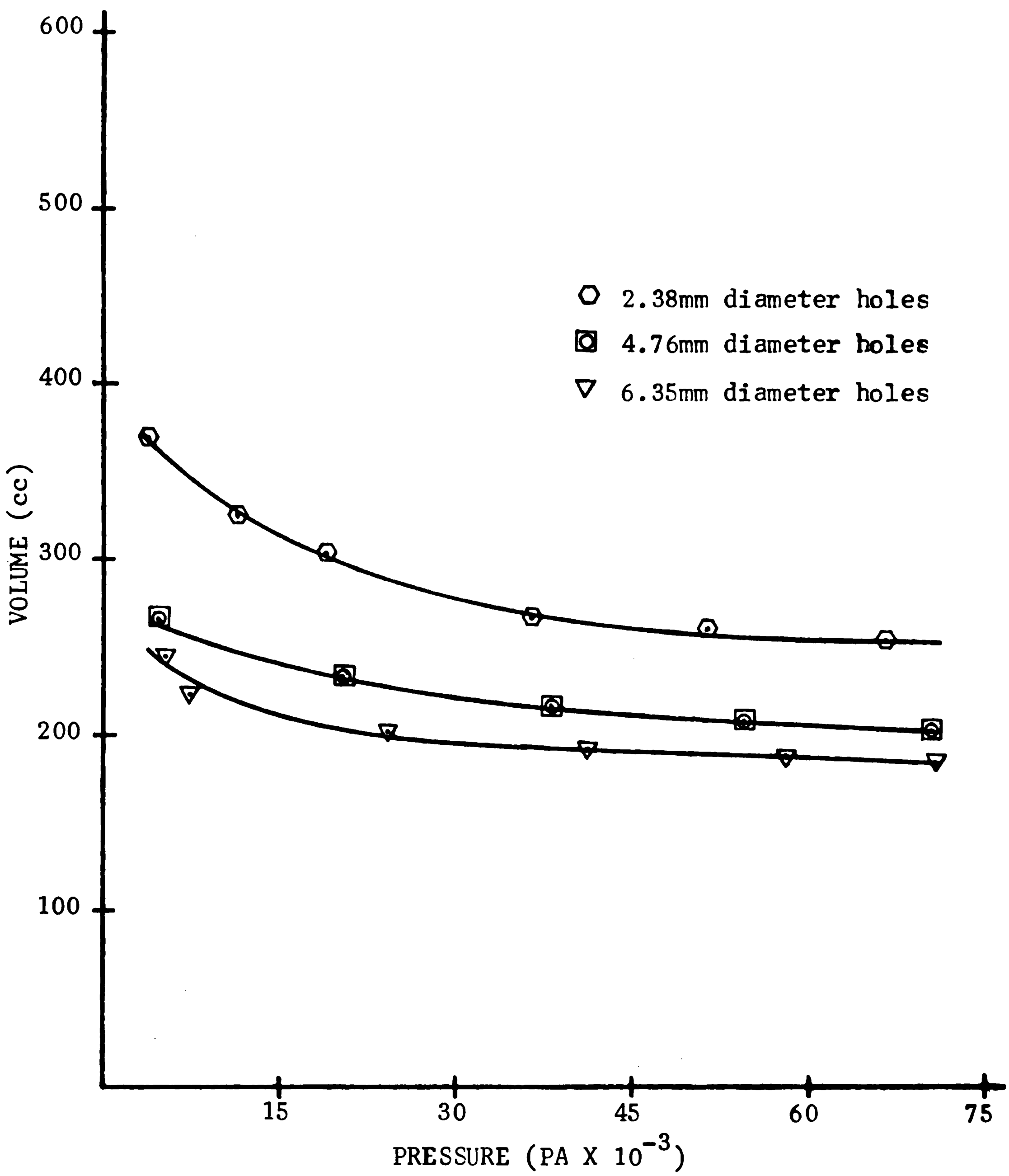


Figure 2. Volume of solid material plus unexpressed liquid at different pressures for pressure plates with different hole sizes. Each test sample was a well mixed slurry of 300g feces and 1000ml water.

TABLE 2.--Volumetric reduction and moisture content data for various compression tests.

Quantity of feces in test sample (g)	Water added to feces (ml)	Degree of Sample Mixing	Diameter of Plate Holes (mm)	Final Cake Volume / Initial Feces Volume (percent)	Cake Moisture Content % w.b.	Effluent Moisture Content % w.b.
300	300	Complete	2.38	168.9	87.6	----
300	600	Complete	2.38	72.4	74.3	96.4
300	1000	Complete	2.38	84.4	73.2	98.0
300	2100	Complete	2.38	72.3	75.3	----
300	1000	Complete	4.76	67.5	74.7	95.6
300	1000	None	4.76	101.2	73.35	99.6
300	1000	Complete	6.35	62.7	72.61	----

fewer solids than the smaller holes. A total solids test was not performed on the effluent which had passed through the 6.4 mm holes because visual inspection showed a mass of solid particles (total depth greater than 1 cm) above the pressure plate. The plate with the 2.38 mm diameter holes appears to be most acceptable because no large solids appeared to have done through the plate and plugging was minimal.

Figure 3 shows the effect of mixing. With equal applied pressure the unmixed sample was compressed less than the mixed sample. There is a 4% difference in the moisture contents of the effluents in the mixed and unmixed samples (Table 2).

The quantity of dilution water added to the sample had a tremendous effect on the expression process. The volume vs. pressure curves for various quantities of added water are shown in Figure 4. The curve was not drawn for the 600 ml test A, only the points are given. Expression was unsuccessful in the 600 ml test B and the 300 ml runs. The "cakes" formed in these tests could be described as a thick slurry. The other tests all produced acceptable cakes.

Cake quality proved to be a difficult parameter to quantify. The cakes with moisture contents in the mid - seventies range (Table 2) retained their shape when removed from the compression chamber. There is a quality factor

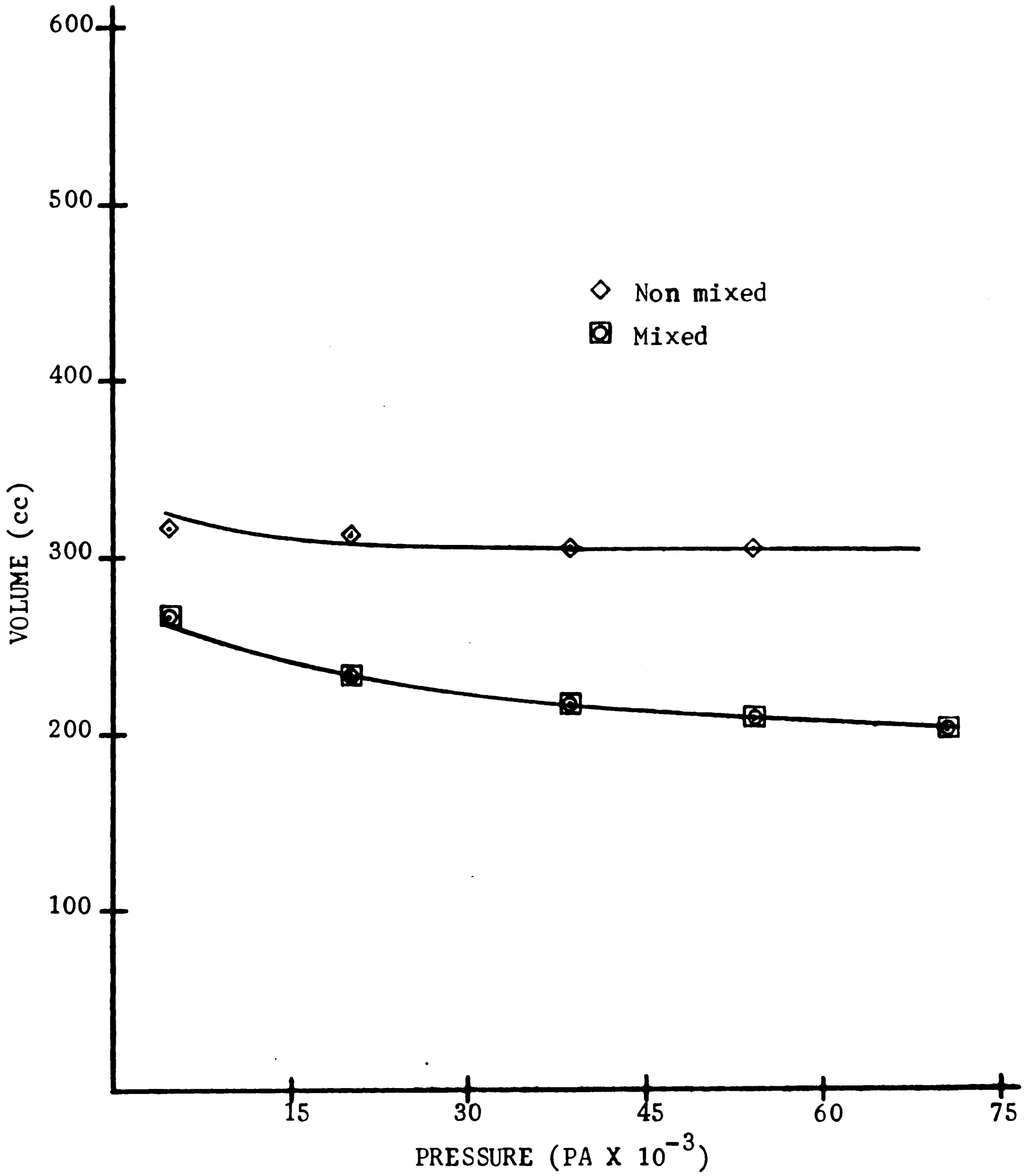


Figure 3. Volume of solid material plus unexpressed liquid at different pressures for a mixed and unmixed sample of 300g feces and 1000ml water. The pressure plate holes for each test were 4.76mm in diameter.

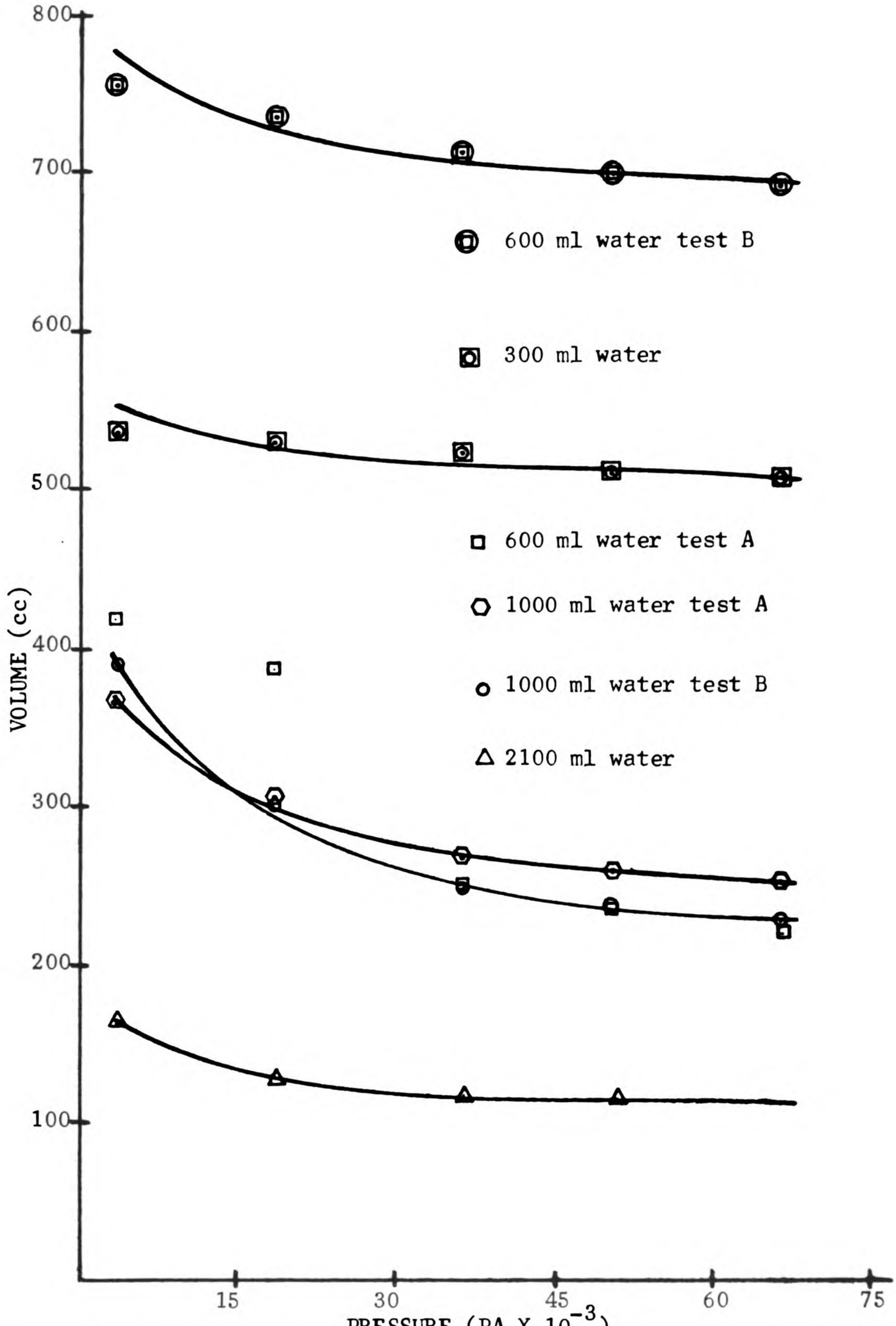


Figure 4. Volume of solid material plus unexpressed liquid at different pressures for a mixed sample of 300g feces and various ammounts of dilution water. The pressure plate holes for each test were 2.38mm diameter.

which is not represented by total solids analyses. The cake resulting from the non-mixed sample was sticky in texture and appeared less dry and fibrous than the other cakes. When the cakes from the mixed and unmixed samples were allowed to air dry for 24 hours (under room conditions) they both formed a crust on their exterior surface. When the crusts were cut open the cake from the unmixed sample appeared lighter in color (light brown) and had the least pleasant odor of the two cakes.

Most of the lines presented in Figures 2, 3 and 4 can be approximated using the Deerr equation (2). No attempt was made to model the two B tests (Figure 4) with this equation. All the constant force data sets presented, with the exception of two (Table 3) have high correlation coefficients. The least acceptable cakes were formed in the cases where the ratio (percent) of the final cake volume to the initial feces volume is greater than 100 (Table 2). For these situations the values of 1/n (Table 3) from the Deerr equation (2) are very large (48.3 and 49.9) indicating that a large increase in pressure will only yield a small reduction in volume.

The variable force tests were performed on the Instron Testing machine. In all four tests the downward piston movement was stopped and held fixed when a force peak of 400 N (90 lbf) was reached. This force peak corresponds to an internal pressure of approximately

TABLE 3.--Statistical information and values of the constants used in the Deer Equation for various test conditions.

Quantity of feces in test sample (g)	Water added to feces (ml)	Degree of Sample Mixing	Diameter of Plate Holes (mm)	C	n	$\frac{1}{n}$	r*	Number of Data Points
300	300	Complete	2.38	641.4	.0206	48.3	.91	5
300	600	Complete	2.38	3872.5	.2561	3.9	.91	5
300	1000	Complete	2.38	1203.7	.1410	7.0	.99	5
300	2100	Complete	2.38	493.6	.0775	12.3	.97	4
300	1000	Complete	4.76	621.8	.0098	10.0	.99	5
300	1000	None	4.76	377.3	.0220	49.9	.97	4
300	1000	Complete	6.35	597.2	.1059	9.4	.99	5

* Correlation Coefficient

90.5 X 10^5 pa (13.1 psi). In Figures 5 and 6 the volume lines are not at the same location at time zero. The reason for this is that I defined the piston location at time zero as the point where the piston movement stopped when the piston was placed in the expression chamber and allowed to descend under its own weight (165 g).

Figure 5 represents the data for mixed and unmixed samples subjected to a piston movement of .508 cm/min. The final cake volume of the mixed sample was less than that of the unmixed sample. The force peak was reached in 9.2 min for the mixed sample and in 5 min. for the unmixed sample.

Figure 6 contains the data for the case where the downward piston movement was 1.270 cm/min. The force for the mixed sample shows a great deal of irregularity. For the mixed sample there was a high force peak after one minute of expression but the upper limit of 400 N did not occur until the piston had moved for 4 minutes.

Discussion of Test Results

To understand the expression process one can consider swine waste to be composed of two fractions. One fraction consists of fibrous solids which rapidly settle in water and appear to be composed mainly of ground corn hulls. The other fraction is made up of fine particles which will become suspended in water when mixed. The fine

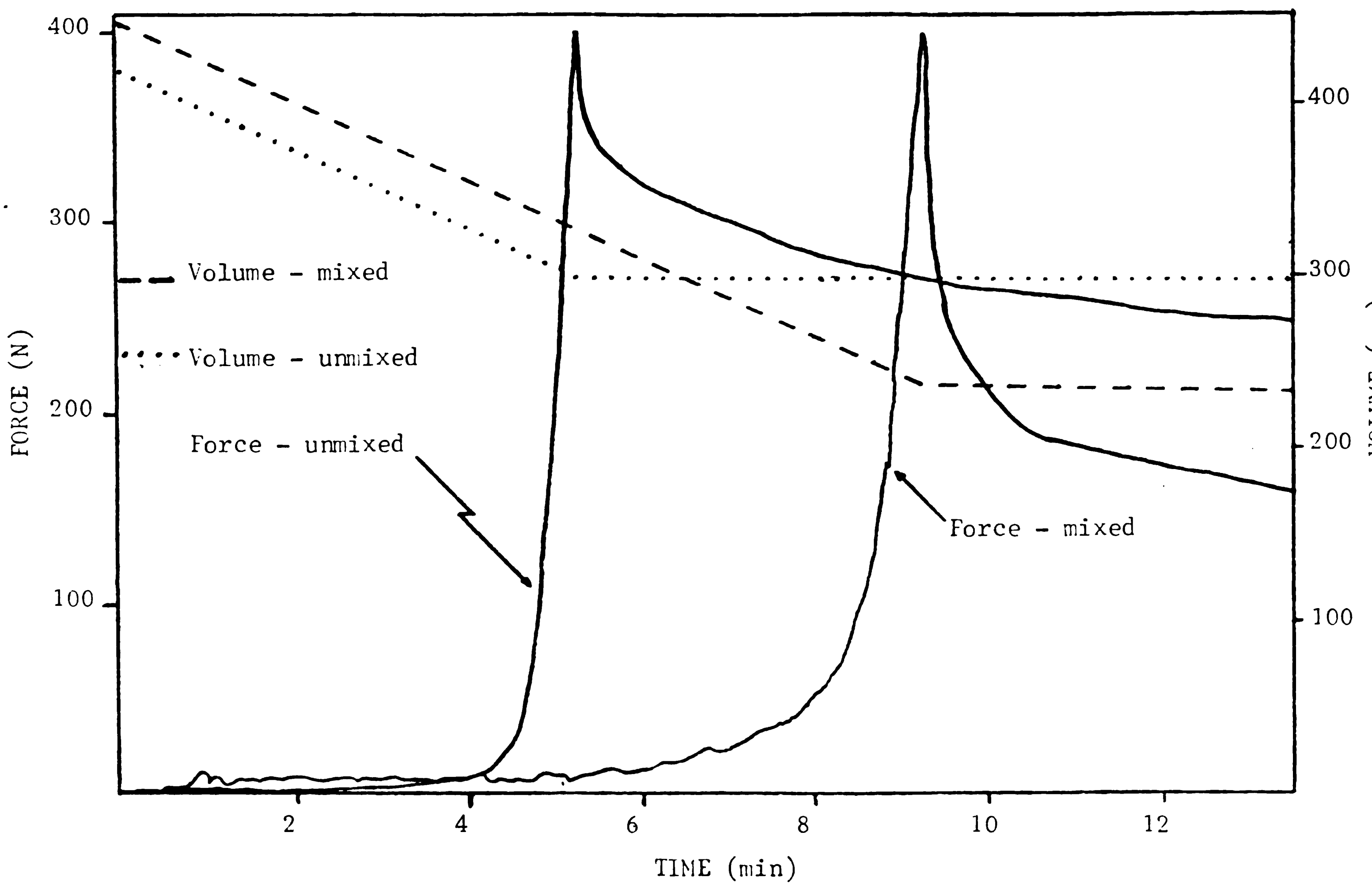


Figure 5. Volume of solid material plus unexpressed liquid and force plotted against time for mixed and unmixed samples of 300g feces and 1000ml water. The slope of the variable volume line is 23.16cc/min which represents a downward piston movement of .508cm/min.

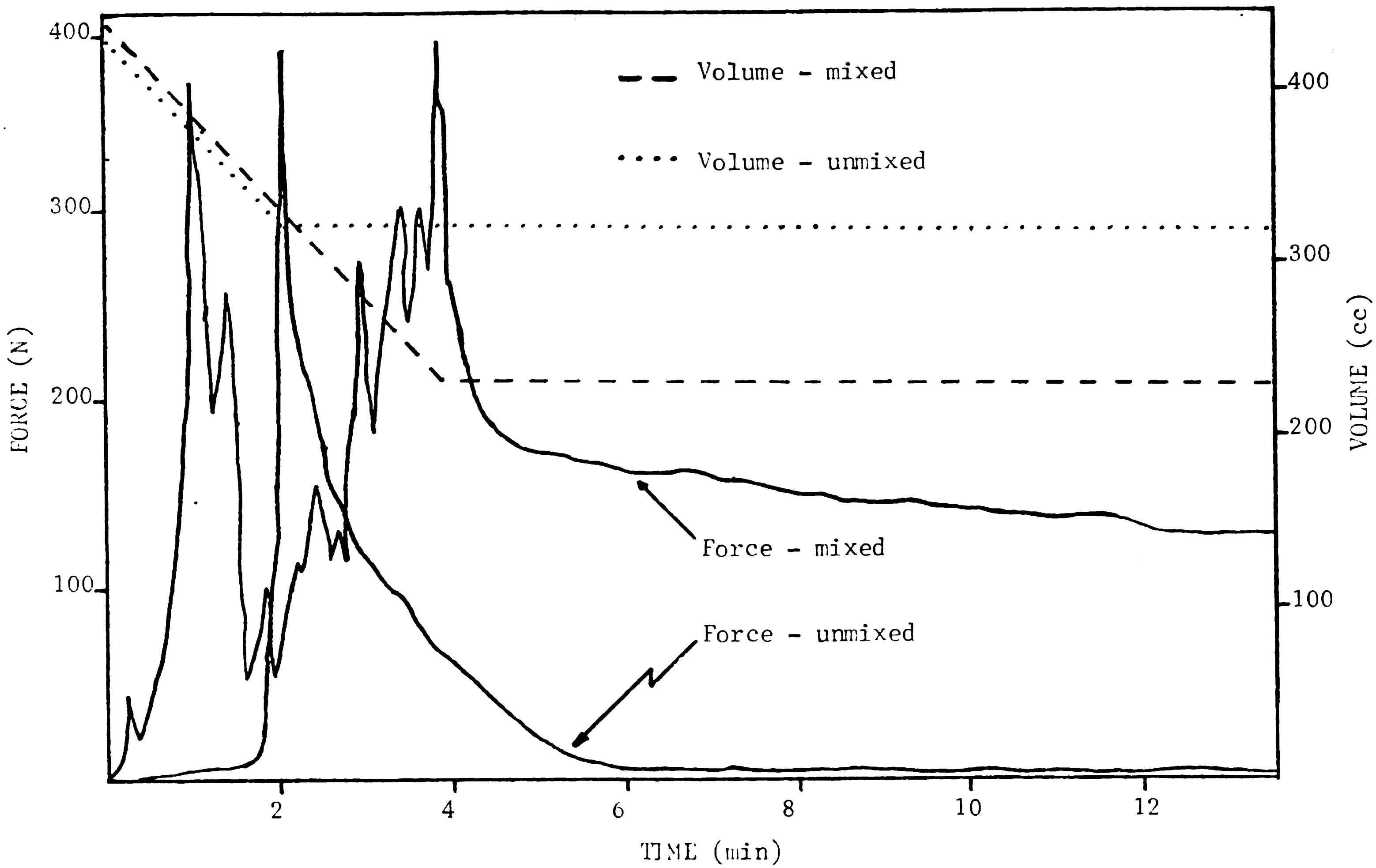


Figure 6. Volume of solid material plus unexpressed liquid and force plotted against time for mixed and unmixed samples of 300g feces and 1000ml water. The slope of the variable volume line is 57.91cc/min which represents a downward piston movement of 1.270cm/min.

particles will flocculate and settle to form a fluffy mass. This fine matter seems to give fresh swine feces its paste-like character. The fibrous material, when removed from the fines, appears as a granular, coarse, crumbly and nonpaste-like product.

The interaction of the fibrous solids, fines and dilution water will greatly affect the success of a swine waste expression process (Table 2). Mixing acts to separate the fines from the fibrous material. If sufficient dilution water is added (with mixing) a large quantity of fine material will be removed from the fibrous solids. The fines in this fluid will easily go through the piston plate as it falls under its own weight. This can be very beneficial in dewatering the solids because the fine material causes plugging problems in the cake by increasing the cake resistance to water movement.

Shortly after the expression process starts, a layer of solid material builds up at the lower surface of the piston face. This layer acts as a filtration medium and becomes thicker as the piston moves downward. The fluid flowing through the piston must also flow through this mass of differentially sized particles. The fines act to fill void spaces and plug water movement channels. Plugging problems, such as these, are apparent when reviewing the constant pressure data. If the amount of dilution water added (e.g., Figure 4 -- 300 ml water) was equal to the quantity of feces present the slurry would not dewater. The most likely reason for this is that there was inadequate removal of the fines from the fibrous solids.

A number of comments can be made concerning the 600 ml dilution curves presented in Figure 4. In the 600 ml test B plugging occurred immediately after the start of the attempted expression. The data from the 600 ml test A (curve not drawn) shows an entirely different pattern. The data point found between 15,000 pa (2.2 psi) and 30,000 (4.4 psi) obviously deviates from the trend found in the other curves. This deviation was caused by plugging problems. When additional dead weight was added to obtain the next data point (from the one mentioned above) the piston dropped very rapidly and a surge of fluid came through the porous plate. No surges were observed while collecting data for the other curves.

An important point can be made in reviewing the curves in Figure 4. The two 600 ml tests show that there is unpredictability associated with this dilution ratio (2 parts water/1 part feces). However, there is good agreement between the results of the two 1000 ml tests. This dilution ratio (10 parts water to 3 parts feces) can be considered as a lower limit for acceptable expression. Let me emphasize that this is not an absolute limit. The 2:1 ratio is certainly too low and the 10:3 ratio worked in two cases. On particular occasions lower ratios may result in acceptable cakes. Fortunately, the feces used in an expression device incorporated into a flushing operation would be diluted in excess of 10 parts water to one part feces (10:1). In a practical application the dilution ratios involved are far above the range where plugging may occur.

In looking at Figure 3, a number of points can be made concerning the use of mixed and unmixed samples. The unmixed sample yielded the least acceptable cake because of its sticky character and poor keeping quality (as previously mentioned). The final volume of the unmixed sample is greater than the mixed sample which, in this case, is indicative of the fact that more water was retained after expressing the unmixed sample. Also, the slope of the curve for the unmixed sample approaches zero at a low pressure because plugging occurred early in the test.

It was evident early in this study that a pressure plate with 2.38 mm diameter holes was well suited for the expression of a swine slurry. Data collected using this plate are represented in Figure 4. Acceptable cakes were formed in cases where the final volume was less than 300 cc. For these tests I got very little volumetric reduction when applying pressures in excess of 45,000 pa (6.5 psi). This is indicative of the low pressures which would be required for a pilot scale expression operation.

Information concerning the rate of expression can be taken from the Instron data. In all tests represented in Figures 5 and 6 the downward piston movement was stopped when a force peak of 400 N (approximately 90 lbf) was reached. With a piston movement of .508 cm/minute (Figure 5) less volumetric reduction was achieved with the unmixed sample. The cake obtained from the unmixed sample could be handled as a solid but it was sticky and paste-like, being very similar to the cake obtained from the unmixed sample in the constant pressure test. The most important point to be made here is that a downward piston movement of .508 cm/minute proved to be a workable rate which sufficiently dewatered the manure slurry.

The extreme variation in force in the mixed sample in Figure 6 can be accounted for by alternate plugging and unplugging across the face of the pressure plate. During the piston movement, I could see periodic surges (geyser like) coming through various holes in the plate. Unpredictable plugging, such as this, would be undesirable in a large scale expression operation because of the small dewatering gain associated with a high energy input. The rapid increases in force required to obtain small decreases in volume could be considered as a dashpot effect. Slower piston movement would allow the water to "ooze" from the slurry. Similar instability did not occur in the other constant pressure tests.

The variation in shape of the force - time curves for the unmixed samples in Figures 5 and 6 can be also explained with reference to plugging. With the faster piston movement (Figure 6) the force peak is reached at a higher final volume (over 300 cc) and when piston movement is stopped the force drops off much more quickly. The rapid piston movement caused plugging to occur after a shorter distance of piston movement. The rapid relaxation of the force - time curve of the unmixed sample may have been due to the lack of volumetric reduction obtained. The cake still contained a lot of water which may have aided in unplugging.

Design Criteria for a Scale Model Expression Device

The expression process as a method of liquid - solid separation of a swine manure slurry is physically feasible. In designing such a system for incorporation into a swine manure flushing operation the relationship between slurry mixing and relative proportions of dilution water and feces must be carefully considered. If the amount of feces is approximately equal to the amount of water in a well mixed slurry, attempts to express liquid from the mixture will fail. Liquid may be expressed from a similar quantity of material which had not been mixed. However, solids separated in this manner are less desirable than those from which the fines have been removed.

Practically speaking, it is unlikely that a system to express liquid from swine waste would operate with an unmixed influent. The hydraulic transport of waste is itself a mixing operation. It is difficult to estimate the degree of mixing which takes place during flushing. Certainly, the solids near the end of the flush channel would be inadequately mixed. To insure proper management of the flocculated solids supplemental mixing equipment should be included in the pilot system.

In summary, the following factors should be considered in an expression system design:

1. The fine material should be separated from the fibrous solids. To ensure good separation the ratio of dilution water to feces should be at least 10/3 and mixing should be sufficient to disperse the feces lumps into their aggregate particles.
2. In an expression device 2.38 mm diameter holes will retain most of the fibrous solids.
3. An upper limit of 45,000 pa (6.5 psi) in the expression chamber will yield an acceptable cake.

Chamber pressure, hole size and rate of expression are interrelated variables. At high rates of expression (for a particular hole size) high chamber pressures will develop and more power will be required for dewatering. This problem occurs because of the large quantity of incompressable fluid (tap water) contained in the mixture under compression. This phenomenon could be considered a dash-pot effect. The upper pressure limit stated above (45,000 pa) was determined from dead weight tests. In these cases chamber pressure was maintained at a constant level and the rate of expression (characterized by downward piston speed) was allowed to vary. Pressures exceeding 45,000 pa could easily be created (as seen from the Instron data) in an expression chamber before sufficient dewatering had taken place if high rates of expression were maintained.

V. THE PILOT SCALE EXPRESSION DEVICE

Purpose

The purpose of building the pilot model expression device was to bridge the gap between the basic information collected using a vertical expression chamber and the farm expression system. I propose a total waste handling system incorporating flushing and liquid - solid separation via expression. Briefly, this system involves the following ideas:

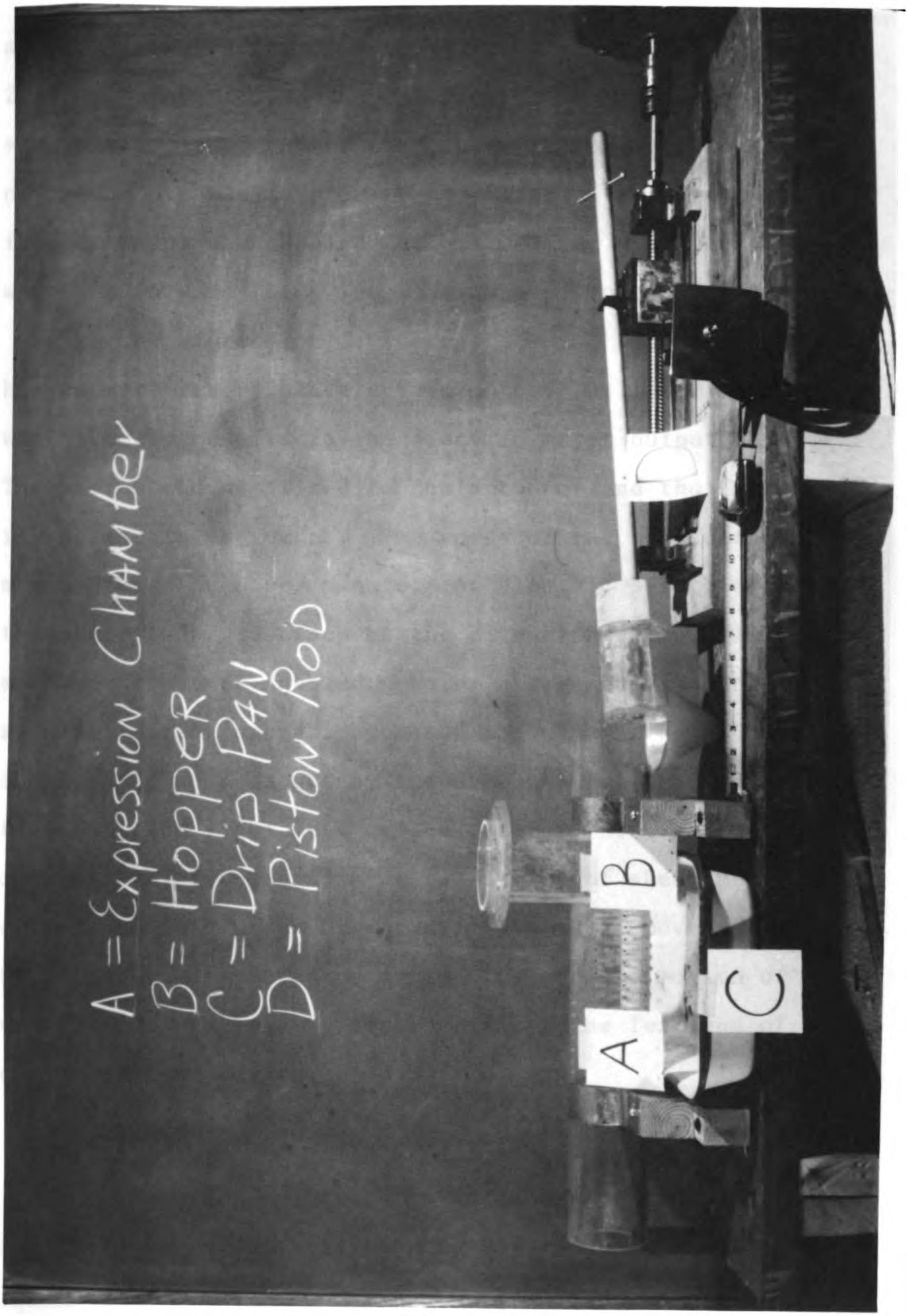
1. Hogs would be housed over slats and manure flushed to a central location (flush pool).
2. The separation of fines from the solid material would be accomplished by mixing in the flush pool.
3. After mixing, the fibrous solids would settle and the liquid (with fines in suspension) above the large solids would be pumped to an anaerobic lagoon.
4. The fibrous solids would be pumped to the expression system.
5. The liquid separated during expression would drain to the anaerobic lagoon. The dewatered solids could be used directly or stored in an appropriate location.

The scale model expression device was designed as a part of the above mentioned waste handling system. The design incorporated a number of unproven methods which needed testing before they could be used in a full scale system. These methods included the use of concentrated fibrous solids (with fines removed) as the influent to the expression chamber, and a start-up procedure involving an initial cake formation and subsequent solids dewatering using the cake (previously dewatered solids) as a containment wall for the influent slurry. These methods will be further discussed in the remaining portions of this chapter.

Physical Description

Figure 7 is a photograph of the expression device. The discussion in this section will refer to that figure. The expression chamber (A) was constructed from a 7.62 cm inside diameter plexiglass cylinder with a .64 cm thick wall. The overall length of the cylinder was 61 cm and 2.38 mm diameter holes were drilled in the center section of the chamber located above the drip pan (C). There were 8 rows of holes uniformly spaced around the cylinder with 15 holes per row. The holes in any particular row were spaced 1.3 cm apart. The center of the hopper (B) was located approximately 45 cm from the left end of the chamber. The hopper inlet to the chamber was a square with sides 6 cm in length. The piston rod (D) was made from a 1.9 cm diameter wooden dowel. The piston head was 7.6 cm in diameter

Figure 7. Pilot Scale Expression Device


A = Expression Chamber
B = HoPPeR
C = DriP PAN
D = Piston RoD
A
B
C
D

and out from .64 cm thick plexiglass plate with eighteen 2.38 mm holes drilled through the piston face. An 18 cm sleeve was placed behind the piston face. The purpose of the sleeve was to prevent the material in the hopper from dropping down behind the piston face when the piston was in a forward (deep into the chamber) position.

The expression device was powered by a 186 W (¼ horsepower) reversible electric motor. A linear actuator was directly coupled to the electric motor output shaft. The piston rod was fixed to the actuator and thus followed its horizontal movement. The speed of the horizontal movement was 3 cm per minute. An electric switch allowed the motor to be reversed so the direction of the piston movement could be changed. Water expressed from solid material during operation passed through the holes in the chamber and were caught by the drip pan, or drained to a funnel at the right edge of the chamber. The expression chamber was strapped down by two strips of sheet metal visible on both sides of the drip pan (C). Movement of the chamber was prevented during the forward motion of the piston by a steel plate located at the left end of the expression device.

System Operation

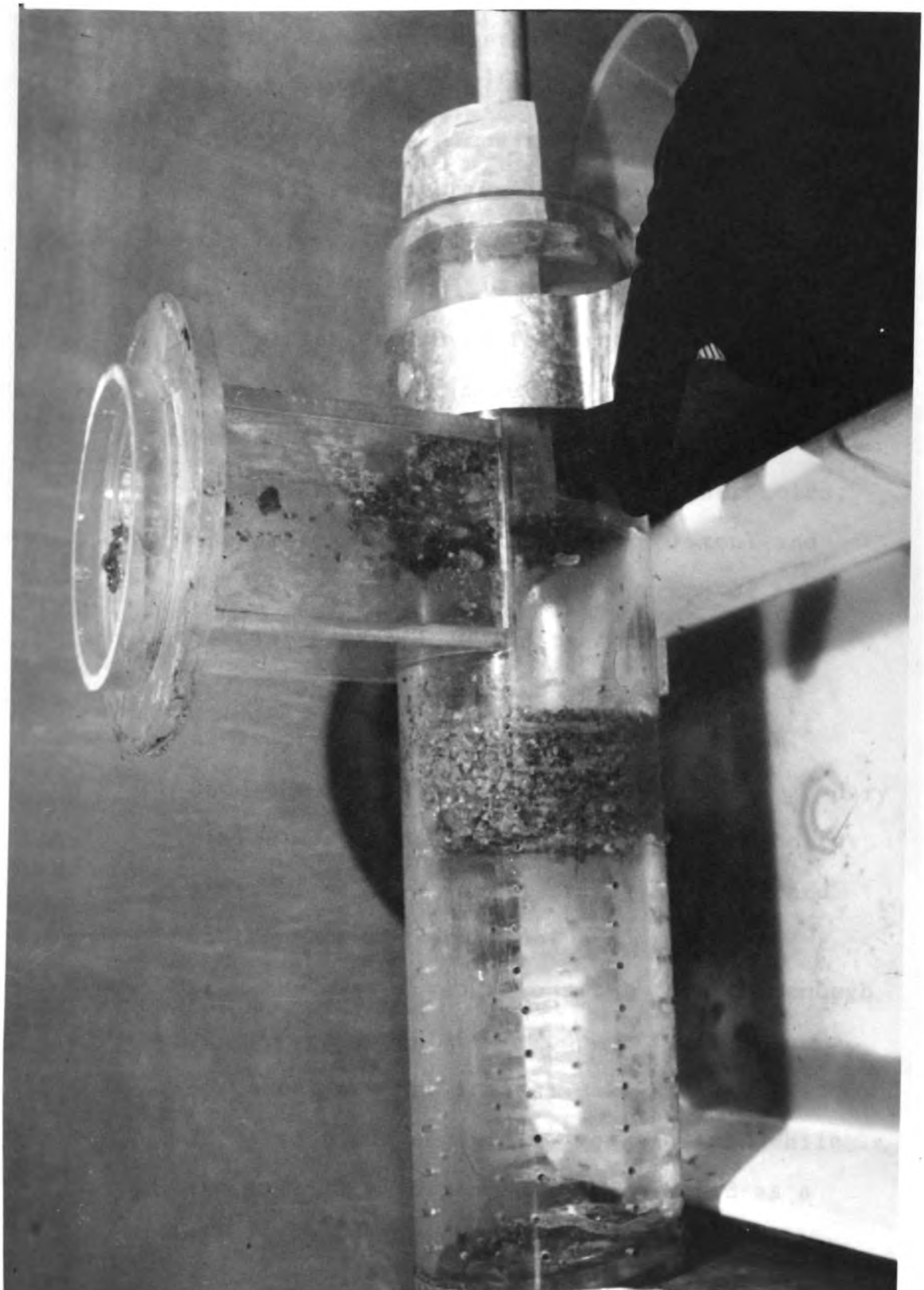
The start up procedure for the expression device required the use of a secondary, unperforated piston.

This piston was used to form an initial cake and then it was removed for the remainder of the test. Figure 8 is a photograph of the solid cake formed between the regular piston, on the right, and the secondary piston on the left (only the head of the secondary piston is visible). The initial cake was used to retain the next batch of influent slurry during dewatering. As the piston moved forward the force would become sufficiently large to dewater the influent while pushing the resulting solid material toward the expression chamber outlet. This semibatch process was repeated until all the material for a particular test was processed. The influent was added manually by pouring a batch of slurry into the hopper when the piston was in the backward position prepared to return on the forward stroke. The maximum backward position of the piston face was the right edge (Figure 8) of the influent hopper. The maximum forward position was 8 cm to the left of the left edge of the hopper.

Being more specific, the following sequence of events was carried out each time the system was operated:

1. The regular and secondary pistons were properly positioned for start up. The secondary piston was placed so the piston face was located at the maximum forward position of the regular piston. The regular piston was put at its full backward position. The rod

Figure 8. Expression Chamber with an initially formed cake.



of the secondary piston protruded from the solids exit point of the expression chamber and was held in place by the operator.

2. A sufficient amount of slurry was poured into the hopper to fill the space between the two pistons.
3. The piston was moved forward by power supplied from the electric motor. The forward piston movement built up pressure in the chamber which forced water out of the chamber holes, the piston face holes (regular piston) and the space between the outer surface of the regular piston face and the chamber wall.
4. Sufficient resistance was provided by the secondary piston to allow cake formation.
5. Once the initial cake was formed, the secondary piston was removed and the regular piston reversed its direction of travel and returned to the backward position.
6. With the piston ready to start forward, enough slurry was added to the hopper to fill the space between the initial cake and the piston.
7. The piston was engaged to move forward while the initially formed solid cake acted as a retaining wall for the manure slurry.

8. As in step 3 (above), the piston movement increased chamber pressure causing water to be expressed from the system. As the piston continued forward, the dewatered solids were forced to move toward the exit end of the expression chamber.
9. When the piston reached the maximum forward position it was retracted to receive another batch of slurry.

The sequence of steps (5 - 9) was repeated until the total quantity of influent slurry for a particular test was dewatered.

I conducted three separate tests with the expression device. The influent slurry served as the variable for the experiments. In one test, 3580 g of fresh feces were collected and added to 32.22 l of tap water (9:1 dilution). The slurry was thoroughly mixed by gently stirring for a few minutes. The fibrous solids settled and the upper effluent containing most of the fine solids was decanted from the slurry. Enough water was left in the mixture to completely immerse the settled solid material. In the second test, 3120 g of fresh feces were added to 28.08 l of tap water (9:1 dilution). This slurry was mixed as in the first test and then allowed to stand for 24 hours at room temperature before decantation and expression. The effluent from each decantation was poured through a static screen (14 mesh) in order to determine the amount of large solid material lost during decantation. In a third test, 1080 g of fresh feces was added to 1.08 l of tap water (1:1 dilution). This slurry was mixed and put through the expression device without decantation or soaking. For the purposes of illustration and comparison a small portion of the 3,580 g feces sample discussed above (fines removed and no soaking) was poured on a static horizontal screen (14 mesh) and allowed to drain. After 30 minutes a total solids test was conducted on the remaining fecal matter.

During this phase of the study, two sets of experiments using a Buchner Funnel (8.2 cm mouth, 1.19 mm holes) were carried out. In one experiment two tests were performed. For one test, 50 g of fresh feces were mixed with 50 ml of water, which gave a 100 ml total, and poured into the funnel. For the second test, 50 g of feces were mixed with 450 ml of water. The large solids were allowed to settle and the slurry was decanted to give a total volume of 100 ml. At this point the mixture was poured into the funnel. During each test the accumulated volume of liquid which had passed through the funnel (the filtrate) was measured as a function of time.

Three tests were conducted during the second Buchner Funnel experiment. The funnel was modified by fixing a plexiglass cylinder to the funnel mouth. The cylinder acted to extend the sides of the funnel by 50 cm. A 100 g sample of feces was mixed with 900 ml water and poured into the extended funnel. Accumulated drainage through the funnel was measured as a function of time for 16 minutes. When this test was completed the original sample was reconstituted by mixing the drained fluid with the slurry which remained above the base of the funnel. The mixing was done in a 2 l beaker. After mixing of the fibrous solids were allowed to settle and the liquid (with fines in suspension) above the large solids was decanted and saved. Fresh water was then added to the fibrous solids until the total volume of material was 800 ml. This new slurry was then mixed and poured into the modified funnel. The accumulated drainage was measured over a 16 minute period. After the completion of this test the material was placed in a beaker and the excess liquid was decanted to leave the fibrous solids. The liquid containing the fine material, which was previously decanted and saved, was put in the beaker and mixed with the fibrous solids. Again, accumulated drainage was measured as a function of time for 16 minutes.

Results and Discussion

In the three expression tests which were performed, the nature of the influent was the only variable. When the influent contained material from which the fines were not removed, the expression system would not operate properly. Much of the water would drain from the sample, but it would not maintain its shape which made initial cake formation impossible. Solids, which had been pushed into cake formation would collapse when the piston was removed. Figure 9 is a photograph of the feces without fines removed, after expression and attempted cake formation. Note that the material is slumping and barely able to support itself. Figure 10, for comparison, is a photograph of fresh feces after fine removal and expression. It obviously maintains its shape much better than the material in Figure 9. When the solids of Figure 10 were crumbled by hand and piled upon themselves, the angle of repose was measured as 76.6°.

Two samples that had gone through the fine removal procedure were tested in the expression system. The difference between the two samples was the soaking period--one sample was used after 24 hours of soaking while the other was used while fresh. Acceptable cakes were made from both these samples. There was, however, one drawback from soaking. During decantation more solid material was lost in the effluent of the soaked sample than in the effluent of the nonsoaked sample. The solid material seemed "less settlable," i.e., a significant amount of the large solid material was in suspension. When the decantation of the soaked sample was half compete, the

Figure 9. Fresh fecal material, without fine removal, after expression and attempted cake formation.

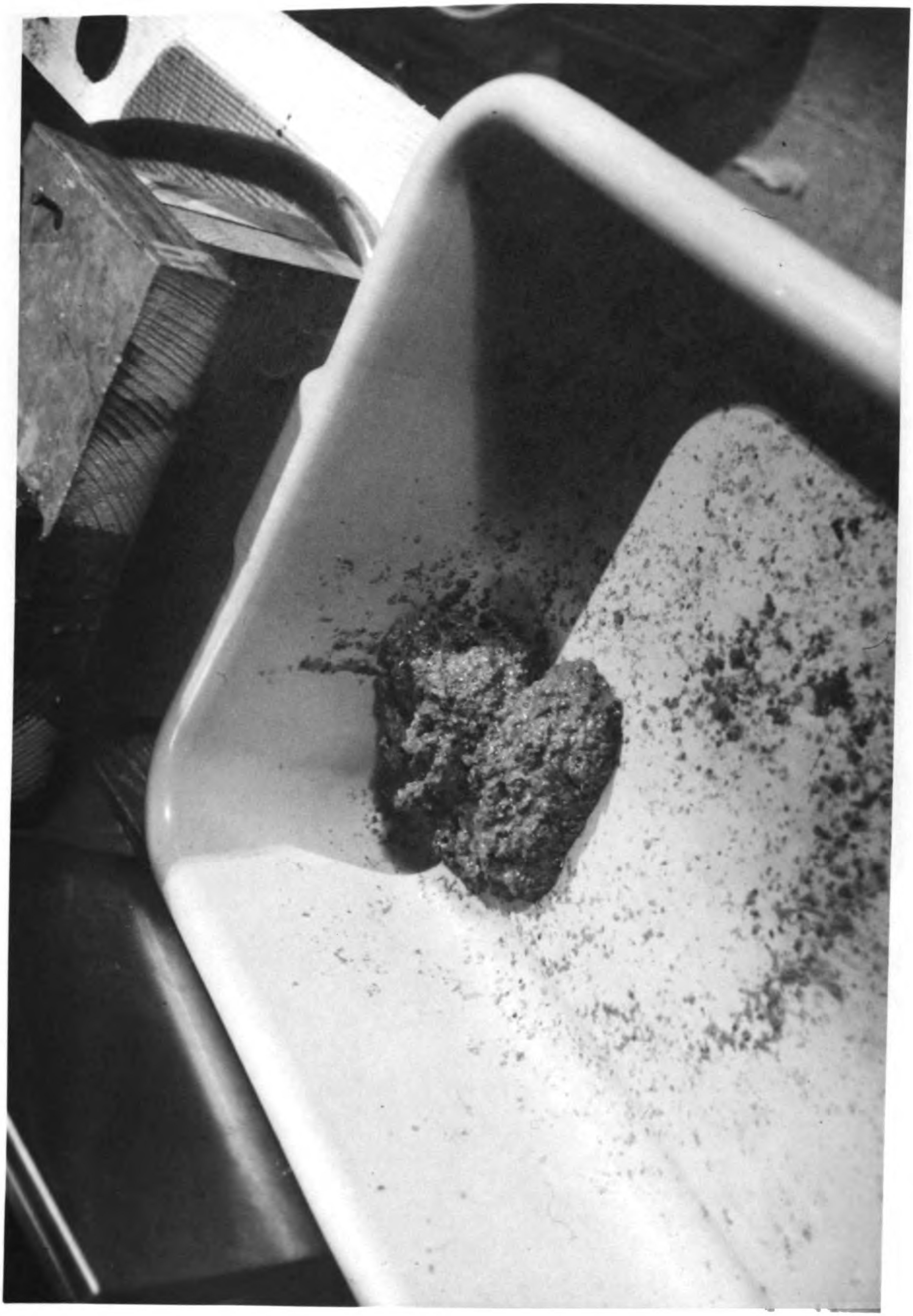
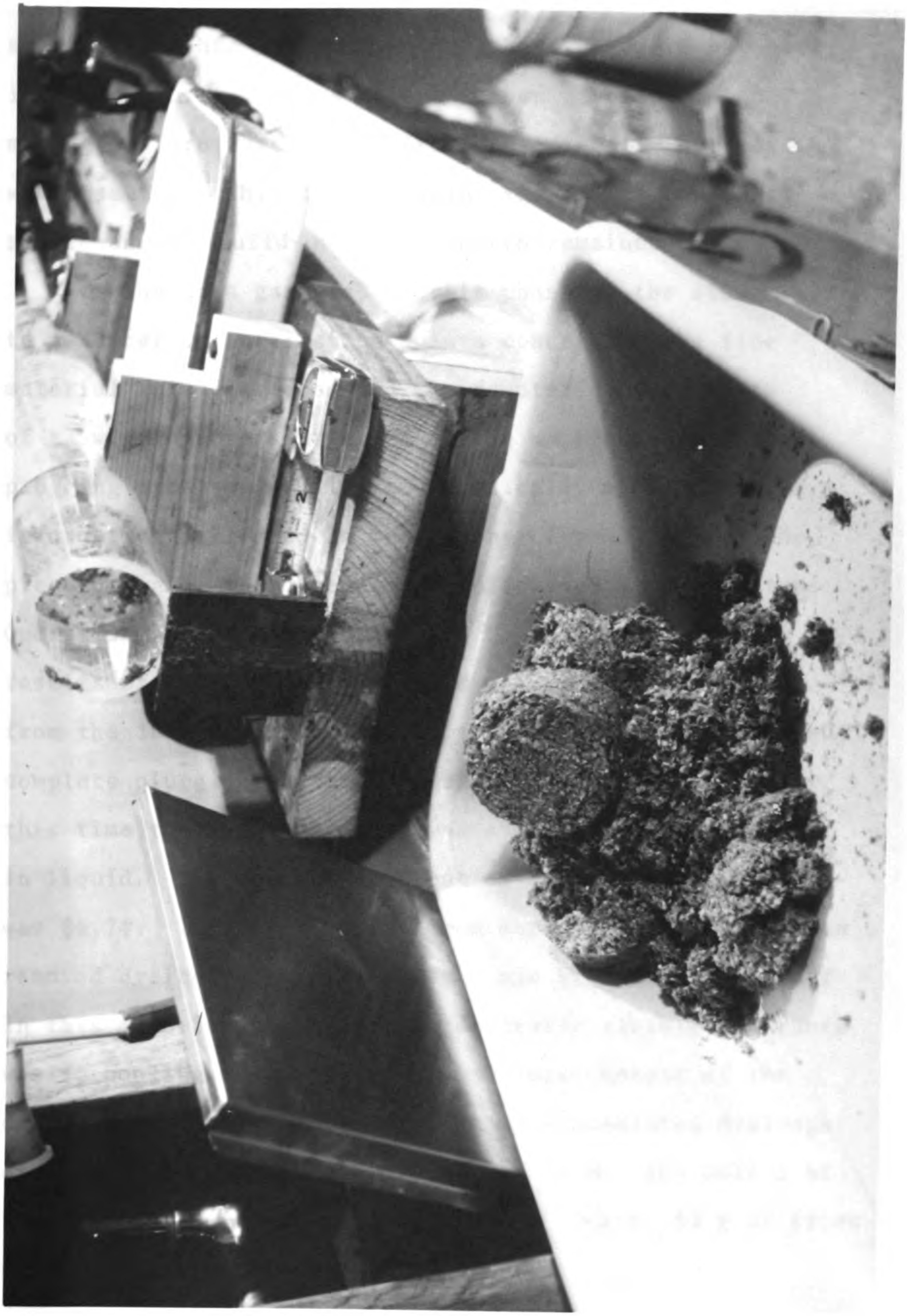


Figure 10. Fresh fecal material after fine removal, expression and cake formation.



solids which had accumulated on the screen were put back into the slurry. The sample was then given additional mixing, before further decantation to see if the solids would settle. This did not help, the solids would not settle and the build-up on the screen remained large.

The data gathered in this phase of the study lead to a number of interesting points concerning the fine material found in feces and the dewatering capability of a swine manure slurry. The fine material does create plugging problems. This is dramatically shown from the information collected in the Buchner funnel tests. The preparation of these samples is discussed in the System Operation section of Chapter V. Figure 11 shows the results of the tests where fluid was allowed to drain from the 100 ml samples. When the fines were not removed, complete plugging occurred after 3 sec. of draining. At this time the solid material was still visibly immersed in liquid. The moisture content of this thick slurry was 86.7%. The fecal solids from which the fines had been removed drained continually for 2 min before leveling off. In this material the solids were clearly visible and there was no pooling of liquid. The moisture content of the drained sample was 82.9%. The final accumulated drainage of the sample with fines removed was 40 ml, and only 3 ml in the sample without fines removed. Recall, 50 g of feces were used for each test.

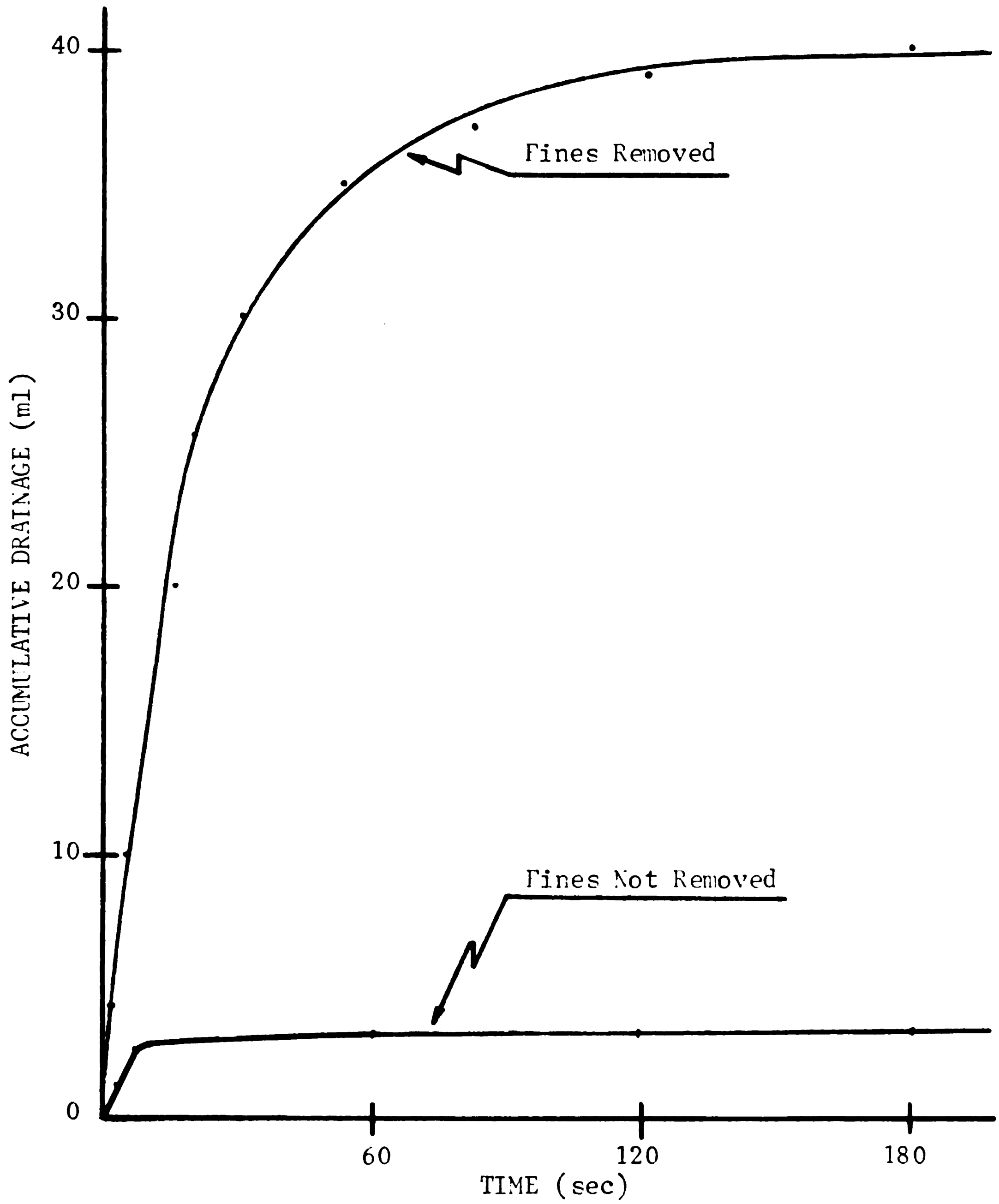


Figure 11. Accumulated drainage from a Buchner Funnel versus time for a feces sample with fines removed (9:1 dilution) and a feces sample without fine removal (1:1 dilution).

The results of tests using the modified Buchner Funnel are presented in Figure 12. Again, these results clearly show that the fine material contained in swine feces cause plugging problems. Liquid was easily drained from the slurry containing fibrous solids and water in comparison to the slurries containing high amounts of fine material. The sample of feces (fines and fibrous solids) plus water plugged almost immediately after the start of the test. The sample which contained fibrous solids and water with fine suspended material showed slow but continuous drainage. This sample drained better than the feces plus water mixture because it contained less fine material; some of the fine material was lost during sample preparation. As mentioned earlier, the fibrous solids for the last test were the same solids retained after decantation of the fibrous solids plus water mixture used in the previous test.

The moisture content of the three samples put through the expression system and the sample allowed to screen drain are compared in Figure 13. As one would expect, the samples which had liquid expressed from them had lower moisture contents than the screen drained sample. The moisture content of the soaked feces with fines removed was 74.7%. The moisture content of the screen drained solids with the fines removed was 80.2% while that of the sample without fines removed was 77.5%. These

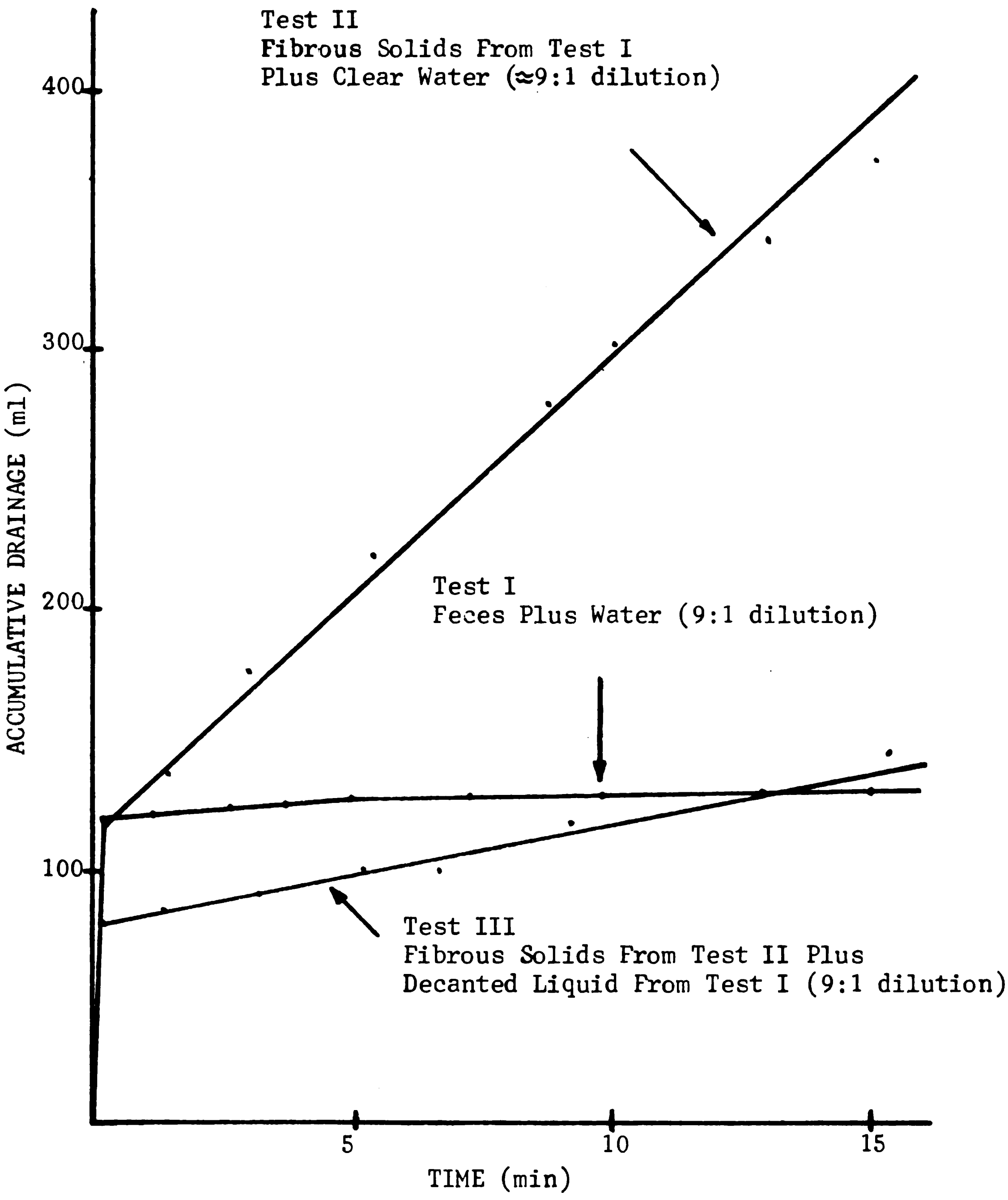


Figure 12. Accumulated drainage from a modified Buchner Funnel versus time for a feces sample mixed with various dilutants.

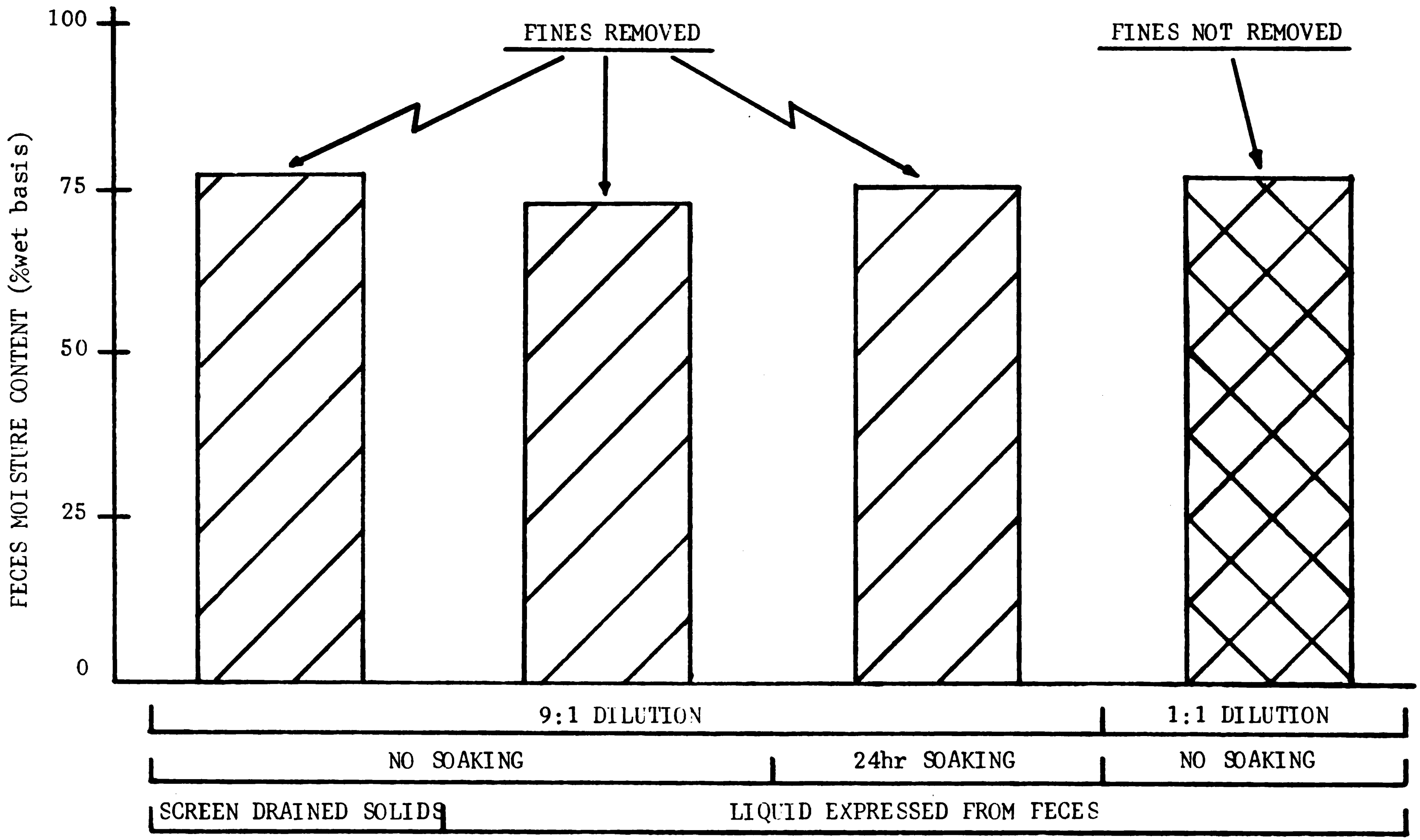


Figure 13. Moisture content of feces having undergone various types of treatment.

differences do not appear to be large, but they are very meaningful. The screen drained sample and the sample with fines removed would aptly be called a semi-solid. They would act fluid-like in solids handling equipment.

Considerations for a Full Scale Expression Device

This study has demonstrated the possibility of expression as a swine manure liquid - solid separation process. The true test of utility, however, will be to build a full scale system and operate it in a farm situation. It must be subjected to continual usage under a variety of conditions. The system must be developed to meet the needs found in practical operation. This type of study would be the logical continuation of my research.

In constructing a full scale expression device for developmental studies there are a number of factors which should be considered. Here are some of them:

1. The holes are the most vulnerable feature of the expression chamber. Plugging due to slime and particle build up may be a problem. A solution to the particle accumulation problem may be to drill the expression chamber holes at an angle oblique to the direction of solids travel.
2. It will be difficult to determine the optimum physical size of the expression chamber. The

length of the chamber should provide enough resistance to solids movement for good dewatering. However, if pressure is too high in the chamber, solid material may be extruded through the holes. Besides chamber length, other factors such as surface roughness and chamber orientation will effect resistance to solids movement. The number and distribution of holes will also be an important parameter to consider.

3. It was demonstrated in the pilot model that liquid - solid separation via expression was best achieved when the system influent was fresh feces with fines removed. There will be some handling problems involved in getting this material from the mixing location to the expression chamber. When this type of influent was placed in the hopper of the pilot expression device (with the piston in the forward position) the water in the slurry drained out around the sleeve edges. This created a bridging problem and it was necessary to dislodge the solids from the hopper.
4. For a full scale system, the expression piston (as opposed to the secondary piston) should be constructed without perforations. These

perforations were plugged after the piston had cycled two or three times and acted to loosen particles from the solid cake.

5. A particularly important parameter for the developer to determine will be the optimum rate of expression. A rate of piston movement of 2.1 cm/min was acceptable in the pilot model. From experience with this device it appears that faster piston movement would have been acceptable.
6. There may be scale-up problems encountered in going from pilot scale to full scale device. This can be determined from development and testing.

VI. HYPOTHETICAL EXAMPLE

There are two purposes for presenting this hypothetical example. One is to get an idea of what size expression device could handle a large hog production operation. The other is to demonstrate the potential usefulness (solids removal capability) of liquid-solid separation by expression.

Solids Removal Capability

Consider a finishing hog barn with a average of 300 hogs (average mass equals approximately 67 kg) at any particular time during the year. These hogs would be housed over slats and the manure would be flushed to a mixing basin. Solid material would be pumped from the mixing basin to an expression device for dewatering. Liquid separated during expression and excess liquid from the mixing basin would go to an anaerobic lagoon for treatment. Lagoon water would be recycled for flushing. Assume (Data from Midwest Plan Service, 1975a):

1. Raw manure production = 6.5% of live body weight
2. Feces = 55% of the raw manure produced
3. Raw manure = 9.2% total solids
4. Volatile solids = 80% of the total solids

5. The quantity of total solids contributed from the urine is small and can be neglected.

Total quantity of feces produced per day =

.065 X .55 X 300 hogs X 67 kg/hog = 718.5 kg feces

Total quantity of total solids (T.S.) produced per day =

.065 X .092 X 300 hogs X 67 kg/hog = 120.1 kg T.S.

Total quantity of volatile solids (V.S.) produced per day =

120.1 kg T.S. X .80 V.S./T.S. = 96.0 kg V.S.

An estimate of the total solids retained by expression can be obtained by looking at the data presented in Table 2. Consider the case where there was complete mixing and liquid was expressed through the 4.76 mm holes. In this test, values of 74.7 and 95.6 percent are given for the moisture content of the cake and effluent respectively. Selecting these values for estimating the percent retention of T.S. and V.S. should yield conservative figures because 2.38 mm holes are recommended for a full scale expression device. Less solid material is retained when using the 4.76 mm holes. Using the data for the above-mentioned case, the following estimates can be made:

300 g X .675 X (1 - .747) = 51.2 g T.S. in cake

The value 67.5% used above is a volume ratio. However, it is assumed that the density of the cake is approximately equal to that of water. The same assumption is made in computing the quantity of total solids in the effluent.

1300 ml slurry - (300 X .675) ml cake = 1097.5 ml effluent

1097.5 ml effluent X (1 - .956) = 48.2 grams T.S. in effluent

$$\text{\% T.S. retained in cake via expression} = \frac{51.2}{51.2 + 48.2} \times 100 = 51.5\%$$

$$(51.2 + 48.2) \text{ g T.S.} \times .8 \frac{\text{V.S.}}{\text{T.S.}} = 79.5 \text{ g of V.S. in feces}$$

The quantity of volatile solids contained in washed swine fecal material is found in Ngoody et al. (1971). These researchers found that dried solids taken from a vibrating screen separator were 91.5% volatile. The influent material was a feces - urine slurry which had been diluted with 10 parts tap water and well mixed before separation. This product would be similar to that obtained from an expression process. Taking this into consideration, the percent V.S. retained in the solid cake can be calculated.

$$51.2 \text{ g T.S. in cake} \times .915 \frac{\text{V.S.}}{\text{T.S.}} = 46.8 \text{ g V.S. retained in cake}$$

$$\text{\% V.S. retained in cake via expression} = \frac{46.8}{79.5} \times 100 = 58.8\%$$

Going back to the 300 hog finishing barn, the quantities of total solid and volatile solid material entering the lagoon can be calculated.

Quantity of T.S. entering the anaerobic lagoon per day =

120.1 Kg T.S. X .515 = 61.8 Kg T.S.

Quantity of V.S. entering the anaerobic lagoon per day =

96.0 Kg V.S. X .588 = 56.4 Kg V.S.

It would be reasonable to expect a 58.8% reduction in the quantity of volatile solids going to an anaerobic lagoon when the solids are separated from the manure slurry be expression. Consequently, 41.2% of the normally required lagoon (no solids separation) would be adequate. The fibrous solids left after expression could be stored or immediately spread on farm land. Solids taken from the expression device formed a surface crust when allowed to air dry overnight. Ngoddy et al. (1971) found that fibrous solids taken from a vibrating screen were odor free, relatively stable, and did not attract flies.

The Scaled Up Expression Device

In this section the pilot expression model discussed in Chapter V (Figure 7) will be scaled up to handle the waste generated from a hog farming operation. A number of assumptions will be made and an example for the general case will be worked through. Power requirements for a particular expression device will be estimated.

Physical Size

Assume:

1. There are no scale up problems involved in going from the pilot to the full size expression device.
2. Raw manure production equals 6.5% of the live body weight.
3. The expression chamber is circular and the length of the piston stroke is equal to 1.5 times the cylinder diameter.
4. The length of the hopper opening to the chamber, in the direction of piston movement, is 1/2 the chamber diameter.
5. The total amount of material to be processed by expression will be equal to the feces produced plus 1/3 of that volume. The additional volume would enter the system while transporting the feces to the expression device.
6. The effective expression stroke (slurry contained on all sides) is one chamber diameter in length.

Variables:

D = density of feed material (Kg/cm^3), approximately equal to water

d = chamber diameter (cm)

s = forward piston speed (cm/min)

r = fraction of raw manure which is feces

h = number of 67 kg hogs in the system

t = processing time allowed for a 24 hr waste load (hr)

s' = backward piston speed (cm/min)

Time required for piston to cycle =

$$\left(\frac{1}{s'} \text{ X } 1.5d\right) + \left(\frac{1}{s} \text{ X } 1.5d\right) = 1.5d \left(\frac{s+s'}{ss'}\right) \text{ min}$$

Amount of material processed per piston cycle = volume swept by the effective piston stroke =

$$\pi \left(\frac{d}{2}\right)^2 d = \frac{\pi}{4} d^3 \text{ cm}^3$$

Volume of material the expression device must process = volume of feces produced + 1/3 that volume =

$$\frac{rh}{D} (67)\ (.065)\ \frac{4}{3} = \frac{rh}{D} (5.80) \text{ cm}^3$$

$$\frac{\text{Volume of waste to be processed}}{\text{Allowed processing time}} = \text{Expression system capacity}$$

$$\left(\frac{1}{t}\right) \left(\frac{rh}{D}\right) \left(\frac{5.80}{60}\right) = \frac{\pi d^3}{4} \Big/ \left(1.5d\left(\frac{s+s'}{ss'}\right)\right) =$$

$$\frac{\pi d^2 \ ss'}{4 \text{ X } 1.5(s+s')}$$

Solving for d (required chamber diameter) yields:

$$d = 13.6 \left(\frac{rh}{t}\right)^{1/2} \left(\frac{s+s'}{ss'}\right)^{1/2} \text{ cm}$$

where $D = 10^{-3}$ Kg/cm^3

With 300 hogs, a 10 hr processing time, r equal to .55, aforward speed of 2.1 cm/min, and a backward speed of 30 cm/min a chamber diameter of 39.4 cm is required. From experience gained in this research a chamber length, measured from the forward edge of the hopper, of 3d is recommended. If the hopper opening is 1/2d in the direction of piston movement, and a length of chamber 1/2d is provided at the back of the hopper, then the overall chamber length would be 4d or 158 cm (5.2 ft).

Power Requirements

From the basic expression data I found that acceptable cakes could be formed using 45000 pa (6.5 psi) as an upper pressure limit in the expression chamber. Taking the above mentioned chamber (32.5 cm diameter), an estimate of the power required to drive the expression device can be calculated.

Assume:

1. A pressure of 45000 pa is maintained in the chamber during expression.

2. Power required for the action of the expression device other than actual expression (backward piston movement, etc.) equals the power required for expression.

Work done during expression =

$$(45000) \quad (\pi) \quad \left(\frac{.323}{2}\right)^2 \quad (.323) = 1190.9 \text{ N m}$$

Time required for expression =

$$\frac{32.2}{2.1} = 15.33 \text{ min} = 919.9 \text{ sec.}$$

Power required for expression =

$$\frac{1190.9}{919.9} \quad \frac{\text{N m}}{\text{sec}} = 1.29 \text{ watts } (1.72 \text{ X } 10^{-3}\text{hp})$$

Total power required =

$$(1.29)2 = 2.58 \text{ watts } (3.45 \text{ X } 10^{-3}\text{hp})$$

Power requirements are small. If the chamber resistance to cake movement was very high and the power estimate were off by a factor of 100, then 258 watts (.34 hp) would be required to drive the expression device.

VII. SUMMARY AND CONCLUSIONS

Basic variables affecting the expression of a swine manure slurry were identified using a vertical expression chamber. The chamber consisted of a plexiglass cylinder sealed at one end with a porous piston used as the third retaining wall. Degree of mixing and quantity of dilution water added to the fresh feces were significant influent treatment variables. Variables considered when operating the expression chamber were the piston plate hole size and the force used to move the piston into the slurry. Constant and variable forces were applied and the rate of expression was considered.

The basic expression studies demonstrated that swine feces consist of large fibrous solids and fine solids. The fine solids give fresh feces their paste-like character and cause plugging problems when expressing liquid from swine manure slurry. The fibrous solids, when separated from the fine material, form a relatively stable, odor free product which dries rapidly when exposed to air.

Expression is a viable method of separating the liquid and solid parts of a swine manure slurry if the fine material contained in the feces is properly managed.

The fine solids should be removed from the fibrous solids before expression is attempted. Fines removal can be accomplished by mixing fresh feces with water and removing excess liquid after settling of the fibrous solids. The fine matter is contained as a suspended solid material, in the liquid above the settled solids. In less than 30 minutes after the fibrous solids settle, the fine solids will flocculate and fall forming a fluffy mass on the top of the larger particles. When a swine manure handling system includes flushing, sufficient water is always available for fines removal.

A pilot model expression device was constructed to test a particular design concept. The design incorporated two unique operating methods. These were (1) the use of concentrated fibrous solids (fines removed) as the influent to the expression chamber, and (2) an operating procedure involving the use of previously dewatered solids for slurry containment. These methods proved successful and suggestions were made for the design and development of a full scale expression system.

A hypothetical example is presented to demonstrate the potential usefulness of liquid - solid separation by expression and to project the size of an expression device (scaled up pilot model) which might be required to handle a particular hog operation. The solids removal capability of expression is promising. If expression was used to separate solids from a swine slurry (after flushing) before the waste was sent to an anaerobic lagoon for treatment a 58.8% volatile solids removal could reasonably be expected. In other words, if an expression system was incorporated as an add on to a flush - lagoon system, only 41.2% of the existing lagoon would be required to effectively treat the waste.

The size of an expression system required to effectively treat the waste from a normally sized hog operation is quite reasonable. Based on data found in this study, a 39.4 cm diameter expression cylinder 158 cm in length could effectively treat the daily waste from 300 market hogs in 10 hours. Testing and development of a full scale expression device may show that this performance can be improved due to higher rates of expression.

APPENDIX

TABLE 4.--Chemical composition of fresh feces, fibrous solids and fine solids on an air dry basis. (Analysis preformed by Animal Husbandry Dept., Michigan State University)

	Fresh Feces	Fine Solids	Fibrous Solids
DM%	97.99	96.16	98.91
CP%	19.59	24.93	17.99
Fe ppm	1433.	1928	1405
Zn ppm	565.8	947.5	494.9
Cu ppm	82.55	126.5	63.26
Ca%	2.21	4.59	2.40
Mg%	.84	1.28	.70
Na ppm	6370	5338	3236
K ppm	4213	5614	2755

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