ABSTRACT

AGITATION IN LIQUID MANURE TANKS AS AFFECTED BY PHYSICAL PROPERTIES OF MANURE AND SHAPE OF TANK

by Robert Harry Shaw

The primary objective of this thesis, carried out by building models and using model analysis, was to determine which shape of liquid manure holding tank could be agitated with the most efficiency. Fluid flow laws must be followed in the model analysis; and to maintain these laws, certain physical properties, viscosity and density of the liquid manure was needed.

The study of physical properties was carried out on samples collected from several dairies in Michigan. Viscosity tests were run on each sample at varying moisture contents using a rotating Brookfield viscometer. The density and the moisture content of the original samples were determined by the Bio-Chemistry Laboratories at Michigan State University.

Two model tanks (square and rectangular) were used for the agitation studies. The sides of the tanks were constructed of plexiglass, so that the movement of fluid could

be observed through the sides. A photographic technique was developed and used to record the flow lines of the fluid in the tank. The viscosity of the liquid used in the model tank was varied (to meet the model laws) using a cellulose product as a thickening agent.

A recirculating agitation system was chosen for the study, which is commonly used for agitating liquid manure in holding tanks.

The study of physical properties of liquid manure shows that it behaves as a pseudoplastic liquid with the density being similar to that of water. The study also showed that the viscosity of the liquid manure is primarily dependent on the moisture content and not on type of bedding.

Of the two different shapes of model tanks under study, it was shown that the square tank lends itself to most efficient agitation. It is desirable to be able to rotate the pump discharge nozzle 360° and be able to adjust it in elevation.

The study carried out in this thesis was primarily for dairy cattle, but similar methods could be used, and results obtained for liquid manure from other farm animals.

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AGITATION IN LIQUID MANURE TANKS AS AFFECTED BY PHYSICAL PROPERTIES OF MANURE AND SHAPE OF TANK

By

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INTRODUCTION

The methods of handling the waste products of farm animals as a liquid has progressed in the United States until we have what is known today as the liquid manure system. In this system, the manure is pushed, scraped or pumped from the barns or holding areas of farm animals into a large holding tank, usually through a slit in the top (see Figure 1) in which the manure is stored. Some additional liquid may be added to the manure to make it handle more like a liquid. After a period of time, the mixture of manure and liquid is agitated together, then the liquid manure is removed from the holding tank and spread on the fields. (Tanks are used as shown in Figures 2 and 3 to spread the liquid manure in the field.)

To begin with this method was most widely used by swine producers. These systems were relatively small and inexpensive. Today the system is also used by beef feeders and dairymen and the systems have become large, sophisticated and expensive.

The liquid manure system provides an efficient method of handling sloppy manure. This method uses a minimum of physical labor to clean the holding and bedding area

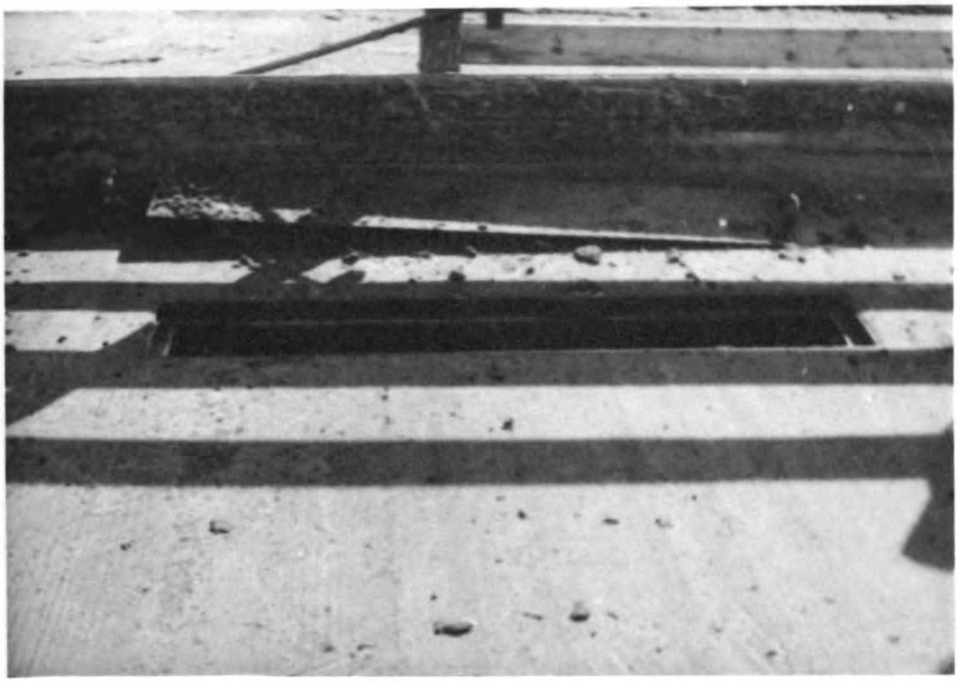

Fig. 1.--Shows opening which the liquid manure is put into a holding tank. Bruce Miller, Howell, Mich.

Fig. 2.--Tank that is used to spread the manure in the field. Quandt Dairy, Watertown, Mich.

Fig. 3.--Another example of a tank that is used to spread the liquid manure on the fields. Bruce Miller, Howell, Mich.

Fig. 4.--A typical example showing that the top of tank is at ground level. Ross Dairy, Marlette, Mich.

of farm animals in that these areas may be washed down or the manure can be scraped into the holding tank periodically. The manure handled in this manner has greater fertilizer value (Fitzgerald, 1965) than manure handled by some of the other conventional methods. There is less loss of plant nutrients due to evaporation and leaching and the liquid manure can be applied to crops (Fitzgerald, 1965) when it will be most advantageous. Also, it provides a means of storing the manure through the busy planting and harvesting seasons and through the periods of bad weather. The manure handled in this manner helps to keep the fly and odor problems (Fitzgerald, 1965) at a minimum and usually the bedding requirements are less. Bedding is not required to absorb the excess liquid in the manure when it is handled as a liquid.

The holding tank, usually built about eight or ten feet deep with the top or cover level with the ground (see Figure 4), has been built to fit the space available for the structure. Also, many of the manufacturers of liquid manure systems have a size and shape that is standard with them for manufacturing reasons. Little consideration has been given to determining an optimum size or shape of the holding tank with respect to agitation.

Agitation is the mixing of solids and liquids in the holding tank. The length and number of times that agitation is required with respect to filling and emptying the holding tank has the greatest dependence on the type of agitation system used. Some systems require that agitation of the holding tank be done periodically every day while other systems require agitation only at emptying time.

In this thesis the recirculation type of agitation system will be considered. This system of agitation is in common use today. This system removes the liquid from or near the bottom of the tank. The liquid containing solids goes through a chopper impeller pump (Figures 5 and 6) which cuts or breaks up the solids into smaller particles. The liquid or slurry is then ejected through a nozzle near the surface of the liquid. The jet of liquid from the nozzle is then directed toward the crust layer that may have formed on the surface of the tank. As the liquid comes in contact with the solids, they tend to dissolve and become a part of the slurry. Agitation is usually required just before the holding tank is emptied.

Fig. 5.--Shows the chopper impeller of a typical recirculating pump. Fred Braun, Saline, Mich.

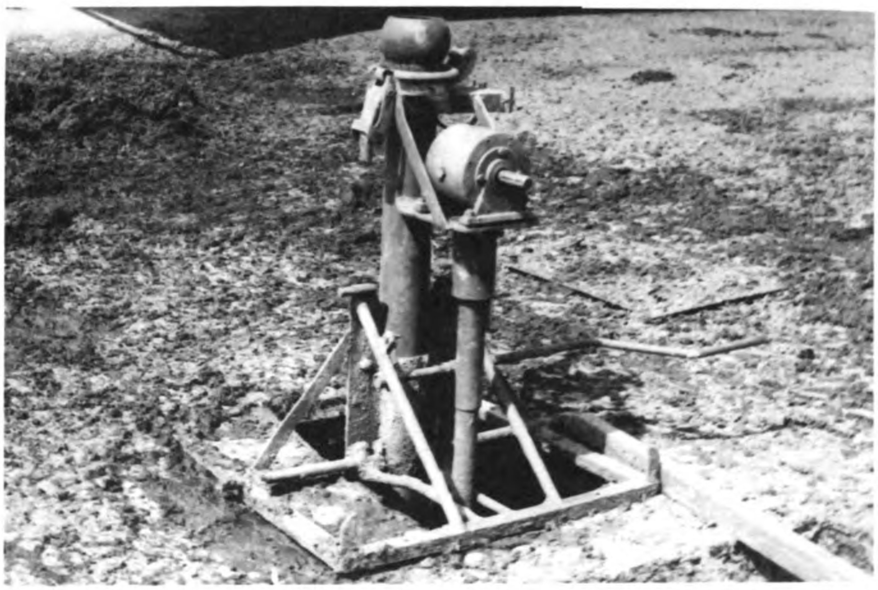

Fig. 6.--Shows the recirculating pump in place. Quandt Dairy, Watertown, Mich.

OBJECTIVES:

1. To study the physical properties of liquid manure.

2. To determine the effect of size, shape of holding tank and certain manure characteristics on the efficiency of agitation.

REVIEW OF LITERATURE

Liquid Manure and Liquid Manure Systems

The following section concerns itself with general information on liquid manure and liquid manure systems.

Moisture Content and Contents of Liquid Manure

Liquid manure for dairy cattle is defined (Sobel, 1965) as a liquid above 95% moisture content and as a semi-liquid between the moisture content range of about 88% to 95%.

In a survey (Speicher, 1965) of eight dairies in Michigan with liquid manure systems, it was determined that the average moisture content was 91.55%. The survey showed that the liquid manure contained an average of .047% phosphorus, .42% potassium and .30% nitrogen. It consisted of 1.65% ash and 6.93% organic matter.

Density of Liquid Manure

The average density (Speicher, 1965) from the samples of the eight dairies was 8.52 lbs. per gallon.

Excrement of a Dairy Cow

Fitzgerald (1965) quoted the following figures collected by one manufacturer of a liquid manure system. The total excrements of a dairy cow is about 8% of the body weight per day. Therefore, a 1000 pound cow would excrete

80 pounds or 9.6 gallons per day. This is equal to 2400 pounds per month or 290 gallons. The moisture content is about 84%. These figures were comparable to other studies (Speicher, 1965) that about a 500 gallon capacity tank is required for a dairy unit[1] per month when the moisture content of the liquid manure is about 91%.

Shapes and Sizes of Holding Tanks

Two shapes of holding tanks are commonly used. They are the round tank and long rectangular. The diameter of the round tank varies from 20 to 25 feet and is usually about ten feet deep. The common dimensions for the rectangular tank are eight feet deep, ten feet wide and some multiple of 30 feet in length up to about 120 feet. Another common size of a rectangular tank is 20 feet by 60 feet by 10 feet in depth. The latter example is made of precast concrete slabs.

Capacity of Pumps

According to the survey of manufacturers, the capacity of the pump for the recirculation system varies up to about 1500 gallons per minute.

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[1]Mature dairy cow equivalent to 1 dairy unit; replacement heifer or steer equivalent to .75 unit.

Theoretical Considerations

Models and model analysis can be used in the compilation of objective two. In order to relate the models to the prototype certain laws must be maintained. In this section, these laws and the theory of models are reviewed. In the second part, the theory of viscosity with certain relationships are discussed. These were found necessary to study physical properties of liquid manure.

Theory of Models

The objective for using a model is to determine or predict the behavior of the prototype. Models may be used, and are used in many cases, when the problems are too complicated for a mathematical or graphical solution. Models are also used to illustrate or study certain phenomena that takes place. The main reasons for using a model in this study were size considerations and the mechanics of handling large volumes.

A general equation may be written for the prototype with the use of the Buckingham Pi theorem.

$$\pi_1 = F(\pi_2, \pi_3, \pi_4 \ldots . \pi_s) \tag{1}$$

Two restrictions are placed on the π term. They must be dimensionless and independent. The number of π terms in the general equation is determined by the formula $s = n - b$ where s is the number of π terms, n is the total number of quantities involved and b is the number of basic dimensions. The same general law governing equation (1) can be applied to the model, so that

$$\pi_{1m} = F(\pi_{2m}, \pi_{3m}, \pi_{4m} \ldots \pi_{sm}) \qquad (2)$$

Now by dividing equation (1) by equation (2) and letting it be equal to one:

$$1 = \frac{\pi_1}{\pi_{1m}} = \frac{F(\pi_2, \pi_3, \pi_4 \ldots \pi_s)}{F(\pi_{2m}, \pi_{3m}, \pi_{4m} \ldots \pi_{sm})} \qquad (3)$$

It follows from equation (3) that $\pi_{1m} = \pi_1$, thus the different dimensionless parameters for the model can be determined from the prototype so that

$$\pi_{2m} = \pi_2,\ \pi_{3m} = \pi_3,\ \pi_{4m} = \pi_4, \ldots,\ \pi_{sm} = \pi_s$$

for a true model.

Textbooks on Fluid Mechanics (Olson, 1961 and Murphy, 1950) have indicated that for a small model that has a free surface of liquid both Reynolds law and Froude law are important for a dynamic similarity between the model and the prototype.

Reynolds number R_e, equal to the product of density ρ, velocity V, and length L divided by dynamic viscosity μ,

$$R_e = \frac{\rho VL}{\mu} \qquad (4)$$

is important in the flow of viscous fluid. Froude number F_r, equal to the velocity V, divided by the square root of the product of gravity force g and length L,

$$F_r = \frac{V}{(gL)^{1/2}} \qquad (5)$$

is important where gravity forces govern the flow. A study of the dimensions of Reynolds and Froude numbers, where density is equal to lb_m/Ft^3, velocity is equal to ft/sec., length is equal to ft., dynamic viscosity is equal to slug/ft. sec. and gravity force is equal to ft/sec^2 (American Engineering System); can be shown that they meet the requirement of the π terms in that they are dimensionless and independent.

From the above discussion, it can be determined for a geometrically similar model such as the holding tank of liquid manure that the properties and the flow of the liquid should be controlled by Reynolds and Froude numbers. The dimensionless terms of the model should represent as closely as possible those of the prototype in order to maintain a dynamic similarity between the model and prototype.

Theory of Viscosity

Viscosity η is a proportionality constant called the coefficient of viscosity which relates the shear stress τ between the layers of liquid to the rate of shear $\frac{d\gamma}{dt}$. The relation follows the equation

$$\eta = \frac{\tau}{\frac{d\gamma}{dt}} \qquad (6)$$

where η may be expressed in poises, τ in dyne/cm^2 and the rate of shear has the unit of 1/sec (metric system).

Newtonian, pseudoplastic, and dilatant fluids are three common types of fluids. For an ideal Newtonian fluid such as pure water and many lubricating oils, the viscosity remains constant as the shear rate increases. The viscosity is not constant (Behn, 1960) for the other two types of fluids. It varies depending on the molecule characteristics of the fluid and on the amount of certain suspensions that are in the fluid. The viscosity of a pseudoplastic fluid decreases as the shear rate increases (Illustrated by curve b or Figure 7). This type of fluid is very common. Curve c or Figure 7 illustrates the behavior of a dilatant fluid. The viscosity increases as the shear rate increases. This type of fluid is less common than the pseudoplastic fluid. Examples are found in some types of enamels and in some clays and sands.

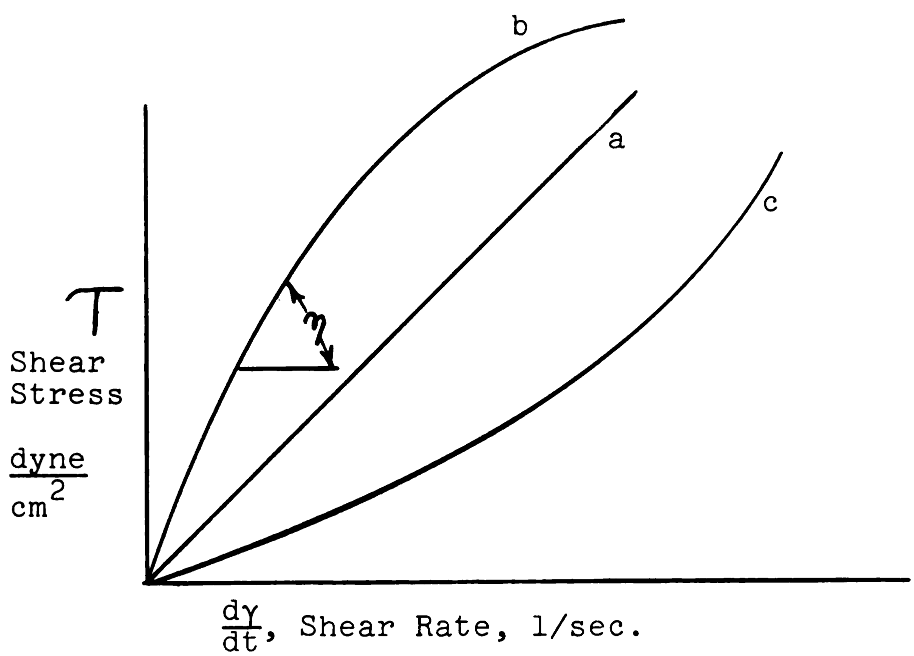


Fig. 7.--Shows the relationship of different types of fluids, a - Newtonian, b - pseudoplastic, c - dilatant.

The relationship between shear stress and shear rate of a non-newtonian fluid may be represented by the equation

$$\frac{d\gamma}{dt} = B\tau^{n} \qquad (7)$$

where B and n are constants depending on the characteristics of the material. However, when n = 1, it can be concluded that the fluid is newtonian. When n > 1 the material is pseudoplastic in character and when n < 1 it is a dilatant fluid.

Rotational Viscometer

Van Wazer, Lyons, Kim and Codwell (1963) stated that for a rotational viscometer the viscosity will have a relationship where

$$\eta = K(\text{stress term/rate of shear term}) \qquad (8)$$

K is known as an instrument constant. The stress term may be given in terms of dyne-cm, degrees of deflection, etc., and rate of shear term may be expressed in rpm, rps., and etc. In case of the Brookfield viscometer, model L.V.F., the scale reading may be equivalent to the stress term and the rpm would equal the rate of shear term. The constant K varies depending on the spindle number. The K values are given in Table One.

TABLE 1

CONSTANTS FOR EQUATION NO. 8

	Spindle Number			
	1	2	3	4
K	6	3	12	60

Review of Different Types of Fluid Flow

In the following section, short definitions of laminar and turbulent fluid flow are given. Laminar and turbulent fluid flow are important in relation to agitation and the carrying capacity of fluids.

Laminar Flow

In laminar flow in a liquid each layer travels parallel to the adjacent layers. The velocity of the layers are the same or slightly different and the particles in the fluid do not change layers.

Turbulent Flow

In this type of fluid flow, there are cross current velocities and there is a mixing of the fluid. The forming of eddies in the fluid is a characteristic of turbulent flow and their presence is resposible for the additional amount of energy loss.

Agitation and Carrying Capacity of Fluids

The greatest amount of agitation or mixing would occur in liquid where there is turbulent flow present because of the cross current velocities.

Little information was found on the carrying capacity of flowing liquids. The amount of particles that fluid will carry at a certain velocity depends on the size, density and shape of the particles. No information was available for liquid manure.

APPARATUS AND TESTING PROCEDURE

Physical Properties

Collection of Samples

Three liquid manure samples were collected by the farmers on different dairies in Michigan. The names and addresses of these dairies are as follows:

Case A - Virgil Pung, Ionia
Case B - Ross' Dairy, Marlette
Case C - Quandt's Dairy, Watertown

Throughout the remainder of this thesis the above three samples will be referred to as Case A, B, or C.

No set procedure was specified in the collection of the samples. Each farmer used a different method. Case A collected the sample by catching the drippings from the filler pipe as the holding tank was being emptied. This was accomplished just after the power to the pump was disengaged. Case B collected the sample of the liquid manure off the top of the holding tank after it was agitated for ten minutes. The tank was full. Case B had a type of agitation system that required agitation twice daily during the summer months and 4 or 5 times a day during the winter months. Cases A and C had the recirculation type of agitation systems. Case C had collected a number of samples for the dairy department and one of the two quart containers was given to the author for the study of physical properties. The samples were collected by taking a small sample from each load of liquid manure removed from the holding tank.

Notes on Bedding

Each farmer used different kinds and amounts of material for bedding. The bedding characteristics of each case were recorded. Case A used sawdust and bark shavings. This farmer used a sufficient amount of the bedding material and noticeable amounts were present in the sample. Case B also used sawdust for bedding but his supply had become depleted two months ago. There was no evidence of sawdust in the sample but there was some hay present. Case C used chopped straw for bedding. There was a noticeable amount of straw present in this sample.

Instruments Used to Measure Viscosity

A Brookfield viscometer, model L.V.F. was used as the instrument for measuring the viscosity of the liquid manure samples. This instrument measures the torque of the spindle at a predetermined speed. Speed is defined as the revolutions of the spindle per minute. The torque required for a full scale reading of the instrument is equivalent to 673 dyne-cm. The scale is graduated in one-half units from 0 to 100. The instrument is calibrated by the manufacturer and maintains an accuracy of one percent of full scale with guard on and in a container larger than 800 c.c. (see Figure 8). It is desirable to use the instrument near full scale in order to keep the error to a minimum. The range of viscosity reading at full scale is varied by using different spindles at different speeds.

The Brookfield viscometer, model L.V.F. has a range of four speeds; 6, 12, 30 and 60 rpm. It has four standard spindles, one cylinder, two disks and one straight shaft (see Figure 9). The viscosity values, in centipoise, are obtained by multiplying the scale reading by the factors given in Table Two.

TABLE 2

CONSTANTS TO MULTIPLY THE SCALE READING BY IN ORDER TO OBTAIN THE VISCOSITY IN CENTIPOISES

	SPINDLE NUMBER			
RPM	1	2	3	4
6	10	50	200	1000
12	5	25	100	500
30	2	10	40	200
60	1	5	20	100

The constants given with the viscometer (as in Table Two) are usually valid only for Newtonian fluids. When this constant is used for computing viscosity for a

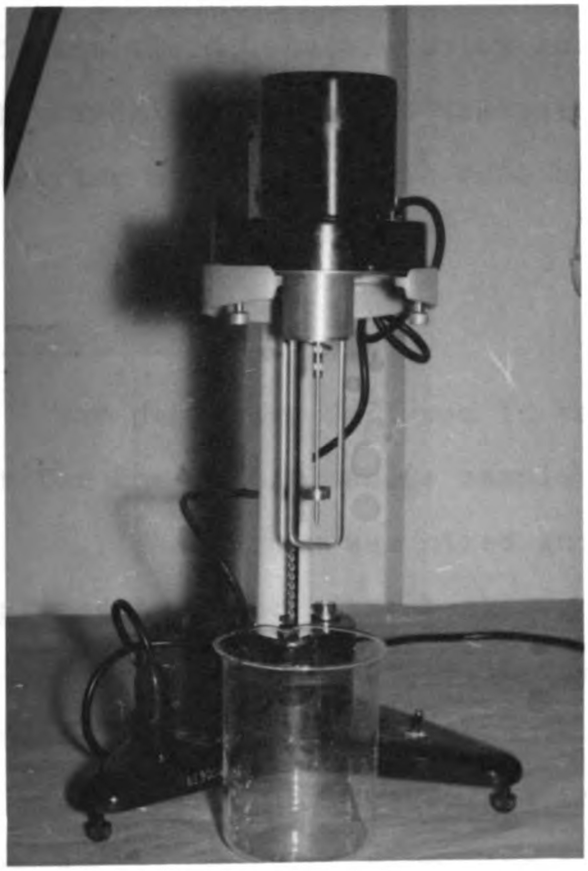


Fig. 8.--Shows the Brookfield viscometer with the guard installed, and the beaker used for the test.

Fig. 9.--Shows the spindles, number 4 through 1, from left to right.

non-Newtonian fluid, the viscosity should be referred to as apparent viscosity. Apparent viscosity is the ratio of the total shearing stress to total rate of shear at a given value.

Testing Procedure

The procedure followed in taking the viscosity readings for the liquid manure samples was as follows:

1. The sample was mixed and a portion of the sample placed in a one liter beaker.

2. The liquid manure in the beaker was mixed again and a viscosity reading taken. The viscometer spindle was removed from the beaker and the liquid manure mixed again and another viscosity reading was recorded. The procedure was followed until five readings were obtained.

3. Step 2 was repeated for each of the four speeds of the viscometer. The lowest number of spindle was used at all times in order to utilize the maximum amount of the scale on the viscometer.

4. Steps 2 and 3 were carried out and repeated with the liquid manure at the same moisture content as collected, and for four other varying amounts of water added to the sample. The amount of water added is indicated as a percentage of final volume (see Table Three).

TABLE 3

THE AMOUNTS OF WATER ADDED TO EACH SAMPLE

	% H_2O ADDED	% OF TOTAL VOL. AS COLLECTED
a.	0	100
b.	12.5	87.5
c.	25	75
d.	37.5	62.5
e.	50	50

Steps one through four were carried out for each case; A, B, and C. The temperatures of the liquid manure in the beaker were recorded as the tests were run. Also, general notes on the qualitative characteristics of the liquid manure and the material (bedding) in the liquid manure were recorded.

The final step of the test procedure was to determine the density and moisture content of the remaining portion of the liquid manure samples. This was accomplished in the biochemistry department laboratory under the supervision of Dr. E. J. Benne.

After the moisture contents of the original samples were determined, the moisture content (appendix A) was calculated for the different stages (part a, b, c, d and e of Table Three). This gives a common reference for the data of each liquid manure sample.

The average, standard deviation and the 95% confidence range of the viscosity readings recorded in step two, were calculated. The confidence range gives the limits which may be assumed to contain 95% of the data from any future tests. Also it gives an indication of the accuracy and reliability of the data. The calculations were done by using the t distribution test, with a program that was available for the digital computer. Some modifications were required on the program in order to adapt it to the data.

Agitation

Assumptions Made in the Design of Model Tanks

In order to apply the information to actual conditions, the tanks were models of a prototype tank of 40,000 gallons capacity. This tank would have usable space of about 34,000 gallons. The loss of usable volume in the tank is accounted for by the material left in the tank when it is emptied and some space near the top of the tank which cannot be used. The accumulation in the bottom is due to improper agitation and tank characteristics causing some material to settle. The tank of this size would have capacity to store the excrement from a 35 cow dairy unit for two months. The prototype tank would therefore be ten feet deep. The rectangular tank would be ten feet wide by

53.5 feet long and the square tank would be 23.1 feet on a side.

The reduction factor for length in the models was eight which resulted in the model tanks inside dimensions being as follows: The square tank was 15 1/8 inches deep and 34 5/8 inches square. The rectangular tank was 14 15/16 inches deep, 80 3/4 inches long and 15 1/16 inches wide.

Construction of Model Tanks

The bottoms for the model tanks were 20 gage sheet metal. One-fourth inch thick plexiglas was used for the sides (see Figure 10). Vertical corners were reinforced with an extra thickness of plexiglas and the sides were bolted together. A liquid cement was used in the corners and other areas to join the plexiglas. This made the seams waterproof and added strength as well. The edges of the sheet metal bottom were turned up and the plexiglas sides set inside. The sides were attached to the bottom and all joints were caulked. A steel frame constructed of 3/8 inch angles to fit around the top edges of the tank gave rigidity to the tank.

Pump and Nozzle Size

For the design of pump capacity, Froude modeling was used. The following equation was used, where Q is

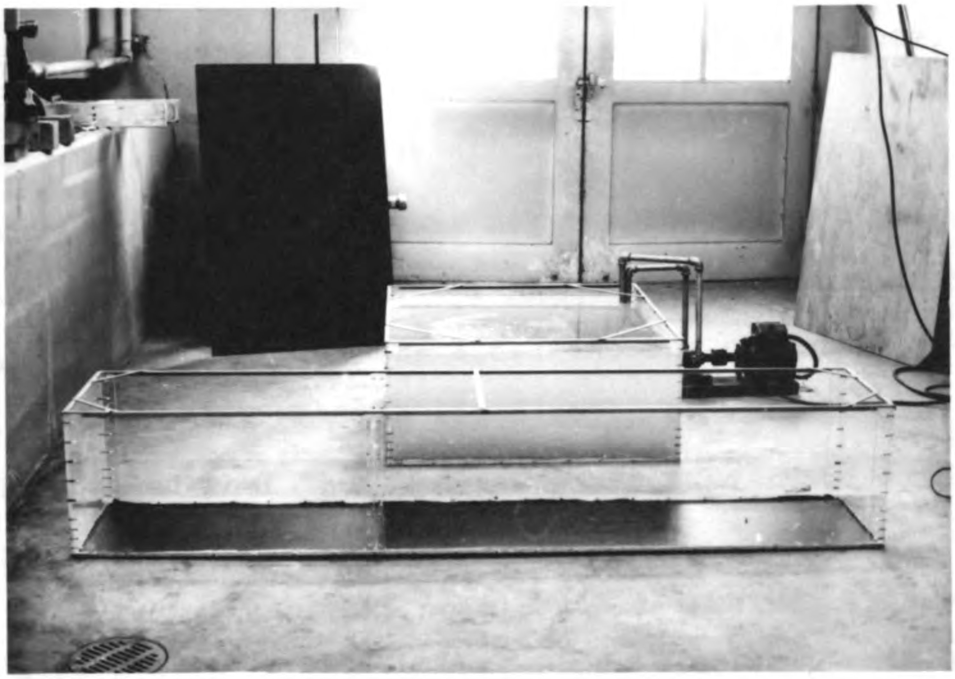


Fig. 10.--Model tanks built for the agitation test.

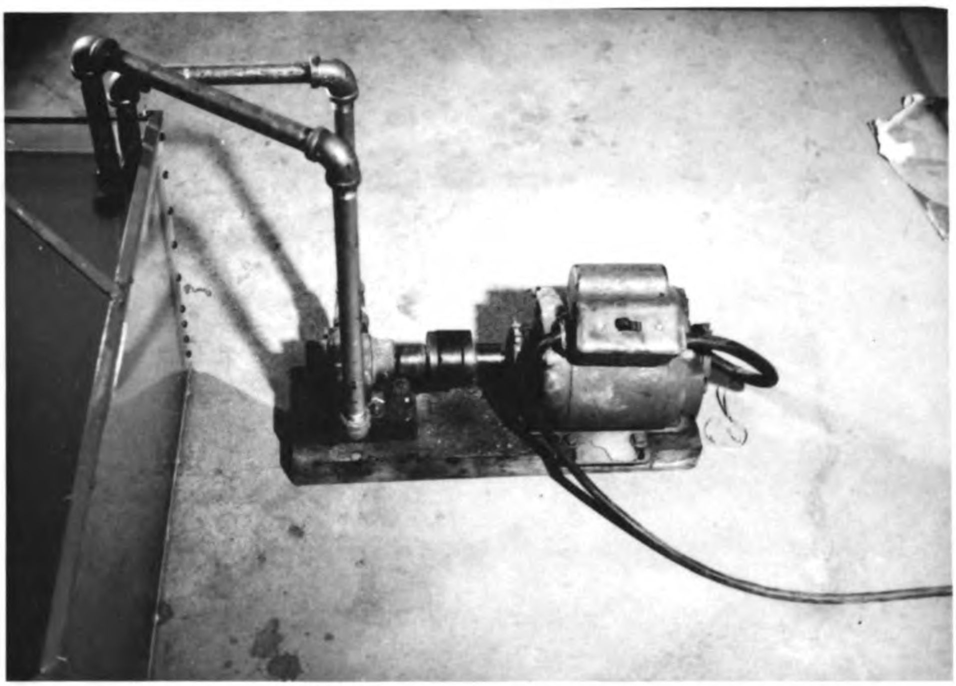


Fig. 11.--Small roller radial pump used in the agitation test.

equal to the output of the pump in gallons per minute.

$$Qm = Qp\left(\frac{Lm}{Lp}\right)^{5/2} \qquad (9)$$

In using equation (9), it was assumed that the output of the prototype was 1500 gallons per minute and that gravitational acceleration for the model and the prototype are the same. In carrying out the calculation of equation (9), it was determined that the Qm desired was equal to 8.32 gallons per minute.

The size of the nozzle was determined by assuming that nozzle size of the prototype was five inches in diameter. Dividing this by the scale factor eight indicated a model nozzle of 0.625 inches.

A small radial pump with a small electric motor was used (see Figure 11). A primary check showed that the pump capacity was about eight gallons per minute when a one-half inch pipe (inside diameter equal to .622 inches) was used for a nozzle.

Thickening Agent

To meet the model similarity requirements it was necessary to use some thickening compounds that could be added to water, which would remain reasonable clear. It was desired to regulate viscosity of the liquid in order to satisfy Reynold's model number.

A number of samples of a cellulose product were acquired for testing and a material called methocel Hg, Grade Standard, type 65 Hg, 4000 cps, manufactured by Dow

Chemical Co., was best suited for the purpose.

It was necessary to heat the water to near boiling point and then agitate it as the thickening compound is being added. The mixture should be allowed to cool to normal room temperature before the viscosity is checked. The viscosity is temperature dependent. Water may be added and mixed into the cooled solution to lower the viscosity.

Photograph Technique

A study of flow lines by the use of models and model analysis was done in an attempt to accomplish objective two. In the study of the flow lines, it was desirable to maintain a record. This was accomplished by developing a photographic technique. Aluminum powder was put in the liquid so that flow lines could be traced and photographed.

A 35 mm camera with panatomic-x film was used for the photographic work. Kodabromide F5 print paper was used to acquire the maximum contrast. A lens speed of 1/4 second gave the best results for observing the flow lines.

It was also desirable that only a narrow vertical strip of the fluid flow lines appear on the film to eliminate a complete blurr caused by all the aluminum powder in the solution. This was accomplished by providing a narrow slit of light through the liquid so only the aluminum in this slit would be photographed. A box with a slit 1/2 inch wide and 15 inches high was placed over a 750 watt photospot lamp. A stand constructed of two 5 inch boards about 18" long placed 1/2" apart was placed between the light source and model tank. This helped to keep the narrow light ray from dispersing.

The bottom of the tank was painted flat black and a piece of sheet metal painted black was placed in the tank on the opposite side from where the photographs were taken. The photographs were taken at night which helped to keep reflections to a minimum.

Testing Procedure

Tests were run from two positions in the square tank and at three different positions in the rectangular tank (see Figure 12) for each liquid. Tests were run with water and two other liquids of different viscosities. For each test, photographs were taken of each side of the tank and the top. Where the clearness of the fluid permitted, photographs were also taken with the light strip at varying distances from the side. As the photographs were taken, a sketch was made so a record could be maintained as to the direction of movement of flow lines. The movement on the film was a white straight line and could not indicate direction.

Series of tests were also run with the discharge nozzle at varying depths. Tests were run with the nozzle at liquid level and at four other depths. These tests were run to try to study and determine the desirable depth for the discharge nozzle for most efficient agitation.

RESULTS

Physical Properties

Description and Characteristics of Each Sample

The liquid manure sample from Case A, which used sawdust and bark shavings for bedding, appeared to be quite thick. The sample had the flow characteristics that would be represented by a Bingham model. It requires a certain amount of shear stress before the fluid would flow. The sample appeared to be quite homogeneous in that the sawdust and bark shavings were evenly distributed. The bedding material did not tend to settle to the bottom or float to the top.

Case B, which had hay present in the sample, appeared to flow more like a liquid than Case A. However, the hay material tended to settle to the bottom in a short period of time after the sample was agitated. It was also noted that the hay tended to matt up in a ball during agitation.

The liquid manure sample with straw present (Case C) was very thin. The bedding material settled out as in Case B, but the straw did not tend to matt up in a ball as the sample was agitated.

Density and Moisture Content of the Samples

The density and moisture content of each liquid manure sample is given in Table Four.

TABLE 4

DENSITY AND MOISTURE CONTENT

Case	Density lbs/gal	Moisture Content (% w.B.)
A.	8.27	87.93
B.	8.25	90.17
C.	8.33	92.71

The average density of the liquid manure samples was 2.8% less than the average in the survey indicated in the literature review. The average moisture content was 1.4% less. Considering the type of material and methods used in the collection of the samples the density and moisture content of the samples were very close to the surveys.

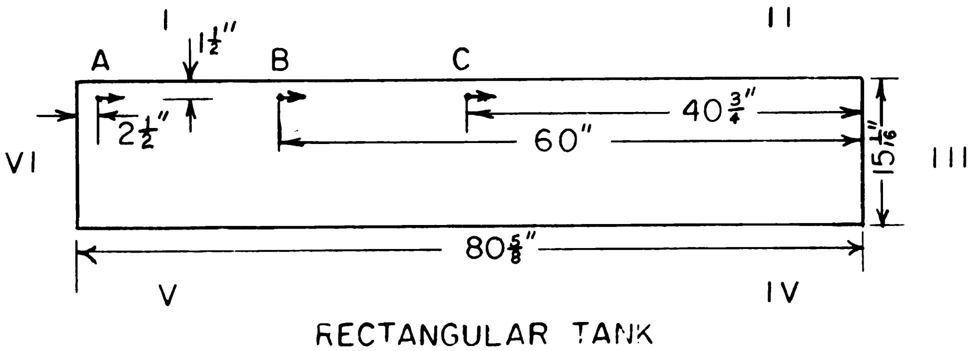
Viscosity

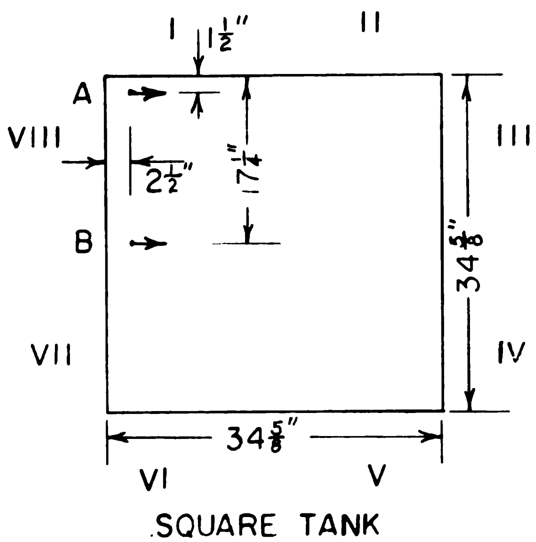
The viscosity and other data related to viscosity or calculated as the result of the viscosity are recorded in Appendix A.

Figures 13 through 15 indicate that there is a linear logarithmic relationship between the apparent viscosity and the speed of the spindle of the viscometer. The 95% confidence limits for each average viscosity reading were also plotted. If in theory, there is a linear relationship and in reality a straight line falls within the 95% confidence limits, then the straight line is justified. The linear straight line fell within the limits in all cases except two. This is good in that the linear logarithmic relationship between the viscosity and spindle speed is valid and also indicates that the viscosity data are reasonably accurate. The curves were drawn in graphically to illustrate the different relationships between the variables.

On these chart lines of nearly the same moisture content fall within the same region on the graphs and with similar slopes. The difference may be due in part to the different types of material in suspension. It is also noted that the slope of the curves for each case becomes more positive as the moisture content of the sample increases. This indicates that the viscosity becomes more of a constant with respect to the speed of the spindle of the measuring instrument as the moisture content of the sample increases.

The apparent viscosity was plotted against the moisture content of the samples with a semi-log scale (see Figures 16 through 19). Data from the three cases were plotted with the speed of the spindle on the viscometer held





Capital Letters - Position of Pump Nozzle
Roman Numerals - Position of the Camera (view of the picture)

Fig. 12.--Position of pump nozzle and camera (℄ of nozzle about 1 1/4" below the surface of liquid).

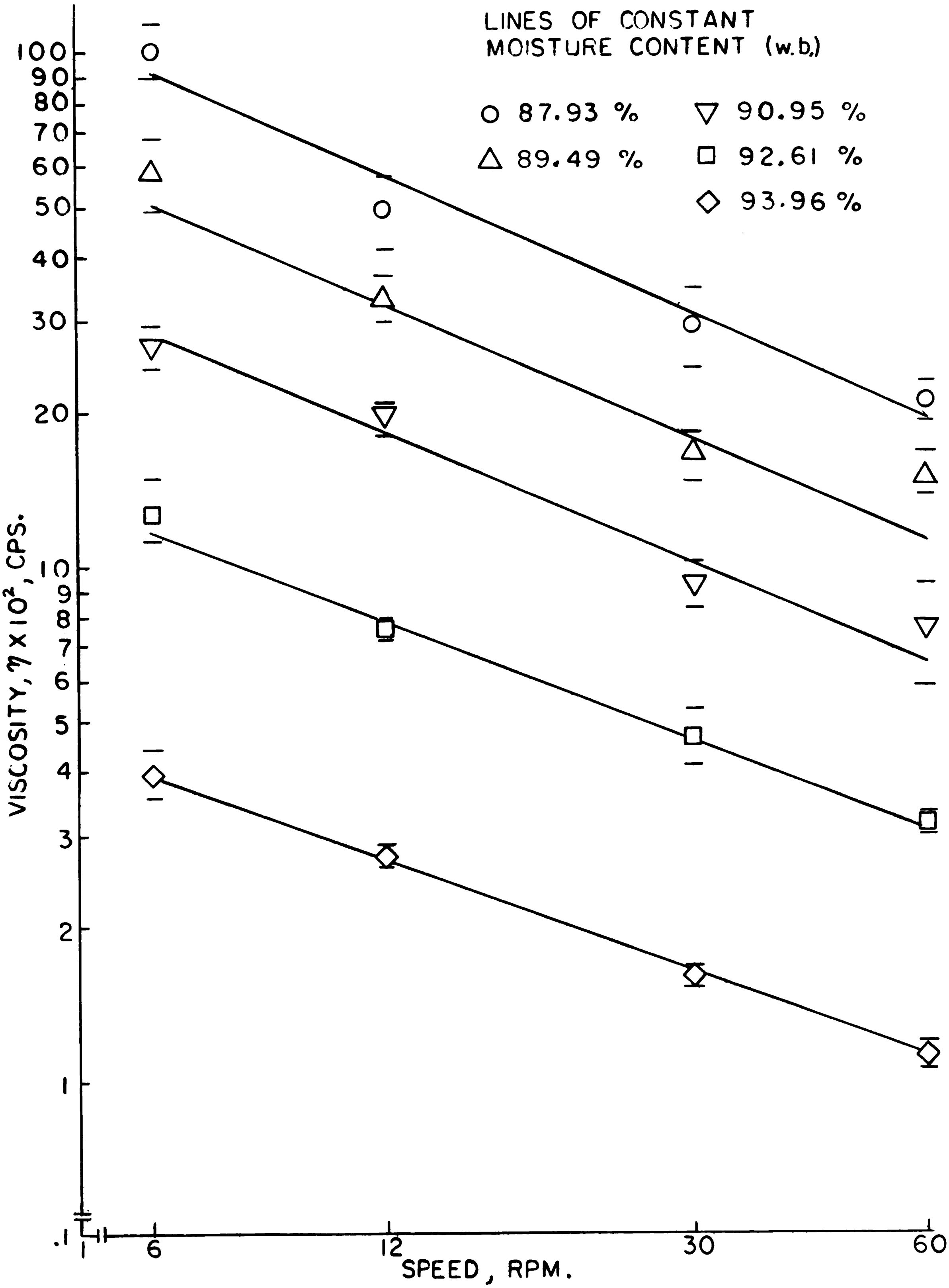


Fig. 13.--Viscosity vs. spindle speed of the viscometer for Case A.

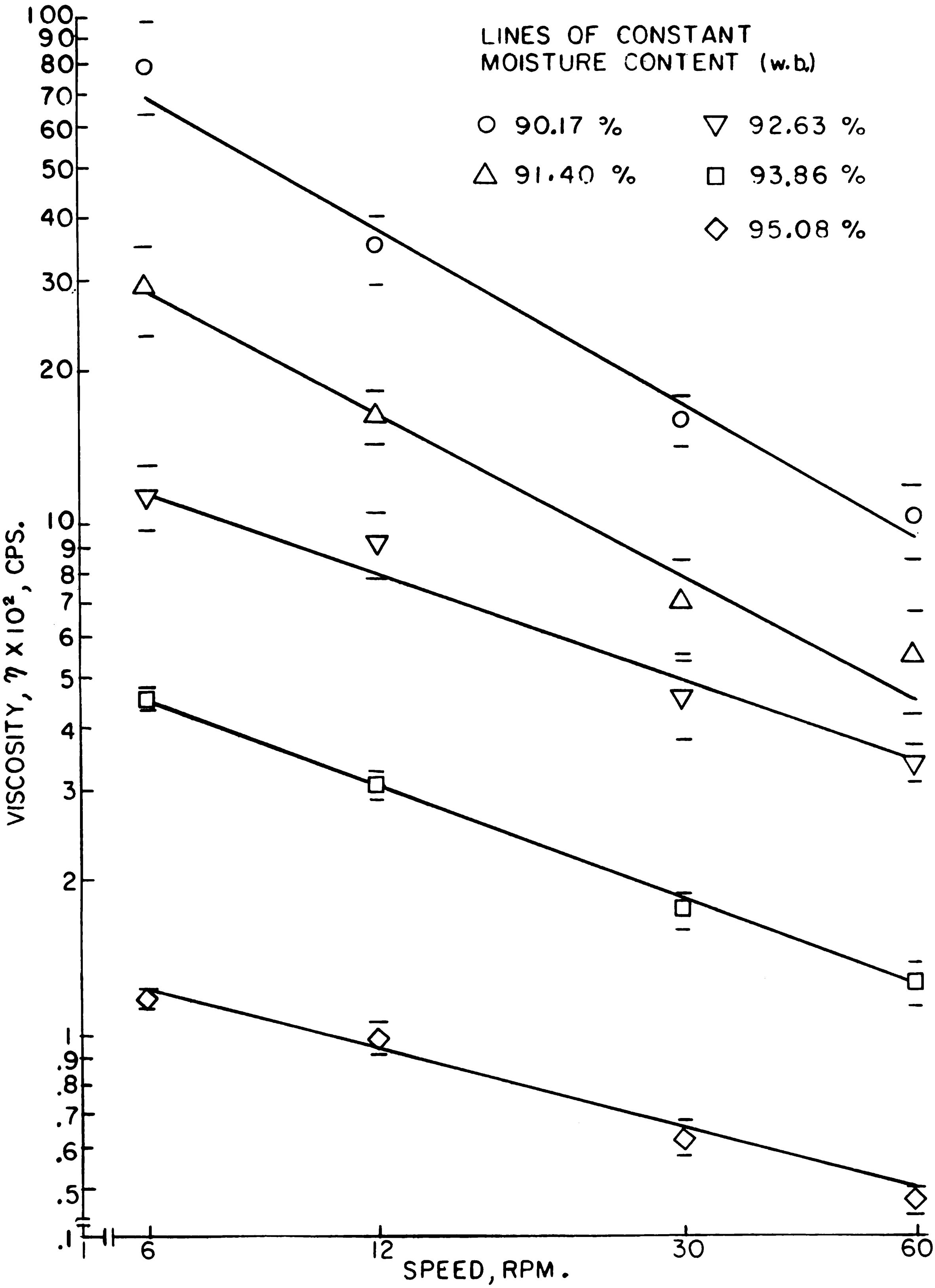


Fig. 14.--Viscosity vs. spindle speed of the viscometer for Case B.

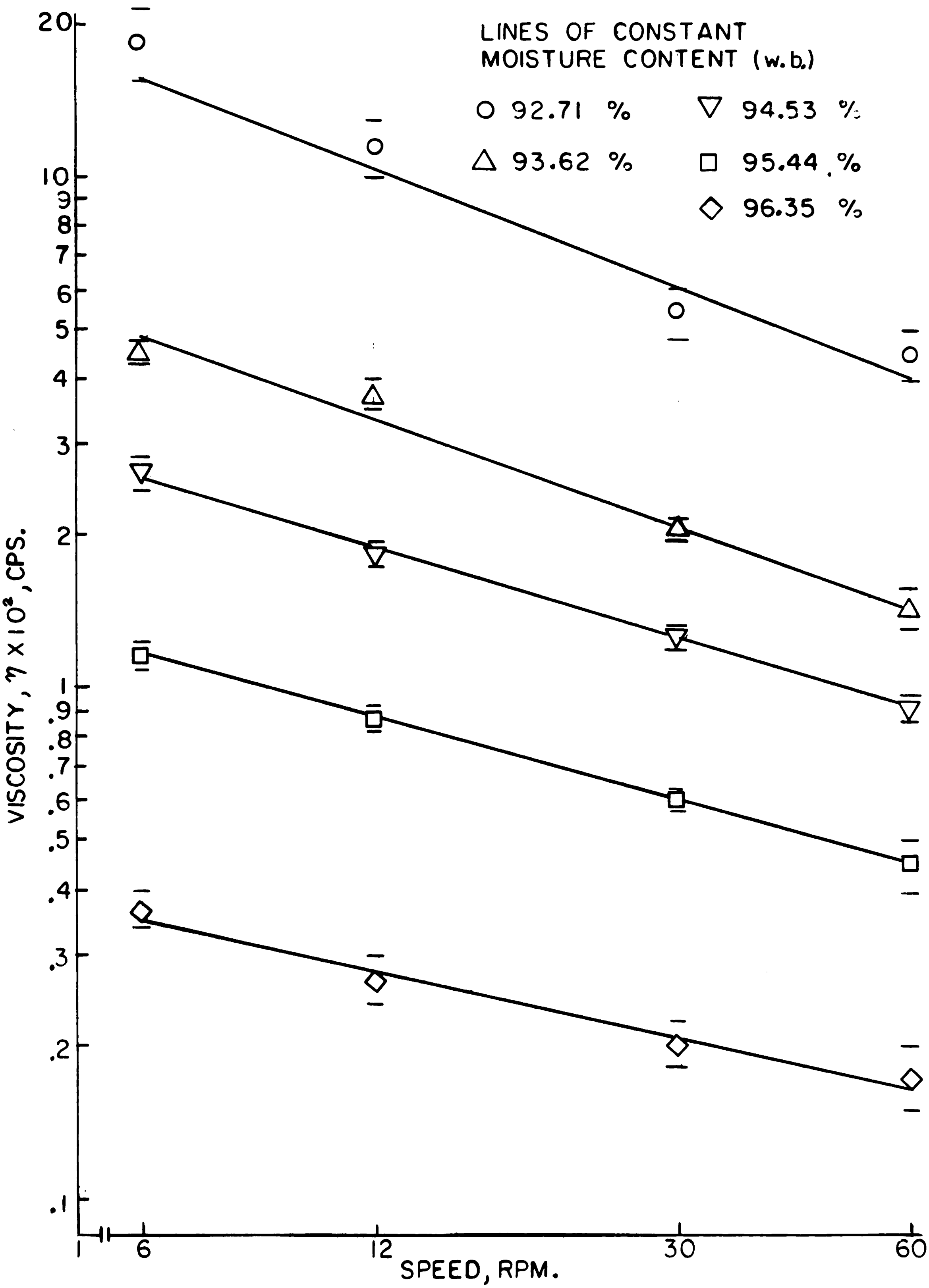


Fig. 15.--Viscosity vs. spindle speed of the viscometer for Case C.

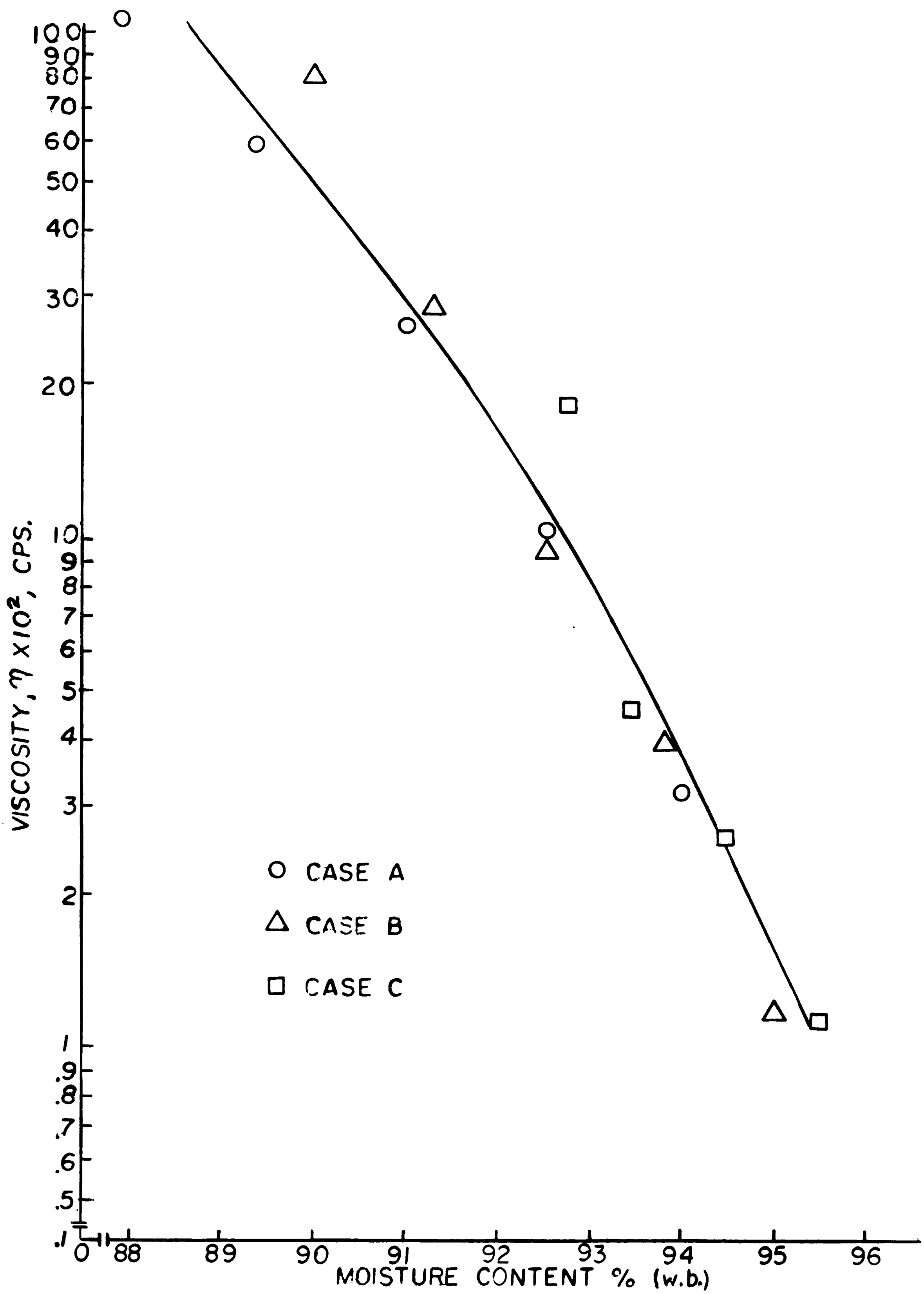


Fig. 16.--Viscosity vs. moisture content of liquid manure, with a constant spindle speed of 6 R.P.M.

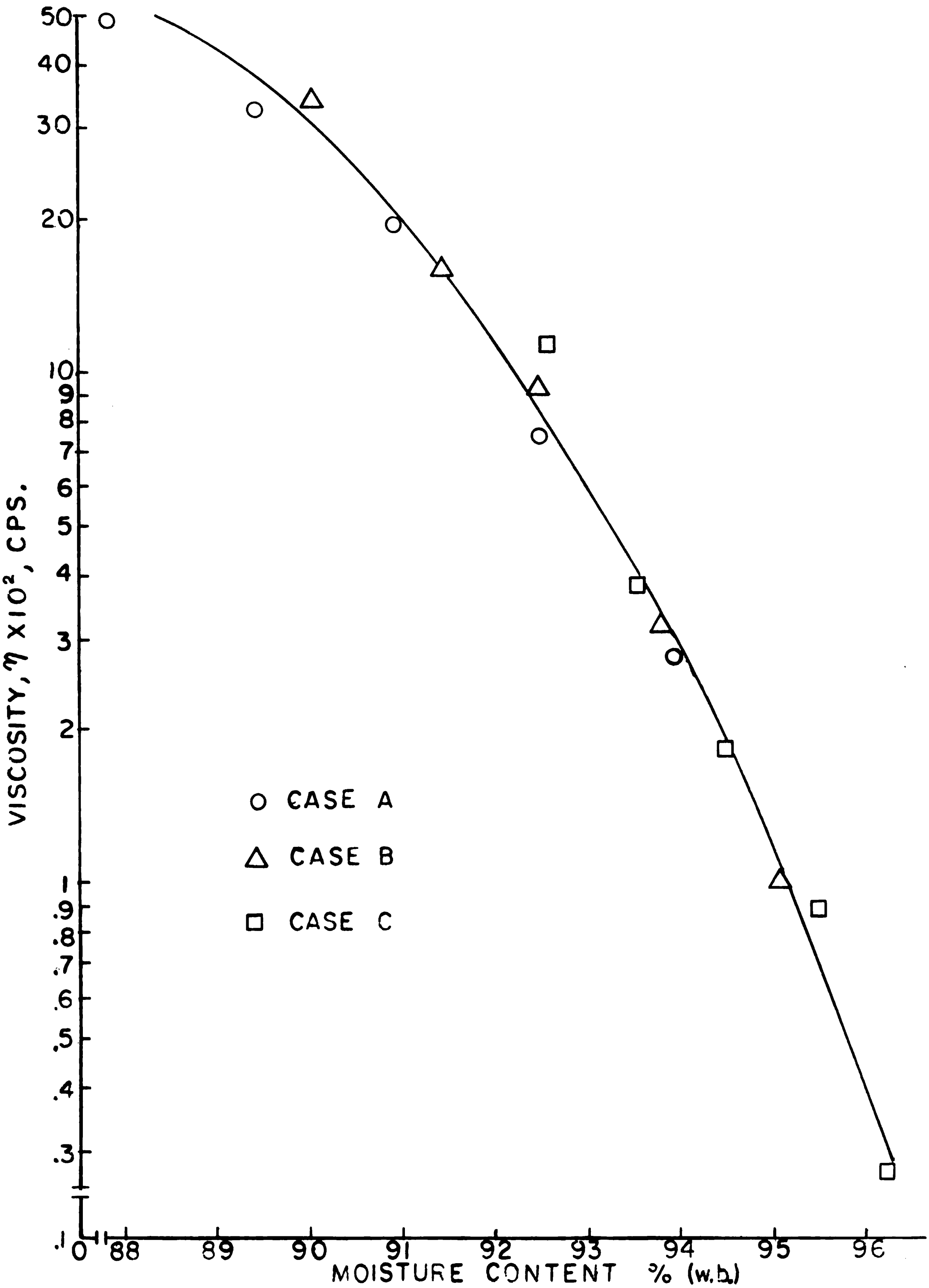


Fig. 17.--Viscosity vs. moisture content of liquid manure, with a constant spindle speed of 12 R.P.M.

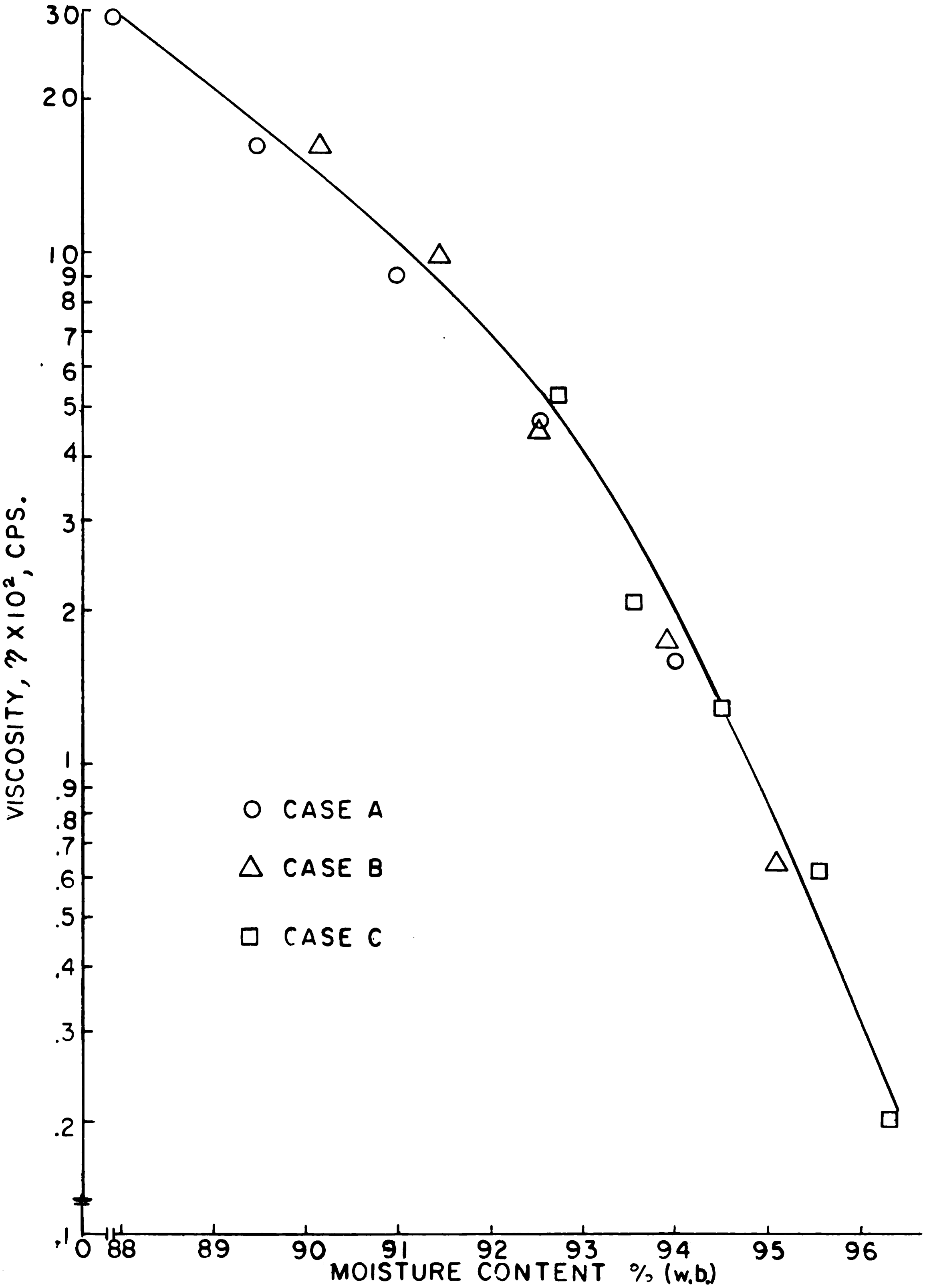


Fig. 18.--Viscosity vs. moisture content of liquid manure, with a constant spindle speed of 30 R.P.M.

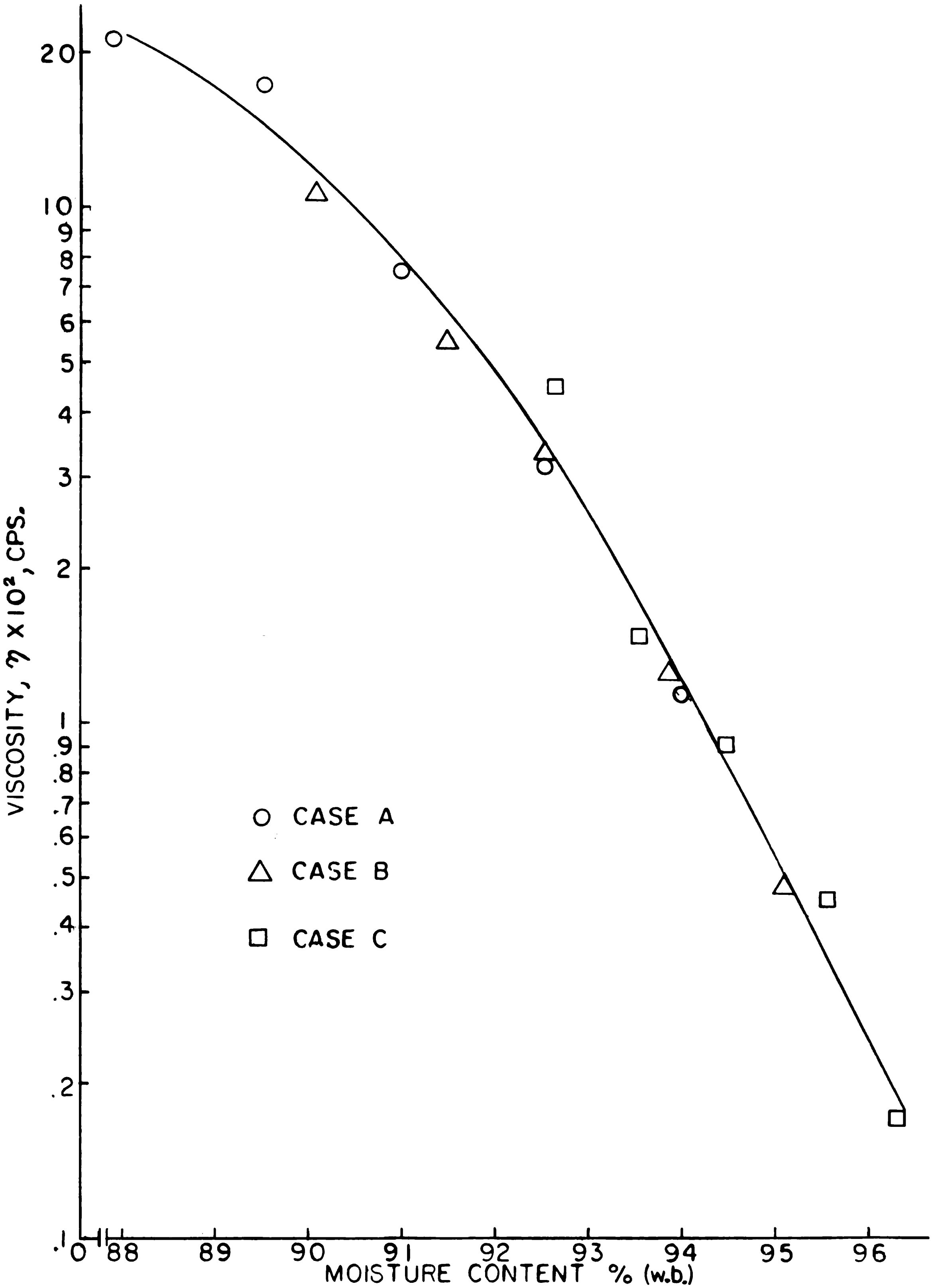


Fig. 19.--Viscosity vs. moisture content of liquid manure, with a constant spindle speed of 60 R.P.M.

at constant. The data approximates a smooth curve which indicates that the viscosity of the liquid manure samples was primarily dependent on the moisture content.

The theoretical considerations indicated that the rate of shear, $\frac{d\gamma}{dt}$, was equal to a function of the shear stress, τ. It followed the relationship $\frac{d\gamma}{dt} = B\tau^n$ where B and n are constants. N is the slope of the curve which indicates the type of fluid. (Speed of the viscometer represents the rate of shear while the scale reading represents the shear stress.) The rate of shear term $\left(\frac{d\gamma}{dt}\right)$ was plotted against the shear stress term (τ), with a constant moisture content, on the log-log scale.

Figures 20, 21 and 22 indicate that the relationship $\frac{d\gamma}{dt} = B\tau^n$ is valid for the liquid manure samples. The value of constant n was evaluated for each curve. Constant B was not determined because it is dependent on which spindle was used during the tests.

The n value, larger than one, indicates that the liquid manure closely represents a pseudoplastic fluid. Graphs (Figures 20, 21 and 22) show that the n values decrease toward one as the moisture content of the liquid manure increases. This indicates that the liquid manure becomes more Newtonian in nature as the moisture content approaches 100%. This can be verified by observing graph Figure 23, where the slope, n, is plotted against the moisture content of the sample.

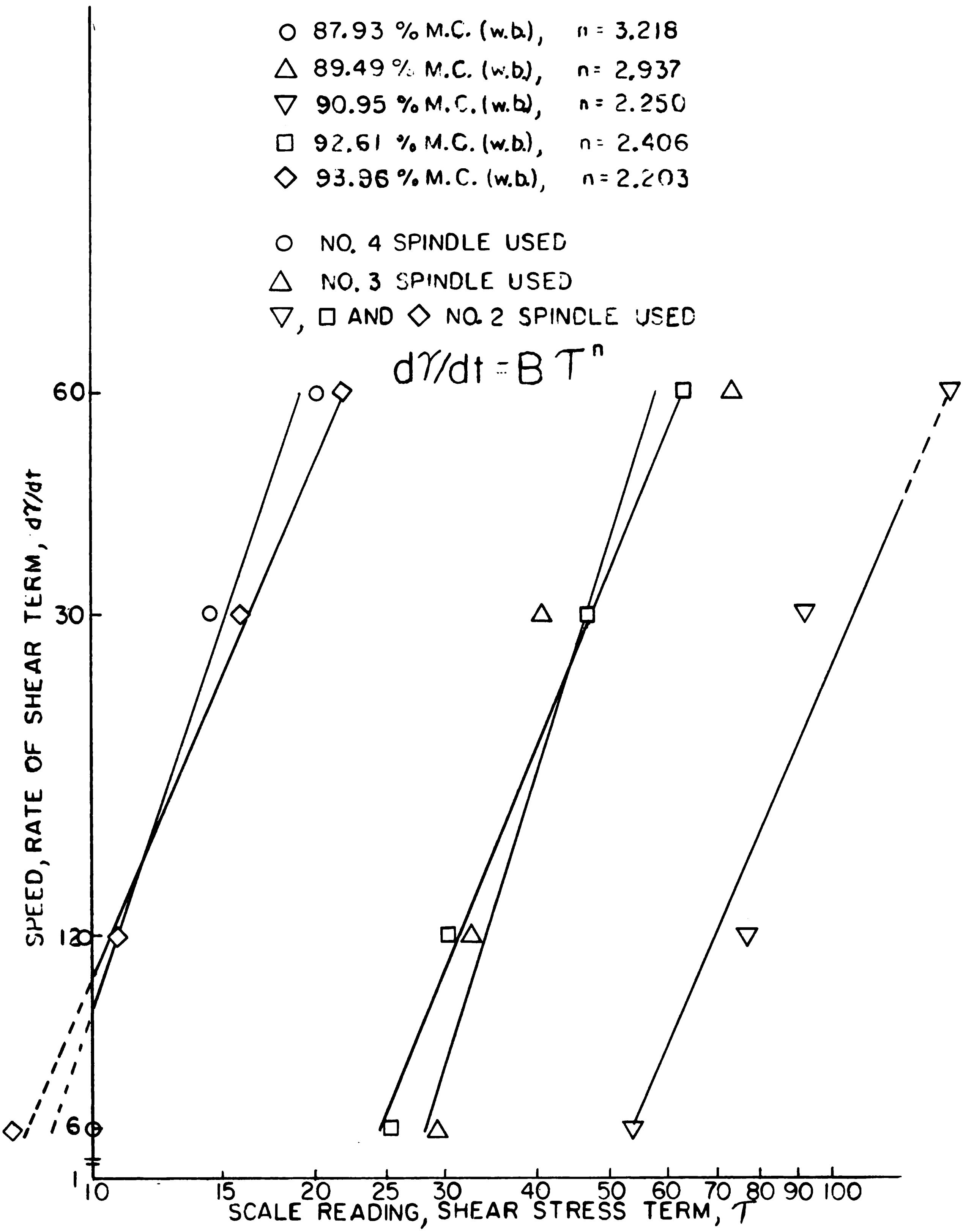


Fig. 20.--Rate of shear vs. shear stress for Case A.

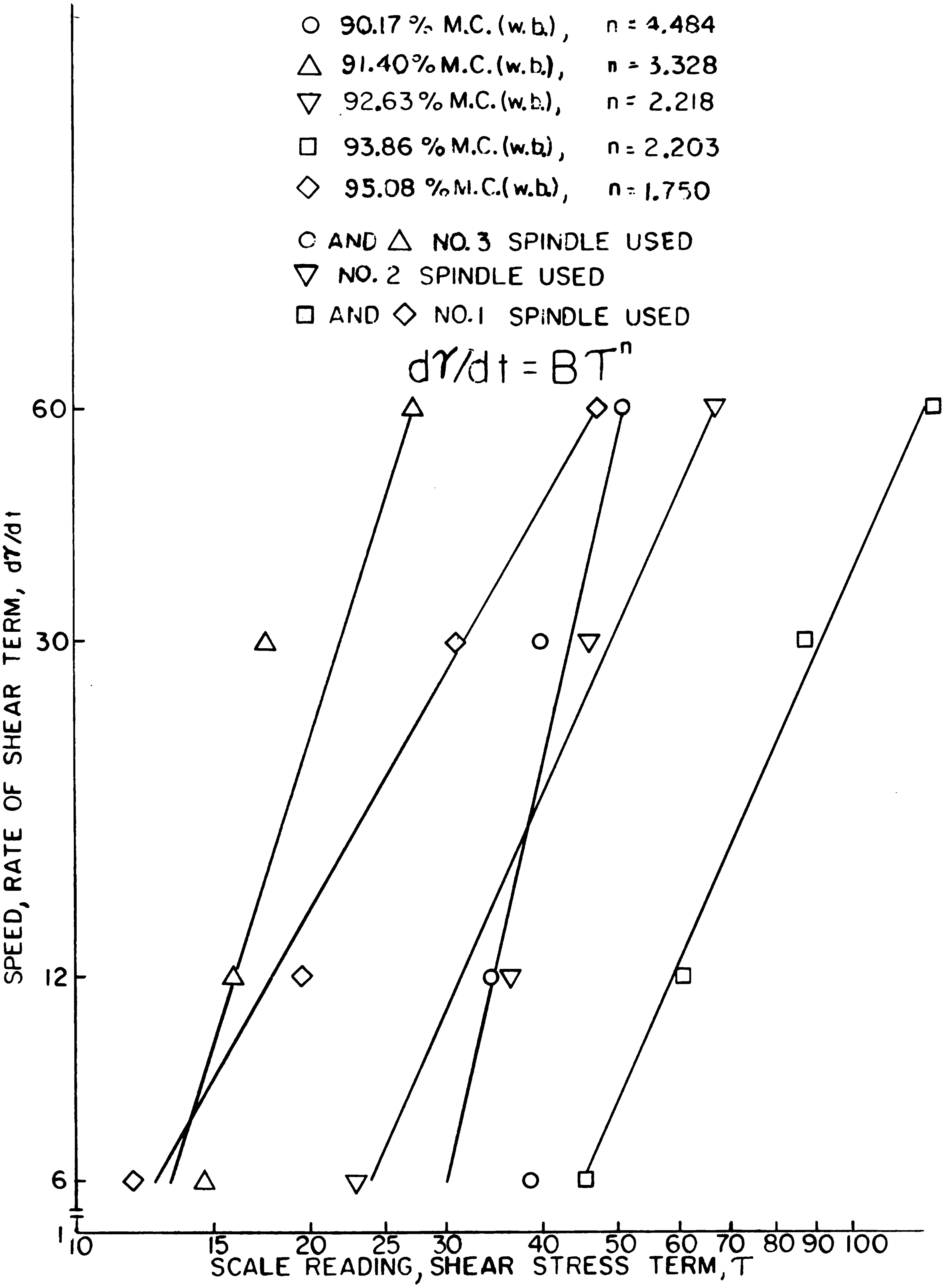


Fig. 21.--Rate of shear vs. shear stress for Case B.

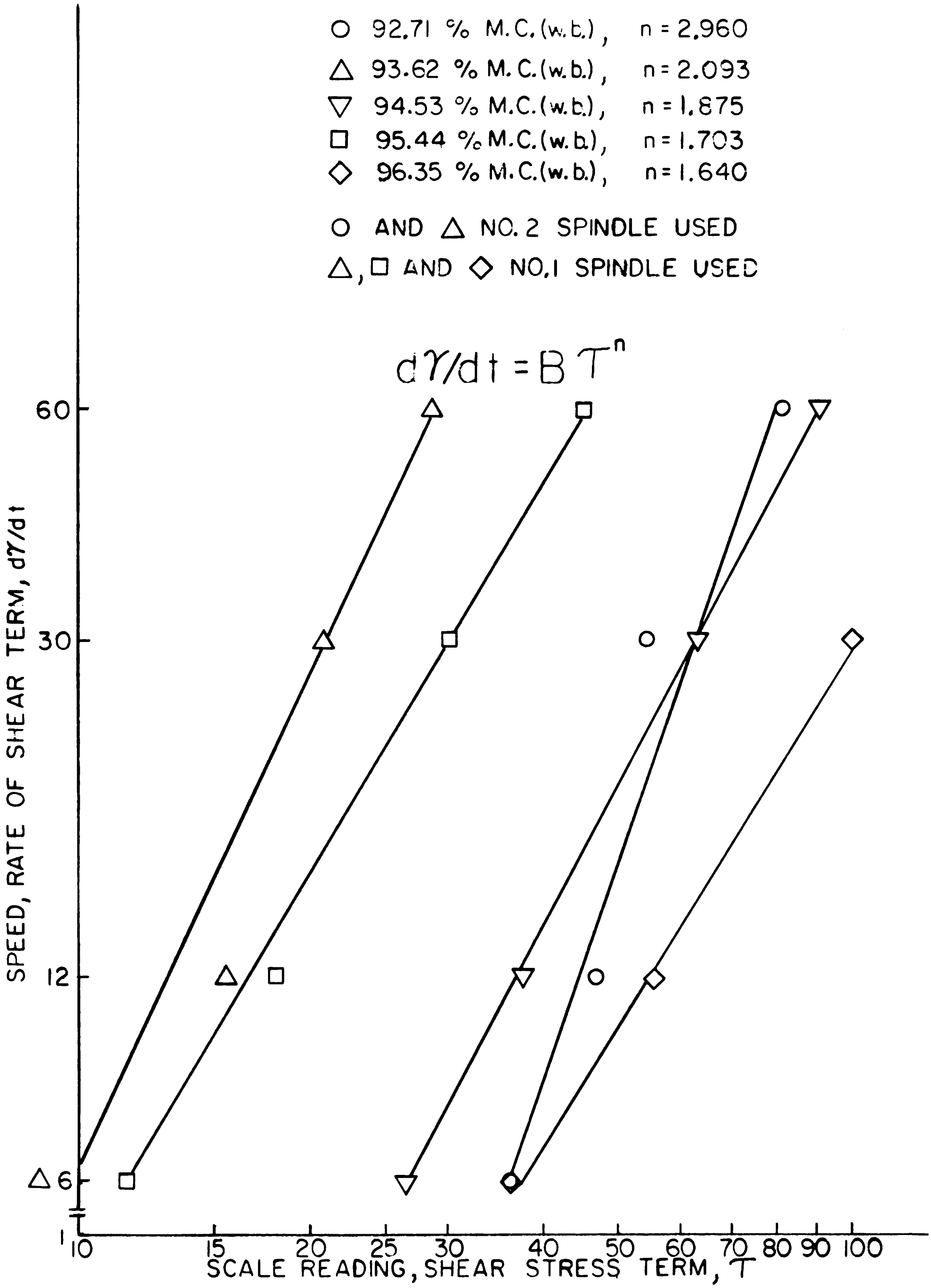


Fig. 22.--Rate of shear vs. shear stress for Case C.

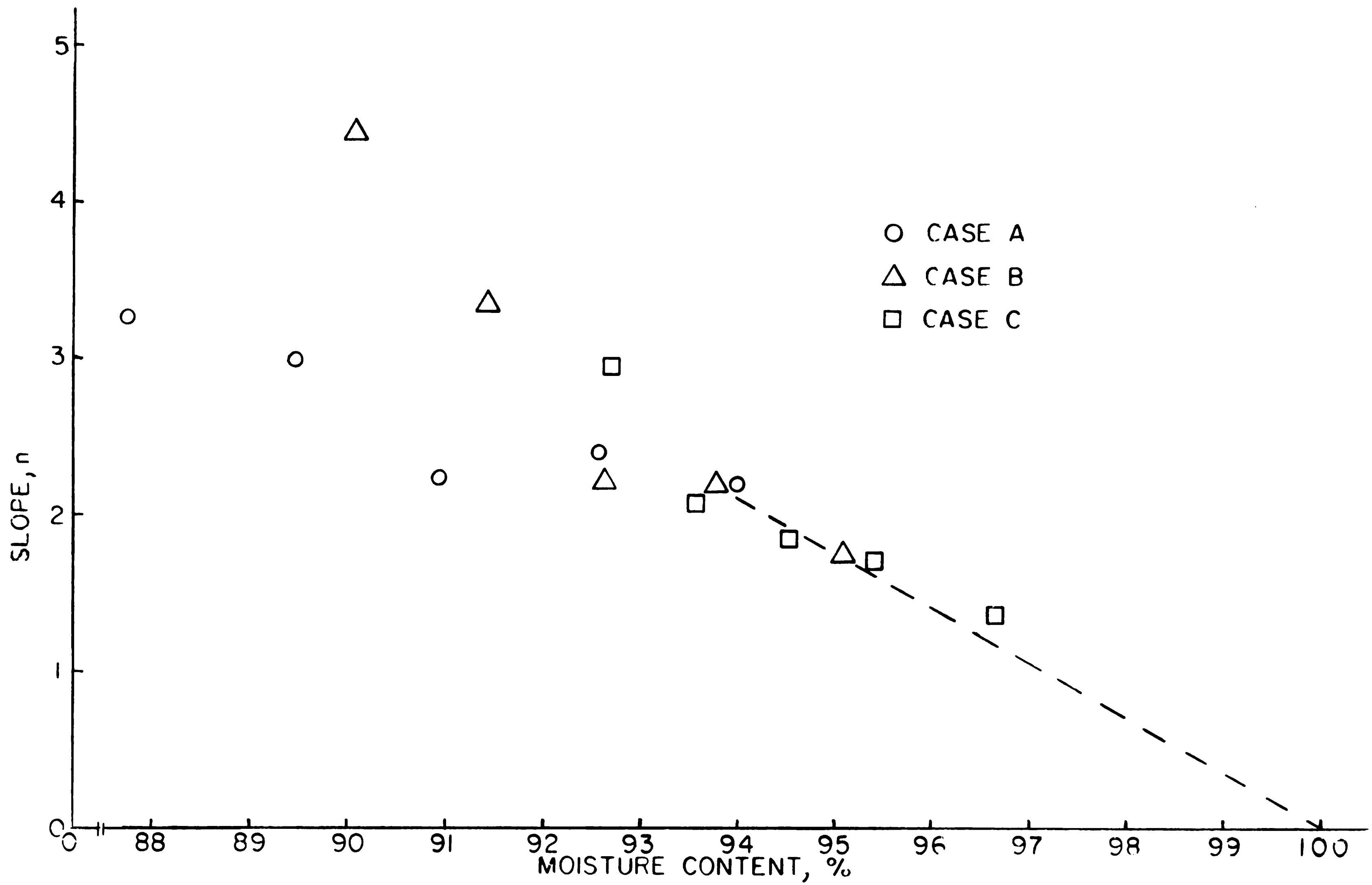


Fig. 23.--Slope, n, (from Figs. 20, 21, and 22) vs. moisture content of liquid manure.

The wide variation of points on graph Figure 23 indicates that it is difficult to obtain accurate data below the 93% moisture content level.

Agitation

Viscosity

In part one of this chapter, it was shown that the viscosity of liquid manure is pseudoplastic. This makes it difficult to determine a value for the viscosity of the liquid manure under any known conditions. The viscosity varies depending on the shear rate.

From data obtained on physical properties of liquid manure, a range of viscosity was determined. For the model analysis, three different viscosities were selected, one centipoise (water), 1500 centipoises and 3000 centipoises. These three included a major portion of the range of viscosities found in the actual samples.

In relating viscosity of the prototype to the model, as indicated in the chapter on theoretical considerations, the Reynolds number was used. Reynolds number of the prototype is equal to the Reynolds number of the model (Rep = Rem). This is equivalent to the following formula.

$$\frac{Qp}{Lp}\,\frac{\rho p}{\mu p} = \frac{Qm}{Lm}\,\frac{\rho m}{\mu m} \qquad (10)$$

The model viscosity (μm) can be determined by rearranging equation (10), giving

$$\mu m = \frac{Qm \ \rho m \ \mu p \ Lp}{Lm \ \rho p \ Qp} \tag{11}$$

In part one, it was shown that the density of liquid manure was close to that of water, therefore the ratio of ρm to ρp is approximately one. The scale ratio $\left(\frac{Lp}{Lm}\right)$ is equal to eight. Assuming that the capacity of a prototype pump is 1500 gal/minute and using the desired capacity of the model pump of 8.32 gal/minute (determined in chapter on testing procedure and apparatus), equation (11) reduces to

$$\mu m = \frac{8.32}{1500} \cdot 8 \cdot \mu p \tag{12}$$

Using equation (12), the desired viscosity of the model which would be equivalent to 1500 cps. and 3000 cps of the prototype is 66.6 cps and 133.2 cps, respectively.

The viscosity of the liquid used for each test in model tanks, along with the model pump output and equivalent viscosities for the prototype are recorded in Table Five. The final equivalent viscosities of the prototype are significantly close to the desired viscosities. The differences are due to some variation of the output of the pump and to changes in the viscosity of model liquid. The viscosity of the model liquid is temperature dependent.

TABLE 5

EQUIVALENT VISCOSITY OF THE PROTOTYPE

Run No.	Pump Output	Vis. of Model (cps)	Equiv. Vis. of Prot. (cps)
		Square Tank	
1	9.1	1	20.6
2	8.8	*68.3	1460
3	8.6	144	3140
		Rectangular Tank	
1	8.7	1	21.6
2	8.2	62.5	1440
3	8.6	157	3400

*Average of two runs on same liquid.

The author feels that the three model viscosities represent three different cases of liquid manure at different moisture contents. The lower viscosity representing liquid manure of about 97% moisture content, middle viscosity about 91% manure and the higher viscosity representing manure at a moisture content of about 89%.

Study of Flow Lines

For proper mixing of the liquid, the discharge nozzle of the pump must be directed toward a wall, and close enough so that sufficient energy remains in the flow streams to cause hydraulic action as the liquid comes in contact with the wall. The hydraulic action will cause agitation. It is theorized that if enough energy is in the liquid as it hits the wall to produce vertical flow lines and some eddies, then there is enough energy to cause agitation by the hydraulic action. If the flow lines are short and have no sudden change in direction as the liquid approaches the wall, insufficient agitation will result.

The theories and ideas from the preceding paragraph are used in the evaluation of the photographs throughout the remainder of this thesis. If the flow lines (white streaks) are long and have vertical movement in the corner, it is assumed that there is sufficient movement for agitation. It is assumed that there is insufficient action for agitation if the lines are short (or just dots) with very little vertical movement.

There appears to be sufficient hydraulic action for agitation with the pump in positions B and C of the rectangular tank (see Figure 12) using the liquid of the three model viscosity ranges (Figures 24 and 25). There is sufficient agitation with the pump positioned at A for the lower two viscosity ranges, but for the higher viscosity, liquid movement is insufficient for agitation even though there is still some movement of fluid (Figures 26 and 27). Figures 28 through 31 show the fluid movement from view no. IV (see Figure 12). The long white streaks show that

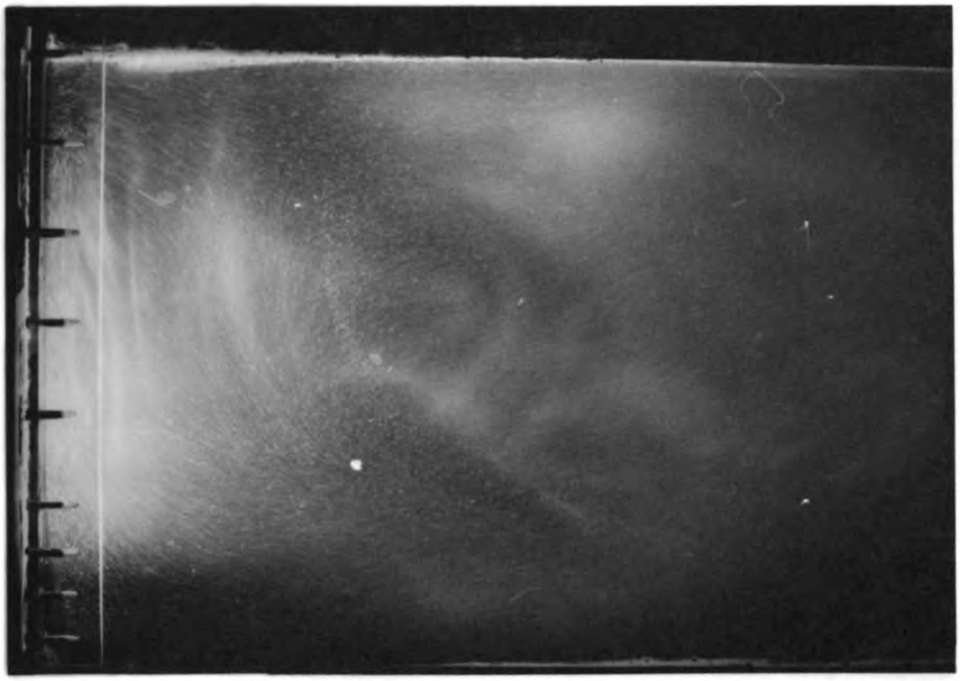


Fig. 24.--Flow lines in the rectangular tank. Viscosity of liquid is 157 cps. (Nozzle position B, view II, Ref. Fig. 12)

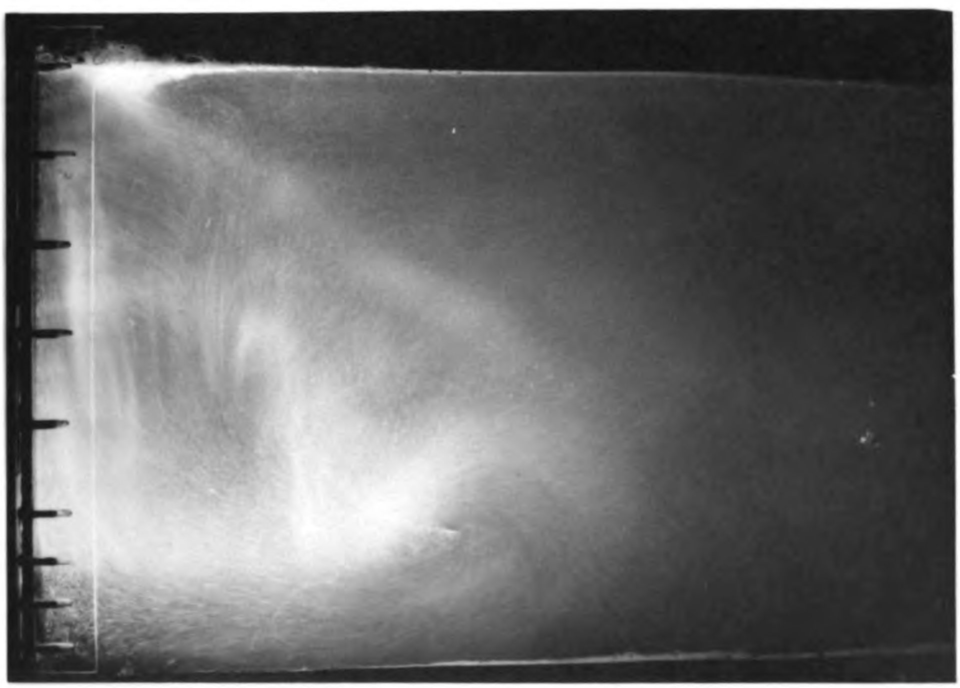


Fig. 25.--Flow lines in the rectangular tank. Viscosity of liquid is 157 cps. (Nozzle position C, view II, Ref. Fig. 12)

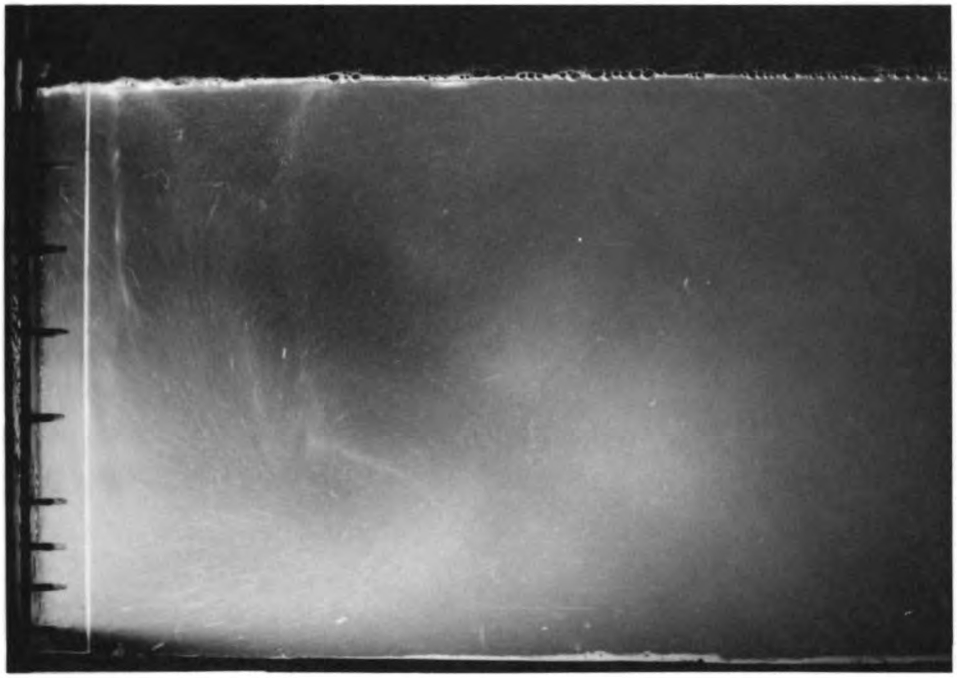


Fig. 26.--Flow lines in the rectangular tank. Viscosity of liquid is 62.5 cps. (Nozzle position A, view II, Ref. Fig. 12)

Fig. 27.--Flow lines in the rectangular tank. Viscosity of liquid is 157 cps. (Nozzle position A, view II, Ref. Fig. 12)

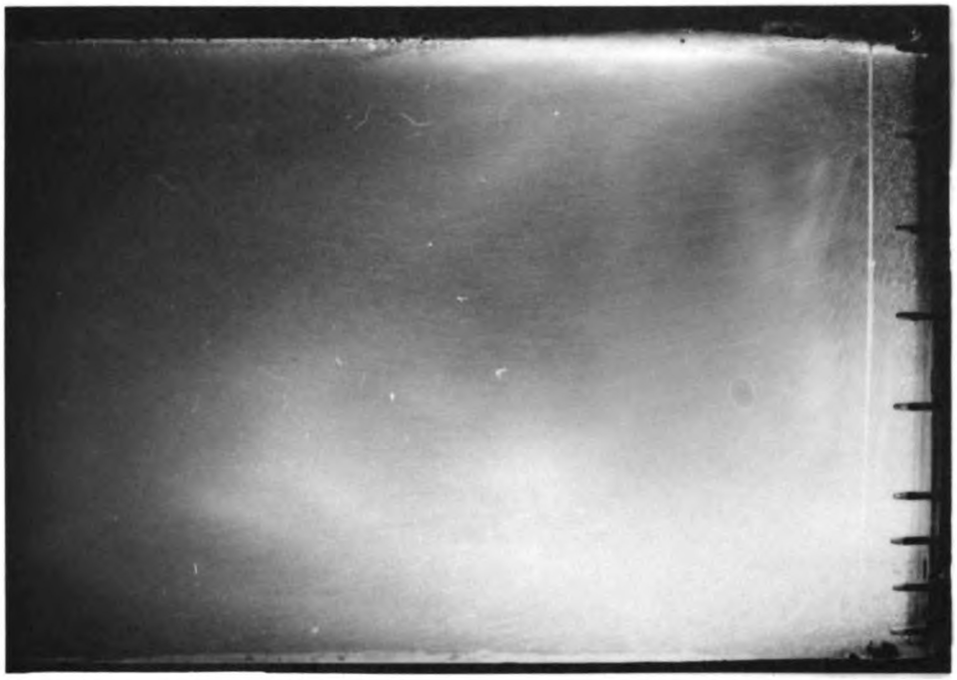


Fig. 28.--Flow lines in the rectangular tank. Viscosity of liquid is 157 cps. (Nozzle position C, view IV, Ref. Fig. 12)

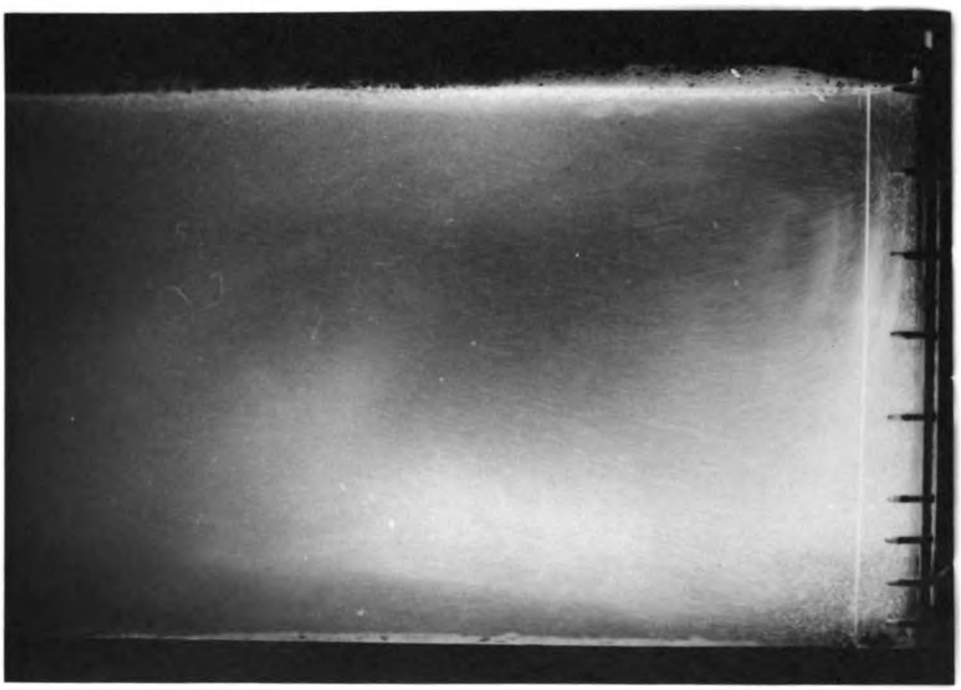


Fig. 29.--Flow lines in the rectangular tank. Viscosity of liquid is 157 cps. (Nozzle position B, view IV, Ref. Fig. 12)

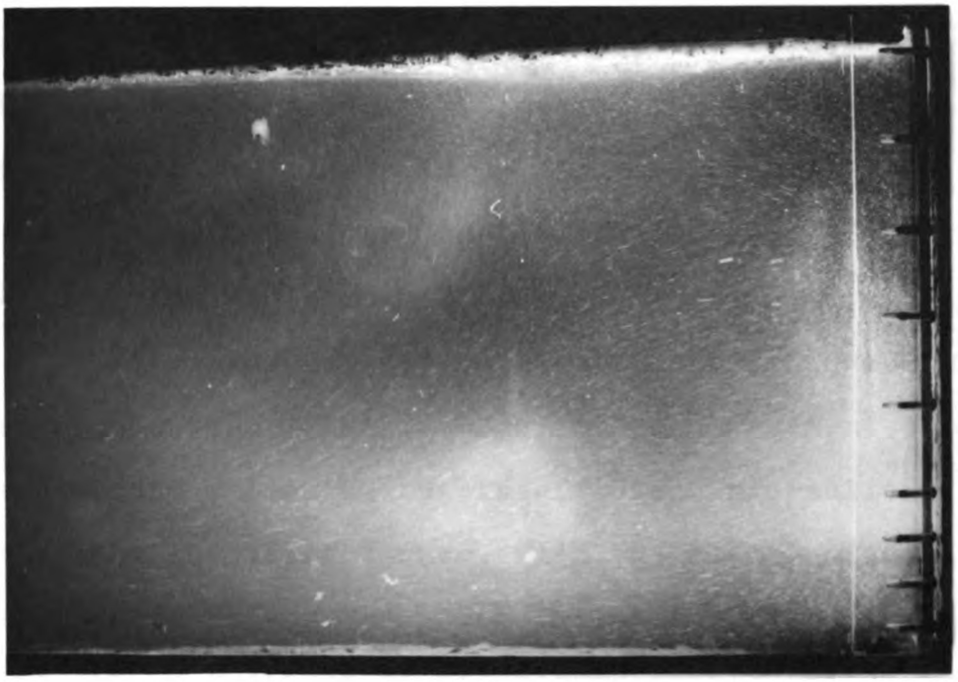


Fig. 30.--Flow lines in the rectangular tank. Viscosity of liquid is 157 cps. (Nozzle position A, view IV, Ref. Fig. 12)

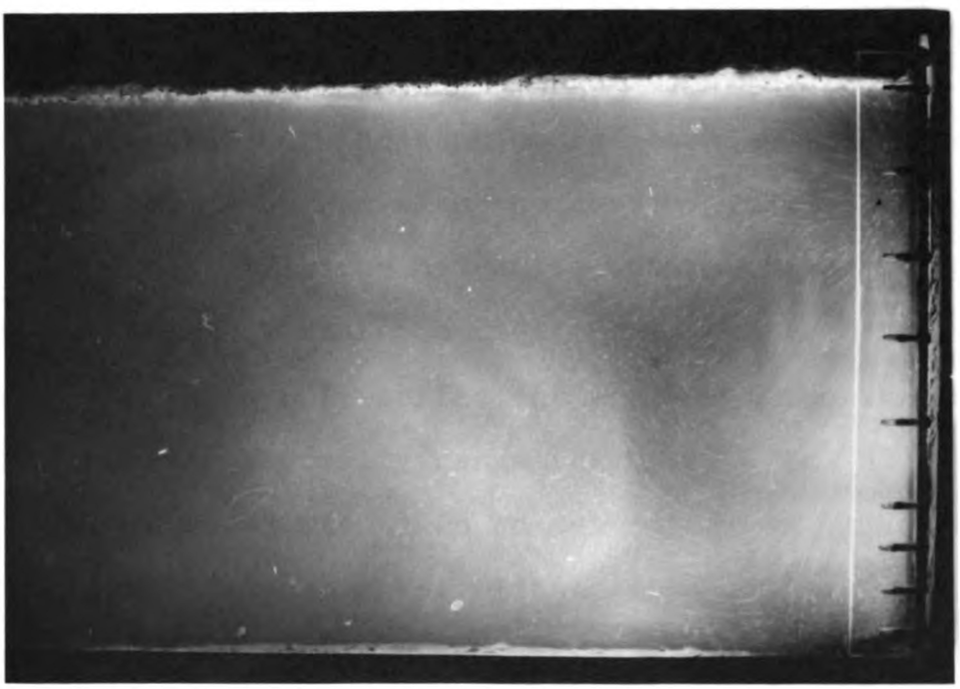


Fig. 31.--Flow lines in the rectangular tank. Viscosity of liquid is 62.5 cps. (Nozzle position A, view IV, Ref. Fig. 12)

there is sufficient movements in all cases except for the single case where the pump is located at the end and with highest viscosity. There is no fluid movement at the end of the tank which would be on the suction side of the pump nozzle (Figures 32 through 34).

With the pump discharge nozzle positioned in the corner of the square tank, there is fluid movement completely around the tank, but insufficient hydraulic action after making the first corner, with the higher viscosity range (Figures 35 and 36). For the middle viscosity, hydraulic action received at the second corner (Figure 37) is sufficient while there is no action at the third corner (Figure 38). At the lower viscosity range there appears to be sufficient hydraulic action for agitation at all three corners (Figure 39). With the agitating pump placed at the center of one side of the tank, more movement is evidenced throughout the tank than with the nozzle placed at the corner. There is sufficient hydraulic action at the second corner (second wall that the fluid hits) for agitation (Figure 40), while only sufficient action at the third corner in the lower viscosity range (Figures 41 and 42).

Figure 43 was taken to determine the liquid movement close to the pump. Very little movement is indicated in the area about one foot from the pump inlet near the bottom of the tank. This condition also existed in the process of mixing the thickening agent to change the

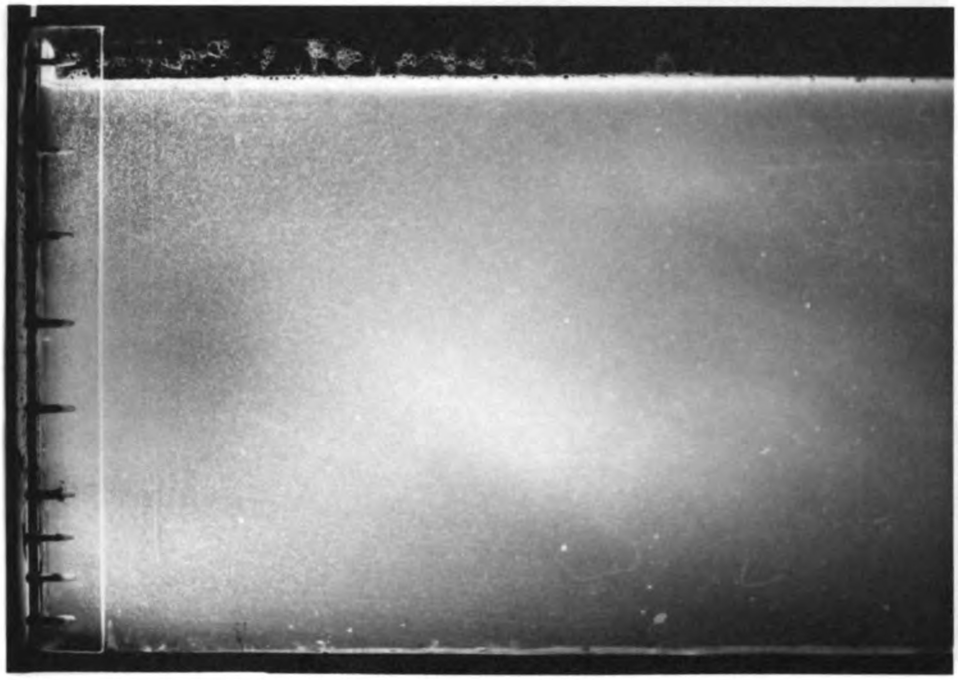


Fig. 32.--Flow lines in the rectangular tank. Viscosity of liquid is 157 cps. (Nozzle position A, view V, Ref. Fig. 12)

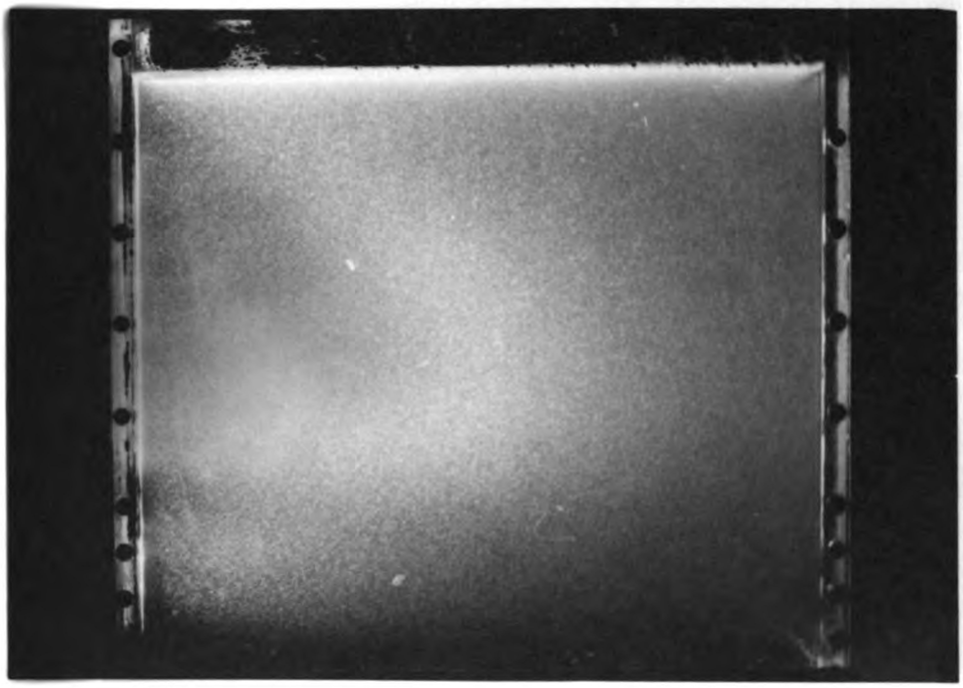


Fig. 33.--Flow lines in the rectangular tank. Viscosity of liquid is 157 cps. (Nozzle position B, view VI, Ref. Fig. 12)

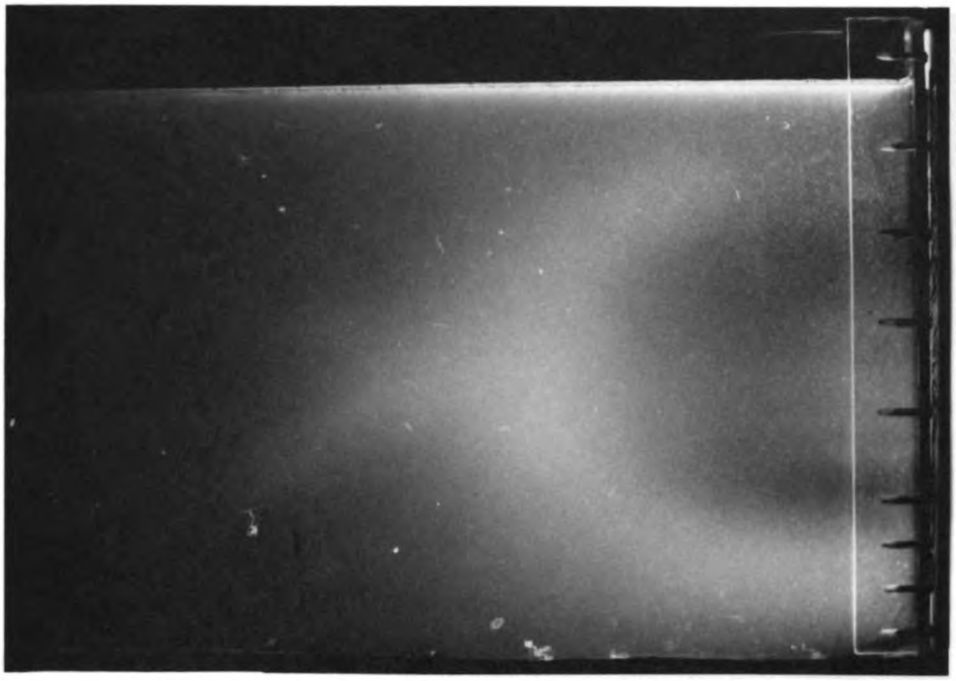


Fig. 34.--Flow lines in the rectangular tank. Viscosity of liquid is 62.5 cps. (Nozzle position C, view I, Ref. Fig. 12)

Fig. 35.--Flow lines in the square tank. Viscosity of liquid is 144 cps. (Nozzle position A, view II, Ref. Fig. 12)

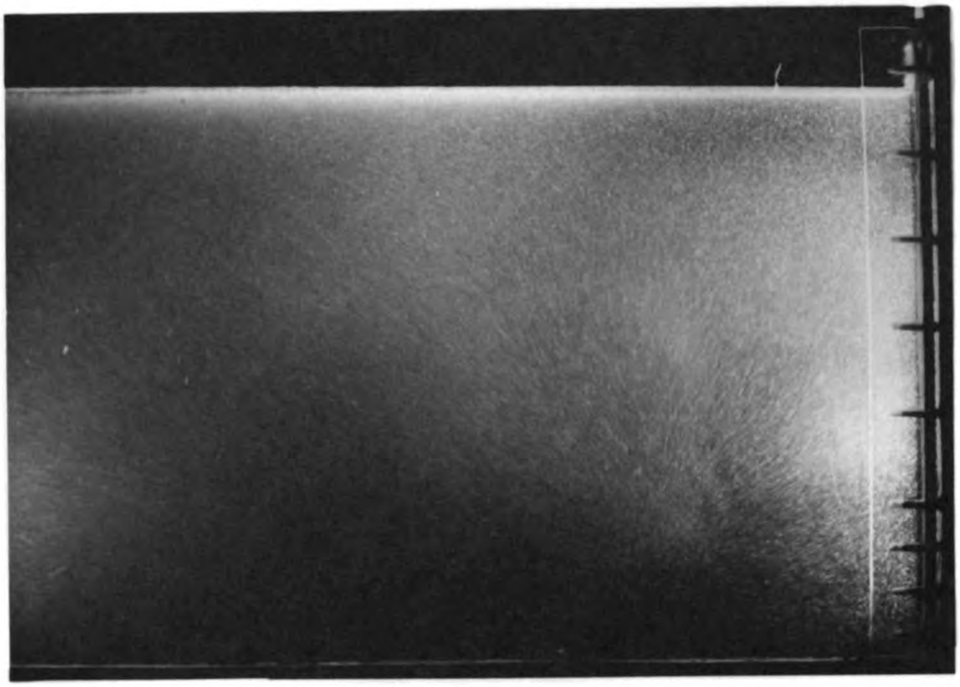


Fig. 36.--Flow lines in the square tank. Viscosity of liquid is 144 cps. (Nozzle position A, view V, Ref. Fig. 12)

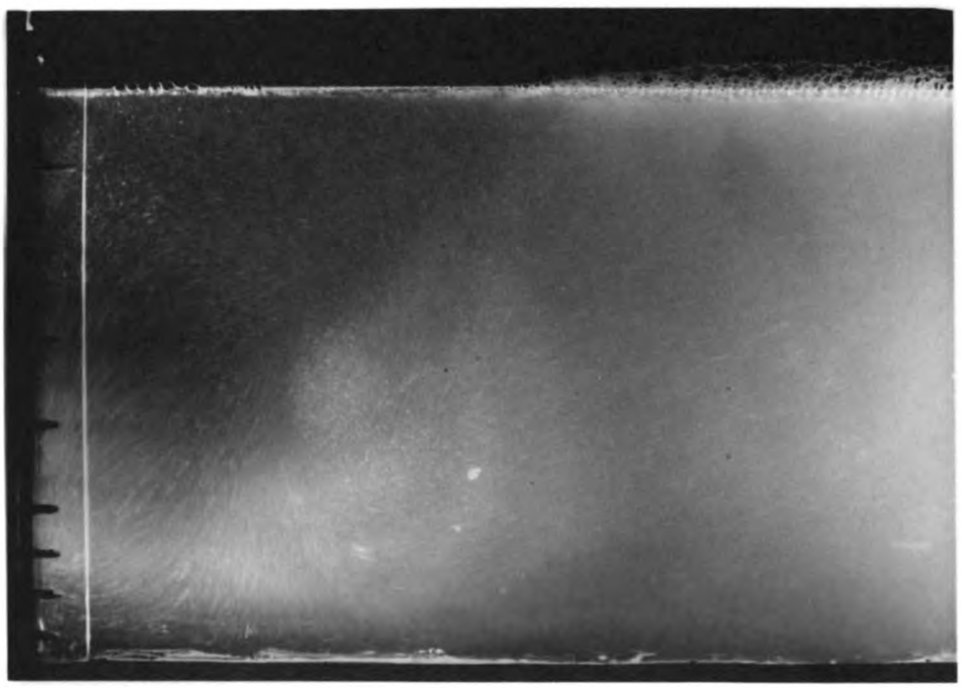


Fig. 37.--Flow lines in the square tank. Viscosity of liquid is 68.3 cps. (Nozzle position A, view IV, Ref. Fig. 12)

Fig. 38.--Flow lines in the square tank. Viscosity of liquid is 68.3 cps. (Nozzle position A, view IV, Ref. Fig. 12)

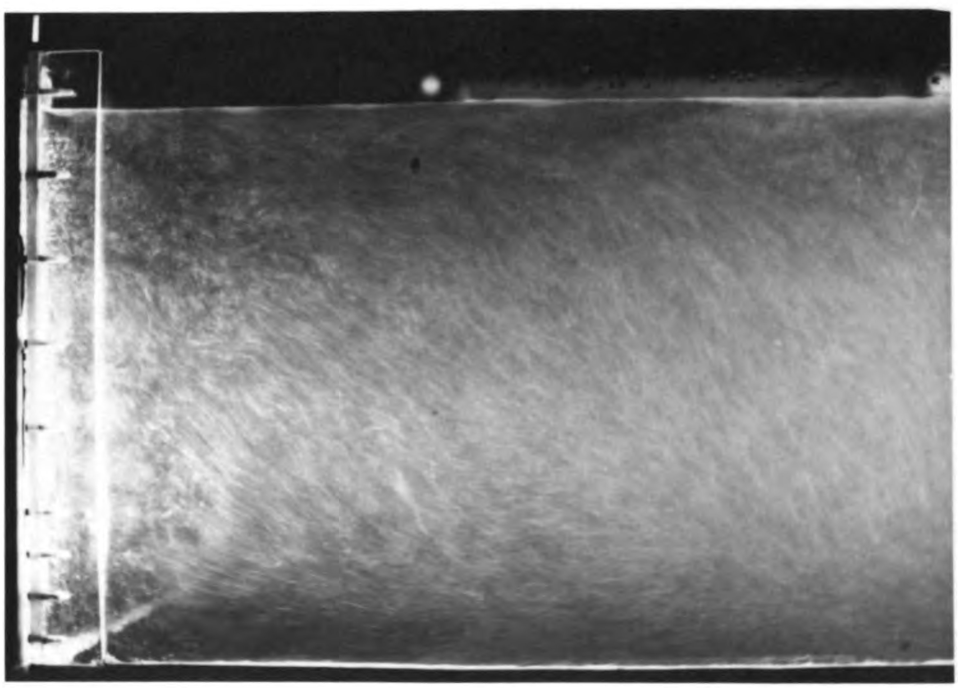


Fig. 39.--Flow lines in the square tank. Viscosity of liquid is 1 cps. (Nozzle position A, view VI, Ref. Fig. 12)

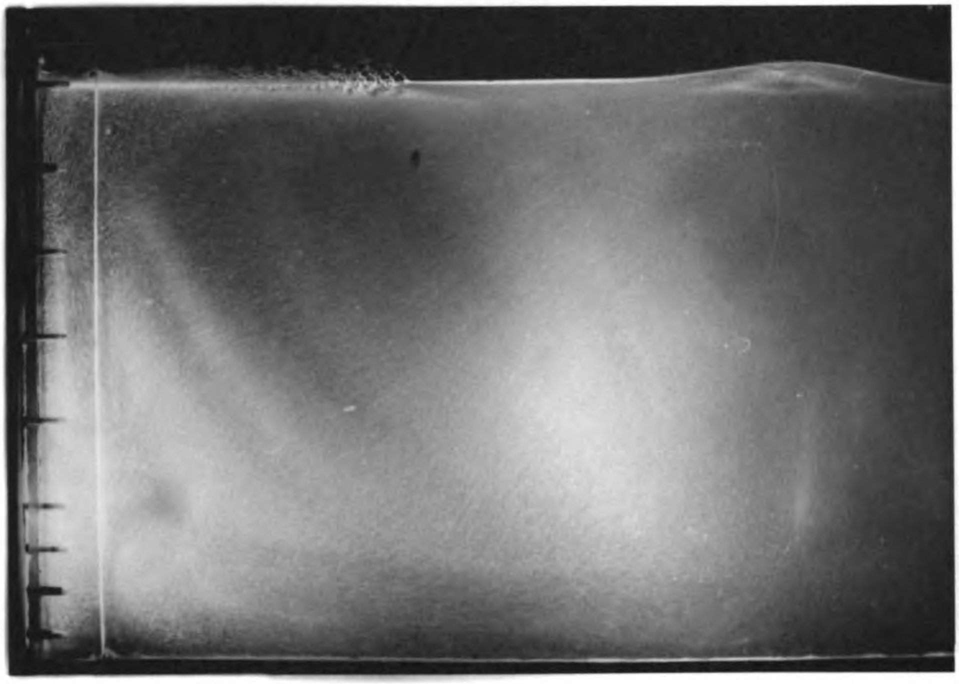


Fig. 40.--Flow lines in the square tank. Viscosity of liquid is 144 cps. (Nozzle position B, view IV, Ref. Fig. 12)

Fig. 41.--Flow lines in the square tank. Viscosity of liquid is 68.3 cps. (Nozzle position B, view I, Ref. Fig. 12)

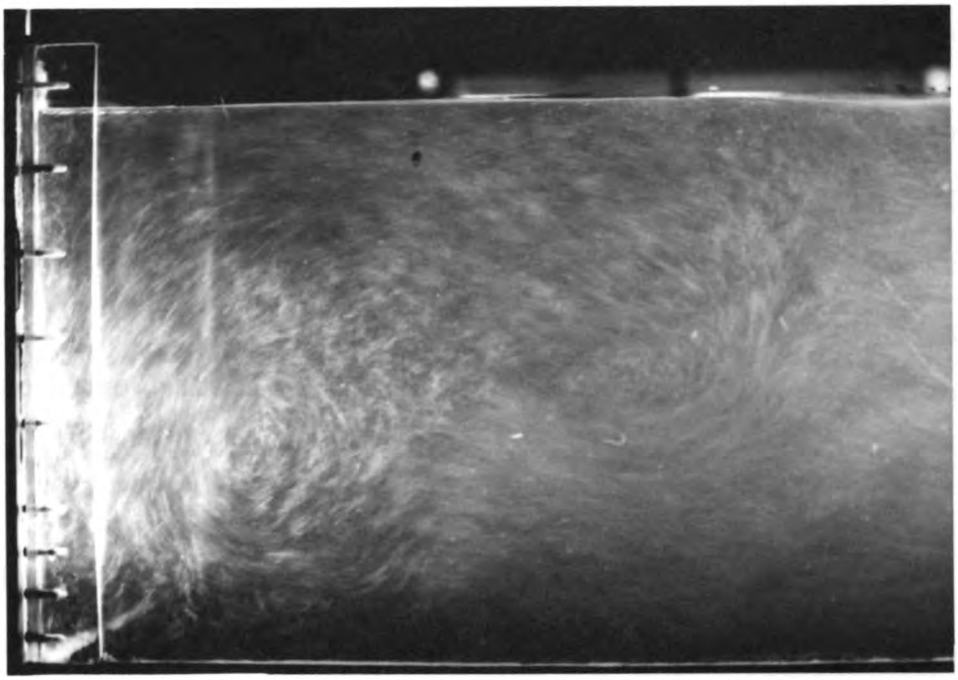


Fig. 42.--Flow lines in the square tank. Viscosity of liquid is 1 cps. (Nozzle position B, view VI, Ref. Fig. 12)

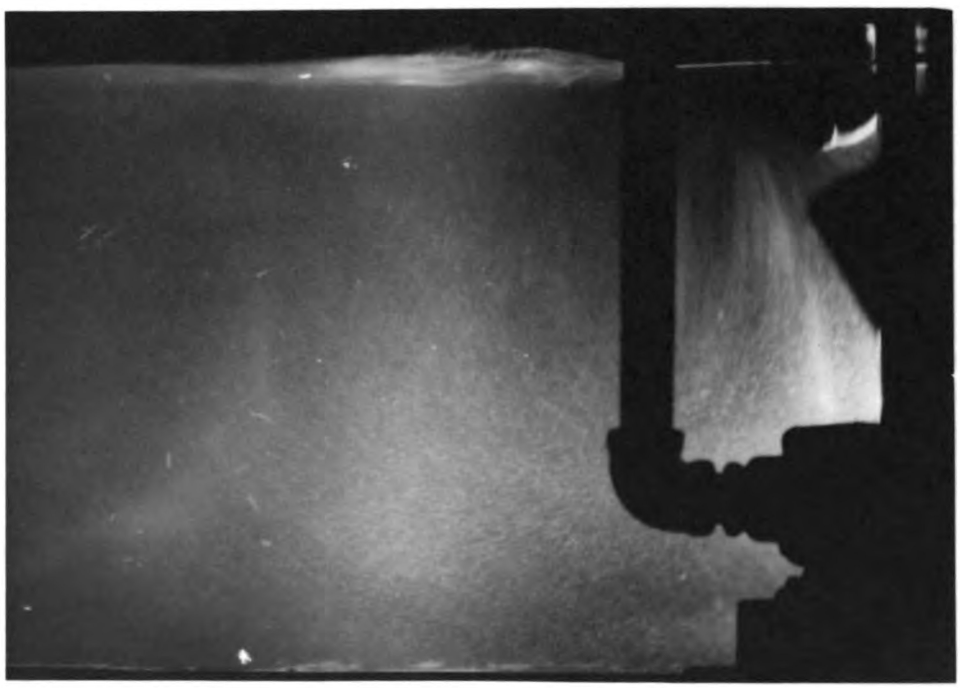


Fig. 43.--Flow lines in the square tank. Note the fluid movement in center of picture near bottom. Viscosity of liquid is 144 cps. (Nozzle position A, view I, Ref. Fig. 12)

viscosity of the model liquid. A layer about two inches thick collected on the bottom of the tank. This layer was mixed into the solution using the model pump as an agitator, but it was noticed that the layer would not go into solution a short distance away from the pump inlet. The layer did go into solution at the corners where there was sufficient action.

Varying the depth of the discharge nozzle gave little indication as to which depth gives the better agitation. However, the nozzle placed with the center line at the water surface is not as effective as when the nozzle is submerged. Directing the nozzle at the surface might be a good possibility to help to dissolve a surface crust (Figure 44). A nozzle placed near the bottom will help to put the material that has settled out, back into the solution (Figure 45).

It was concluded from the study of flow lines, that the most efficient position to agitate a liquid manure tank would be where the distance to the farthest wall is as short as possible. A reasonable distance could be up to 40 feet, while a distance of about 30 feet would be safer for the more extreme conditions.

The maximum distance that the pump nozzle can be away from the wall for efficient agitation will vary depending on the moisture content of the liquid manure and on type of bedding material that is used. Study of physical

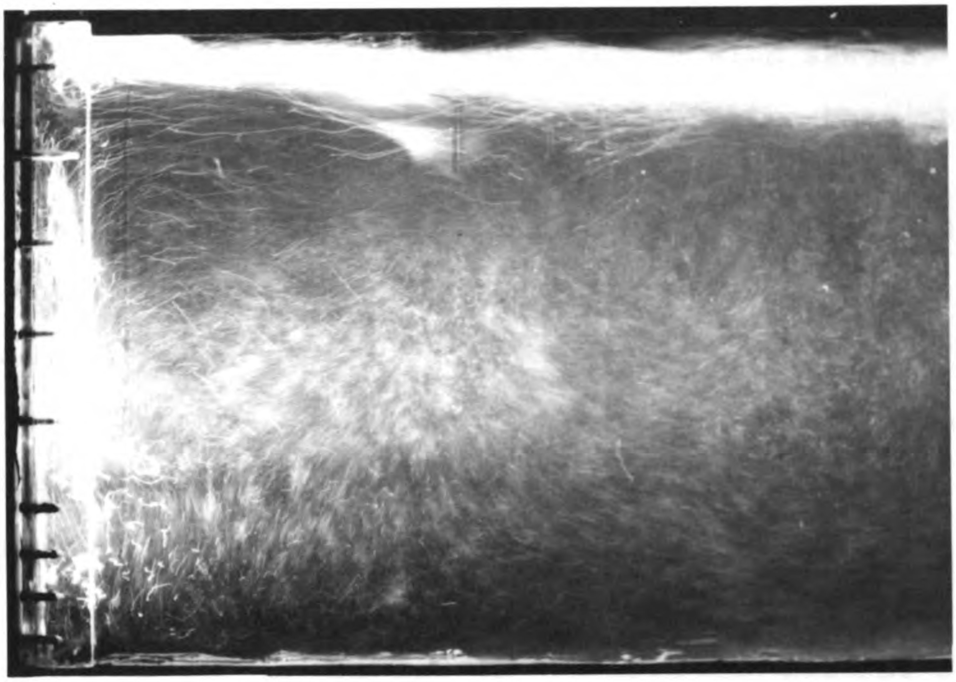


Fig. 44.--Flow lines in the square tank. Center line of nozzle is at surface level. Viscosity of liquid is 1 cps. (Nozzle position A, view II, Ref. Fig. 12)

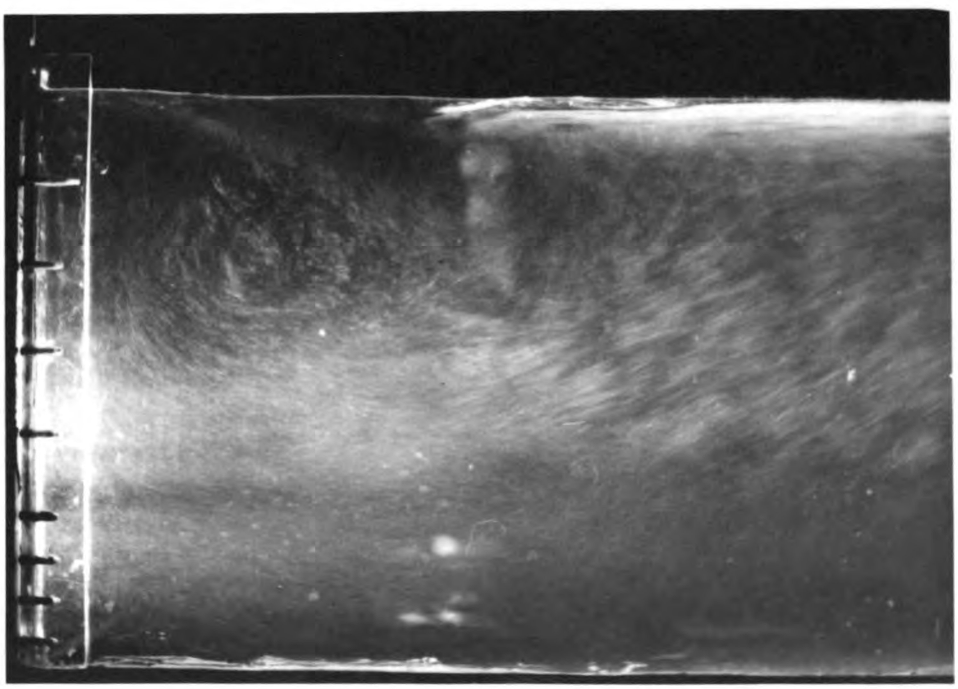


Fig. 45.--Flow lines in the square tank. Center line of nozzle is 3 1/2 inches from bottom of tank. Viscosity of liquid is 1 cps. (Nozzle position A, view II, Ref. Fig. 12)

properties showed that the liquid manure with sawdust in it remains homogenous for a longer period of time than the samples with straw or hay. It concluded that the liquid manure with sawdust would be easier to agitate at a greater distance than that with chopped straw or hay of the same moisture content.

The most efficient position for agitation, of those studied, is the square tank with the pump nozzle located at the center of one side. It is necessary to be able to rotate the discharge nozzle 180° and desirable to be able to adjust the height of the nozzle, or have two nozzles at different vertical positions. One nozzle could be located just under the liquid surface, when the tank is full, and a second located about three-fourths of the depth from the top. The lower nozzle would be used to put into solution the settled material on the bottom, while the upper nozzle would be used for the major portion of the agitation process.

The study with the rectangular tank indicates that it is feasible to agitate from one position with an agitation system similar to the one in the square tank. The position is near the center of the tank.

It seems from the preceding discussion and photographs that the most efficient tank for agitation might be a round tank with the agitation pump nozzle discharging from the center radially to the edge of the tank. It would be necessary to rotate the nozzle 360° and be able to raise or lower the nozzle.

CONCLUSIONS

Conclusions based on the samples of liquid manure are:

1. Liquid manure represents a pseudoplastic liquid.
2. The viscosity of liquid manure is primarily dependent on the moisture content while the material (sawdust, straw or hay) used for bedding in the liquid manure is of secondary importance.
3. The density of liquid manure is similar to that of water.

Conclusions based on the study of flow lines in the model tanks are:

1. For the most efficient agitation in a liquid manure tank, the pump nozzle should be placed so that the distance to the farthest wall is as short as possible.
2. The maximum distance that the pump nozzle can be away from the wall and still cause proper agitation will depend on the moisture content and the material used for bedding.
3. The most efficient shape of tank for agitation would be square and rectangular, in that order.

4. It should be feasible to agitate a 60 ft. rectangular tank from one position near the center. It would be necessary to rotate the pump nozzle 180°. One end could be agitated at a time.

SUGGESTIONS FOR FUTURE STUDIES

1. Make changes in some of the parameters and run tests similar to ones in this thesis (Example: Make a change in the scale ratio).

2. Construct a round tank and run the series of tests.

3. Do an extensive study on prototype tanks to help to verify the conclusion made from the model tanks.

4. Do similar studies with different types and new ideas of agitation systems.

5. Do an economic study on the construction of different shapes of tanks.

6. Do a more extensive study on how the different types of bedding material in liquid manure affect agitation.

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APPENDIX

VISCOSITY DATA OBTAINED ON THE THREE SAMPLES OF LIQUID MANURE

Case A

Spindle Number	Speed (rpm)	Scale Reading (Ave)	Viscosity (cps - ave)	Std. Dev.	95% Conf. Limit
(Sample as collected) (Moisture cont. of sample - 87.93% w.b.) (Temp. increased from 47 to 58° F)					
3	6	50.6	10,120	954.99	8933-11037
4		10.1			
4	12	9.7	4,850	652	4040-5661
4	30	14.4	2,880	409	2372-3388
4	60	20.4	2,040	151.7	1851-2229
(12.5% of vol. - added H_2O) (Moisture cont. of sample - 89.49% w.b.) (Temp. - 62° F)					
3	6	29.3	5,860	786	4883-6837
3	12	32.8	3,280	277.5	2935-3625
3	30	40.4	1,616	145.9	1435-1797
3	60	74.3	1,486	113.5	1345-1627

Spindle Number	Speed (rpm)	Scale Reading (ave)	Viscosity (cps - ave)	Std. Dev.	95% Conf. Limit
		(25% of vol. - added H_2O) (Moisture content - 90.95% w.b.) (Temp. - 68° F)			
2	6	53.6	2,680	201.9	2429-2931
2	12	77.2	1,930	115.1	1787-2073
3	30	22.8	912	76.9	816-1010
2		91.2			
3	60	36.9	738	136	570-907
2		147.6			
		(37.5% of vol. - added H_2O) (Moisture content - 92.61% w.b.) (Temp. - 69° F)			
2	6	25.1	1,255	115.1	570-907
2	12	30.2	755	20.9	1112-1398
2	30	46.4	464	48.3	729-781
2	60	63.6	318	23.9	404-524
		(50% of vol. - added H_2O) (Moisture content - 93.96 % w.b.) (Temp. - 69° F)			
2	6	7.7	385	28.5	350-420
2	12	10.9	273	10.4	260-286
2	30	15.8	158	4.47	152-164
2	60	22.0	110	5.97	103-118

Case B

Spindle Number	Speed (rpm)	Scale Reading (ave)	Viscosity (cps - ave)	Std. Dev.	95% Conf. Limit
		(Sample as collected) (Moisture content - 90.17% w.b.) (Temp increased from 49 to 56° F.)			
3	6	38.6	7,960	1315	6326-9504
3	12	35.0	3,500	418.3	2980-4020
3	30	40.0	1,600	149.7	1414-1786
3	60	51.1	1,022	139.7	848.3-1196
		(12.5% of vol. - added H_2O) (Moisture content - 91.40% w.b.) (Temp. increased from 60 to 64° F.)			
2	6	58.3	2,916	471.7	2330-3502
3		14.6			
2	12	65.2	1,630	160.5	1431-1830
3		16.3			
3	30	17.5	696	119	548-844
3	60	27.2	544	96.3	424-664

Spindle Number	Speed (rpm)	Scale Reading (ave)	Viscosity (cps - ave)	Std. Dev.	95% Conf. Limit
		(25% of vol. - added H_2O) (Moisture content - 92.63 % w.b.) (Temp. - 64° F)			
2	6	22.8	1,140	129.4	979-1301
2	12	36.8	921	113	781-1060
2	30	45.8	458	63.8	379-537
2	60	67.2	336	25.2	304-366
		(37.5% of vol. - added H_2O) (Moisture content - 93.86% w.b.)			
1	6	45.6	456	16.4	436-476
1	12	61.6	308	16.4	288-328
2	30	17.4	174	11.9	159-188
1		87.0			
2	60	24.8	124	9.07	113-136
1		124.0			
		(50% of vol. - added H_2O) (Moisture content - 95.08% w.b.)			
1	6	11.8	118	2.74	115-121
1	12	19.8	99	5.9	91-106
1	30	31	62	3.7	57-67
1	60	47	47	2.5	44-50

Case C

Spindle Number	Speed (rpm)	Scale Reading (ave)	Viscosity (cps - ave)	Std. Dev.	95% Conf. Limit
(Sample as collected) (Moisture content - 92.71% w.b.) (Temp. increased from 57 to 62° F)					
2	6	36.9	1,845	242.6	1543-2147
2	12	46.0	1,150	119.9	1001-1299
2	30	54.1	541	49.3	480-602
2	60	90.4	452	43.1	398-505
(12.5% of vol. - added H_2O) (Moisture content - 93.62% w.b.)					
2	6	9.2	460	13.7	443-477
2	12	15.2	380	20.9	354-406
2	30	20.8	208	7.5	205-211
2	60	28.8	144	9.3	132-155
(25% of vol. - added H_2O) (Moisture content - 94.53 % w.b.)					
1	6	26.7	267	15.3	248-286
1	12	36.8	184	8.9	173-195
1	30	63.0	126	4.0	121-131
1	60	91.0	91	3.9	86-96

Spindle Number	Speed (rpm)	Scale Reading (ave)	Viscosity (cps - ave)	Std. Dev.	95% Conf. Limit
		(37.5% of vol. - added H_2O) (Moisture content - 95.44%)			
1	6	11.7	117	4.5	111-123
1	12	17.6	88	3.7	83-92
1	30	30.0	60	1.4	58-62
1	60	45.0	45	4.6	39-50
		(50% of vol. - added H_2O) (Moisture content - 95.44%)			
1	6	3.7	37	2.7	34-40
1	12	5.4	27	2.1	24-30
1	30	10	20	1.8	18-22
1	60	17	17	2.0	15-20