A TECHNIQUE FOR THE STUDY OF THE MECHANISM OF THE IMPROVEMENT OF CYCLONE COLLECTION OF ALFALFA DUST BY LIQUID FAT ADDITION

by

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INTRODUCTION

Alfalfa dehydrating mills have long been recognized as a source of particulate air pollution. Alleged damages from their effluent include allergic reaction and discomfort, soiling effect of settled dust and objectionable odors from the volatiles emitted to the atmosphere [13].

The typical alfalfa dehydrating mill operates 24 hours a day, seven days a week during the period from early May to late October. Figure 1 is a schematic diagram of a representative mill. Chopped alfalfa is transported to the mill and fed into a rotary drum dryer at a uniform rate. The dryer reduces the moisture content of the alfalfa to about 7 to 9 per cent [6]. The alfalfa and moisture-laden air stream are then directed through primary and secondary cooling cyclones. These cyclones represent the first two effluent sources in the mill, since entrained particulates escape along with the moist air.

The product collected in the secondary cooling cyclone, dehydrated alfalfa, is reduced to meal in a hammer mill. A blower delivers this ground product to a third cyclone, the air-meal separator, where the meal is collected for bagging, bulk storage, or pelletizing. It is at this cyclone where the greatest mass of particulates is emitted to the atmosphere [13].

Various control methods have been employed in an attempt to minimize or eliminate alfalfa mill effluent. Examples of these are bag collectors or multiple cyclones following the air-meal cyclone and the use of liquid additives. The bag collectors, although highly efficient, are expensive to install and operate. Additional cyclones often do not operate efficiently enough to reduce the effluent to the desired level [13].

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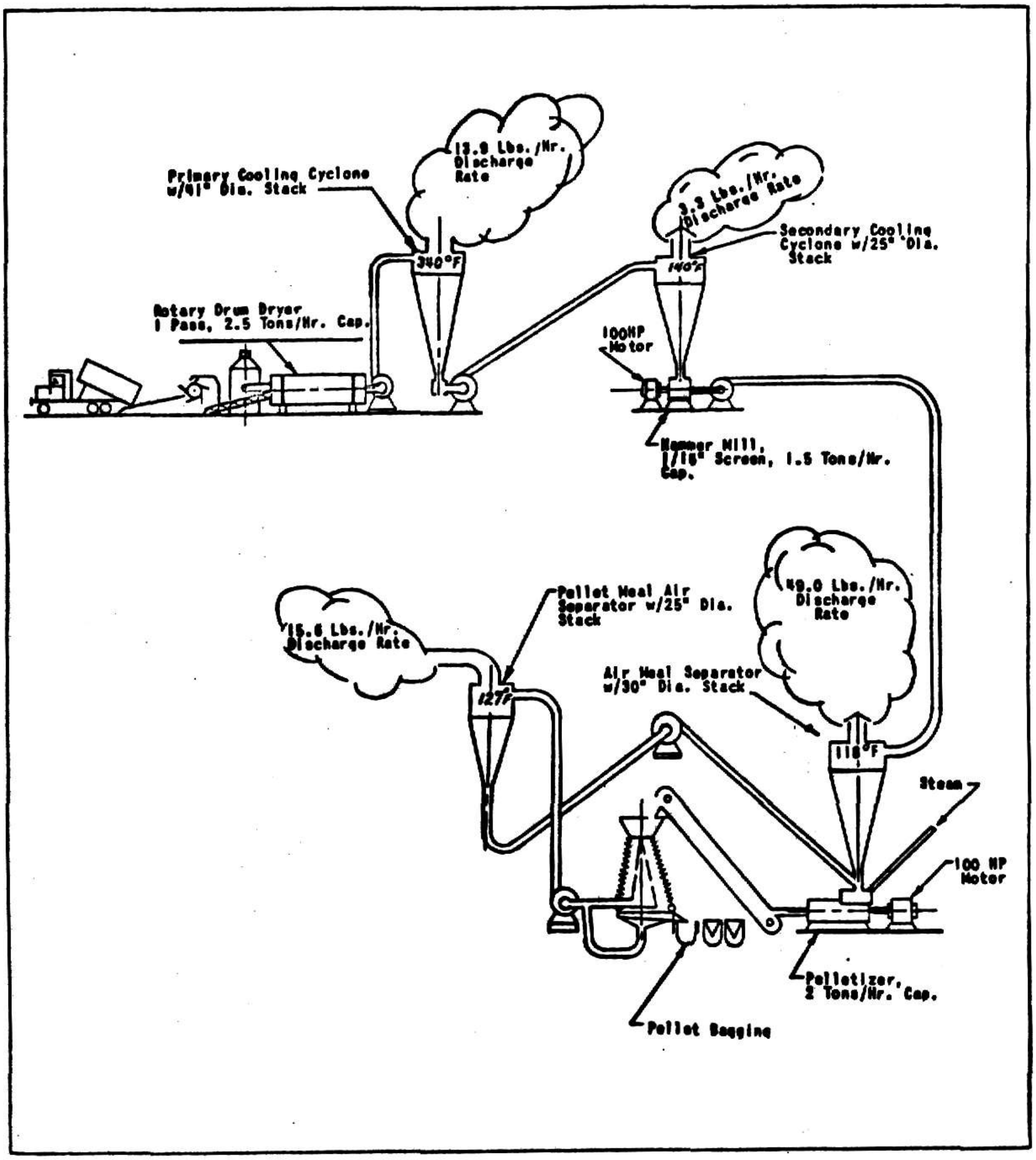

Figure 1. Schematic of Representative Alfalfa Dehydrating Mill

Vegetable oil or liquid animal fat has often been added to the alfalfa at the hammer mill to enhance the nutritive properties of the product and found to be useful, also, as a means of effluent reduction. Lima [5], in an experiment using a small commercial hammer mill and air-meal cyclone on dehydrated alfalfa, obtained 30-fold and 180-fold reductions in the mass penetration of the cyclone by the addition of 2% and 4% animal fat, respectively. Some advantages of animal fat as an effluent control method are: application facilities are present in many mills; installation is inexpensive for mills requiring new equipment; product quality is enhanced; and installation of more expensive control devices may be avoided.

The improvement in cyclone performance in Lima's study [5] was assumed due either to decreased production of fine particles in the hammer mill, or to increased agglomeration of the alfalfa particles. In either case, a coarser size distribution would be presented to the cyclone for collection, allowing it to perform more efficiently.

Knowledge of the mechanisms of fat-induced cyclone efficiency enhancement would allow prediction of its feasibility as an effluent control in milling feed grains.

Clarification of Terminology

The following terms are frequently used in the context of this study:

Micrometer (μm): A unit of length representing the millionth part of a meter (10^{-6} m. = $\frac{1}{25400}$ in.), commonly used in measuring diameter of particulate material. Often referred to as micron (μ), particularly in literature prior to about 1970.

Agglomeration: Bonding of smaller particles into a single larger unit. Unless otherwise stated in this study, it will be used to indicate bonding induced by the addition of animal fat, as opposed to agglomeration due to natural forces usually present in any particulate system.

Comminution: The production of new surface area from solid material by the rupture of chemical bonds.

Average Particle Size: A term with various meanings depending on whether the particle size distribution is weighted by number, by area, or by volume (weight). In this study, the mass median diameter will be used as a measure of central tendency of the particle size distribution. It is defined as that particle size above and below which half the mass of the particles is found.

Mass Efficiency: That percentage of the mass of solid material going into a collector which is retained by the collector.

Mass Penetration: That percentage of the mass of solid material going into a collector which escapes the collector. Penetration, %, = 100% - Efficiency, %.

Fractional Efficiency: With respect to cyclone collectors, the mass efficiency of the collector for a given particle size, or small range of particle sizes.

Objectives

The primary objective of this study was to develop a method for determining the mechanism of cyclone efficiency improvement when liquid animal fat is added to dehydrated alfalfa prior to grinding. If two or more mechanisms were found to be active, it was desired to be able to determine to what extent each contributed to the improvement of cyclone performance.

A secondary objective was to verify predictions on cyclone performance when fat is added to a cereal grain prior to grinding, based on the determination of the mechanism or mechanisms involved in improving the collection of alfalfa dust.

LITERATURE REVIEW

A review of current technical literature reveals little which is of direct applicability to the objectives of this study. Some general inferences may, however, be drawn.

Lima [5] showed a definite improvement in cyclone collection efficiency of ground dehydrated alfalfa when liquid animal fat was added to the alfalfa prior to grinding in a hammer mill. He hypothesized that the improvement in collection efficiency was due either to reduced shattering in the hammer mill or to agglomeration of the alfalfa particles.

Cyclone Collection Efficiency

Dimensional factors, gas characteristics and dust properties affecting cyclone collection efficiency have been summarized as follows [14]:

Collection efficiency increases with:

1. Dust particle size
2. Particle density
3. Inlet gas velocity
4. Cyclone body length
5. Number of gas revolutions
6. Smoothness of cyclone wall

Collection efficiency decreases with:

1. Gas viscosity
2. Cyclone diameter
3. Gas outlet duct diameter
4. Gas inlet area

Stairmand [12] reported that "sticky dusts" are easily collected in cyclones since they agglomerate easily. He added that trouble may arise from chokage of the cyclone ducts or dust discharge orifice. He attributed the main cause of emission from cyclones to be from "base pick-up," in which dust which has already been collected is re-entrained into the air stream due to vertical eddies. Any chokage due to dust adhesion might be expected to emphasize this effect.

Stairmand listed factors for cyclone efficiency generally in agreement with those listed above. He also showed empirical curves of cyclone efficiency vs. particle size. These curves generally are relatively steep and S-shaped, showing efficiency to increase directly with particle size.

Cyclone collection efficiency has also been shown to increase with inlet dust concentration [14]. The cause for this increased efficiency is thought to be a tendency for increased agglomeration, as well as a tendency for the air drag of larger particles to carry smaller ones, which would normally drift toward the center of the cyclone and hence out the clean gas discharge, toward the walls to be collected. The effect of inlet concentration on collection efficiency was confirmed by Lima [5].

Several workers have attempted to derive relationships predicting cyclone collection efficiency [12,14]. These have achieved only limited success in application. An example of such an equation is the Rosin-Rammler-Intelmann formula [14], which is intended to predict "cyclone cut size," defined as the particle diameter collected at 50% efficiency on a weight basis. The formula is:

$$D_{pc} = \sqrt{(9\mu b)/2\pi Ne\ V\ (\rho_p - \rho_g)}$$

where

D_{pc} = diameter of particle collected with 50% efficiency

μ = gas viscosity,

b = width of cyclone inlet,

Ne = number of effective turns within the cyclone,

V = inlet gas velocity,

ρ_p = density of the particulate matter, and

ρ_g = density of the gas.

A severe limitation in the use of this equation is the inability to accurately predict the number of effective turns within the cyclone. The flow patterns are essentially unpredictable, particularly when the gas is laden with solid particles [12].

The literature agrees that, for constant cyclone geometry and carrier gas, the only factors which could alter collection efficiency are particle size and density. The addition of 2-4% fat should not change the density of individual particles. Therefore, it appears that the fat addition is causing generally larger particles to be presented to the cyclone for collection. The effects proposed by Lima [5] seem most likely on an intuitive basis. These are agglomeration and reduced shattering.

Agglomeration

According to Rumpf [10], agglomeration occurs because of the presence of bonding forces between the particles. He classified these bonds as follows:

1. Solid bridges between the agglomerating particles;
2. Boundary surface forces and capillary pressure in movable liquid surfaces;

3. Adhesional and cohesional forces in bonding bridges which are not freely movable;
4. Attraction between the solid particles (including so-called Van der Waals' forces);
5. Interlocking, depending on the shape of the particles.

Pietsch [8] elaborated on these bonding mechanisms, attributing the first primarily to sintering, chemical reation, melting adhesion, hardening agglutinants, and crystallization of dissolved substances.

He explained the second bonding mechanism in terms of liquid bridges between particles, capillary forces at the surface of a liquid-filled pile and surface tension of solid-filled droplets.

Bonding mechanism no. 3 was explained in terms of viscous bonding media and thin adsorption layers.

The fourth bonding mechanism depends on molecular and electrical forces, while no. 5 depends on particle shape and application of exterior forces. In neither case is a material bridge involved.

Bonding mechanism no. 3, with viscous bonding media, provides a possible explanation for the action of fat on alfalfa particles.

Reduced Shattering

If the addition of fat to alfalfa prior to grinding could sufficiently alter the physical properties of the alfalfa, it is feasible that reduced shattering might take place.

Friedrich [2] stated that, for impact grinding, rupture would occur when a maximum stress exceeding the ultimate strength was reached. This maximum stress was expressed in the following functional relationship:

$$\frac{\sigma_{max}}{E} = \text{const.} \left(\frac{\rho\ V^2}{E}\right)^n$$

where

σ_{max} = maximum stress,

E = modulus of elasticity,

ρ = density,

V = impact velocity.

The exponent, n, depends on the geometry of the particles and is assigned a value of 1/5 for spheres. For spherical particles, the maximum stress would thus be proportional to the 4/5 power of the modulus of elasticity.

Various studies of the rheological properties of alfalfa have been made. None, however, has considered the effect of an additive on these properties. Prince, et al [9] and Halyk and Hurlbut [4], showed that the modulus of rigidity and ultimate tensile strength of alfalfa stems were inversely proportional to moisture content. Halyk and Hurlbut also showed that ultimate tensile strength was directly proportional to dry-matter bulk density.

The effect of fat addition on the yield strength of the alfala is difficult to assess on the basis of current literature. It could be expected to increase bulk density slightly. The possibility nonetheless exists that the fat would have a toughening effect on the alfalfa stem and leaf.

O'Callaghan [7] studied the performance of hammer mills on barley grinding. By the use of dimensional analysis and experimental test results he found the degree of comminution produced in a hammer mill to depend primarily on design paramters of the mill itself, rather than of the physical characteristics of the ground barley.

Conclusions

General conclusions only are possible due to a lack of specific information in the literature. It would seem unquestioned that the addition of a viscous medium to any system of particles would promote agglomeration. To what extent reduced shattering occurs, if indeed it occurs at all, cannot be predicted.

RATIONALE OF EXPERIMENT

Based on the results obtained by Lima [5], a review of current literature, and conversations with persons familiar with milling technology, (a) fat-induced reduced shattering or (b) fat-induced agglomeration were the most logical alternative mechanisms accounting for the improvement of cyclone collection efficiency. The experimental technique was selected accordingly.

Two basic methods of investigating the mechanism involved were selected:

1. Implications of comparative particle size distributions.
2. Application of cyclone fractional efficiency curve to size distributions obtained.

Implications of Particle Size Distributions

In a system of hammer mill and cyclone collector, where dehydrated alfalfa is ground with and without fat, several size distributions can be obtained. The size distributions obtainable depend on the site at which the sample is taken, whether or not fat was present, and whether or not the sizing method retains the agglomerative effect of the fat.

Possible sampling sites are:

1. Cyclone clean gas discharge (effluent)
2. Cyclone dust discharge (collected product).
3. A combination of 1 and 2 (combined collected distribution).

The possibilities concerning fat are limited to its presence or absence. The sizing methods considered are:

1. Sizing in a solvent which dissolves the fat and removes the effect of fat-induced agglomeration. Size distributions so obtained from alfalfa ground with fat will be referred to hereafter as "deagglomerated distributions."
2. Sizing in a liquid which does not dissolve the fat, thus retaining the effects of fat-induced agglomeration. Size distributions so obtained from alfalfa ground with fat will be referred to hereafter as "agglomerated distributions."

Alfalfa ground without fat may be sized by either method, and will be referred to as "fat-free distributions."

Distributions may further be identified as effluent, collected product, or combined, depending on their sampling site. The following are expected results for comparisons of the various distributions as dependent on fat activity:

1. Deagglomerated effluent with respect to fat-free effluent: Should be coarser if reduced shattering is active, and can be coarser, finer, or not changed if agglomeration is active. This is true if the cyclone fractional efficiency curve remains constant with different size distributions, as reported by Stairmand [12].
2. Agglomerated effluent with respect to fat-free effluent: Should be coarser regardless of mechanism.
3. Deagglomerated collected product with respect to fat-free collected product: Should be finer if agglomeration is active, since fine particles formerly effluent in the fat-free situation would be retained in collected product when

fat is added, then liberated by solvent. Should be coarser if reduced shattering is active.

4. Agglomerated collected product with respect to fat-free collected product: Should be coarser regardless of mechanism.
5. Combined deagglomerated distribution with respect to combined fat-free distribution: Should be coarser if reduced shattering is active, should have no change if agglomeration is active.
6. Combined agglomerated distribution with respect to combined fat-free distribution: Should be coarser regardless of mechanism.

Comparisons between different sampling sites are not considered meaningful.

Application of Cyclone Fractional Efficiency Curve

The mechanisms of reduced shattering and agglomeration are not mutually exclusive; there is a possibility that each contributes a portion to cyclone collection improvement.

The following is a method of determining the extent of each mechanism. First, a fractional efficiency curve for alfalfa dust is obtained for the test cyclone. The combined deagglomerated distribution, when applied to this curve, will give the collection efficiency if reduced shattering alone were active, since the deagglomerated distribution retains any effects of reduced shattering, but does not retain the effect of agglomeration. Any improvement in collection efficiency over the fat-free distribution can be attributed to reduced shattering. The total improvement in collection efficiency when fat is added can be noted experimentally. The difference between the total improvement and the improvement due to reduced shattering is improvement due to agglomeration.

TEST FACILITIES AND APPARATUS

This research project was done at the facilities of the Department of Mechanical Engineering and the Institute for Environmental Research, Kansas State University.

To determine changes induced in ground alfalfa when fat was added, it was necessary to investigate particle size distribution of the alfalfa as it exited the hammer mill, as well as the size distributions at the cyclone dust discharge and clean gas outlet. Due to the wide size distributions, high air velocities, and non-uniform concentrations involved, obtaining a representative sample would have been extremely difficult on full-size equipment. Therefore, the decision was made to miniaturize the test apparatus so that full-stream samples might be taken. The main parts of the test equipment were the miniaturized grinding mill, with provision for feeding alfalfa and capturing the cyclone effluent, and the fat application and mixing system.

Experimental Alfalfa Grinding and Collection Apparatus

The grinding apparatus consisted of feeding system, hammer mill, cyclone collector, filter holder, blower, and flow nozzle. The dehydrated alfalfa feeding system was a fabricated screw conveyor of 15-inch length and 1-1/2-inch inside diameter, with a screw pitch of approximately 2-1/2 inches. At one end the upper half of the tube was removed for a length of 4-1/2 inches and a feeding hopper with a capacity of approximately 1 lb_m of dehydrated alfalfa added. A stirring rod driven by a small 18 rpm gearmotor was utilized to prevent briding of alfalfa stems across the inlet to the screw. The screw conveyor was powered by a 1/3 HP, 24 v. DC motor at a speed of approximately 180 rpm. An electrical resistance heating tape was wrapped around the outer tube of the conveyor, and covered with neoprene foam insulation.

The hammer mill was an Udy Analyzer Co. Laboratory mill driven by a 5/8 HP. 115 v. motor. Figure 2 shows the mill and auxiliary equipment. It had 6 rows of two hammers alternating with 6 rows of one hammer each. Hammer dimensions were 1-7/16 x 1/2 x 1/8 inches. The mill was furnished with a screen with 0.040 in. perforations; these were drilled out with a no. 56 drill to a diameter of 0.0465 in. to correspond closely to the 3/64-in. perforations commonly used in commercial dehydrating mills [13]. The rotor radius to the outer edge of the hammers was 2-1/2 in. Rotor rotation was 9,000 rpm, giving a hammer tip speed of 11,750 fpm. This mill was designed for use in grinding small unit samples of about 30 gm; however, it functioned well in grinding samples of approximately one pound for grinding times extending over several minutes.

The cyclone collector was fabricated in a conventional reverse-flow pattern. Dimensions and details of construction are shown in Figure 3.

The system for collecting the cyclone effluent consisted of a conical section leading into a right-angle transition from circular to rectangular cross-section. This was attached to a Gelman Instrument Co. 8 in. x 10 in. filter holder intended for use in high volume air sampling. The effluent dust was captured on General Electric "Nuclepore" polycarbonate sheet filters of 0.4 μm nominal pore size. Pressure taps were added to the filter holder to allow pressure drop across the filter to be read on a mercury manometer. Gasket material of felt and glass fiber material was added to the filter holder to ensure sealing around the edges of the filter sheets.

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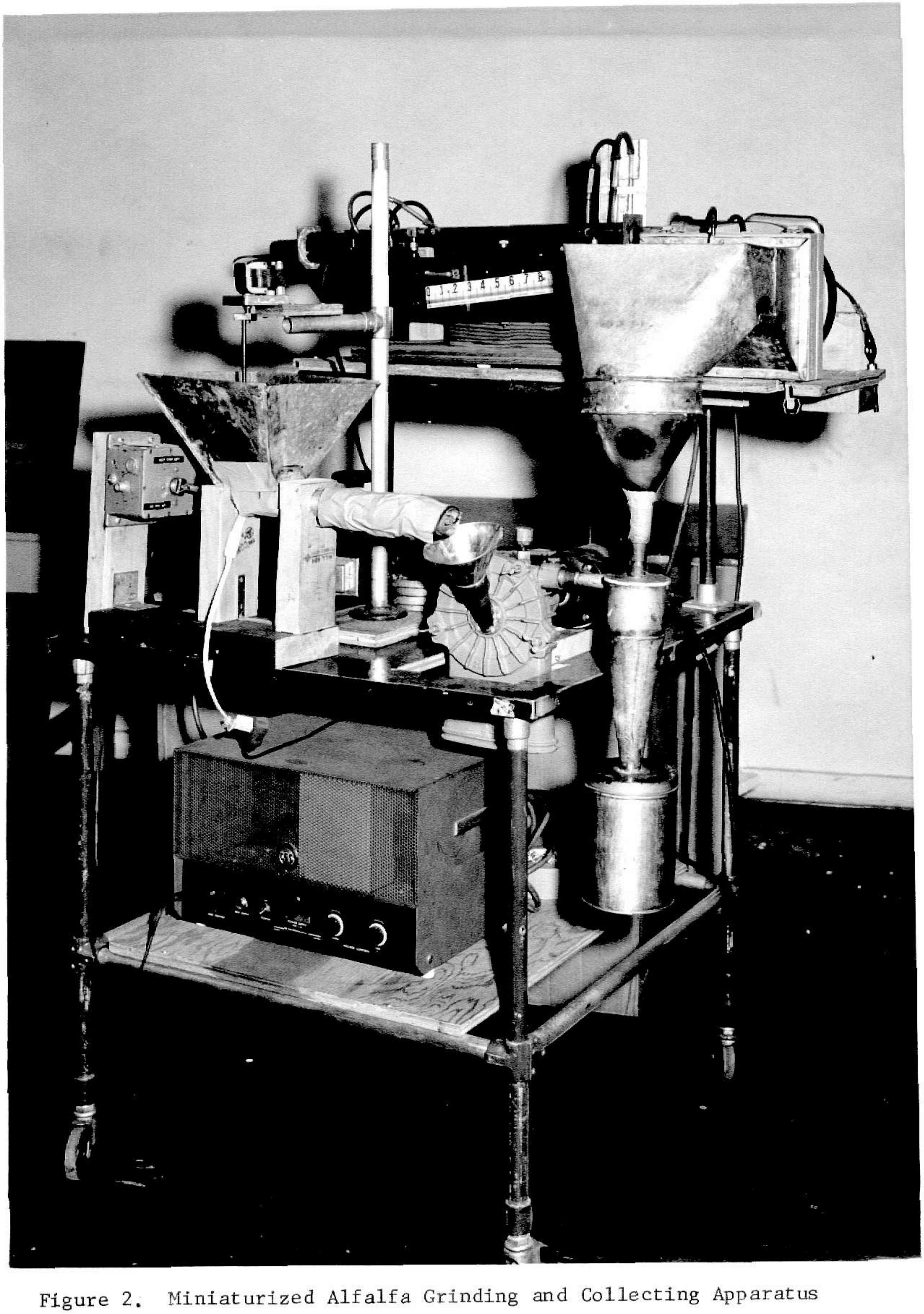


Figure 2. Miniaturized Alfalfa Grinding and Collecting Apparatus

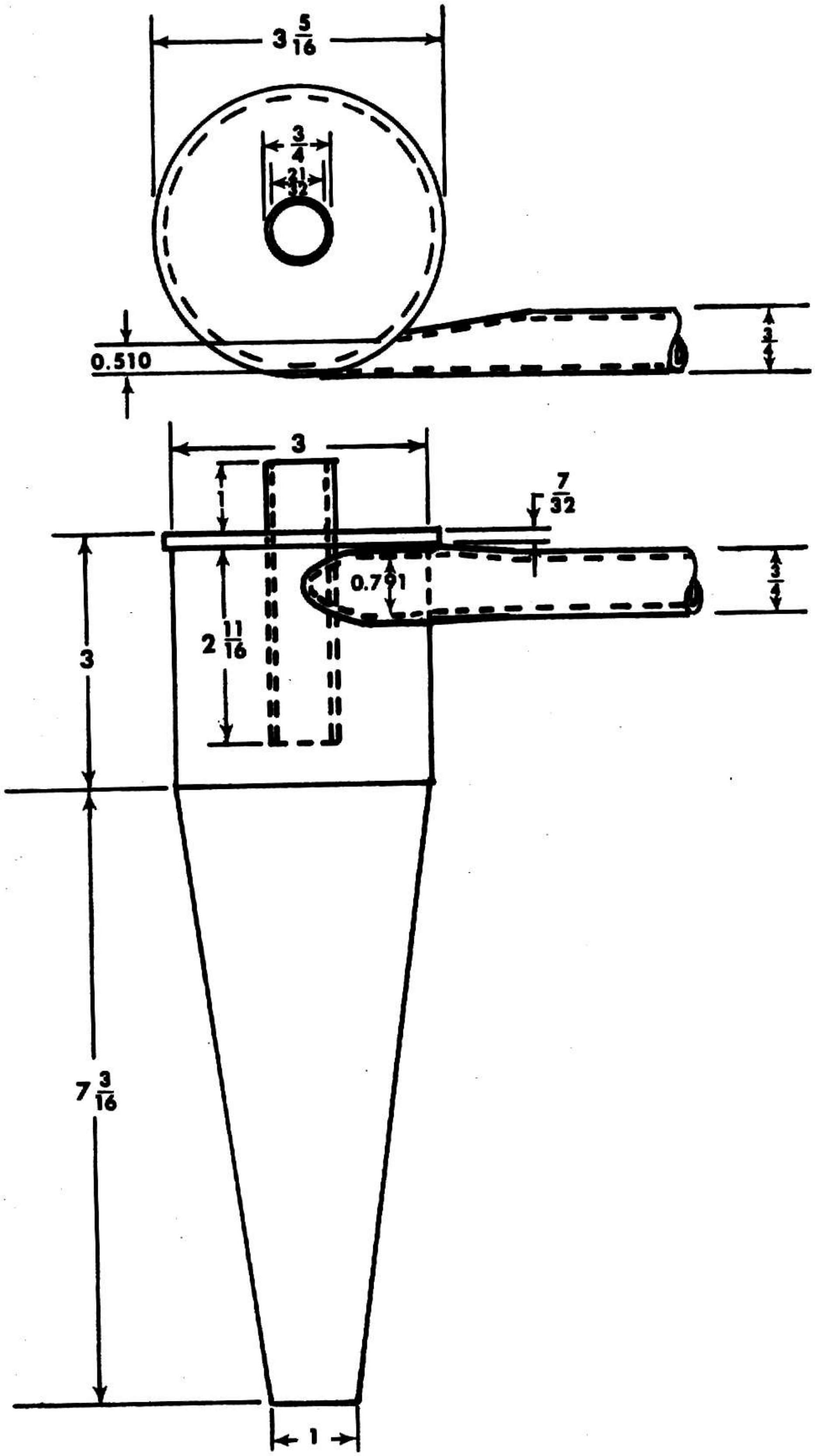


Figure 3. CYCLONE DIMENSIONS (IN INCHES)

Air flow through the system was provided by a Clements Mfg. Co. Model Hp3A Flow Prover blower. This blower was capable of providing air flow of 15 ft^3./min. at static pressure drops of 2-1/2 inches of mercury, and was attached to the downstream side of the filter holder. Blower speed was controlled by a variable transformer. Flow was monitored by means of a flow nozzle with draft gage manometer at the blower discharge.

The assembly of ductwork, filter holder, and blower could be disconnected from the remainder of the apparatus at the cyclone clean gas discharge and at the flow nozzle. The assembly could then be rotated 90°, with the blower still running, to leave the filter in a horizontal position. The blower could then be turned off and the filter removed without danger of the alfalfa dust falling off.

Liquid Animal Fat System

The animal fat used in this and the previous study [5] is known in the milling trade as "yellow fat." The primary source of this material is from animals which have died from various causes on farms or in feedyards, and which are then collected by rendering companies.

The considerable solid impurity in yellow fat, which plugged nozzles at low flow rates, made it impracticable to apply it to the alfalfa as it was being fed into the hammer mill. To avoid this difficulty, the fat was sprayed onto the alfalfa in larger lots, which could then be broken down into batches of appropriate mass for the test grinding apparatus.

The fat was heated in an aluminum recptacle of about 2 gal. capacity by means of a thermostatically controlled electrical resistance heater. Fat temperature was maintained between 120 F and 130 F.

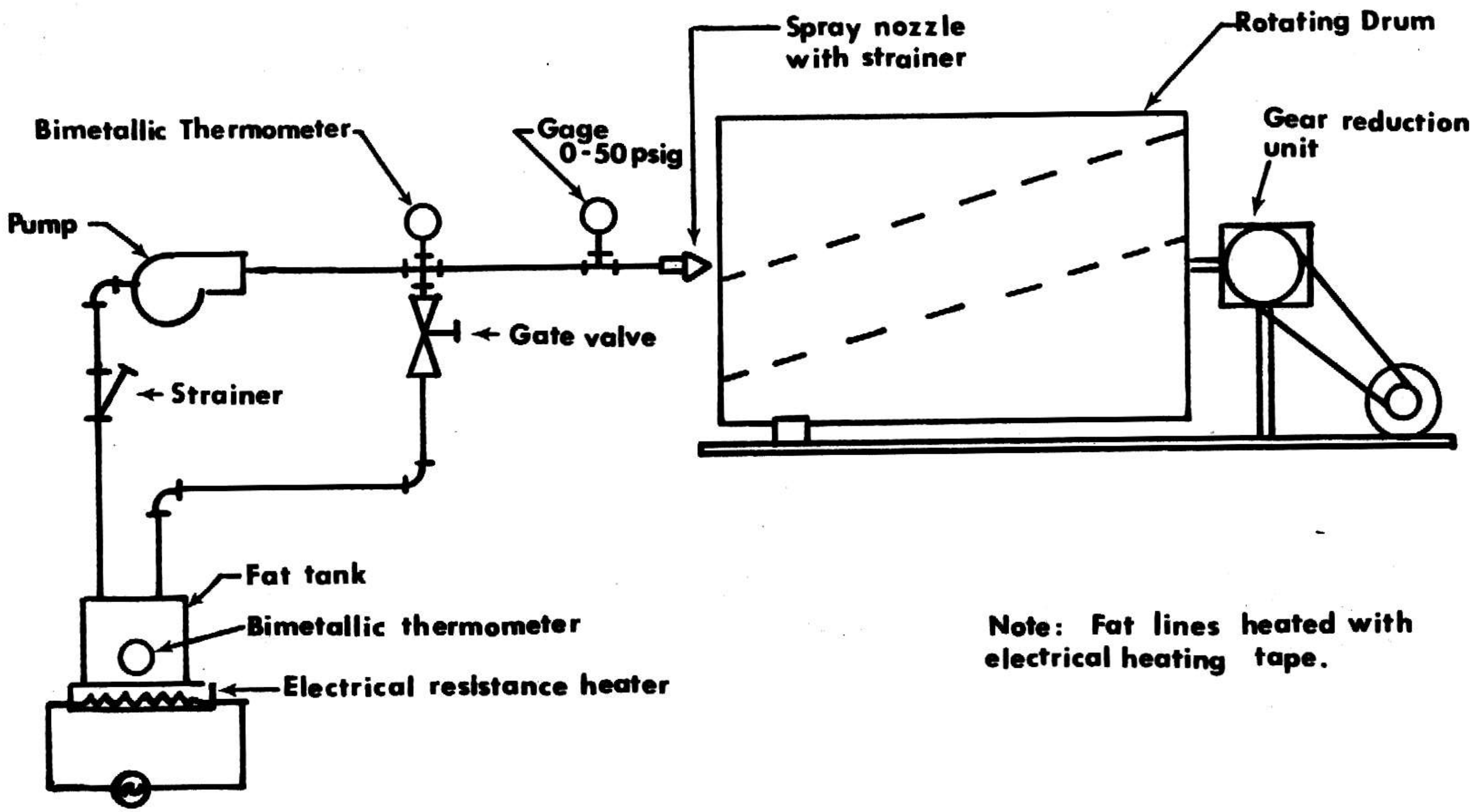
A Roper model F5 positive displacement pump powered by a 2 HP electric motor was used for spraying the fat. Suction and discharge lines were heated with electrical resistance tape to maintain the fat temperature at about 130 F throughout the system. A bimetallic thermometer provided temperature readings of the fat within the discharge line. Since the pump's output was excessive for the flow required, a large portion of the fat was recycled back into the heating receptacle. Flow was regulated by means of a gate value. Figure 4 is a schematic view of this system.

A Delvan FS-4 nozzle, designed to give a fan shaped discharge at an included angle of 65°, was used to spray fat. This nozzle was found to deliver 0.466 lb_m/min. at a line pressure of 12 psig. The required amount of fat to give the desired percentage weight of dehydrated alfalfa was obtained by varying the running time of the pump. The nozzle was provided with a 100-mesh wire strainer (opening size of approximately 149 μm). It was necessary to clean this screen between sprayings in order to maintain constant flowrate.

A rotary tumbler was fabricated from a 30 gal. steel drum by fitting longitudinal vanes of sheet aluminum on the inside and providing a speed reducer which gave a drum rotation of 24 rpm when powered by a 1725 rpm motor. This tumbler proved convenient for spraying fat on 8-10 lb lots of alfalfa. The end of the drum was removable for loading and removing the dehydrated alfalfa, and a hole 1-1/2 in. in diameter was drilled in its center as a port for the spray nozzle. Figure 5 shows the drum in position relative to the fat spraying system.

Particle Size Analyzing System

Particle size distributions were obtained by sieving, sedimentation, and a combination of these two methods. Sieving was accomplished with a series of 5 in. diameter sieves of U.S. Sieve Series numbers 20, 35, 60, 100, 140 and 200. The sedimentation analysis was performed on an MSA-Whitby Particle Size Analyzer, as shown in Figure 6.



Note: Fat lines heated with electrical heating tape.

Figure 4. FAT SPRAYING SCHEMATIC

Figure 5. Fat Spraying Equipment

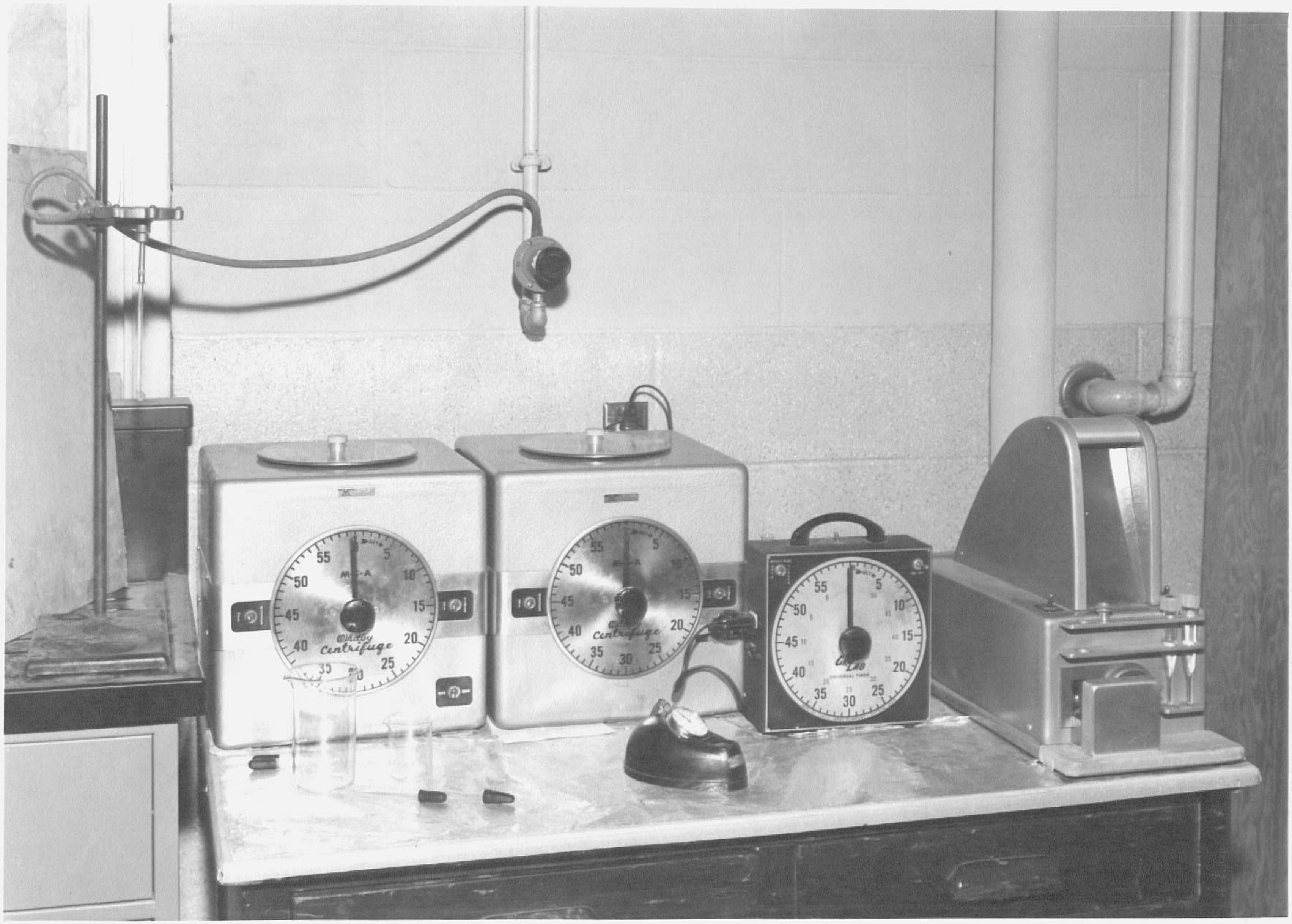


Figure 6. MSA-Whitby Particle Size Analyzer

EXPERIMENTAL PROCEDURES

These experiments were designed to study the effects of fat addition to dehydrated alfalfa on particle size distributions, and hence on cyclone collector efficiency. The particle size distributions of the following materials were measured:

(a) Alfalfa ground without fat.

(b) Alfalfa ground with fat.

(c) Alfalfa ground with fat but with the fat dissolved out.

As many of the operating variables were controlled as possible. The use of miniaturized equipment with a full-scale product led to difficulties in this respect.

Air flow through the grinding and collection apparatus was selected as 8.0 ft^3/min. This gave an inlet velocity to the cyclone of 3640 ft/min, which is in accordance with recommendations [12].

Due to the small diameter of the passages in the grinding and feeding apparatus, stoppages often occurred in the hammer mill inlet making constant feed rate of alfalfa difficult. In addition, partial blockage of the hammer mill screen and cyclone inlet tube sometimes occurred, particularly when grinding alfalfa with fat.

Since cyclone efficiency usually depends on the air/solids ratio entering it [14], tests were made at inlet conditions other than those used in normal grinding. Conditions were changed both by increasing the flowrate of air while holding a normal alfalfa feed rate and by decreasing the alfalfa feed rate while holding the air flowrate at a normal 8.0 ft^3/min. The results of these tests are shown in Table 1 and indicate that cyclone loading is not critical for the miniature cyclone over this range.

Table 1: Cyclone Collection Efficiency under Varying Dust Loadings for Fat-Free Alfalfa Dust.

	No. of Test Runs	Air Flow ft^3/min	Approximate Inlet Mass Concentration, $Grains/ft^3$	Collection Weight Efficiency, %
Test # 1*	10	8.0	125	99.55
2	1	9.0	125	99.42
3	1	10.0	136	99.41
4	1	14.0	102	99.66
5	1	8.0	64	99.65

*Average of Standard Tests

Fat Application Method

Fat was sprayed on alfalfa in a rotating horizontal drum after the alfalfa was warmed by an infrared heating lamp. After spraying the required time to obtain the desired fat level, the drum was rotated for 5 min to ensure thorough mixing and penetration. As a check on the amount of fat added, the alfalfa was weighed before and after spraying on a platform balance sensitive to 0.01 lb.

Mass Efficiency Determination

The material collected by the cyclone was collected in 4.75 in. dia x 6.5 in. metal cans at the cyclone dust discharge. These cans were weighed before and after grinding on a Mettler P1200 balance to obtain net weight of product collected.

The polycarbonate (Nuclepore) filter sheets were enclosed in aluminum foil and weighted before and after grinding on a Mettler H 10T balance with a sensitivity of 0.1 mg.

Prior to usage, the 0.4 μm Nuclepore filter was tested for efficiency on the alfalfa dust as produced by the test hammer mill. A 47-mm dia. Nuclepore filter was placed in series with a Millipore type AA filter of the same configuration and known to be 99.9% efficient on alfalfa particles as small as 0.2 μm. Alfalfa dust was aspirated through the system with the Nuclepore filter in the upstream position. The Millipore AA filter was then examined under the light microscope for alfalfa particles. None was found, leading to the conclusion that the Nuclepore filters were suitable for the test.

Nuclepore's polycarbonate filter material was chosen over other types because its flexibility allowed the sheets to be folded and thus accurately weighed on a conventional analytical balance. Large filter area was needed due to the high pressure drop across small pore-size filters.

Wall losses on the sheet metal transition section prior to the filter holder were found to be negligible. Visible accumulation appeared only after repeated grindings. Comparison of the weight collected at the cyclone dust discharge with the weight of effluent material captured on the Nuclepore filter thus provided a direct, accurate measurement of the cyclone's mass efficiency.

Particle Size Distribution Determination

Three different particle size distributions were examined, for alfalfa ground both with and without fat. These were the size distributions of the effluent, the collected product, and the combined effluent and collected product.

For that material which was gound with fat, it was necessary to obtain size distributions as they naturally occurred and size distributions with the fat dissolved out. For this purpose it was necessary to find two liquids whose physical properties were suitable for sedimentation sizing [15], one which would and one which would not dissolve animal fat.

Hexane (C_6H_{14}) was finally selected as the best solvent for the fat. Its density of 0.664 gm/cm^3 and viscosity of 2.94 x 10^{-3} gm/cm•sec at room temperature (20C) made it suitable for a sedimentation fluid. However, its electrolytic properties caused some difficulty in reading the sedimentation centrifuge tubes, particularly during periods of low relative humidity.

As a non-solvent of fat, a mixture of 80% by weight methyl alcohol (CH_3OH) and 20% by weight demineralized water was chosen. It was found by observing changes in volume of alfalfa dust in a graduated cylinder that this mixture would not cause appreciable swelling of the alfalfa particles.

Tests for fat solubility in this liquid were made by adding a known weight of fat to a test tube and shaking it in a quantity of the alcohol-water mixture. The liquid was filtered through a 0.4 μm pore-size Nuclepore filter and poured into a small dish of known weight, from which it was allowed to evaporate. The dish was then weighed again to get the weight of the dissolved fat. An average of 2.48% of the fat dissolved, insufficient to appreciably reduce fat-induced agglomeration of alfalfa particles.

Sieve analysis was performed wet in the same liquids as used for sedimentation. A sample size of 8-10 gm was taken for sieving after cone-and-quartering on a neoprene sheet (material chosen to avoid static charge).

The sample to be sieved was weighed to 0.0001 gm, transferred to a beaker, and the desired sieving liquid added. The contents were poured through the coarsest sieve (841 μm) into a 4000-ml beaker of diameter slightly larger than the sieve. The first beaker was rinsed with a wash bottle containing the sieving liquid. The sieve was oscillated vertically through the liquid in the 4000-ml beaker. Wire bails were added to the sieves to facilitate handling. Sieving time varied from one to four minutes, depending on the amount of material retained on the sieve. Figure 7 shows the sieving equipment used.

This procedure was followed throughout the sieve series, alternately sieving into one 4000 ml beaker from another, until the last sieve was reached. The subsieve fraction of alfalfa dust, with liquid, was transferred to a 1000 ml beaker. The liquid was evaporated off and the subsieve fraction weighed.

The material captured on the sieves was transferred to previously weighed, 6-1/2-in. dia milk filters by inverting the sieves over the filters and directing wash water through the screen. Two thicknesses of the milk filter were used for the final three sieves (100, 140, and 200 mesh). The milk filters with alfalfa dust were covered to prevent foreign material settling on them, and air-dried for 36-48 hrs. They were finally weighed and the weight of captured material determined.

The size distribution of the subsieve fraction was determined by sedimentation in the same liquid. Centrifuge schedules were prepared for both liquids. Whitby [15] reported the density of alfalfa meal as 1.45 gm/cm^3, and this value was verified by test.

Prior to evaporating the liquid from the subsieve material, it was held in a beaker with 400-800 ml of liquid. The amount of liquid was varied to give the particulate concentration required by the MSA-Whitby particle size analyzer. Uniform distribution of the particles in the liquid was ensured by stirring for several minutes with a pneumatic stirrer. Settling time of the largest expected particle for the given height of liquid was calculated by means of Stokes' law. The sample was withdrawn with a long-tube dropper within this length of time after vortex motion subsided.

To minimize the effects of density streaming, it is desirable to add a "second liquid" and create a feeding liquid less dense and more viscous than the sedimentation liquid [15]. Due to inability to find a suitable "second liquid," this was not done with the alcohol-water mix. Only occasional density streaming occurred, necessitating discarding of that particular run.

A feeding liquid was found to be desirable with hexane, pentane fulfilling the requirements of a "second liquid." Due to the volatility of pentane, it was impractical to pre-mix feeding liquid and take the sample from it. Therefore, enough sample was taken of the hexane suspension to fill one-half the feeding chamber of the particle size analyzer. The remaining volume of the feeding chamber was filled with pentane and shaken vigorously between the fingers to mix the two liquids. The dropper used to collect the sample aspirated a consistent amount of liquid each time, so the proportions of hexane and pentane remained sufficiently constant throughout the test series. The remainder of the size analysis was performed in accordance with the instructions furnished with the MSA-Whitby particle size analyzer.

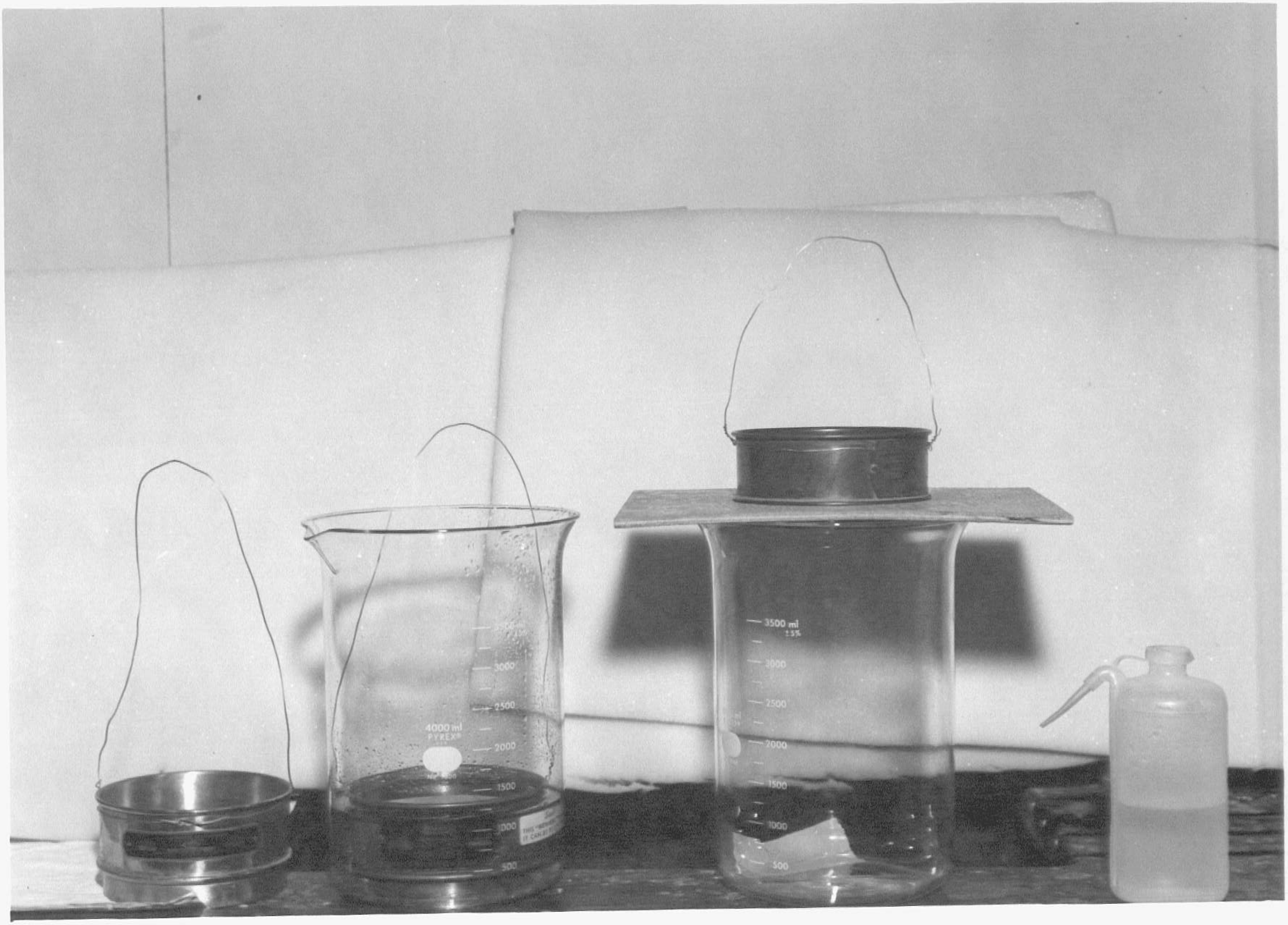


Figure 7. Sieving Equipment

RESULTS AND DISCUSSION

The purpose of this research was to develop techniques for studying the mechanism of cyclone collection improvement by the addition of liquid animal fat to dehydrated alfalfa prior to grinding. It was hypothesized that the increase in efficiency was caused by a coarser particle size distribution, resulting from reduced shattering in the hammer mill, from increased agglomeration of alfalfa particles, or from a combination of the two effects. The basic source of information was the particle size distributions obtained in liquid systems designed to either eliminate or retain the effects of agglomeration.

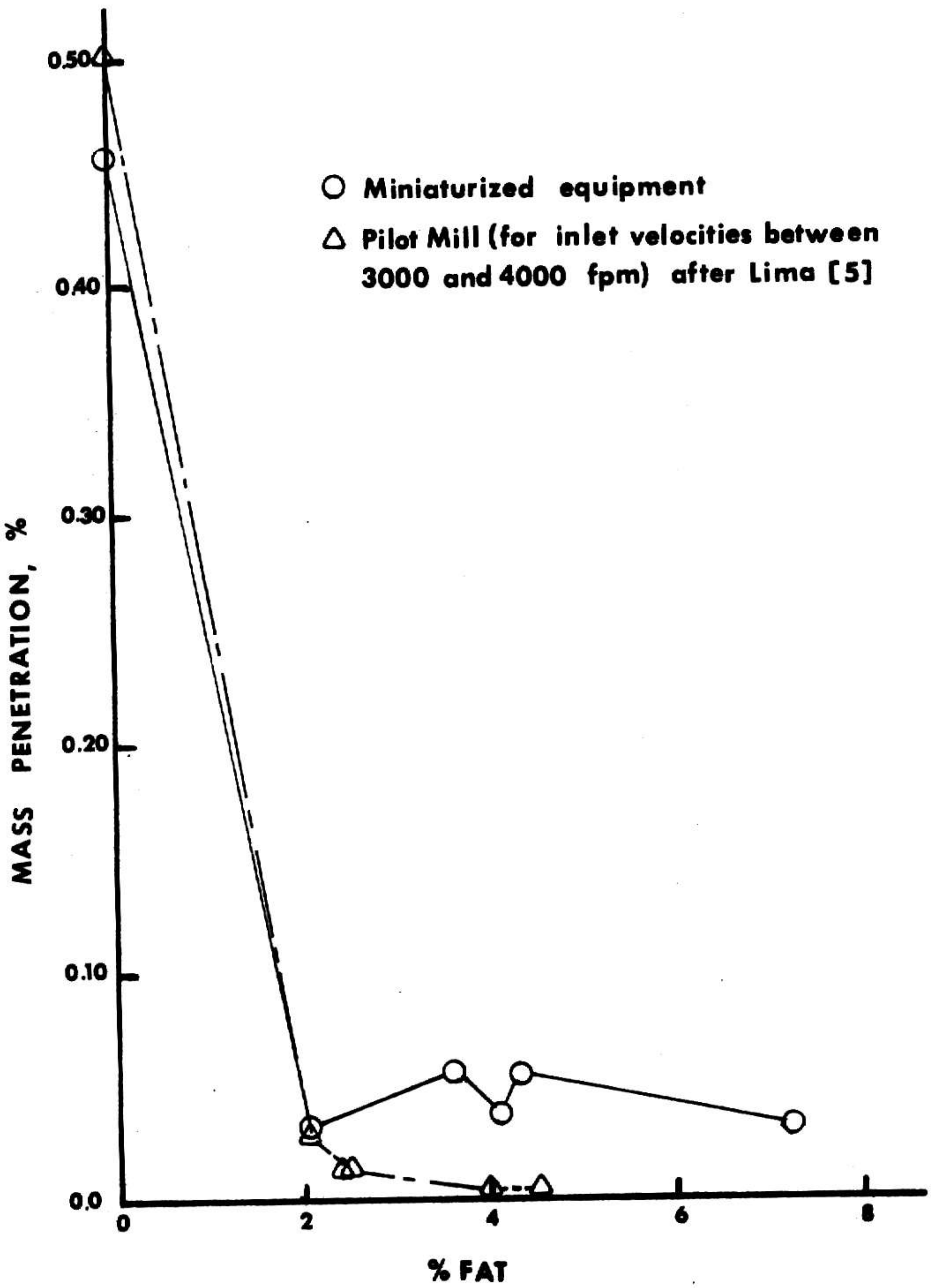
Mass Efficiency Results

The mass efficiency results for the test cyclone are shown in Table 2. Since it is the escaping effluent which causes air pollution, the "penetrations" are most relevant. These results compare favorably to those reported by Lima [5], for the lower fat levels and at similar inlet velocities, indicating the feasibility of using miniaturized equipment for testing the phenomena involved. Figure 8 shows comparative results plotted. The lack of improvement in efficiency with higher fat levels is thought to be due to the tendency of the small scale test apparatus to undergo stoppages due to accumulation of fatty dust, thereby entraining material into the cyclone's inner vortex and allowing it to escape as effluent from the clean gas discharge. Several test batches were discarded from consideration where it was obvious that this effect had taken place to a noticeable extent.

Table 2: Summary of Mass Efficiency Results for Cyclone Collection for Ground Dehydrated Alfalfa

% Fat	Avg. Mass Penetration, %		Avg. Mass Efficiency, %	
	Pilot Mill [5]	Miniaturized Mill	Pilot Mill	Miniaturized Mill
0	0.556	0.454	99.444	99.546
2.04	0.026	0.031	99.974	99.969
3.64	0.005	0.056	99.995	99.944
4.14	0.002	0.036	99.998	99.964
4.33	0.002	0.055	99.998	99.945
7.28	-----	0.031	------	99.969

FIGURE 8. MASS PENETRATION VS.
FAT PERCENTAGE



Particle Size Analyses

Particle size distributions were obtained for the ground dehydrated alfalfa under several conditions:

1. Fat-free effluent. Both sedimentation liquids were used.
2. Agglomerated effluent.
3. Deagglomerated effluent.
4. Fat-free collected product. A combination of sieving and sedimentation was used.
5. Agglomerated collected product. A combination of sieving and sedimentation was used.
6. Deagglomerated collected product. A combination of sieving and sedimentation was used.

Distributions 1, 2, and 3, above are shown superimposed for comparison in Figure 9. Figure 10 shows the same comparison of distributions 4, 5, and 6, above. Combined distributions (Combination of effluent and collected product) were calculated based on the average mass penetration for the distribution involved. The combined distributions are shown superimposed for comparison in Figure 11.

The mode appearing in the distributions at approximately 75 μm particle diameter coincides with the change from sieving to sedimentation analysis and is thought to be due to inherent inaccuracies in the combined sizing method. Whitby [15] obtained a bimodal distribution for alfalfa meal dust but the modes occurred at about 10 and 80 μm. Size analysis data which gave the distributions are shown in Appendix A.

Significance of the difference between corresponding points of the various distributions was tested using the t-distribution as described in Duncan [1], for those means whose variances were found equal. Test for equality of variance was made using the F-Distribution as described in Fryer [4], and those means with unequal variance were tested with an approximate t-test, also given by Fryer. Results of these tests are summarized in Appendix B.

Cyclone Fractional Efficiency

Using the average value of mass penetration and the size distribution curves for effluent and collected product, a fractional size efficiency curve was constructed for the cyclone collector based on alfalfa ground without fat (See Appendix C). A smooth curve, corresponding in shape to those given by Stairmand [12], was approximated through the points, and is shown in Figure 12. The collection efficiency of the cyclone was then recalculated for the combined fat-free distribution as a check. The results are shown in Table 3.

The combined deagglomerated distribution was the distribution which would occur if no agglomeration took place, i.e. it shows the effect of fat upon the comminution process only. This size distribution, when applied to the fractional efficiency curve of the cyclone, therefore gives the collection efficiency which would occur based only on the change in degree of comminution or shattering inducted by the presence of the animal fat. The results of the calculated collection efficiencies are summarized in Table 3.

A supplementary experiment was performed by grinding polished rice with and without fat. The purpose of this test was to verify the activity of agglomeration as a significant effect on mass penetration of the cyclone. Details and results are in Appendix D, rather than the body of this thesis, because the experimental design was inadequate, although promising.

Discussion of Results

The feasibility of using miniaturized grinding and collection equipment for studying cyclone collection efficiency improvement was established by this study. Methods were developed which enabled quantification of the relative contributions of fat-induced reduced shattering and agglomeration to cyclone collection efficiency.

The experimental results were, in some respects, inconsistent with theory. Principal among these is the fact that the deagglomerated distribution was finer than the fat-free distribution for particle sizes greater than about 6 μm. If these results were true, they might indicate that shattering actually increased for larger particle sizes as fat was added. However, nothing can be found in the literature which would fully substantiate this phenomenon, particularly for a fibrous material. A possible explanation is that natural agglomerates were being broken down by the hexane solvent, causing a shift in distributions not related to the presence or absence of fat. It is also possible that insufficient and atypical data has caused this shift, and that a considerably larger number of test runs would resolve the anomaly.

The increase in penetration from 0.41 to 0.51% obtained by applying the deagglomerated distribution to the cyclone fractional efficiency curve, would eliminate reduced shattering as a significant mechanism. However, since the deagglomerated distribution is finer than the fat-free, it is not justifiable to eliminate reduced shattering as a contributor to cyclone collection improvement.

Differences in the number and alfalfa lot of test runs for collected product and effluent is also noted. Due to the very small mass of effluent compared to collected product, however, this could not be expected to significantly shift the distribution.

Another possibility, which the test techniques were not designed to consider, is that fundamental differences may exist in the action of fat on leafy material as compared to stems. It seems likely that most of the finest particles come from the leafy portion, so this portion would get the most benefit from fat addition, although the test procedures could not distinguish leaf from stem.

A further problem involved in analysis of test results is the high heterogeneity of the dehydrated alfalfa itself. Various proportions of leaf and stem were encountered, as well as varying amounts of extraneous plant material such as weeds, corn husks, etc. Reaction to the fat in grinding thus would be expected to vary.

Table 3: Calculated Collection Efficiencies for Combined Size Distributions

	Fat-free	Deagglomerated
Calculated Collection Efficiency, %	99.59	99.49
Calculated Penetration, %	0.41	0.51
Observed Collection Efficiency, %	99.55	-----
Observed Penetration, %	0.45	-----

FIGURE 9. EFFLUENT SIZE DISTRIBUTIONS

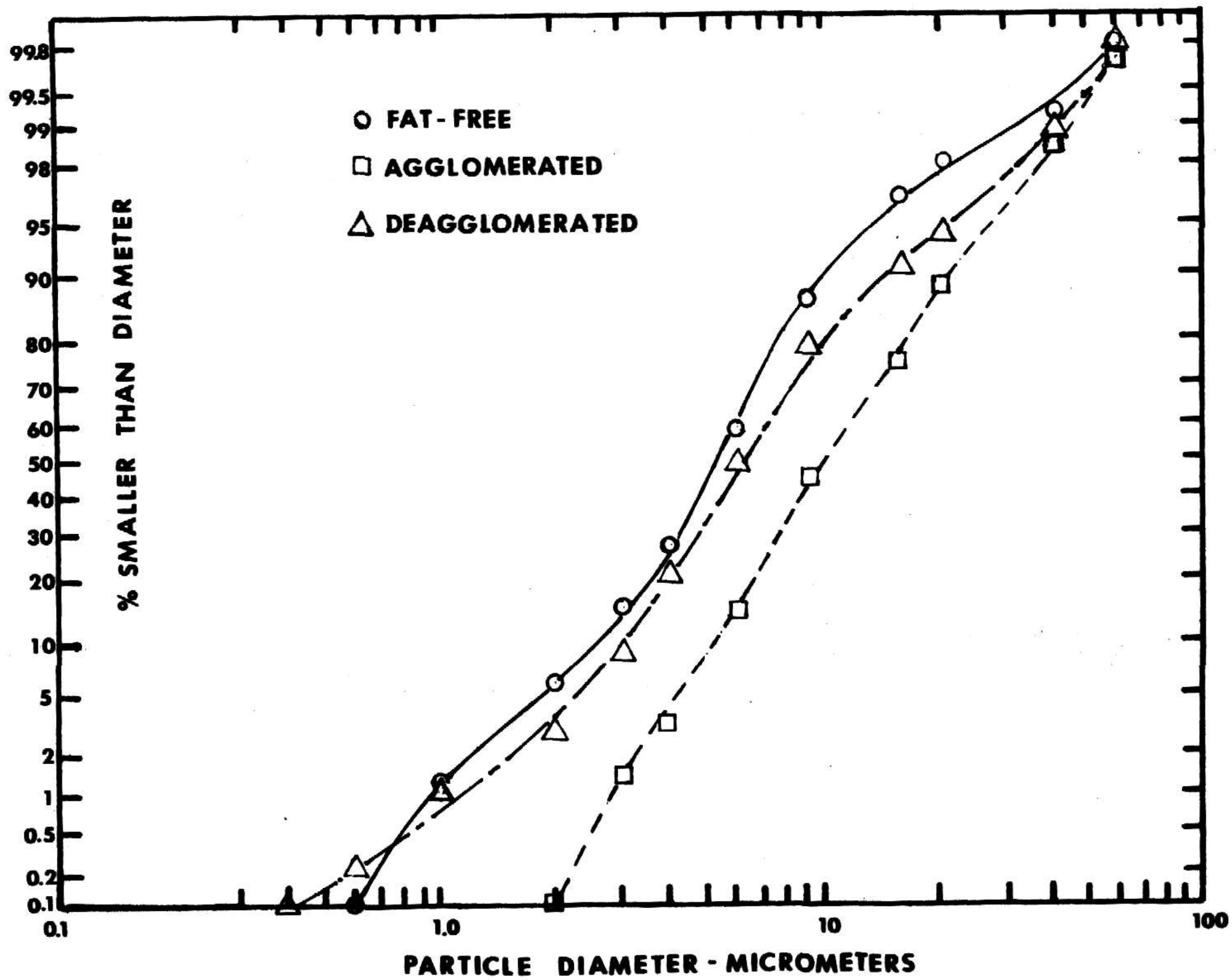


FIGURE 10. COLLECTED PRODUCT SIZE DISTRIBUTIONS

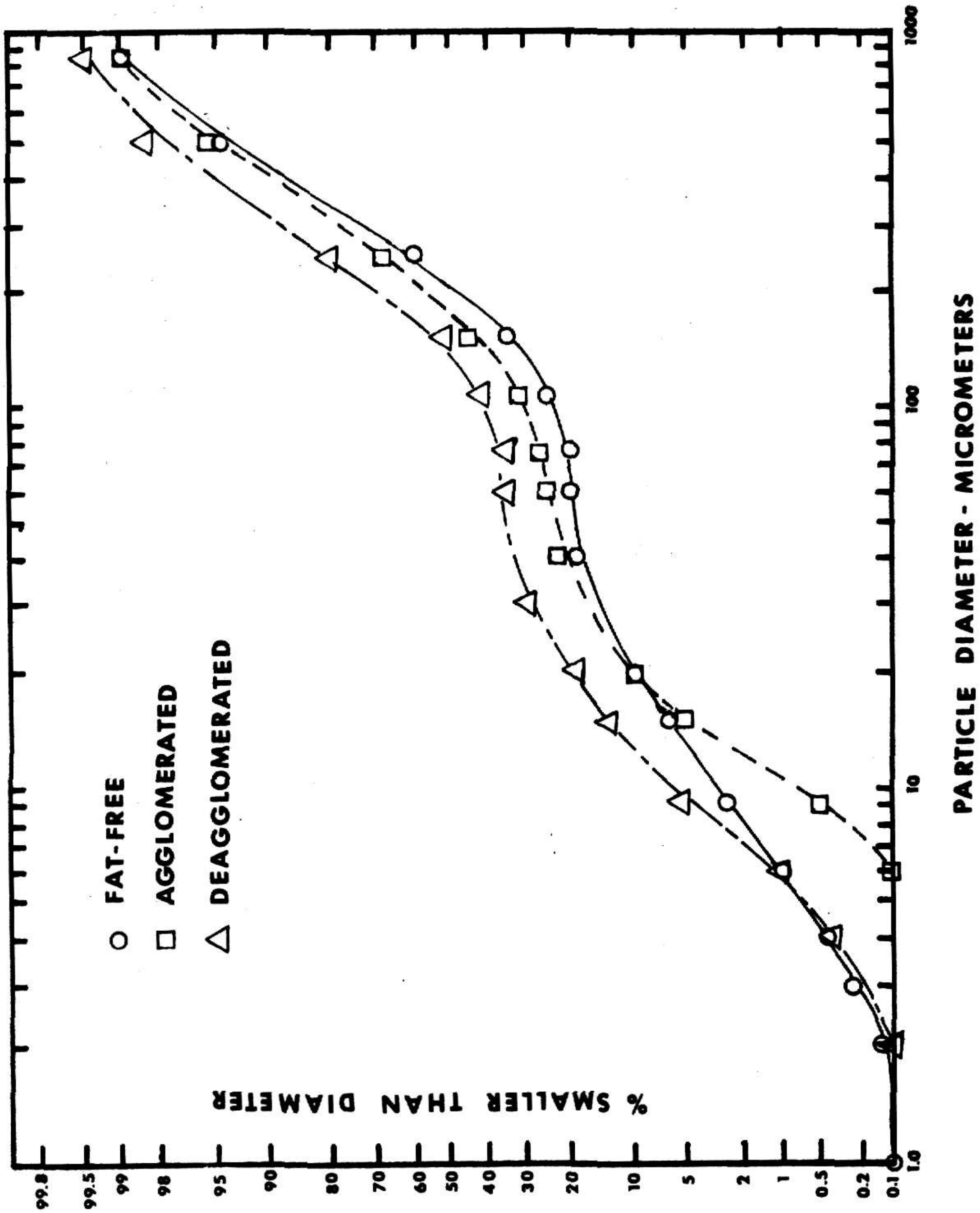


FIGURE 11. COMBINED SIZE DISTRIBUTIONS

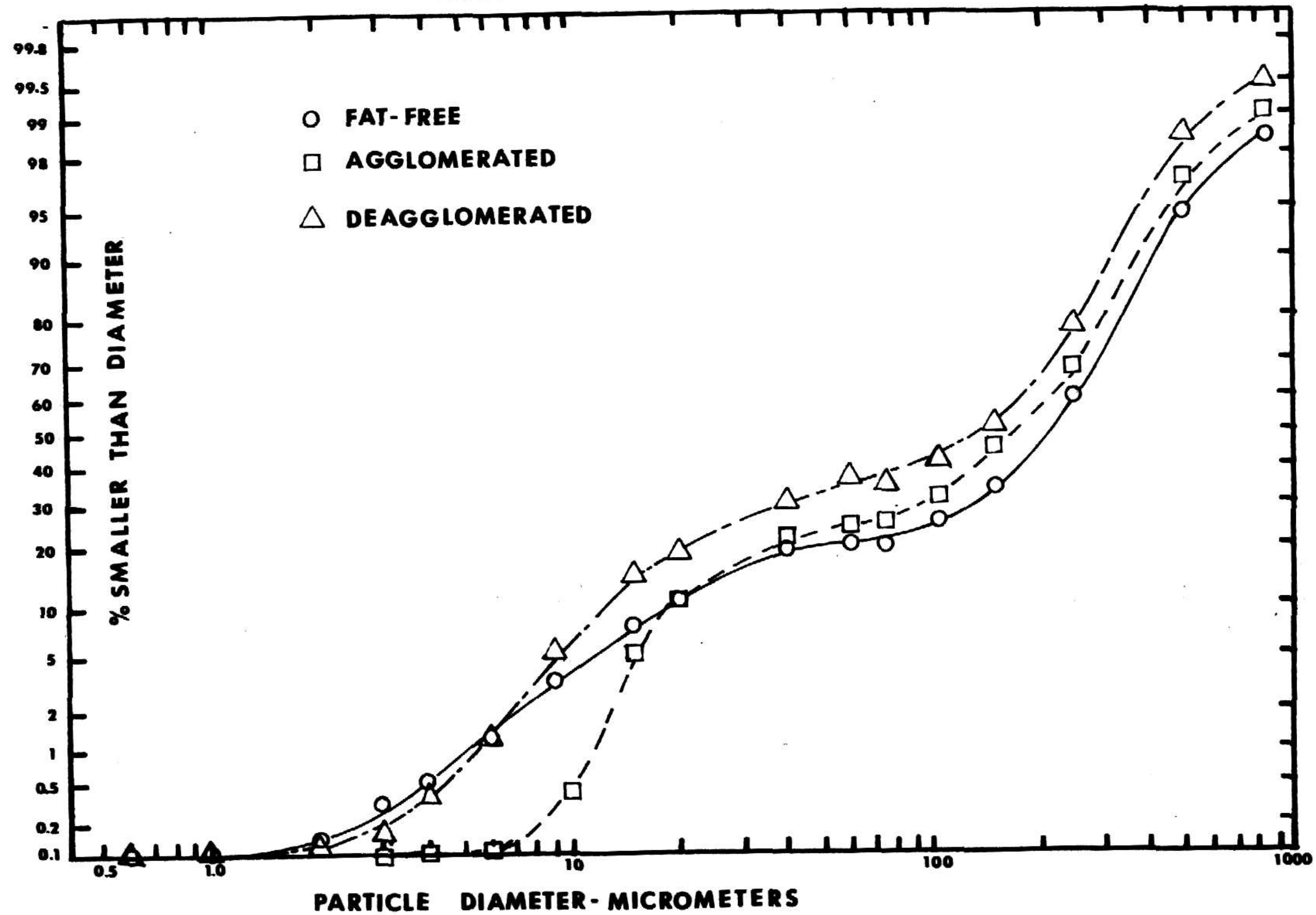
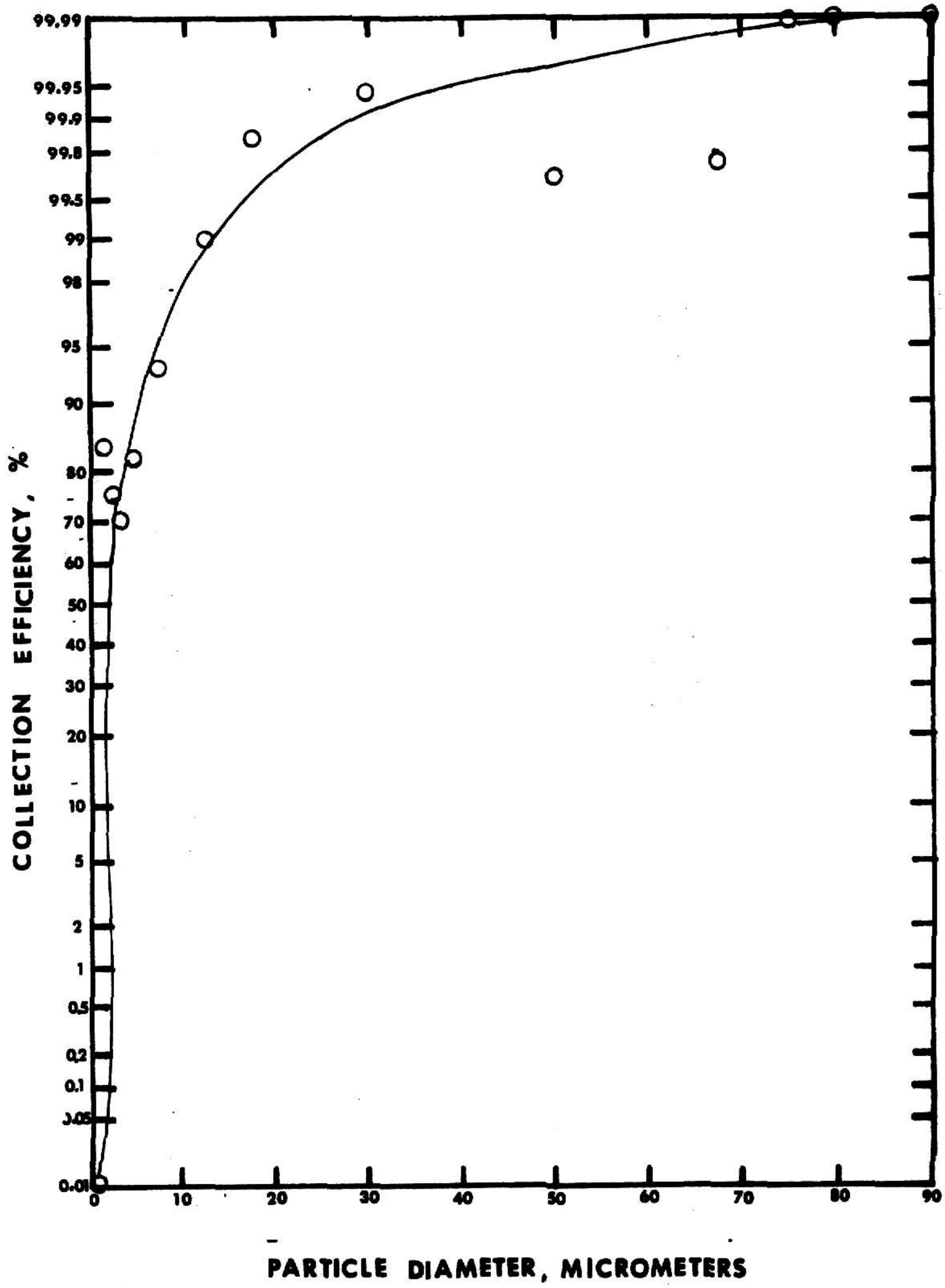


FIGURE 12. APPROXIMATE FRACTIONAL EFFICIENCY CURVE FOR TEST CYCLONE



SUMMARY AND CONCLUSIONS

The study reported in this thesis developed satisfactory or promising techniques for determining the mechanism of improving the cyclone collection of alfalfa dust by addition of low percentages of animal fat prior to grinding. This was done with the intention of improving the process and enabling predictions of the effect of fat addition to feed grain milling effluent. The comparative particle size distributions of the alfalfa ground, with and without fat, were the principal sources of information on the process. For alfalfa ground with fat, size distributions were obtained with and without the fat having been dissolved out.

A fractional efficiency curve was approximated for the test cyclone, based on mass efficiency tests and size distributions for fat-free alfalfa. The combined size distribution obtained for deagglomerated alfalfa particles was applied to this curve.

Results of the preceding tests are as follows:

1. The size distribution of the fat-free effluent was not significantly different from that of the deagglomerated effluent, although slightly coarser (Fig. 9). If reduced shattering had been active, the deagglomerated distribution should have shifted significantly to the coarser side of the fat-free distribution.
2. The size distribution of the fat-free collected product was somewhat finer than for the deagglomerated collected product at the fine end of the distributions (less than 5 μm, Fig. 10). This would be an indication of reduced

shattering, at least in the fine portion of the distribution. However, the fine ends of size distributions obtained by sedimentation are subject to inherent inaccuracies. The difference between the two distributions thus does not offer substantiative proof of the activity of reduced shattering.

3. For sizes greater than about 6 μm, the fat-free combined distribution is coarser than the deagglomerated distribution (Fig. 11). This is in opposition to expectation if reduced shattering had occurred throughout the range of particle sizes.

4. The agglomerated effluent distribution (Fig. 9) showed no particles smaller than 3 μm, and the agglomerated collected product (Fig. 10) had no particles smaller than 6 μm. For particle sizes greater than about 20 μm, the combined agglomerated distribution (Fig. 11) was finer than the combined fat-free distribution, although not significantly so at the 5% level of rejection. The fat-free distribution was expected to be finer if reduced shattering had occurred.

5. The deagglomerated combined distribution (Fig. 11) was significantly finer than the fat-free combined distribution for the particle sizes larger than about 15 μm. The expectation was that the deagglomerated should have been coarser for reduced shattering, and show no change for agglomeration. The observed result indicates that perhaps factors not considered are affecting test results.

6. The deagglomerated combined distribution proved less efficiently collected than the fat-free combined distribution when applied to the fractional efficiency curve for the test cyclone (Table 3). This indicates that reduced shattering contributes nothing to cyclone collection improvement. This conclusion, however, is dependent on the validity of the deagglomerated distribution.

The test results are inconclusive with regard to reduced shattering as a significant mechanism in the improvement of cyclone collection efficiency of ground dehydrated alfalfa. No test result could be interpreted as tending to eliminate agglomeration.

Some reduced shattering may be occurring, particularly at the finest end of the size distributions. If so, however, the effect was not large enough to affect substantiative computations. The results do show evidence that agglomeration contributes to improvement in cyclone collection efficiency by fat addition.

Additional research in this area should study the effects of fat on the various components of dehydrated alfalfa, and by suitable methods determine the actual effect on physical properties. This could be followed up with grinding tests, and perhaps a more complete answer to the question of reduced shattering could be found. A greater number of replicate runs and analyses will be necessary. Since the fat addition process seems to show promise for collection improvement in grain grinding, studies on the effects of fat on the nutritive quality and storage life of ground grains would be helpful.

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APPENDICES

APPENDIX A

SIZE DISTRIBUTION DATA

The following tables show raw size distribution data as obtained by:

1. Sedimentation of Effluent
2. Sieving of Collected Product
3. Sedimentation of Sub-sieve Fraction of Collected Product.

Pooled data show mean percentages less than stated size, standard deviation, and standard error.

The average distributions obtained are shown plotted in Figures A-1 through A-6.

Table A-1: Percentages Less Than Diameter: Effluent

	Particle Diameter, µm											
	75	60	40	20	15	9	6	4	3	2	1	0.6
					Fat-Free							
Run #1	100	99.918	98.39	97.58	95.97	90.33	70.2	38.7	18.6	3.2	0.0	
	100	99.493	98.99	96.96	95.43	91.87	63.6	33.5	18.8	9.2	0.0	
		100	99.42	98.26	95.35	93.62	76.2	48.8	26.2	13.9	6.4	0.0
		100	99.564	99.13	98.25	93.88	65.1	34.0	18.3	4.4	1.2	0.0
		100	99.426	98.85	98.28	93.68	68.9	31.0	13.3	7.0	0.7	0.0
Run #2			100	99.656	99.31	98.28	72.2	38.1	19.7	5.5	0.4	0.0
			100	99.272	98.91	93.81	66.6	32.8	20.0	6.8	0.9	0.0
			100	99.617	98.86	98.09	69.4	33.2	19.5	6.4	0.4	0.0
		100	99.716	99.147	98.87	92.91	60.8	32.6	16.1	3.5	1.2	0.0
		100	99.666	98.970	97.94	93.81	72.2	35.3	17.1	8.0	0.5	0.0
		100	99.724	99.447	99.17	97.79	73.5	43.4	24.3	9.4	1.2	0.0
Run #9	100	99.433	97.80	95.58	91.18	62.8	29.5	14.5	9.6	3.6	2.3	0.0
		100	99.44	96.73	93.26	70.8	36.1	10.7	10.1	4.5	1.1	0.0
	100	99.618	99.31	98.61	97.27	77.4	41.3	6.6	5.3	4.5	0.6	0.0
					Pooled Results							
$\bar{x}$	100	99.806	99.174	98.159	96.462	86.397	58.517	27.90	15.607	6.11	1.32	0.0
σ	---	0.289	0.734	1.197	2.374	10.547	14.711	11.663	5.487	2.882	1.549	---
s	---	0.087	0.196	0.320	0.634	2.819	3.932	3.117	1.466	0.770	0.414	---

Table A-1: Percentages Less Than Diameter: Effluent (Cont'd)

	Particle Diameter, µm									
	75	60	40	20	15	9	6	4	3	2
					Agglomerated					
Run #5		100	99.338	96.03	93.39	61.6	21.1	6.6	0.0	
		100	99.692	96.92	94.45	68.5	34.6	15.3	6.8	0.0
		100	99.412	95.88	93.52	63.6	24.1	6.4	4.6	0.0
		100	99.493	97.97	90.36	59.4	23.8	3.1	0.0	
	100	99.355	96.780	94.84	88.40	57.4	18.1	0.0		
	100	99.343	98.680	96.71	93.91	----	23.0	0.0		
		100	98.820	97.06	93.53	63.5	21.2	6.5	0.0	
Run #12	100	99.534	97.67	86.4	-----	33.6	14.8	1.9	0.0	
	100	99.466	97.86	81.8	64.7	22.4	4.2	0.0		
	100	99.643	98.57	81.8	56.4	20.5	0.5	0.0		
		100	98.98	78.6	54.4	28.8	4.7	0.7	0.0	
	100	99.528	97.64	72.6	55.2	27.9	7.6	1.4	0.0	
					Pooled Results					
$\bar{x}$	100	99.724	98.516	88.363	75.092	44.49	15.03	3.11	1.44	0.0
σ	---	0.262	0.912	10.691	18.737	20.422	10.36	4.309	2.526	---
s	---	0.076	0.263	3.086	5.409	5.895	2.99	1.244	0.792	---

Table A-1: Percentages Less Than Diameter: Effluent (Cont'd)

	Particle Diameter, μm												
	75	60	40	20	15	9	6	4	3	2	1	0.6	0.3
						Deagglomerated							
Run #5		100	99.324	98.65	97.97	94.60	70.9	31.1	12.7	1.4	0.0		
		100	99.334	98.67	98.00	93.34	55.4	24.0	12.7	3.4	0.7	0.0	
		100	99.301	97.21	95.80	85.30	56.7	29.4	13.3	2.8	0.8	0.0	
		100	99.409	98.82	98.22	89.95	47.9	18.3	11.2	3.6	2.8	1.8	0.0
		100	99.330	98.66	97.32	91.27	52.3	25.6	10.8	4.1	2.4	0.6	0.0
		100	99.471	98.94	98.41	93.66	63.5	19.6	5.8	3.2	2.6	0.5	0.0
			100	99.43	98.85	95.98	63.7	25.3	10.4	1.3	0.6	0.0	
Run #10	100	99.212	96.01	83.10	72.9	51.3	27.9	10.2	4.8	0.9	0.5	0.0	
	100	99.614	97.68	87.96	80.7	58.3	30.8	14.4	6.2	0.8	0.0		
		100	99.21	96.85	92.9	85.8	61.6	30.0	12.5	5.4	2.2	0.0	
	100	98.215	91.97	75.90	69.7	50.9	38.4	19.7	11.6	7.2	2.7	0.0	
		100	99.25	85.71	79.0	60.9	36.8	20.3	11.3	9.0	6.0	0.0	
Run #11		100	99.324	97.97	96.62	80.4	48.7	24.2	11.5	4.1	0.0		
		100	99.324	97.30	95.95	84.6	58.2	10.1	4.2	2.1	0.0		
		100	99.329	97.98	95.97	81.2	57.1	24.2	4.8	0.7	0.0		
		100	99.405	97.62	94.65	69.1	41.1	14.8	6.0	1.2	0.0		
		100	99.384	98.15	95.67	84.6	48.2	11.7	3.9	0.6	0.0		
						Pooled Results							
$\bar{x}$	100	99.802	98.543	94.111	90.866	78.24	49.46	20.23	8.8	3.1	1.2	0.24	0.0
σ	---	0.461	1.914	6.765	9.309	14.921	11.619	6.585	5.411	2.329	1.60	0.548	---
s	---	0.029	0.464	1.641	2.258	3.619	2.818	1.597	1.312	0.565	0.39	0.17	---

Table A-2: Percentages Less Than Diameter: Sieve Fraction of Collected Product

	Particle Diameter, μm					
	841	500	250	149	105	75
			Agglomerated			
Run #5	99.343	96.566	72.134	46.256	33.416	26.612
6	99.253	96.409	60.896	35.197	26.383	21.306
7	98.169	95.401	69.894	54.716	33.862	25.970
8	99.092	96.644	67.356	46.313	31.837	24.860
			Pooled Results			
$\bar{x}$	98.922	96.125	67.641	45.390	31.220	24.628
σ	0.533	0.516	4.856	7.992	3.426	2.367
s	0.267	0.258	2.428	3.996	1.713	1.184
			Deagglomerated			
Run #5	99.674	99.004	76.117	45.405	35.449	29.393
6	99.402	98.065	79.415	54.725	47.678	39.158
7	99.463	98.424	78.161	52.082	41.236	34.958
8	99.629	98.655	84.883	57.815	48.310	40.801
			Pooled Results			
$\bar{x}$	99.513	98.498	77.896	50.737	41.454	34.503
σ	0.116	0.387	1.36	3.922	4.99	3.99
s	0.058	0.194	0.68	1.961	2.495	1.995
			Fat-Free			
Run #1	98.806	97.110	58.885	34.101	22.735	17.939
2	98.330	92.815	61.250	30.894	22.916	16.667
3	99.966	97.187	59.719	36.281	25.809	19.363
4	98.512	94.825	59.114	34.747	28.037	23.486
			Pooled Results			
$\bar{x}$	98.936	94.949	60.028	33.974	25.588	19.838
σ	0.732	1.786	0.899	2.660	2.097	2.804
s	0.366	0.893	0.450	1.33	1.049	1.402

Table A-3: Percentages Less Than Diameter, Subsieve Fraction of Collected Product

	Particle Diameter, μm											
	75	60	40	20	15	9	6	4	3	2	1	0.6
Fat-Free												
Run #1	100	99.605	97.23	----	41.6	14.6	4.7	1.6	0.8	0.0		
2	100	99.314	93.81	49.8	31.6	11.4	4.8	1.7	1.1	0.4	0.0	
3	100	99.481	94.54	51.3	36.9	14.3	5.2	1.7	0.8	0.0		
4	100	99.612	95.35	55.8	37.9	17.4	6.3	2.7	1.9	0.4	0.0	
Pooled Results												
$\bar{x}$	100	99.528	95.232	52.3	37.0	14.43	5.25	1.68	1.15	0.20	0.0	
σ	---	0.124	1.275	2.550	3.576	2.124	0.634	0.043	0.450	0.20	---	
s	---	0.062	0.814	1.275	1.788	1.062	0.317	0.022	0.225	0.10	---	
Agglomerated												
Run #5	100	98.97	90.37	42.3	22.0	2.7	0.0					
6	100	99.36	90.68	51.7	29.3	0.7	0.0					
7	100	99.21	92.38	40.6	21.3	2.6	0.0					
8	100	99.50	90.26	38.1	11.0	0.8	0.0					
Pooled Results												
$\bar{x}$	100	99.26	90.92	43.175	20.9	1.7	0.0					
σ	---	0.196	0.856	5.144	6.518	0.951	---					
s	---	0.098	0.428	2.572	3.259	0.476	---					

Table A-3: Percentages Less Than Diameter, Subsieve Fraction of Collected Product (Cont'd)

	Particle Diameter, μm										
	75	60	40	20	15	9	6	4	3	2	1	0.6
					Deagglomerated							
Run #5	100	99.814	90.47	60.3	49.1	29.4	12.8	5.0	2.7	0.6	0.0	
6	100	99.583	92.48	50.9	42.4	21.9	6.3	2.2	1.8	1.4	0.6	0.0
7	100	98.910	89.60	49.6	41.4	24.6	9.0	2.3	1.9	1.1	0.8	0.0
8	100	99.582	93.93	64.6	51.8	16.5	3.4	2.9	0.7	0.3	0.0	
					Pooled Results							
$\bar{x}$	100	99.472	91.62	56.35	46.175	23.10	7.88	3.10	1.78	0.85	0.2	0.0
σ	---	0.388	1.694	6.303	4.395	4.662	3.465	1.129	0.712	0.423	0.34	---
s	---	0.169	0.847	3.152	2.198	2.331	1.732	0.564	0.356	0.214	0.17	---

FIGURE A-1. FAT-FREE EFFLUENT

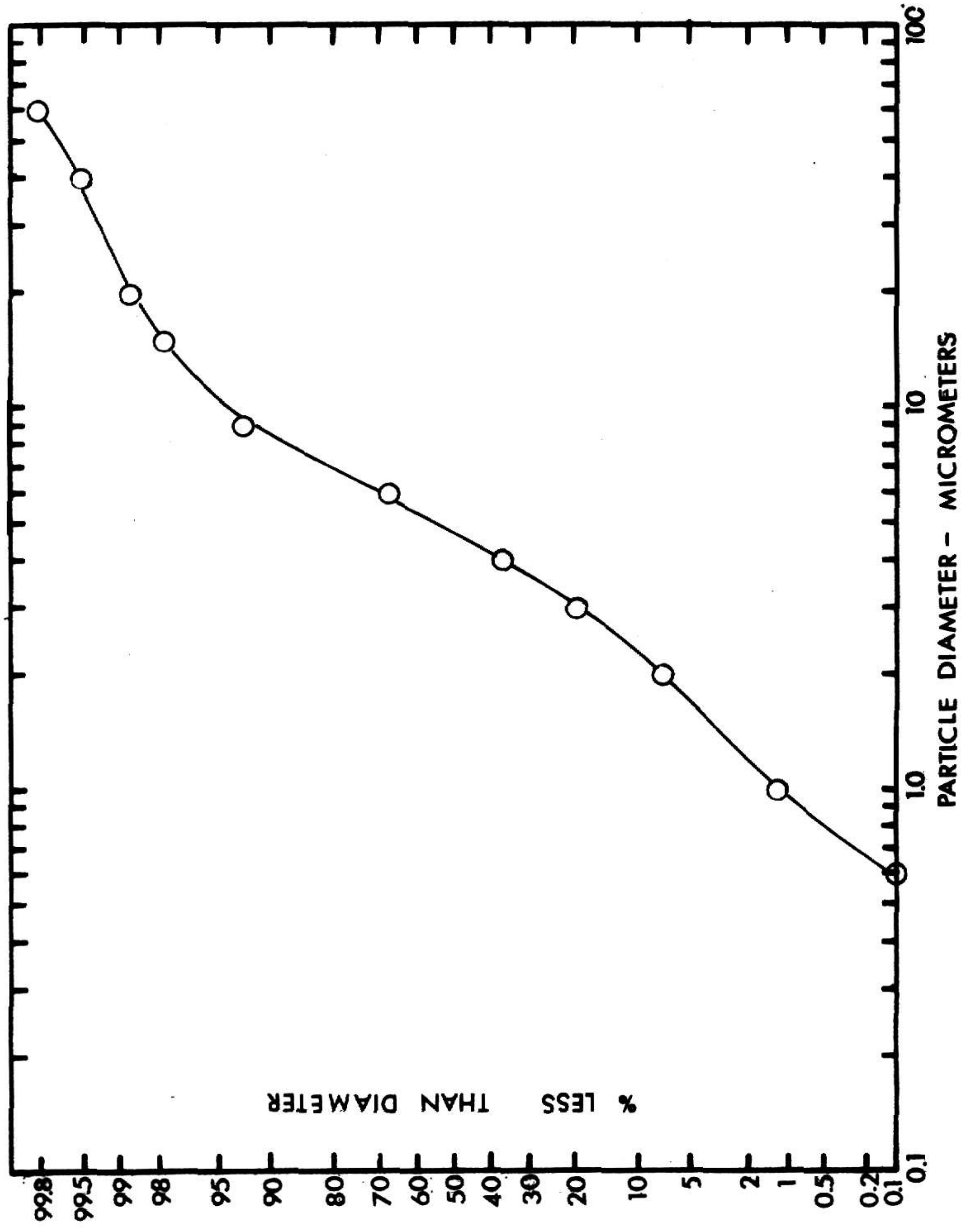


FIGURE A-2. AGGLOMERATED EFFLUENT

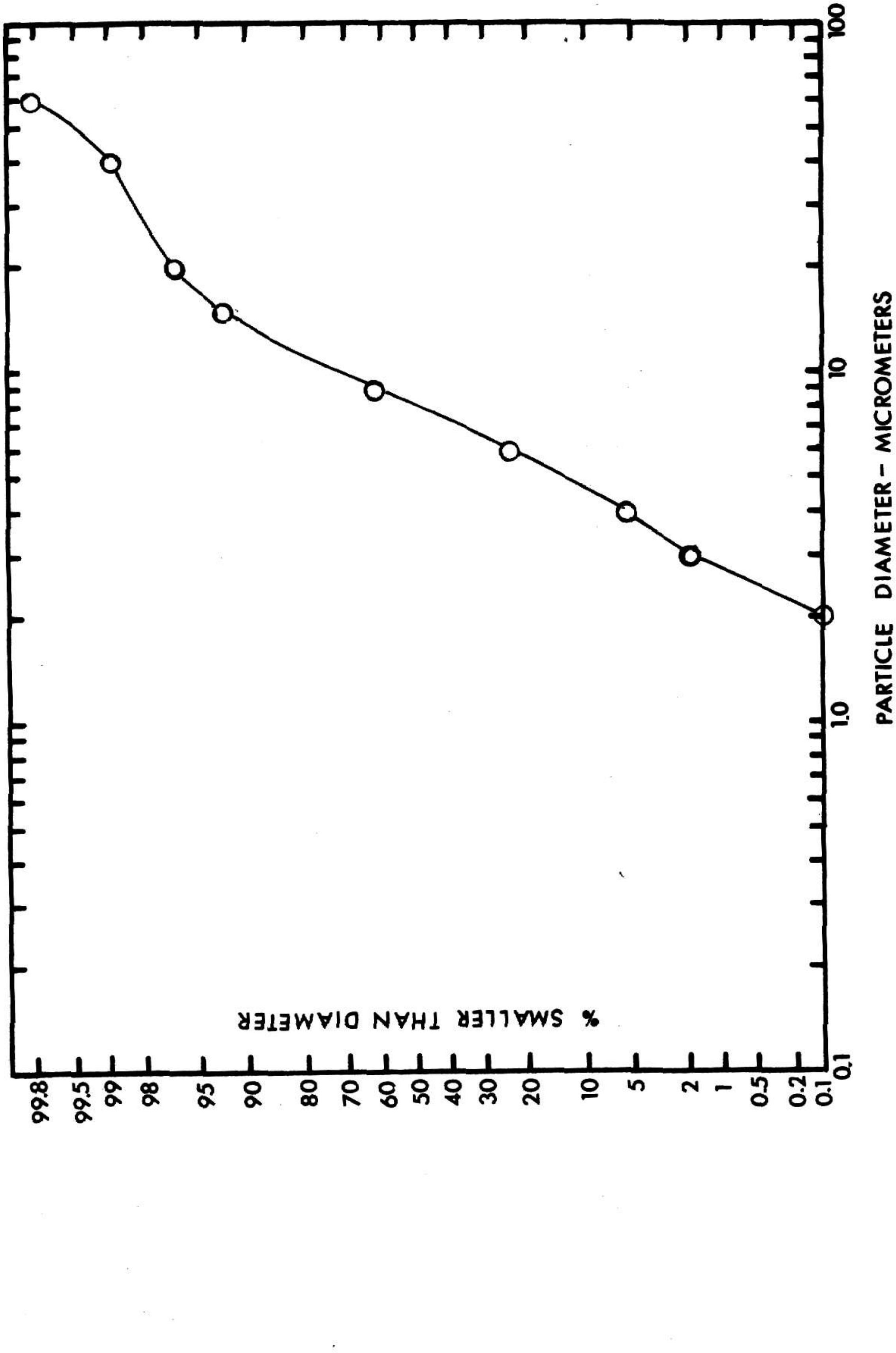


FIGURE A-3. DEAGGLOMERATED EFFLUENT

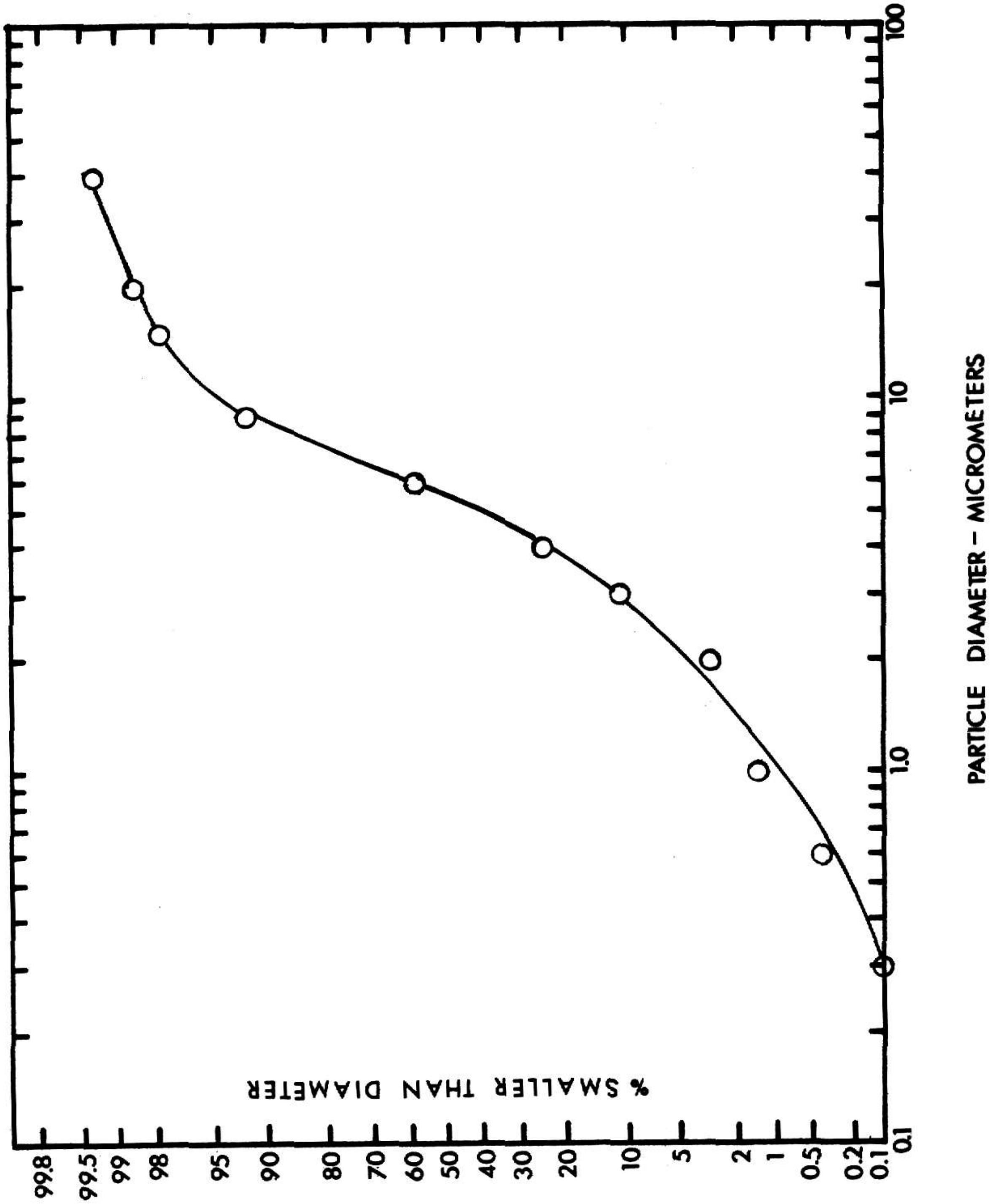


FIGURE A-4. FAT-FREE COLLECTED PRODUCT

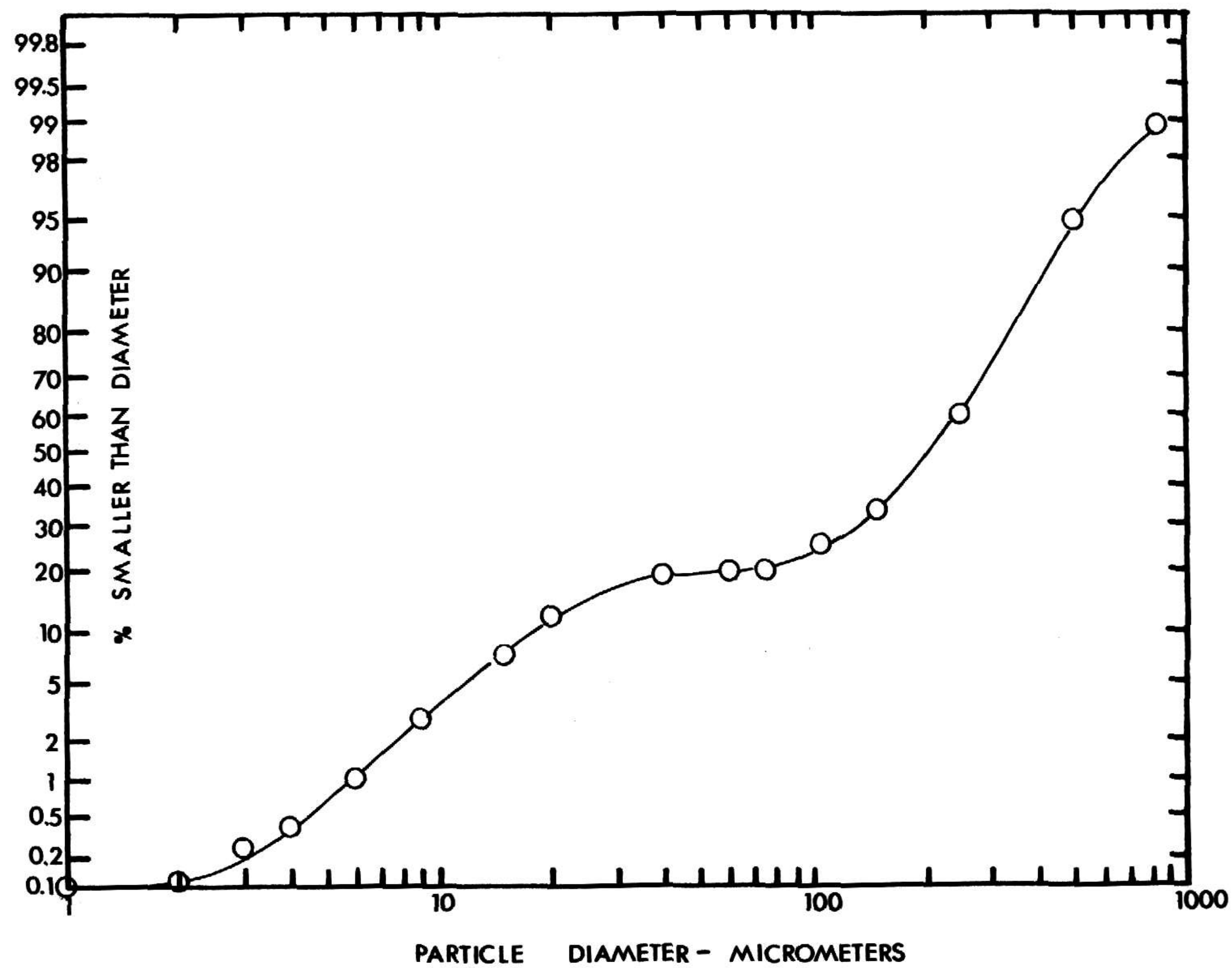


FIGURE A-5. AGGLOMERATED COLLECTED PRODUCT

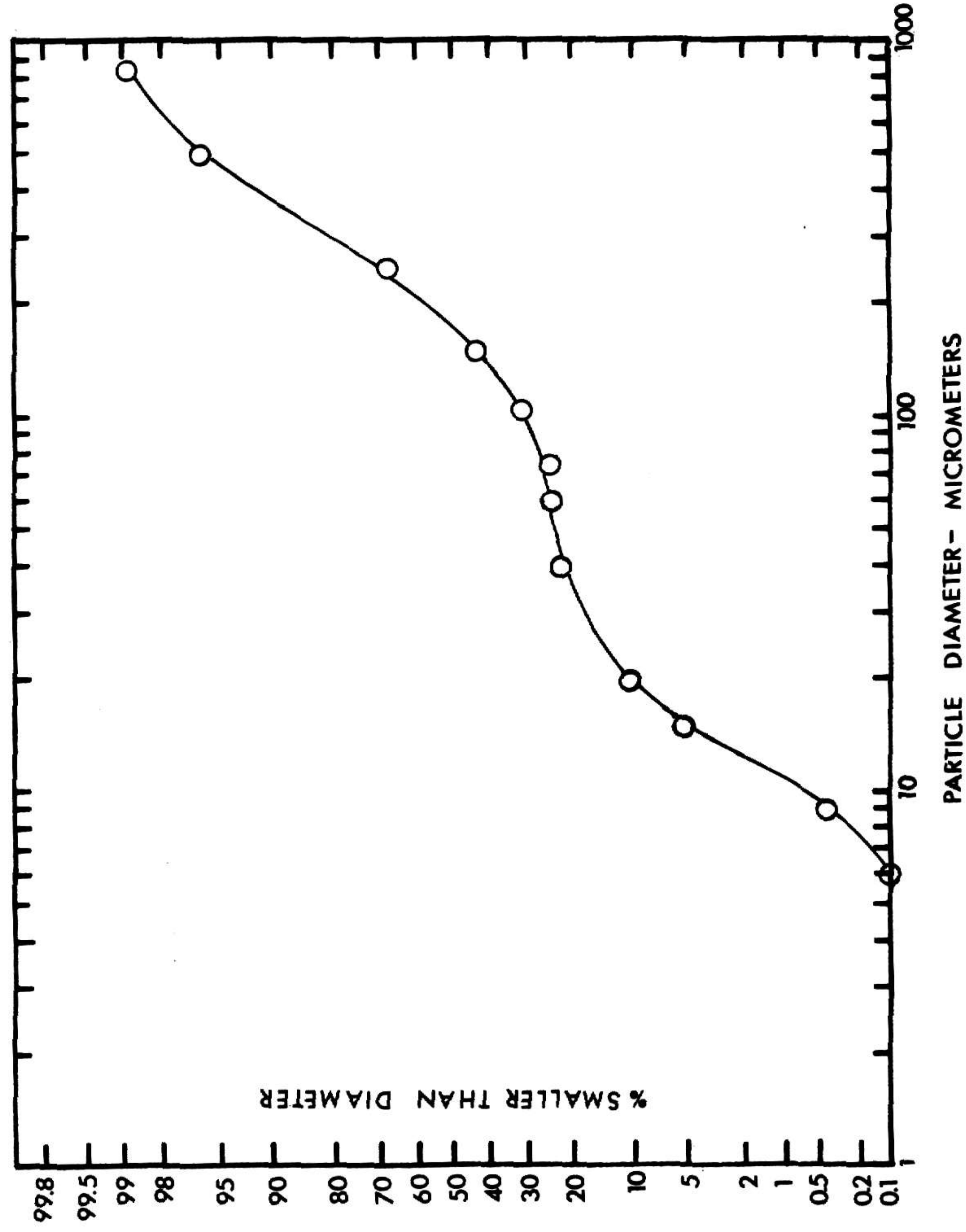
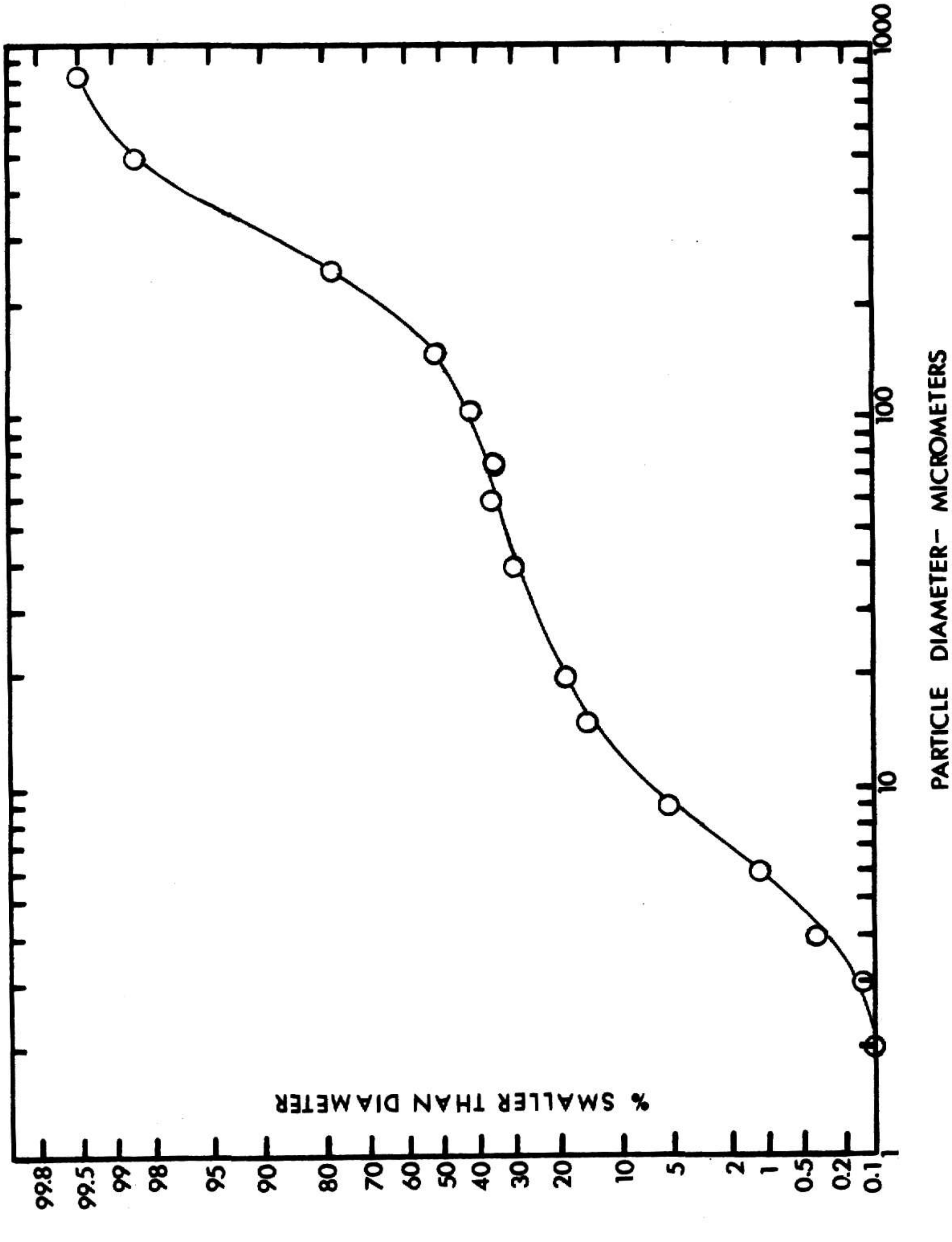


FIGURE A-6. DEAGGLOMERATED COLLECTED PRODUCT



APPENDIX B

TESTS FOR EQUALITY OF MEANS

Assuming mean percentages less than a given particle diameter to be normally distributed, equality of the directly sampled means was tested.

Null hypothesis: $\bar{x}_1 = \bar{x}_2$

Alternative hypothesis: $\bar{x}_1 \neq \bar{x}_2$

The test statistic is: $$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{s_1^2 + s_2^2}}$$

with $N_1 + N_2 - 2$ degrees of freedom. Table B-1 shows tests for effluent, and Table B-2 shows tests for collected product.

Table B-1: Tests for Equality of Replicate Means: Effluent

	Particle Diameter, μm									
	60	40	20	15	9	6	4	3	2	1
	<u>Deagglomerated Effluent vs. Fat-Free Effluent</u>									
$\bar{x}_1 - \bar{x}_2$	0.078	0.027	5.748	15.774	33.753	34.433	17.119	7.343		
t	0.959*	0.051*	1.645*	2.691	4.879	8.379	8.457	4.791		
	<u>Deagglomerated Effluent vs. Fat-Free Effluent</u>									
$\bar{x}_1 - \bar{x}_2$	0.004	0.631	4.048	5.596	8.158	9.054	7.674	6.825	3.037	0.089
t	0.044*	1.253*	2.421	2.386	1.778*	1.872*	2.191	3.469	3.180	0.157*
	<u>Agglomerated Effluent vs. Fat-Free Effluent</u>									
$\bar{x}_1 - \bar{x}_2$	0.082	0.658	9.796	21.370	41.911	43.487	24.793	14.168		
t	0.709*	2.006*	3.157	3.924	6.414	8.802	7.387	8.503		

*Denotes no significant difference at 5% level.

Table B-2: Tests for Equality of Replicate Means: Collected Product

	Particle Diameter, μm							
	841	500	250	149	105	75	60	40
				Fat-Free vs. Agglomerated				
$\bar{x}_1 - \bar{x}_2$	0.0145	1.177	7.614	11.416	5.63	4.79	4.70	3.50
t	0.028*	0.026*	2.669*	2.380*	2.428*	2.261*	2.232*	1.767*
				Agglomerated vs. Deagglomerated				
$\bar{x}_1 - \bar{x}_2$	0.591	2.372	10.254	5.348	10.234	9.875	11.868	7.558
t	1.875*	6.36	3.521	1.038*	2.926*	3.681	6.474	5.349
				Fat-Free vs. Deagglomerated				
$\bar{x}_1 - \bar{x}_2$	0.577	3.549	17.868	16.763	15.866	14.665	16.567	11.06
t	1.348*	3.363	18.971	6.409	5.073	5.201	8.163	6.574

Table B-2: Tests for Equality of Replicate Means: Collected Product (Cont'd)

	Particle Diameter, μm						
	20	15	9	6	4	3	2
$\bar{x}_1 - \bar{x}_2$	0.258	2.193	2.443	1.042			
t	0.249*	3.305*	10.26	12.28			
			<u>Agglomerated vs. Deagglomerated</u>				
$\bar{x}_1 - \bar{x}_2$	8.087	9.558	4.789	1.189			
t	13.281	31.57	5.762	6.386			
			<u>Fat-Free vs. Deagglomerated</u>				
$\bar{x}_1 - \bar{x}_2$	8.34	7.365	2.345	0.147	0.007	0.140	0.108
t	9.698	12.128	2.719*	0.718*	0.105*	6.368	12.23

*Denotes no significant difference at 5% level.

APPENDIX C

CYCLONE FRACTIONAL EFFICIENCY CALCULATIONS

Data for construction of the fractional efficiency curve for the test cyclone consisted of the fat-free combined distribution, fat-free effluent distribution, and average mass penetration for fat-free grinding. The collected product, effluent, and combined particle size distributions for fat-free alfalfa are shown in Table C-1.

The calculation of the fractional efficiency curve is given in Table C-2. Table C-3 shows the calculation of efficiencies based on the curve for fat-free (check of computational method) and for the deagglomerated combined distributions.

Table C-1: Fat-Free Size Distribution

Particle Dia., μm	% Less Than Diameter: Collected Product	Effluent	Combined
841	98.936		98.487
500	94.948		94.517
250	60.028		59.756
149	33.974		33.819
105	25.588		25.472
75	19.838		19.748
60	19.745	99.806	20.108
40	18.892	99.174	19.256
20	10.376	98.159	10.774
15	7.340	96.462	7.744
9	2.862	86.397	3.241
6	1.042	58.517	1.303
4	0.382	27.90	0.507
3	0.248	15.607	0.318
2	0.114	6.113	0.141
1	0.000	1.320	0.0060
0.6		0.000	0.000

Table C-2: Cyclone Fractional Efficiency

(1) Particle Size Range, μm	(2) Inlet, %	(3) Exit, %	(4) Exit as % of inlet: $\frac{(3)(\text{Mass Pen.})^*}{100}$	(5) Efficiency with respect to grade $\frac{(2)-(4)}{(2)}$
> 250	40.2443	Nil		100
250–75	40.0077	Nil		100
75–60	0.3601	0.194	0.00087	99.76
60–40	0.8519	0.632	0.0029	99.66
40–20	8.4820	1.015	0.0046	99.95
20–15	3.0299	1.697	0.0077	99.85
15–9	4.5034	10.065	0.0456	98.99
9–6	1.9382	27.880	0.1265	93.48
4–3	0.1891	12.293	0.0557	70.51
3–2	0.1765	9.494	0.0431	75.60
2–1	0.1361	4.793	0.0217	84.03
< 1	0.0060	1.320	0.0060	0.00

*Mass Penetration = 0.454%

Table C-3: Calculation of Collection Efficiencies

The following collection efficiency calculations are based on the approximate fractional efficiency curve for the test cyclone and on the individual combined size distribution curves for the fat-free and de-agglomerated alfalfa dust.

Fat-Free

Percentile Midpoints	Particle Dia, μm	Eff., %
99	> 841	100
97	620	100
95	510	100
⋮	⋮	⋮
23	85	100
21	60	99.99
19	40	99.96
17	34	99.94
15	29	99.91
13	24	99.85
11	20	99.77
9	17	99.60
7	14	99.40
5	11.5	98.20
3	8.6	96.3
1	5	87.5
		4979.89

Deagglomerated

Percentile Midpoints	Particle Dia, μm	Eff., %
99	600	100
97	440	100
95	370	100
⋮	⋮	⋮
37	76	100
35	60	99.99
33	47	99.97
31	40	99.96
29	35	99.94
27	32	99.93
25	28	99.90
23	25	99.83
21	23	99.82
19	20	99.77
17	18	99.67
15	16	99.54
13	14	99.40
11	12.8	98.9
9	11.5	98.5
7	10	97.8
5	9	97.0
3	7.5	95.0
1	5.5	90.0
		4974.92

Fat-Free:

$$\text{Avg. Efficiency} = \frac{4979.89}{50} = 99.59\%$$

Deagglomerated:

$$\text{Avg. Efficiency} = \frac{4974.92}{50} = 99.49\%$$

APPENDIX D

RICE GRINDING EXPERIMENT

As a supplemental means of understanding the mechanism involved, and to aid in the prediction of effects on other materials, it was desired to observe the results of fat on a hard-surfaced material, into which fat absorption would be nil. Polished rice was selected as the test material.

Preliminary grinding tests without fat gave very little mass penetration of the cyclone; sieving the ground rice showed that a very small fraction of particles smaller than 75 μm was being produced. To ensure the presence of fine particles whose collection efficiency would be less than unity in the test cyclone, the rice was milled in a ball mill for approximately one hour. This produced a substance varying from unfractured kernels to a very fine powder. Three batches of this material were then fed through the hammer mill as previously. Mass penetration then was similar to that for fat-free dehydrated alfalfa. The ball-milled rice was then sprayed with 3% by weight liquid animal fat exactly as done for the alfalfa. Three batches of this material were then run through the hammer mill; mass penetration was similar to that for alfalfa for fat. The results of these tests are shown in Table 4.

Since the ball-milled rice was known to have fine particles present, and it was known that the hammer mill did not produce a large fraction of fines when grinding rice, the addition of fat could not have caused any reduced shattering among the finest fraction of the ball-milled rice. The bulk of the improvement in cyclone efficiency when fat was added, therefore, had to be due predominately to agglomeration. This test, while not eliminating the possibility of reduced shattering in that portion of the rice which was not fractured in the ball mill, shows that agglomeration plays a significant role in collection improvement of a ground grain. The results of the ground rice mass efficiency tests are shown in Table D-1.

Table D-1: Mass Efficiency Tests for Ground Rice

	% Fat	Product Collected, Grams	Effluent, Grams	Mass Efficiency, %	Mass Penetration %
Rice Not Previously Ball Milled	0	322.07	0.149	99.954	0.046
	0	307.60	0.519	99.832	0.168
	0	306.19	0.405	99.868	0.132
				Avg = 99.886	Avg = 0.114
Rice Previously Ball Milled	0	673.76	3.229	99.533	0.477
	0	627.22	2.508	99.602	0.398
	0	610.66	3.275	99.467	0.533
				Avg = 99.531	Avg = 0.469
	3	408.33	0.021	99.995	0.005
	3	495.49	0.136	99.973	0.027
	3	550.82	0.136	99.975	0.025
				Avg = 99.979	Avg = 0.020

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A TECHNIQUE FOR THE STUDY OF THE MECHANISM OF THE IMPROVEMENT OF CYCLONE COLLECTION OF ALFALFA DUST BY LIQUID FAT ADDITION

by

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B.S., University of Kansas
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AN ABSTRACT OF A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

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1973

ABSTRACT

This study was concerned with the development of a technique for studying the mechanism of improvement of cyclone collection of alfalfa dust when liquid animal fat is added prior to grinding. The alternative mechanisms considered were fat-induced reduced shattering and agglomeration.

In order to avoid problems in obtaining representative samples of ground alfalfa, miniaturized grinding and collection equipment was used. Dehydrated alfalfa was ground in batches of approximately one pound mass. Fat application was done separately from the grinding apparatus on larger lots of alfalfa in order to avoid clogging of fat application equipment at the low feed rates required. Collection efficiency improvement on this miniaturized equipment compared favorably to those previously reported for similar levels of fat.

The basic method selected for studying the cyclone improvement mechanism was by observing the particle size distributions of alfalfa ground with and without fat. Size distributions were obtained for effluent material, for material collected by the cyclone, and a combination of the two locations. Size distributions were obtained by sieving, sedimentation, and the combination thereof. For alfalfa ground with fat, sizing was done both in a solvent which dissolves the fat, and in a non-solvent. Sizing in the solvent removed the effects of fat-induced agglomeration, but retained any effects of reduced shattering. Sizing in the non-solvent retained both effects.

A fractional efficiency curve was obtained for the test cyclone by means of the size distributions of collected product and effluent for fat-free alfalfa, as well as the relative mass at each location. The

collection efficiency was then calculated for the distribution derived by deagglomerating the alfalfa ground with fat in a solvent. Any improvement in collection efficiency shown by this derived distribution over the fat-free collection efficiency is due solely to reduced shattering.

The results of the tests performed tend to establish agglomeration as a significant mechanism in cyclone collection improvement. Reduced shattering could not be eliminated as a contributor to cyclone collection improvement because the data contained some inconsistent results, based on limited replication. Factors not controllable in the testing, such as variations in the dehydrated alfalfa, apparently had an effect and considerably more data should be used in a study of this type.