FACTORS THAT AFFECT THE GRANULATION AND CAPACITY IN GRINDING OF CORN, OATS, AND SORGHUM GRAIN WITH A HAMMERMILL

by

RICHARD JAMES BAKER

B. S., Kansas State College
of Agriculture and Applied Science, 1956

A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Flour and Feed Milling Industries

KANSAS STATE UNIVERSITY
OF AGRICULTURE AND APPLIED SCIENCE

1960

TABLE OF CONTENTS

INTRODUCTION

The most used grinder in the formula feed industry is the hammermill. In 1959, over 40 million tons of formula feeds were manufactured by this industry. With that production figure, formula feed manufacturing ranked as one of the top ten industries in the United States in dollar volume of sales. Even with a conservative estimate, the hammermill was used to grind one-half of that total or 20 million tons of grain and grain by-products. Considering that much additional grinding was done on farms and in local custom feed mills, it is evident that the hammermill is truly a basic machine to the formula feed manufacturers.

The hammermill is not fully understood as to its performance and design characteristics. When reviewing the available literature, it soon becomes apparent that relatively little work has been reported recently concerning grinding with a hammermill. Results of research that has been done either have not been published or do not fully answer questions being raised by the feed industry. This paper purposes to point out and evaluate some of the factors that may influence the production rate and granulation of the product when grinding corn, oats, or sorghum grain (hereafter referred to by the common name, milo) with a hammermill.

The following variables were studied to determine their influence on granulation of product and capacity of the hammermill:

a. hammer selection

b. screen size (size of openings)

c. screen area

d. moisture content of grain

e. class of grain being ground

f. gravity discharge versus pneumatically assisted discharge from the hammermill.

Granulation (particle size) is an important consideration in the preparation of grains for animal feeds. In the flour milling industry, definite particle size requirements have been set to determine product classification. The feed industry has not as yet set down requirements of this kind. Normally, the feed miller describes a product as having been ground through a certain screen opening on a hammermill. This is not a good method of describing granulation because the great variation in raw ingredient supply and machine performance can cause marked changes in the particle size resulting from the grind through the same screen size. It would be a great help to the feed industry and to equipment manufacturers if standards for ground products could be established. These standards could vary depending on the end use of the product. An example of a standard that might be agreed upon is as follows:

Grain: corn

End use: mash feed

All pass: No. 6 mesh

80% retained on: No. 28 mesh

A simple standard such as this could be tested with a simple laboratory sifter. The machine, or the raw ingredient supply, could be adjusted to meet these requirements.

Production rate and grinding capacity are also related to granulation. From previous research, it was determined that finer grinding takes more power than coarse grinding of the same material. Capacity of the hammermill is therefore directly related to the granulation of the product. For this reason, it is economically sound to grind only as fine as necessary to meet customer and production demands. When a feed is ground finer than necessary, money is lost because of higher power costs.

As previously mentioned, hammermills were used to grind over 20 million tons of grain and grain by-products in 1959. If an average grinding rate of 250 pounds per horsepower hour is used as the basis for calculation, 160,000,000 horsepower hours were required by hammermills for power last year. An increase in grinding efficiency of 10% would mean a reduction in power consumption of 16,000,000 horsepower hours. The resultant savings in power would directly reduce the cost of producing formula feeds. This cost reduction could be passed on to the customer in the form of less expensive, higher quality feeds for tomorrow.

REVIEW OF LITERATURE

The available literature shows little work reported concerning hammermill performance and design. Equipment manufacturers surely have experimentally tested their grinders but the results have not been reported in the literature. Much of the research reported was initiated by agricultural engineers in the late 1920's and early 1930's for the purpose of adapting electric power to farm grinding. Work done during that period on the design and performance of the hammermill is reported by Silver (25) (26), Vutz (30), Kable (17), Krueger (19), Duffee (8), and Fenton (10).

Much of the more recent work has been done on adaption of automatic control to the hammermill. Forth, et al. (12) (13) (14), Kummer (20), and Hundley (16) have published on this subject.

Value of Grinding

The value of grinding or cracking grains by some method was recognized early by nutritionists. This research is indirectly related to nutrition and thus few references will be made on this subject.

Bohstedt (4) states that when whole shelled corn is fed to steers, 10 per cent or more of the corn is wasted by passing through the animal undigested. Shaw and Norton (23) reported as high as 33 per cent of the whole corn can pass through cows undigested. Fitch and Wolberg (11) showed that as high as 62 per cent of Kansas Orange sorgo passes through dairy cows without being digested. In each of these references, whole grain was fed without any cracking or grinding. These statements are not true on all classes and ages of livestock.

Baker (3) answers the question of what and when to grind in table form. (Appendix A). He noted that the recommendations will depend somewhat on type of feeding, class of livestock, and age of the animals being fed.

Martin and Roberts (21) sum up the reasons for grinding as follows:

a. Reduces the amount of grain passing through the animals undigested.

b. Increases palatability.

c. Reduces waste because animals cannot nose out the less palatable feeds.

d. Permits more advantageous mixing and balancing of rations.

e. Increases digestibility by allowing digestive juices to act more readily.

Another important reason for grinding feeds is introduced when feeds are to be pelleted. It is practically impossible to make an acceptable pellet without first grinding the grains to be pelleted.

Fineness of Grind

With the great increase in the volume of pelleted feeds in recent years, fineness of grind has become more important. Even before pelleting of feeds was common, the question of how fine to grind grains was hard to answer. In

1927, Kable (17) noted, "while there was no experimental data to substantiate the feeling, farmers seemed to prefer finely ground feeds." Since this time, nutritionists have done much to evaluate the fineness of grinds with actual digestion trials. From these experiments, general recommendations have been set up that can be used as a guide when grinding grains to be fed in the mash form. Silver (26), Brackett, et al. (5), Martin, et al. (21), Fairbank, et al. (9), and Baker (3) give recommendations for grinding grains for use in mash feeds. In general, these authors agree that for feeding most livestock, a coarsely ground product is desired, while for the poultry feeds a slightly finer feed may be fed.

Wake (29) at the 1959 Feed Production School, said "fineness of grind is one of the most important preparations related to peak pelleting capacity." He also said "the finer the grind the better quality pellet that is produced from this material." Stroup (27) stated that an important influence in determining quality and toughness of the finished pellet is the fineness of grind of the material before pelleting. As expressed by Stroup (27), "material that is finely ground has considerable more surface area exposed to absorb whatever binding quality may be available in the formula."

Researchers thus agree that finer grinding of raw ingredients in a ration results in better pelleting. However, the question of power consumption during grinding is raised. Bruhn (6) noted that the fineness of grind is the most important factor in determining the amount of power required to operate a mill. Fine grinding of oats takes five times as much power as coarse grinding of the same grain. Fine grinding of barley takes three times as much power as coarse grinding, while in grinding corn the relationship is about two to one. As found by Martin and Roberts (21), fine grinding will reduce capacity and decrease the life of the grinder. Vutz (30) wrote, "the limiting factor as to capacity, for a given horsepower, is in most cases the size of the screen." Bruhn (6) concludes, "it is only economical to grind to the very coarsest grind acceptable." All researchers are in agreement on the fact that grinding costs go up as the grind becomes finer.

Fineness Measure

The terms coarse, medium, and fine are vague in their meaning when used to denote fineness of grind. These terms are arbitrary and do not mean the same thing to all people. For this reason, a fineness modulus system was set up by the American Society of Agricultural Engineers. (1) (Appendix B). This system has not been widely accepted in the feed industry but has been used extensively in the research that has been reported. Basically, the fineness modulus system is a means of giving a ground product a numerical value which somewhat indicates a certain degree of fineness. High numbers mean coarse grinds and low numbers signify fine grinding.

Silver (14) presents another method for determining fineness of grind. This method is simpler than the fineness modulus system in that only two sieves are used. A grade is then determined from the amount of material remaining on each sieve. (Appendix C). This method could possibly have practical value to a feed miller since it is easy to determine grade quickly.

Another testing procedure is suggested by the W. S. Tyler Co. Catalog 53 (2). In this method, a graphic interpretation is given to screen analysis data. After sieving a sample, the cumulative per cent retained on each of several sieves is plotted on a standard screen scale sheet. By interpolation, it is possible to find the percentages that would be retained on any screen opening desired. This lends itself well to specific particle size demands. For example, from a typical curve, it is possible to determine what screen will retain 10 per cent and pass 90 per cent of the material or any other specifications which may be set up. Differences of grinds can be easily shown because a picture is given rather than a numerical value.

Grinding Efficiency

Brackett and Lewis (5), Silver (26), and Kable (17) have reported studies on grinding efficiency concerning the hammermill, burr mill, and roller mill. Fairbank, et al. (9) wrote that hammermills have the reputation of pulling hard. When considering pounds production per horsepower input, these men reported the hammermill most efficient of the three machines for fine grinding. Kable (17) ranks them: hammermill first, burr mill second, and roller mill third for fine grinding. However, the burr mill and roller mill are more efficient for coarse grinding, when compared to a hammermill.

In tests conducted at the University of Illinois, corn was ground to the same fineness modulus by a hammermill, burr mill, and a knife mill, and then feed acceptability and feed conversion were checked in feed lot trials. Klies and Newman (18) concluded that "cattle are neutral on grinding methods as neither gains nor feed consumption reflected any preference." The grind in these tests was coarse, having a fineness modulus of 4.2.

Grinding Capacity

Grinding capacity is one of the most important tests that can be made on a hammermill. Martin and Roberts (21) found that the following factors may influence grinding capacity:

a. Power available

b. Kind of grain

c. Fineness of grind

d. Speed of operation

e. Moisture content of grain

f. Type of grinder

Kummer (20) adds to this list by suggesting that the number of hammers and the amount of screen area will affect production capacity.

Wake (29) found that 1/2" thick hammers could be replaced with 50 per cent more 1/4" hammers, 1/8" shorter than the original hammers, with greatly increased grinding capacity. Why the increased production? Was this increased production due to shortening the hammers or to the using of thinner hammers, or a combination of the two? As expressed by Thomas (28), closer spacing between hammer tips and the screen surface will result in a finer grind. Many researchers have found that finer grinding takes more power. Since the spacing between the hammer tips and screen surface was increased in this situation, it could be reasoned that a coarser grind might have resulted and thus at least part of the increase in production found by Wake was due to shortening of the hammers.

When grinding corncobs, the most significant change in grinding rate, power consumption, and mill capacity was due to the effect of moisture content, according to Clark and Lathrop (7). An increase of 12 per cent moisture in the corn cobs resulted in a decrease of 50 per cent in production rate when grinding with a pilot size hammermill. Fairbank, et al. (9) noted that within the average range of moisture, the drier the grain, the easier it can be ground. Very dry grains (10 per cent or under) tend to shatter in the mills and produce more fines than would grains of higher moisture content. Martin and Roberts (21) found that the capacity of a hammermill decreased quite rapidly as the moisture content of the grain increased from 12 to 25 per cent. These statements are in general agreement with work done by Nicholas (22) where in grinding of soybeans with a hammermill, an increase of 2.2 per cent in the moisture content decreased the production rate about one-third and gave a coarser product.

Silver (26) has shown the kind of grain being ground will influence grinding capacity. From graphs presented in this bulletin, Silver shows that oats is the hardest of the cereal grains to grind, with barley next, and corn, the easiest of the three. Martin and Roberts (21) reported kafir was ground more rapidly than the other grains, with wheat, corn, barley, and oats decreasing in thst order when ground with the same hammermill.

Speed of operation is an important design feature of the hammermill. Peripheral speed of the hammer tips, not revolutions per minute, is the primary consideration. Peripheral speed may vary from 9,000 feet per minute to 20,000 feet per minute depending on the revolutions per minute and rotor diameter. Martin and Roberts (21) stated, "speed affects the power required to run the mill, the fineness of grinding, and the rate of grinding." As speed increases, the power required to run the mill empty (no load current) goes up rapidly. Bruhn (6) wrote, "excessive powdr consumption may be the result of unnecessarily high speed due to the additional energy imparted to the ground grain discharging and also due to the additional windage of the mill."

Actual optimum peripheral speed is still uncertain. Most large commercial hammermills now in use are operating with a peripheral speed of 15,000 - 16,000 feet per minute. Silver (25) shows that these speeds may be too high for maximum grinding efficiency.

There is some contradiction about the effect speed has on the rate of grinding. Krueger (19) asserted that capacity and coarseness of the produce increases as mill speed decreases, when grinding with a hammermill. This statement pertains to the normally accepted limits of peripheral speeds of 9,000 - 20,000 feet per minute. Martin and Roberts (21) showed grinding capacity increased as speed incraased as long as the power of the motors was adequate. "After full power of the motors was reached, further increase in speed tended to reduce capacity or rate of grinding." All researchers seem to agree that higher speeds result in finer grinding. Krueger (19) noted, (within normal speed limits) "a larger screen at higher speeds will produce the same product as smaller screens at slower speeds and more efficiently."

Fan Discharge

Most hammermills in use today are equipped with a fan to pneumatically convey the ground material from the mill. The question has been raised as to the necessity of this arrangement. From manufacturers' recommendations and from actual observations of hammermills in use, it can be seen that the conveying fan required about 25 - 30 per cent of the total horsepower available to the machine. For example, a mill which requires 100 horsepower to drive the main rotor shaft will require a 30 or 40 horsepower drive for the fan. If the fan and mill rotor both use the same driver source, 25 - 30 per cent of the available power is consumed by the conveying fan. Since considerable power is used in this operation, the question of need for a fan is a valid and important one.

In tests conducted on very small hammermills ($\frac{1}{2}$ to 1 horsepower) Hendrix (15) found, "a fan is not necessary for general grinding and no considerable gain in capacity or efficiency is obtained by use of a fan." This statement pertains to coarse grinding (modulus of 3.00 and over) rather than to fine grinding. The reverse relationship was found to be true for fine grinding in work done at the University of Tennessee (15).

Duffee (8) reported the horsepower required for the fan increases with incressed capacity and increased speed. On this mill, the conveying fan and rotor were both driven by the same motor. There was 5 horsepower available to the complete unit (fan and rotor). As high as 1.85 horsepower was consumed by the fan when grinding at a rapid rate. This finding is substantiated in a discussion by Bruhn (6) where he indicated, "the power required to operate these fans at excessive speed is considerably above the power required to operate the fan only at sufficient speed to elevate the maximum capacity of the mill." Bruhn also made the observation that at high speed the fan itself becomes an inefficient hammermill.

Kummer (20) assigns the fan a dual purpose - that of conveying and that of providing maximum suction on the screen from below. The action of the air will help in the flow of the material through the mill and also will keep the product cool. The cooling effect of this air flow also helps in fire prevention.

Vutz (30) reports a chain bucket elevator instead of a fan can sometimes be used to convey ground material from the mill. "The output per horsepower will be approximately the same for the same mill with either blower or chain elevator; the fan requires a trifle additional power, but at the same time aids in drawing the ground material through the screen." Vutz (30) surmised that the only advantage for a substitution of this kind is that a smaller source of power can be used.

Many researchers point out that the fan is probably the most convenient method of discharging and elevating from the hammermill.

SUMMARY OF LITERATURE

Most of the available research data pertains to small farm hammermills. Many important questions are discussed but in most instances definite conclusions are lacking. Reference material is particularly lacking on granulation changes that may occur with the variations in raw ingredients and hammermill performance.

Two very important questions were only mentioned and left unanswered. These questions are (1) effect of hammer design on granulation and production, and (2) effect of screen area on granulation and production in grinding with a hammermill.

Other factors related to hammermill grinding can be summarized in the following statements:

1. Grinding of grains will increase digestibility over grains fed whole.
2. Fineness of grind is very important whether the product is to be pelleted or fed as mash.
3. Fine grinding takes much more power than coarse grinding of the same grain.
4. No definite particle size standards have been set to use as guides in the feed industry.
5. When moisture content of the grain being ground is increased, production rate will be decreased.
6. Kind or class of grain being ground will definitely affect production rate.
7. Speed of operation -- peripheral speed -- will affect both granulation and production.
8. It is possible to operate a hammermill without a suction fan but the fan is probably the most convenient means of achieving discharge and delivery from the hammermill.

Sound quantitative data are lacking in some of these areas to substantiate these statements.

MATERIALS AND METHODS

Good quality corn, oats, and milo were the three grains used for grinding in the testing work done. A blended sample of each grain was set aside in a bin from which samples were taken as required. This was done to insure uniform quality of material throughout the testing period. Moisture content and test weight were checked and recorded on each grain at intervals during the testing. Tap water from the University was used to temper a portion of each grain supply for high moisture grinding tests. Tempered grains were allowed to set for 24 hours before grinding.

A Prater number GS 5 hammermill was used for all grinding tests. (Plate 1). Machine specifications are:

a. <u>Power Source</u> - 7 1/2 H.P., 220-440 V. 3 ph. 1760 rpm motor

b. <u>Rotor Width</u> - 12 7/8" (outside hammer to outside hammer)

c. <u>Rotor Diameter</u> - 15 11/16" (hammer tip to hammer tip)

d. <u>Rotor Speed</u> - 3600 rpm

e. <u>Peripheral Speed</u> - 14,750 fpm

f. <u>Screen Sizes</u> - 3/32", 1/8", 3/16", 1/4" (diameter of openings)

g. <u>Screen Area</u> - total - 434 sq. in.

h. <u>Screen Location</u> - lower 180°

i. <u>Feed Inlet</u> - Top-center of machine

j. <u>Feed Control</u> - Variable speed vane type feeder -- 1/2 hp. drive

k. <u>Exhaust Fan</u> - 3 HP centrifugal

EXPLANATION OF PLATE I

Photograph of Prater GS 5 experimental hammermill. Variable speed drive on feeder unit is shown in upper center of picture.

PLATE I

l. Hammer Designs:

1. 1/8" x 1 1/4" x 5 11/16" individual - 3 rows of 15 single hammers.
2. 1/8" x 1 1/4" x 5 11/16" group - 3 rows of 5 groups, 3 to a group.
3. 1/16" x 1 1/4" x 5 11/16" individual - 3 rows of 15 single hammers.

m. Spacing between screen and hammer tips - 1/8" to 3/16"

This hammermill was equipped so that ground material could be discharged by gravity and sacked off directly under the machine, or the ground material could be pneumatically conveyed from the mill to a cyclone dust collector and then sacked off. Each sack-off position was equipped with a two way butterfly valve to facilitate testing work and sack change over. It was possible to have either a gravity or a fan discharge since the blower fan could be easily disconnected by removal of detachable elbow (Plate 2). Ground material was sacked off in burlap sacks during each test run and then weighed and recorded. A Fairbanks Morse 250 No. platform type scale was used for weighing. A tare weight was set on the scale to compensate for empty sack weight.

One half of the 494 square inches of screen area was blanked off for testing purposes on a portion of the grinding tests to see how this change would sffect granulation and production. This was accomplished by fastening a blank curved piece of sheet metal on the inside surface of each size screen on the down side half of the semi-circular screens.

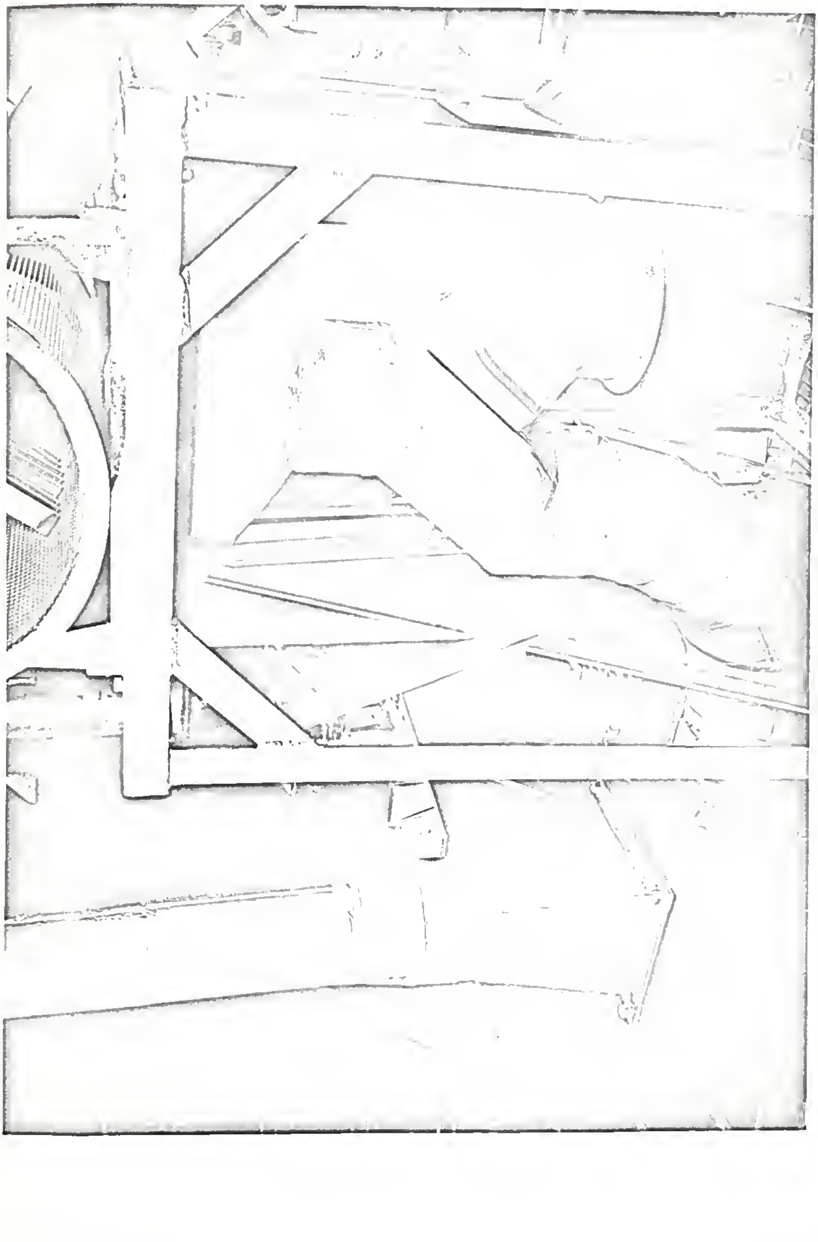
The three hammer types listed above were easily installed and changed to facilitate testing work.

Granulation tests were made by gyrating four 8" diameter Tyler testing sieves in the Tyler Rotap sifter (Plate 3). The following sieve series was used for all granulation tests.

EXPLANATION OF PLATE II

Photograph of side view of hammermill showing two way valve and detachable elbow that connects the fan to the hammermill discharge.

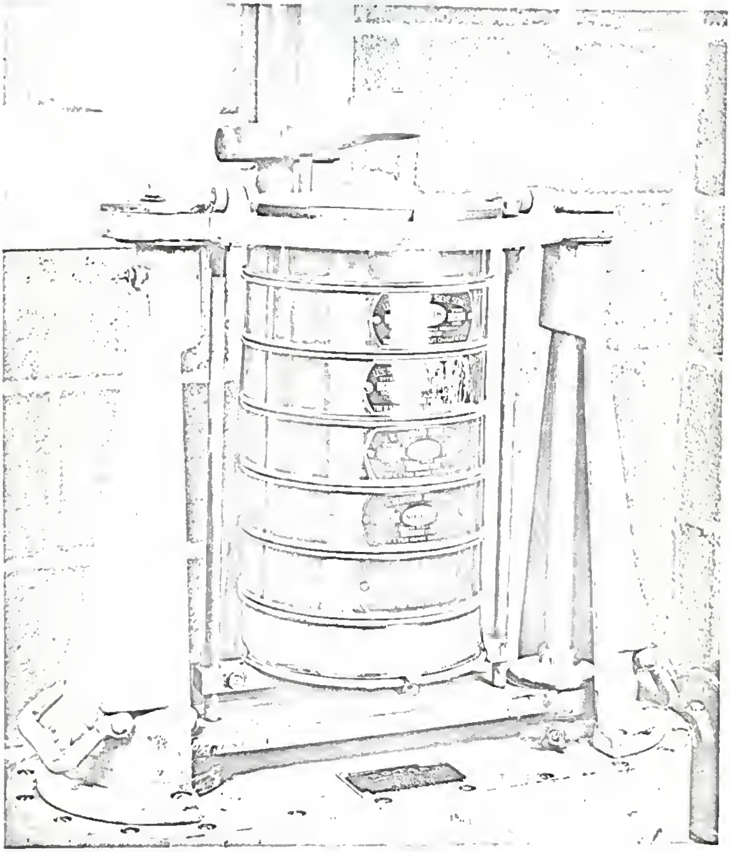
PLATE II



EXPLANATION OF PLATE III

Photograph of Tyler Ro-Tap

PLATE III



Tyler Mesh Number	U.S. Number	Openings Inches	Openings Microns
6	6	.131	3360
9	10	.078	2000
20	20	.0328	840
32	35	.0195	500
Pan	--	--	--

Samples were blended and then divided to obtain correct sample size by a Precision Divider (Plate 4).

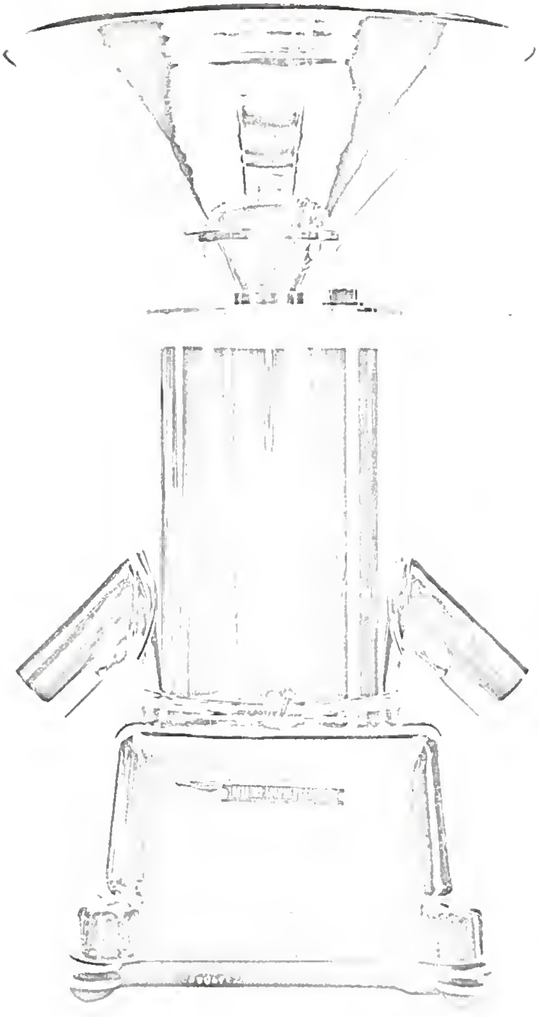
In each test, the feeder speed was adjusted until the ammeter indicated full load current was being used. An ammeter and a watt hour meter were used to measure electrical current (Plate 5). The ammeter (50 amp. scale) is located in the upper right corner of the wall panel, shown in Plate 5, and is equipped with a bypass switch to guard against pegging of the meter due to the initial surge of current upon starting the machine. The watt hour meter shown in the center of the wall panel (Plate 5) is a 15 amp, 480 volt, 3 phase, 3 wire meter with 28.8 K_H factor. The high K_H factor meter will give more accurate power readings than regular meters.

The testing procedure was standardized as much as possible to make the tests more accurate and valuable for comparison purposes. The whole grains to be used in the test were first cleaned (S. Howes separator) and then stored in one large storage bin. From the large storage bin, grain could be transferred as needed to a small holding bin (13.8 cu. ft. capacity) above the experimental hammermill. Samples of the whole grains were taken as the grains flowed into the holding bin. Test weight was determined on a standard test weight machine and moisture content measured by official A.O.A.C. air oven method. These readings were recorded on each data sheet.

EXPLANATION OF PLATE IV

Photograph of Precision divider used for sample division.

PLATE IV



EXPLANATION OF PLATE V

Photograph of wall power panel used for measuring electrical power usage. Watthour meter is shown in center of panel and ammeter is shown at upper right.

PLATE V

Grinding tests were run in triplicate on each grain, screen size, and hsmmermill setting. Hammermill arrangements used are best explained by referring to the dsta sheets and to discussion of experimental results. The grain was metered into the hammermill by means of a variable speed vane type feeder. Feed rste was adjusted so that the hammermill was operating at full load, or 9.6 amps ss measured by the wall ammeter, on all tests. After full load was achieved and maintained for a short period of time, a test was made by diverting the ground product into an empty sack by use of the two-way butterfly valves at the discharge points. Both disc revolutions of the watt hour meter and time were carefully measured during each test. Disc revolutions of the watt hour meter were counted by visual observation and timing of each test run was measured by a stop watch. The stop watch was started at exactly the same instant that the ground product flow was diverted to the test sack and stopped precisely as the material was again diverted from that sack. It was determined that each disc revolution of the watt hour meter should require 18 seconds when the machine was properly loaded. By paying close attention to the ammeter reading, the time elapsed, snd the disc revolutions, very accurate test data were obtained. Upon completion of each test run, the ground material in the test sack was weighed and the weight recorded. One-hundred pound capacity burlap sacks were used for collection of the ground product. The time for each run was governed by the time it took to fill one sack. This was done so that sacks would not have to be changed during the test runs. Runs varied from 54 seconds to 10 minutes depending on the rate of grinding. Temperature of grain before and after grinding was checked on some tests to determine temperature rise in the ground material due to grinding.

After completion of the production tests, grinding rate per unit of power input was calculated. Each disc revolution of the watt hour meter meant 28.8 watt hours of electrical energy had been used. From the number of disc revolutions, the amount of grain ground, the above constant, and time, it was possible to calculate power used and pounds production per kilowatt hour. Grinding capacity in pounds per minute and pounds per hour was calculated from these data. Grinding efficiency is usually given in pounds production per horsepower hour. This figure is obtained by dividing hourly production rate by the horsepower input. (7.5 horsepower used for this study.) Figures used for comparison in these tests are composite averages based on triplicate testing of each setting and grain.

Particle size analyses were made after each series of production tests had been run. Sampling of the ground product is one of the most important parts of a granulation determination. An analysis such as this is no better than the sample used. An attempt was made here to sample the major portion of each sack of test material so that a more representative sample might be obtained. Two large samples were taken from each sack of ground material. Average size of these samples was 3200 grams on corn and milo and 1600 grams on oats. These samples were taken from the sacked ground material by a small hand scoop. A definite sequence was followed so that sampling procedure would be standardized. The following sequence was used, being careful to sample all areas in the sack:

Scoop numbers - 1, 2, 4, 5, 7, 8, 10, 11, 13, 14, 16, 17, 19, 20, 22, and 23 were discarded.

Scoop numbers - 3, 12, 15, and 24 make up sample A.

Scoop numbers - 6, 9, 18, and 21 make up sample B.

After collecting samples A and B from each test run, each sample was blended and divided by the Precision Divider. (Plate 4). Two 200 gram samples were taken from each large sample (A and B of each test run) for sieve analysis. The divider was used to get the approximate desired size and then, by weighing and addition or subtraction of material, exactly 200 gram samples were obtained for use in the sieve analysis tests. This 200 gram sample of ground product was then placed on the top sieve of the sieve series previously described and sifted for three minutes (5 minutes for oats). After sifting, the product retained on each sieve was weighed and recorded. A total of four sieve analyses were made on each test run. Since the tests were triplicated, this made 12 sieve analyses for each hammermill setting. (See sample data sheet, Appendix D.) The average analysis was then calculated and percentages retained on each sieve computed. From these percentage figures, the cumulative per cent weight retained on each sieve size could be plotted on a Tyler Standard Screen Scale sheet.

Approximate fineness modulus values were assigned to each test series composite grind by interpolating data from these Standard Screen Scale sieve curves. This method was checked with actual sieve analysis data and found to be sufficiently accurate for comparison of fineness of grinds. By referring to Figure I, the following data were found by interpolation. [Technique described on page 24, Tyler Catalogue 53 (2)].

Approximate Fineness Modulus Determination

Sieve no.	Per cent weight retained	Curve A Moduli	Per cent weight retained	Curve B Moduli
$\frac{3}{8}$"	0 x 7 =	0	0 x 7 =	0
4	0 x 6 =	0	0 x 6 =	0
8	15 x 5 =	75	9 x 5 =	45
14	38 x 4 =	152	34 x 4 =	136
28	28 x 3 =	84	28 x 3 =	84
48	10 x 2 =	20	14 x 2 =	28
100	4 x 1 =	4	6 x 1 =	6
Pan	5 x 0 =	0	8 x 0 =	0
Totals	100%	335	100%	303

$$\text{F. M.} = \frac{335}{100} = 3.35 \qquad \text{F. M.} = \frac{303}{100} = 3.03$$

Again referring to Figure I. the abscissa is used to denote sieve size and the ordinate gives cumulative per cent weight retained. By noting where sieve curve A cuts the vertical lines which correspond to the sieve sizes used in a fineness

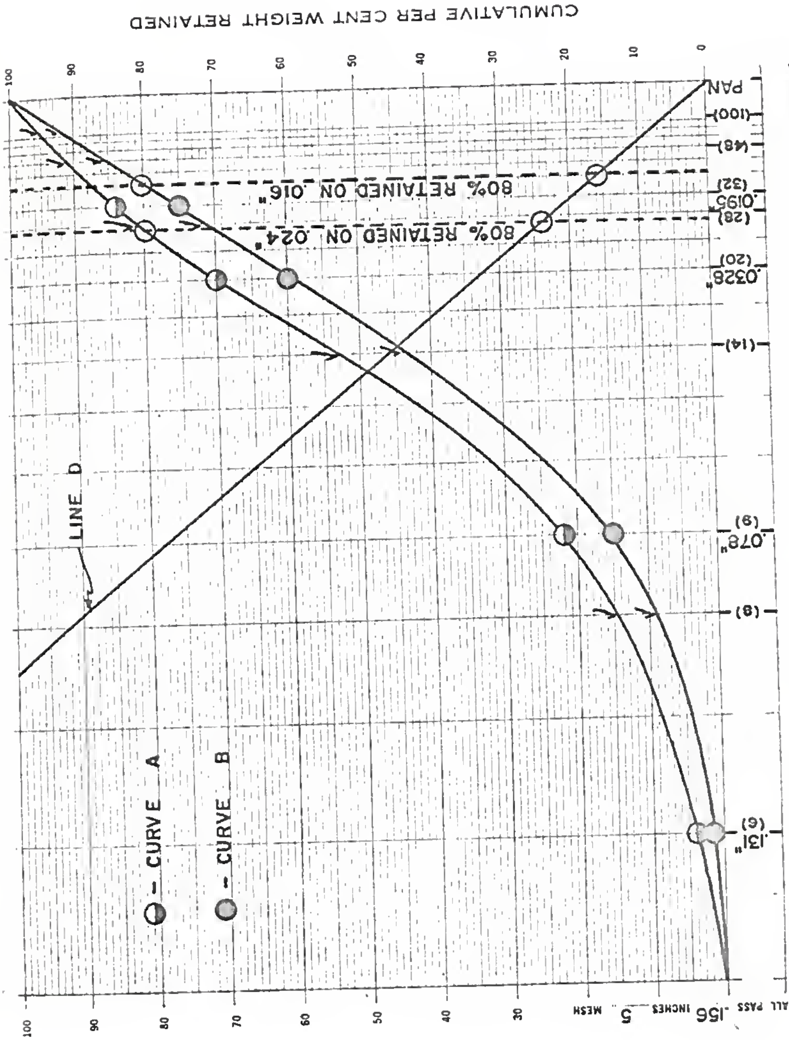


Figure 1. Examples of typical sieve curves. Layout and evaluation procedure explained in text.

modulus determination, the approximate values shown above can be determined. (Intersection points marked ✓.) The sieve sizes are given in parenthesis at the bottom of the graph. Since all the ground product passes a Tyler No. 5 mesh sieve, the 3/8" and number 4 mesh sieves are not shown on the graph.

From Figure I, it is also possible to determine particle size of any portion of the grind. For example, note where Curve A cuts the horizontal line for 80 per cent weight retained. (Point is circled.) By then drawing a line (dotted) perpendicular to the abscissa from this point down to the diagonal line (Line D), one can read sieve size required to retain 80 per cent of the grind. The point of intersection (dotted line and line D - circled) is at 24 on the cumulative per cent weight retained scale at the right of the graph. This value is also the sieve opening in inches which will retain 80 per cent of the ground product. The grind shown in Curve A could be described as follows:

all Pass - .156" (5 mesh)

80% retained - .024" ($\cong$ 27 mesh)

Curve B could be described as follows:

all Pass - .156" (5 mesh)

80% retained - .016" ($\cong$ 36 mesh)

By comparison of the two curves, it is easily determined that Curve B represents a finer grind than Curve A. In general, sieve curves are finer when they are down and to the right, and coarser when higher and to the left on this type plot.

EXPERIMENTAL RESULTS

Kind of Grain Being Ground

The effect of kind of grain being ground on production rate when grinding with the experimental hammermill is shown graphically in Figure 2. The curves given for corn, oats, and milo are taken from data obtained when grinding normal moisture (13-14 per cent) grains with the hammermill operated at 3600 revolutions per minute and equipped with a full (180°) screen, 1/16" thick individual hammers, and fan discharge.[1] From these curves shown in Figure 2, it can be seen that oats grind approximately twice as hard as corn and three times as hard as milo. Note that this relationship is slightly greater for fine grinding (3/32" screen) and somewhat smaller for coarse grinding of these grains. These same relationships held true for all settings of the hammermill throughout the testing period.

Method of Discharge

The results obtained in the testing of gravity discharge[2] versus fan discharge as related to grinding capacity and grinding efficiency are summarized in Figures 3, 4, and 5, and Tables 1a, 1b, and 1c. All pounds per horsepower hour figures are based on an input horsepower of 7.5 (rotor drive motor rated horsepower) unless otherwise specified. The motor horsepower on the fan drive

---

[1] Fan Discharge - denotes method of discharge when pneumatic conveying fan is employed to remove the ground product from the mill and discharge into the cyclone dust collector.

[2] Gravity Discharge - denotes method of discharge where the ground product drops from the machine by gravity and is collected directly under the machine.

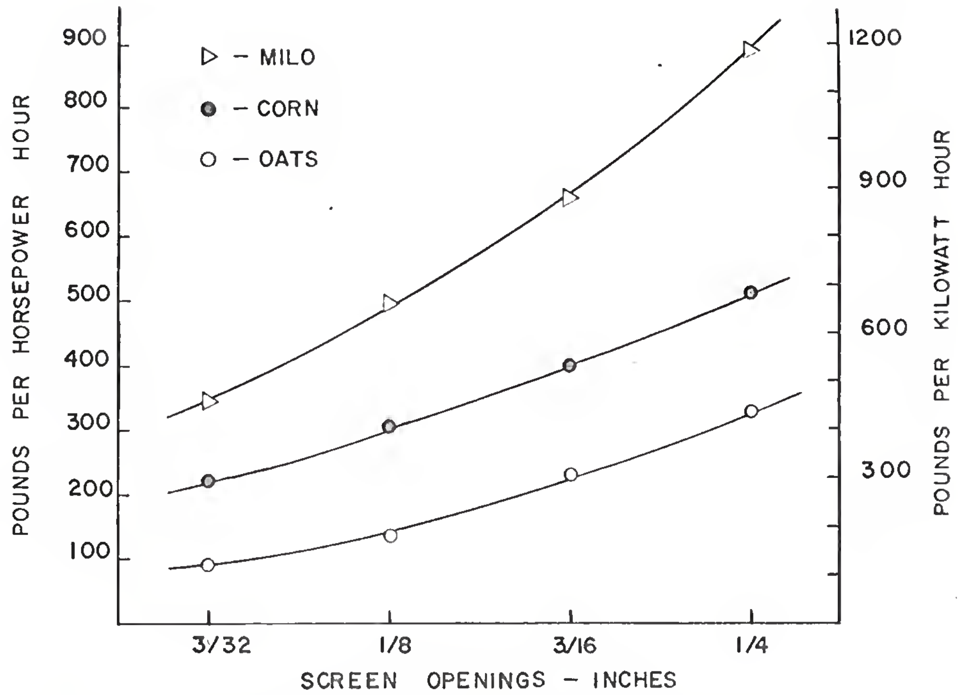


Figure 2. Effect of kind of grain being ground on production rate and efficiency. Hammermill equipped with 1/16" individual hammers, full screen, fan discharge, and operated at 3600 rpm.

is not included in these data presented in the above mentioned tables and figures. Approximate pounds per kilowatt hour can also be taken from tnese graphs by referring to the tables mentioned for each section of the testing.

As shown in Figures 3, 4, and 5, the fan discharge resulted in increased production rate and grinding efficiency when compared to the gravity discharge for the grinding of all three grains and for each screen size when the power used by the fan is not considered. Calculated percentage increase in production rate due to the use of the exhaust fan can be seen by referring to Table 1d shown below.

Table 1d. Percentage production rate increase due to use of fan discharge on the hammermill.

Screen Size in.	Grain Being Ground		
	Milo	Corn	Oats
	% increase	% increase	% increase
3/32	19.2	9.9	22.7
1/8	10.7	7.8	20.5
3/16	8.9	4.2	15.6
1/4	7.7	4.5	15.1

(Data for calculations taken from Tables 1a, 1b, and 1c.)

The percentage figures shown in the Table 1d point out the following important relationships concerning method of discharge: (1) Oats derive the most benefit from use of the exhaust fan, (2) the fan increases grinding efficiency more percentagewise when fine grinding (3/32" screen) than when coarse grinding (1/4" screen), and (3) corn benefita the least from use of the exhaust fan during grinding.

When the total input horsepower figure of 10.5 (7.5 HP on rotor drive and 3.0 HP on the fan drive) is used for calculation of grinding efficiency for the fan discharge grind, a much different picture is presented. It is true that fan

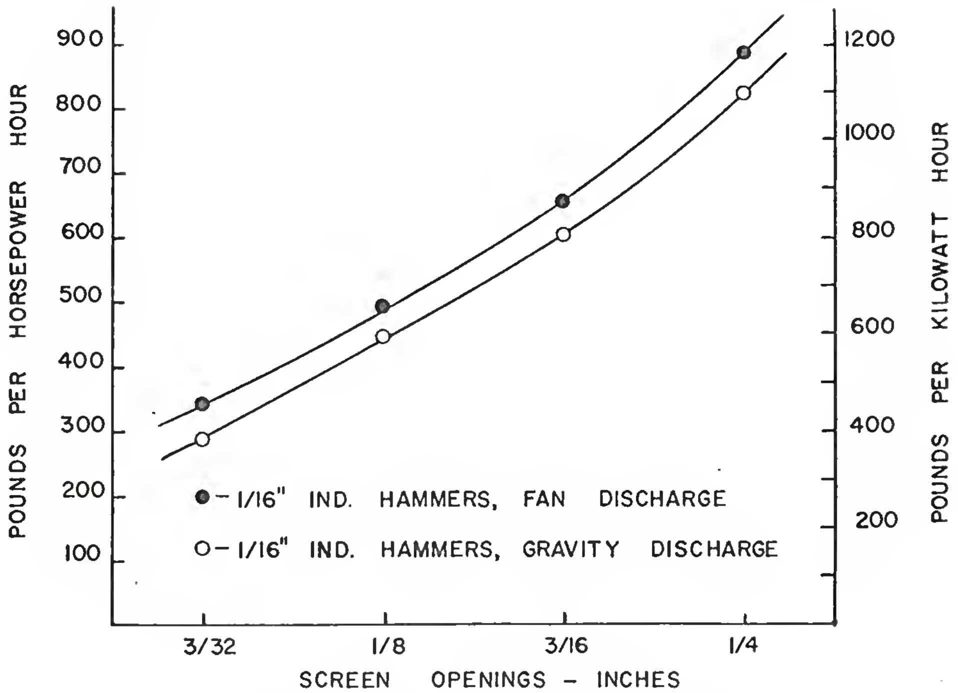


Figure 3. Effect of method of discharge on production rate and efficiency when grinding milo. Hammermill equipped with 1/16" individual hammers, full screen, and operated at 3600 rpm.

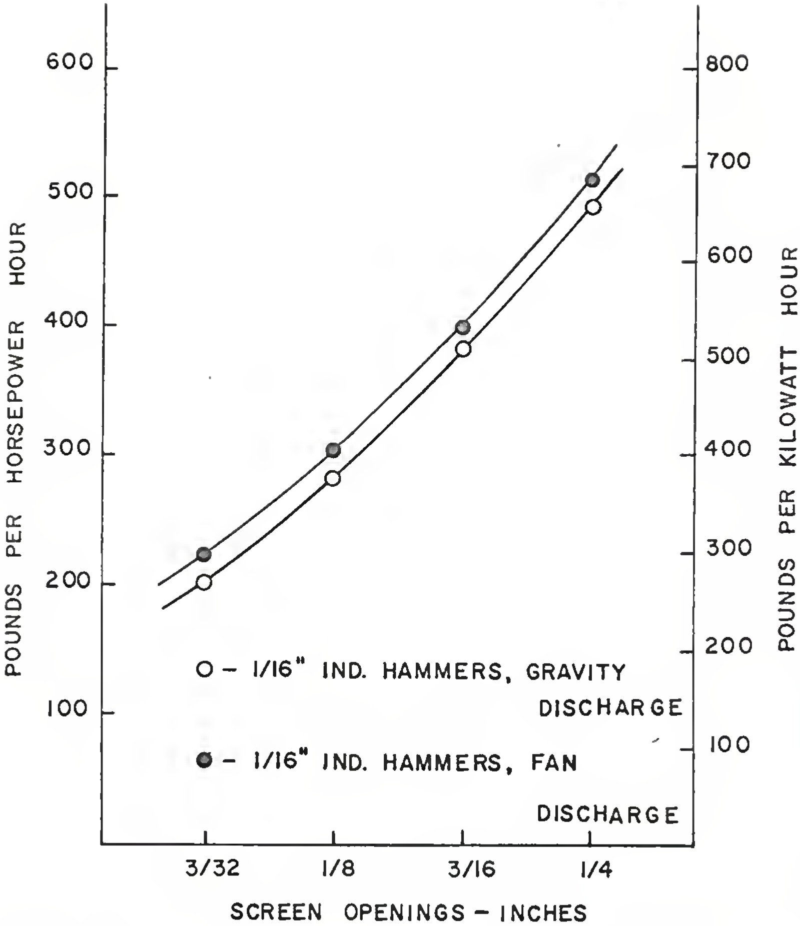


Figure 4. Effect of method of discharge on production rate and efficiency when grinding corn. Hammermill equipped with 1/16" individual hammers, full screen, and operated at 3600 rpm.

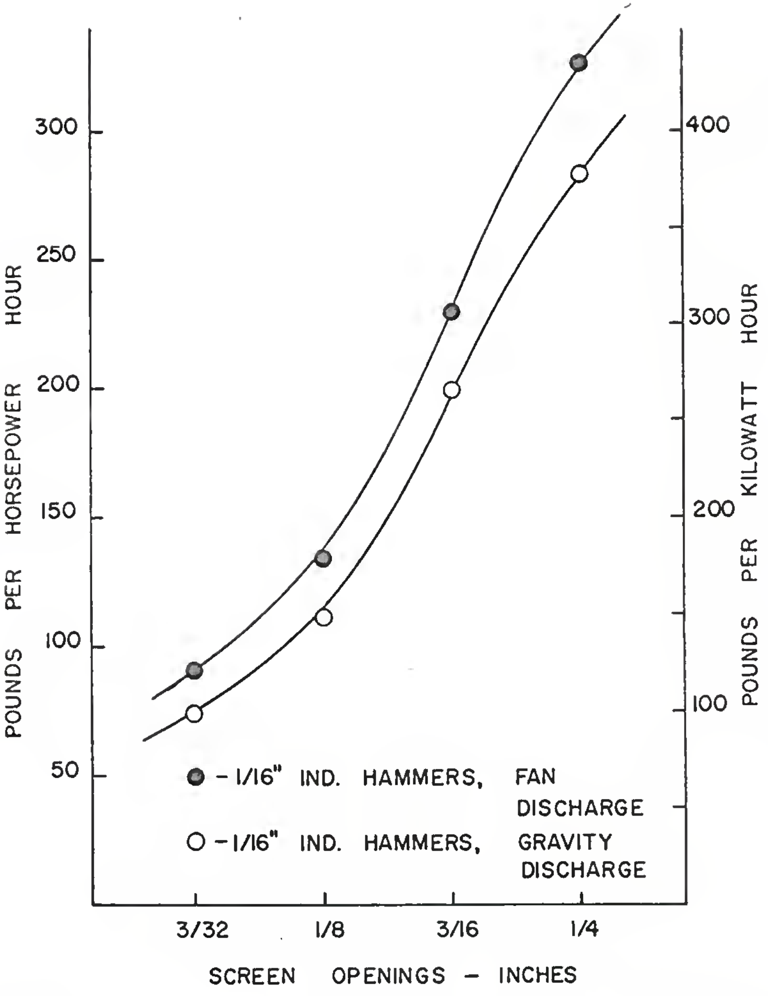


Figure 5. Effect of method of discharge on production rate and efficiency when grinding oats. Hammermill equipped with 1/16" individual hammers, full screen, and operated at 3600 rpm.

Table 1a. Production and granulation as related to method of discharge in grinding milo.[1]

Test series no.	Screen size in.	Type of discharge	Grinding rate lb/hr.	Grinding efficiency lb/HPhr.	Grinding efficiency lb/KWH	Tyler sieve analysis, Per cent retained on each sieve + 6	+ 9	+ 20	+ 32	pan	F. M. [2]
1	3/32	gravity	2160	288	378	0	0	25.8	34.8	39.4	2.20
2	3/32	fan	2572	343	452	0	0	22.3	33.9	43.8	2.11
3	1/8	gravity	3350	447	590	0	.6	43.4	27.1	28.9	2.60
4	1/8	fan	3714	495	648	0	.7	39.5	28.4	31.4	2.52
5	3/16	gravity	4530	605	811	0	3.7	52.7	21.8	21.8	2.84
6	3/16	fan	4946	659	878	.5	2.7	49.9	23	23.9	2.79
7	1/4	gravity	6178	824	1112	1.3	12.1	54.7	15.9	16	3.18
8	1/4	fan	6650	887	1181	.6	6.6	53.7	18.5	20.6	3.01

[1] Composite of three test runs using feed grade milo with a test weight of 58.8 lbs./bu. and moisture content of 13.6 per cent. Hammermill equipped with 1/16" individual hammers, full screen, and operated at 3600 rpm.

[2] Approximate fineness modulus.

Table 1b. Production and granulation as related to method of discharge in grinding corn.[1]

Test series no.	Screen size in.	Type of discharge	Grinding rate lb/hr.	Grinding efficiency lb/HPhr.	Grinding efficiency lb/KWH	Tyler sieve analysis: Per cent retained on each sieve + 6	+ 9	+ 20	+ 32	pan	F. M. [2]
51	3/32	gravity	1512	202	263	0	0	25.4	33.6	41	2.22
52	3/32	fan	1670	222	290	0	0	25	32.7	42.3	2.17
53	1/8	gravity	2114	282	366	0	.9	40.6	26.6	31.9	2.57
54	1/8	fan	2282	304	396	0	1	39.6	26.5	32.9	2.54
55	3/16	gravity	2862	382	505	.4	7.4	45.9	20.9	25.4	2.84
56	3/16	fan	2978	398	517	0	6.5	44	21.2	28.3	2.75
57	1/4	gravity	3692	492	642	1.8	14.9	44	17.4	21.9	3.06
58	1/4	fan	3852	514	679	1.5	15.9	44.3	16.9	21.4	3.11

[1] Composite of three test runs using feed grade corn with a test weight of 58.2 lbs./bu. and moisture content of 13.1 per cent. Hammermill equipped with 1/16" individual hammers, full screen, and operated at 3600 rpm.

[2] Approximate fineness modulus.

Table 1c. Production and granulation as related to method of discharge in grinding oats.[1]

Test series no.	Screen size in.	Type of discharge	Grinding rate lb/hr.	Grinding efficiency lb/HPhr.	Grinding efficiency lb/KWH	Tyler sieve analysis, per cent retained on each sieve: + 6	+ 9	+ 20	+ 32	pan	F. M. [2]
101	3/32	gravity	564	75	98	0	0	26.3	32.4	41.3	2.18
102	3/32	fan	688	92	119	0	0	24.6	32.7	42.7	2.10
103	1/8	gravity	840	112	146	0	0	36.2	25.4	28.4	2.61
104	1/8	fan	1016	135	177	0	0	39.7	27.6	32.7	2.49
105	3/16	gravity	1492	199	258	0	2.6	60.9	17.7	18.8	2.98
106	3/16	fan	1724	230	298	0	2.8	58.6	17.5	21.1	2.93
107	1/4	gravity	2138	284	372	0	10.1	63.2	12.8	13.9	3.27
108	1/4	fan	2450	327	427	0	9.3	60.1	13.8	16.8	3.19

1/ Composite of three test runs using feed grade oats with a test weight of 35 lbs./bu. and moisture content of 13 per cent. Hammermill equipped with 1/16" individual hammers, full screen, and operated at 3600 rpm.

2/ Approximate fineness modulus.

discharge increases production rate but grinding efficiency in pounds production per horsepower hour is lowered considerably by inclusion of the conveying fan horsepower. Figure 6 and Table 2 show that the gravity discharge grind is more efficient (pounds per horsepower hour) than the fan discharge grind for grinding milo thru the same size screen openings when the 3.0 horsepower available to the fan drive are charged to the grinding process. It is questionable whether the 3.0 horsepower available to the fan drive should all be charged to the grinding process, as some conveying of the ground product was done by the fan. When the hammermill was used with gravity discharge, no conveying work was done. If it were necessary to convey the ground product vertically and horizontally from a gravity discharge hammermill, an additional horsepower requirement would be introduced. The fan horsepower that was required to move air into and out of the hammermill and to the cyclone was a legitimate charge to grinding. However, as the hammermill was set up, it was difficult to accurately determine what portion of the power requirement should be charged to the grinding process. For these reasons, all efficiency comparisons will disregard the fan horsepower even though it is realized that some subdivision of this additional horsepower on the fan would be advantageous for efficiency calculations.

Some grinding of product occurs as it passes through the fan, pipe, and dust collector. The data collected on this subject are presented in Tables 1a, 1b, and 1c, and in Figures 7, 8, and 9. Sieve curves and approximate fineness modulus values were used to evaluate the granulation differences found. Figures 7, 8, and 9 (sieve analysis data taken from Tables 1a, 1b, and 1c) are sieve curves for ground milo, corn, and oats. These curves show that when grinding each grain through the same size screen, gravity discharge produced a coarser product than did fan discharge. Fineness modulus values as given in Tables 1a, 1b, and 1c point out the same relationship. The hammermill was

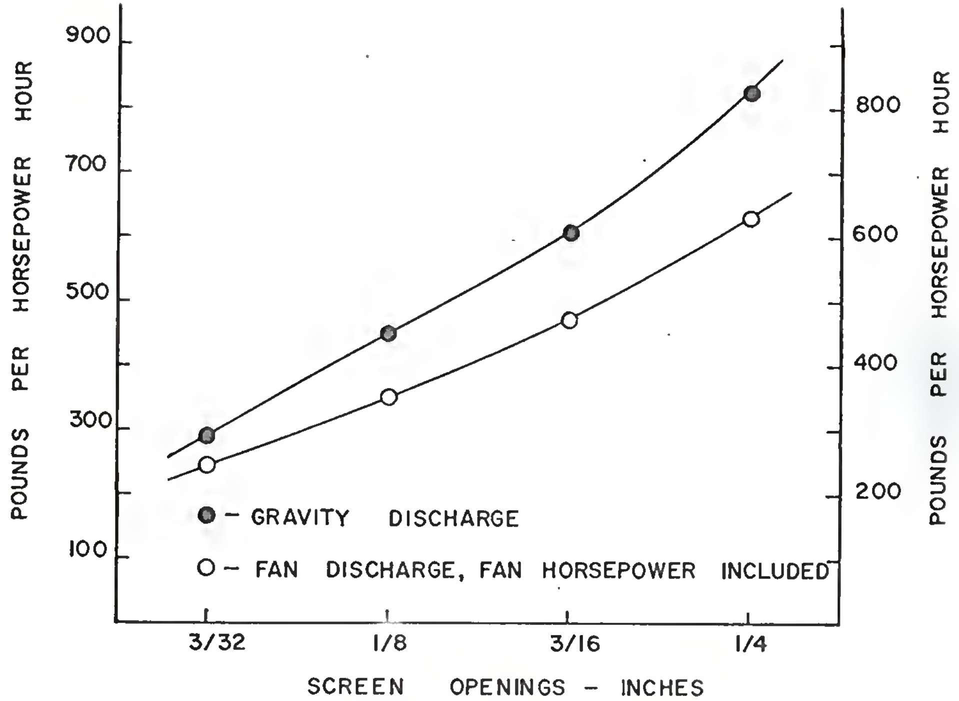


Figure 6. Effect of method of discharge on production rate and efficiency when grinding milo. Hammermill equipped with 1/16" individual hammers, full screen, and operated at 3600 rpm. Note: Fan horaepower included on fan discharge grind.

Table 2. Production rate as related to method of discharge in grinding milo.[1]

Test series no.	Screen size in.	Type of discharge	Grinding rate lb/hr.	Grinding efficiency lb/HPhr. [2]	F. M. [3]
1	3/32	gravity	2160	288	2.20
2	3/32	fan	2572	245	2.11
3	1/8	gravity	3350	447	2.60
4	1/8	fan	3714	353	2.52
5	3/16	gravity	4532	605	2.84
6	3/16	fan	4946	473	2.79
7	1/4	gravity	6178	824	3.18
8	1/4	fan	6659	633	3.01

[1] Composite of three test runs using feed grade milo with a test weight of 58.8 lbs./bu. and a moisture content of 13.6%. Hammermill equipped with 1/16" individual hammers, full screen, and operated at 3600 rpm.

[2] Fan horsepower included on test series numbers 2, 4, 6, and 8. Other tests figured at 7.5 horsepower. Fan motor horsepower is 3 so this makes a total horsepower of 10.5 for usa in figuring pounds per horsepower hour when fan is in operation.

[3] Approximata fineness modulus.

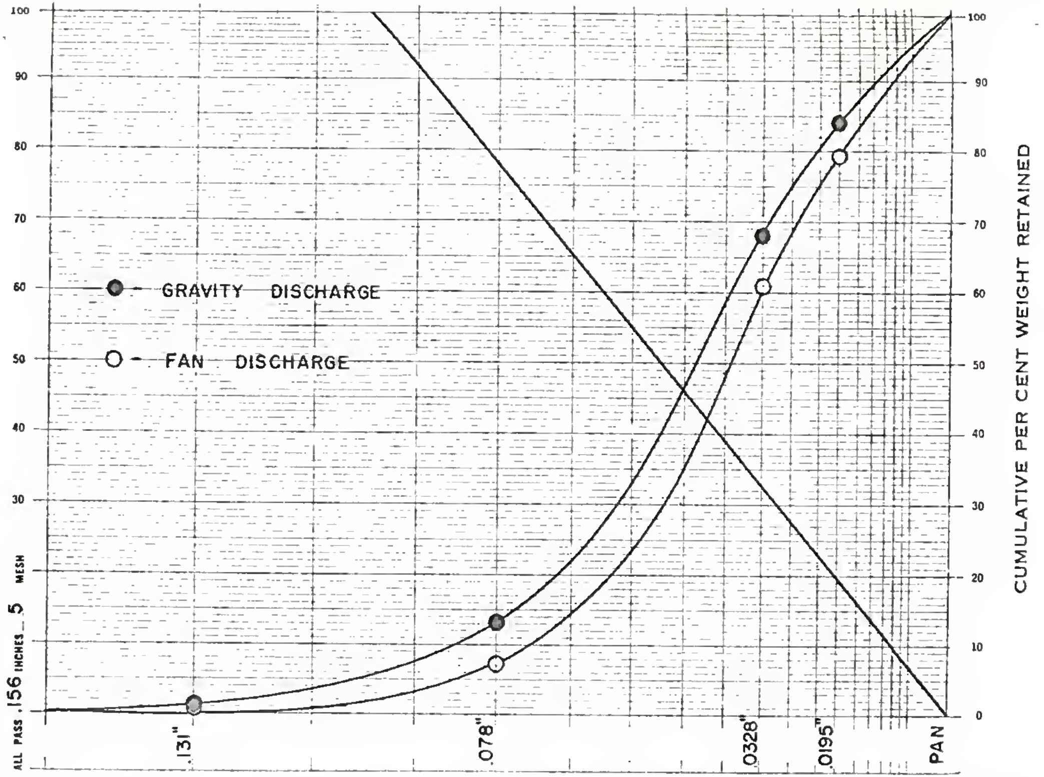


Figure 7. Effect of method of discharge on granulation of product when grinding milo. Hammermill equipped with 1/16" individual hammers, full screen, and operated at 3600 rpm. Curves shown are for 1/4" (size of screen openings) grinds.

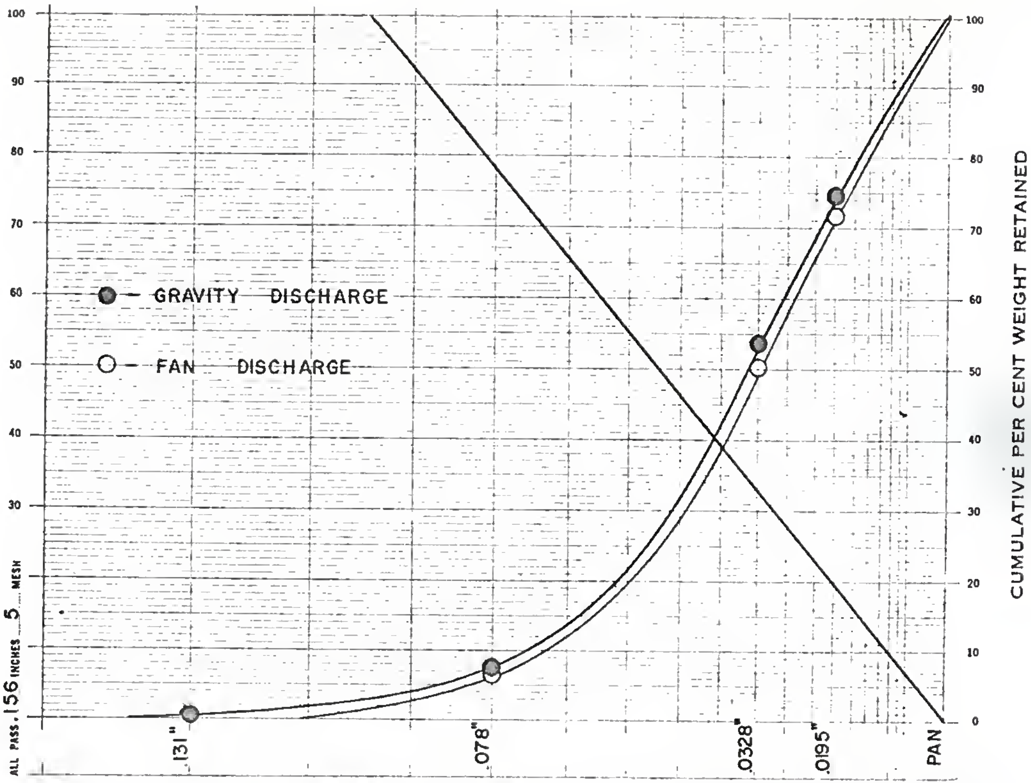


Figure 8. Effect of method of discharge on granulation of product when grinding corn. Hammermill equipped with 1/16" individual hammers, full screen, and operated at 3600 rpm. Curves shown are for 3/16" (size of screen openings) grinds.

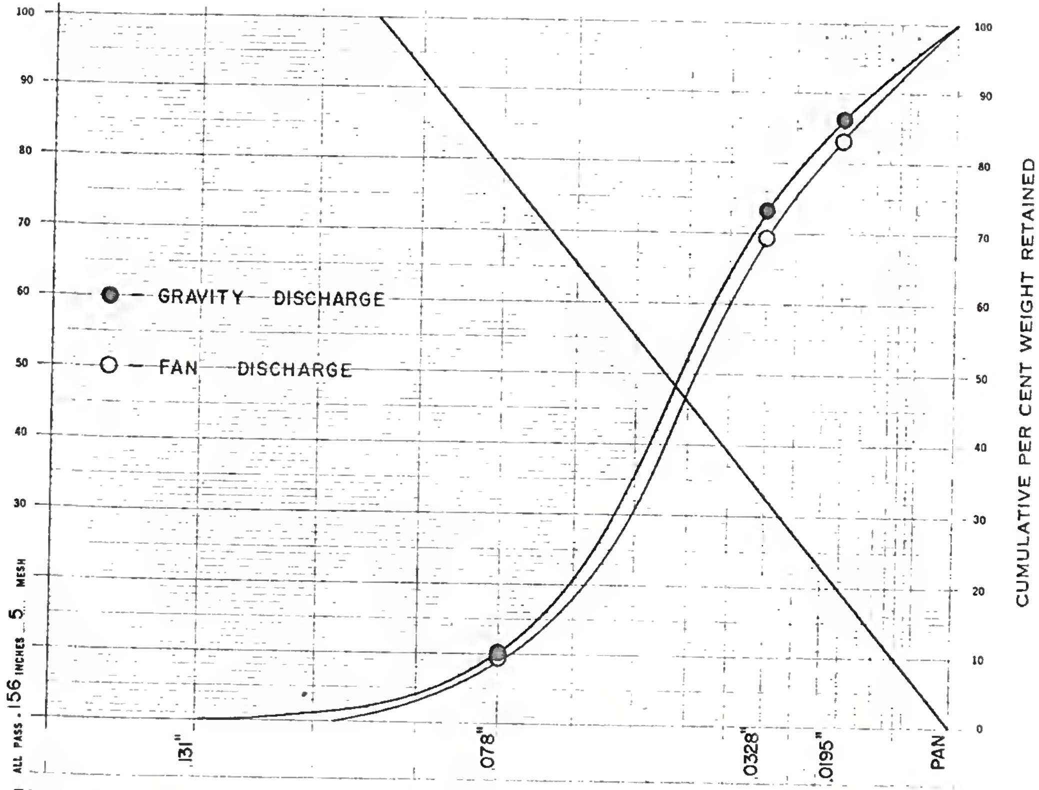


Figure 9. Effect of method of discharge on granulation of product when grinding oats. Hammer-mill equipped with 1/16" individual hammers, full screen, and operated at 3600 rpm. Curves shown are 1/4" (size of screen openings) grinds.

operated with full screen on these tests. When a portion of the screen area wss blanked off, this relationship did not hold true.

By statistical analysis on these granulation data, it was found that the difference, although apparent in most instances, was not always significant for method of discharge. All statistical analysis work was tested for significant differences at the 5% level. From these results, it may be said that the difference in granulation (percentages of fines tested) due to using gravity dischsrge or fan discharge on the hammermill was relatively small.

Some data were taken while testing methods of discharge to see what effect esch method might have on the temperatura change of tha material due to grinding. Temperatures of the whole grains were taken just previous to grinding and the temperatures of tha ground products were taken just after the test runs had been completed. The temperature change data for corn and oats are presented in Tables 3a and 3b. No data of this type were taken on milo but it is balieved thst milo would behave similar to corn, but with slightly less rise in temperature of the ground product due to the grinding process.

Figures 10 and 11 are graphs for corn and oats which present direct comparisons between grinding with fan discharge and gravity discharga. Both graphs show that fan discharge definitely keeps the product cooler than does gravity discharge. This relationship is more pronounced on the smaller screen sizes ss shown by the wider spacing between tha two curves in both Figures 10 and 11 st the 3/32" screen size compared to the 1/4" screen siza.

These two graphs also show that the temperature rise which occurs during grinding with gravity discharga is greater for oats than for corn. Actual messured temperature rise for oats was 24°F. (3/32" screen) while for grinding corn through the same screen size, the measured rise was only 16°F. It is important to note that these data were taken on comparativaly short test runs.

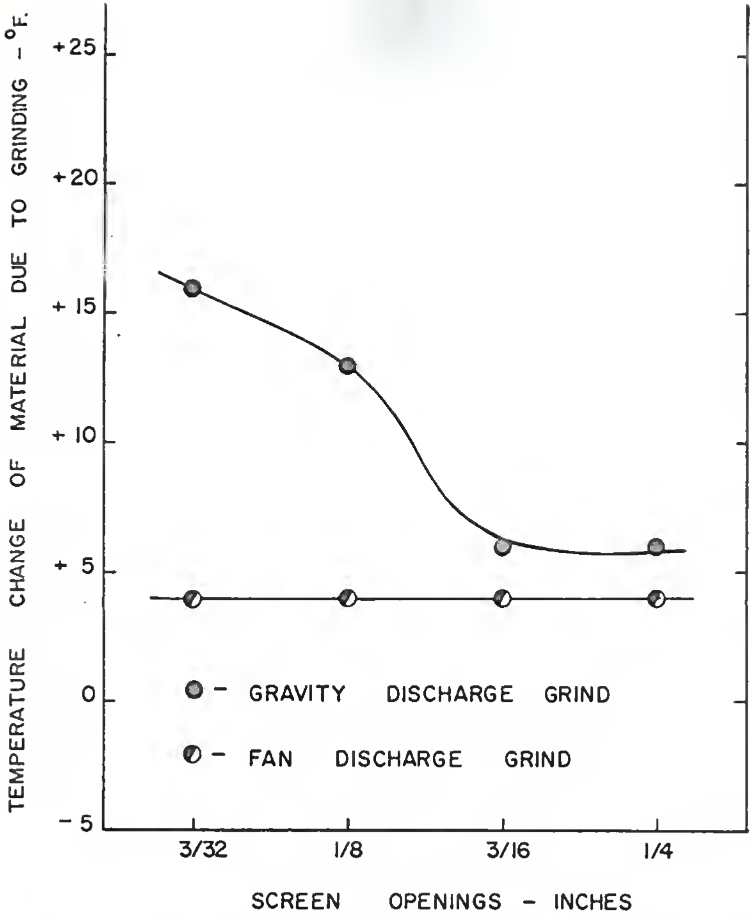


Figure 10. Effect of method of discharge on temperature change of the material due to grinding of corn with a hammermill. Hammermill equipped with a full screen and operated at 3600 rpm.

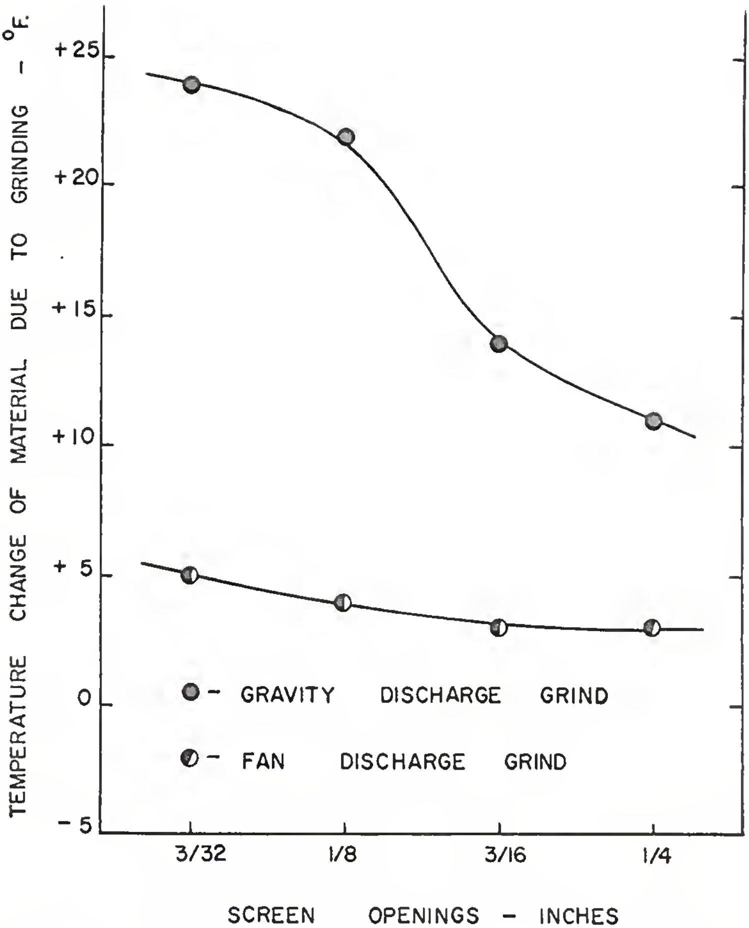


Figure 11. Effect of method of discharge on temperature change of the material due to grinding of oats with a hammermill. Hammermill equipped with a full screen and operated at 3600 rpm.

Table 3a. Influence of screen size, method of discharge, screen area, and moisture content of the grain on temperature of the ground material when grinding corn.[1]

Test series no.	Screen size in.	Type of discharge	Screen area [2]	Moisture content %	Grinding rate lb/hr.	Grinding efficiency lb/HPhr.	Material temperature degrees Farenheit before	after	rise	F.M. [3]
76	3/32	gravity	full	13.4	1250	167	82	98	16	2.07
68	3/32	fan	full	13.4	1306	174	81	85	4	2.04
87	3/32	gravity	½ blanked	13.5	1148	153	84	99	15	2.06
63	3/32	gravity	full	17.2	1044	139	82	99	17	2.31
83	3/32	fan	½ blanked	13.5	1342	179	82	87	5	2.01
78	1/8	gravity	full	13.4	1760	235	82	95	13	2.52
70	1/8	fan	full	13.4	1954	261	81	85	4	2.45
88	1/8	gravity	½ blanked	13.5	1776	237	84	95	11	2.45
64	1/8	gravity	full	17.2	1540	205	82	97	15	2.66
84	1/8	fan	½ blanked	13.5	1954	261	82	86	4	2.47
79	3/16	gravity	full	13.4	2426	323	83	89	6	2.79
72	3/16	fan	full	13.4	2456	327	81	85	4	2.75
89	3/16	gravity	½ blanked	13.5	2200	293	84	92	8	2.67
65	3/16	gravity	full	17	2494	333	82	93	11	2.91
85	3/16	fan	½ blanked	13.5	2434	325	82	88	6	2.66
81	1/4	gravity	full	13.4	3072	409	83	89	6	3.12
74	1/4	fan	full	13.4	3124	417	81	85	4	3.02
90	1/4	gravity	½ blanked	13.5	2820	376	84	91	7	2.94
66	1/4	gravity	full	17	3152	420	82	92	10	3.28
86	1/4	fan	½ blanked	13.5	2990	399	82	86	4	2.91

[1] Composite of three test runs using feed grade corn. Corn used in test series numbers 63, 64, 65, and 66 had a test weight of 53.8 lbs./bu. while all other corn used in these tests had a test weight of 57 lbs./bu. Hammermill equipped with 1/8" group hammers in test series numbers 68, 70, 72, 74, 76, and 78; 1/8" individual hammers in numbers 79 and 81; and 1/16" individual hammers on others, and operated at 3600 rpm.

[2] One-half of the screen blanked off in those tests specified by means of sheet metal on screen surface.

[3] Approximate fineness modulus.

Table 3b. Influence of screen size, method of discharge, screen area, and moisture content of the grain on temperature of the ground material when grinding oats.[1]

Test series no.	Screen size in.	Type of discharge	Screen area [2]	Moisture content %	Grinding rate lb/hr.	Grinding efficiency lb/HPhr.	Material temperature degrees Farenheit before	after	rise	F.M. [3]
101	3/32	gravity	full	13	564	75	68	92	24	2.18
129	3/32	gravity	½ blanked	13	520	69	70	96	26	2.01
113	3/32	gravity	full	17.1	386	51	70	91	21	2.13
125	3/32	fan	½ blanked	13	702	94	71	76	5	2.07
109	3/32	fan	full	17.9	458	61	71	71	0	2.24
103	1/8	gravity	full	13	840	112	68	90	22	2.61
130	1/8	gravity	½ blanked	13	710	95	70	92	22	2.42
114	1/8	gravity	full	17.1	596	79	70	91	21	2.66
126	1/8	fan	½ blanked	13	868	116	71	75	4	2.47
110	1/8	fan	full	17.9	710	95	71	72	1	2.66
105	3/16	gravity	full	13	1492	199	68	82	14	2.98
131	3/16	gravity	½ blanked	13	996	133	70	86	16	2.71
115	3/16	gravity	full	17.8	1114	149	70	85	15	2.94
127	3/16	fan	½ blanked	13	1224	163	71	74	3	2.75
111	3/16	fan	full	17.6	1200	160	71	73	2	2.92
107	1/4	gravity	full	13	2138	284	68	79	11	3.27
132	1/4	gravity	½ blanked	13	1486	198	70	85	15	2.92
116	1/4	gravity	full	17.8	1724	230	70	82	12	3.42
128	1/4	fan	½ blanked	13	1826	243	71	74	3	2.97
112	1/4	fan	full	17.6	2034	271	71	73	2	3.32

[1] Composite of three test runs using feed grade oats. Oats used in test series numbers 109, 110, 111, and 112 had a test weight of 34.8 lbs./bu. All other oats used in these tests had a test weight of 35 lbs./bu. Hammermill equipped with 1/16" individual hammers and operated at 3600 rpm.

[2] One-half of the screen blanked off in those tests specified by means of sheet metal on screen surfaces.

[3] Approximate fineness modulus.

Even greater temperature rises may occur if the hammermill were operated continuously.

When grinding either corn or oats with fan discharge, the temperature rise of the ground product was found to be fairly constant. This is possibly explsined by the fact that even though there is more heat and work loss when grinding with a small screen compared to a larger (size of openings) screen, production rate is sufficiently lower for the small screen to allow the air pulled through the machine by the fan to carry away more of this heat that is produced during grinding. This presents a relatively flat line for temperature rise for grinding with fan discharge for all screen sizes as shown in Figures 10 and 11.

There appears to be little difference on the amount of temperature rise due to use of one-half screen, full screen, and high moisture grain when grinding the same grain. Measured temperature changes for these various hammermill settings are given in Tables 3a and 3b. The primary difference in temperature variation of the ground product was due to the effect of screen size and method of discharge.

Moisture Content of Grain Being Ground

The object of this phase of the research was to measure the effect of high moisture grain on production rate and granulation when grinding with the experimental hammermill. Data gathered on this subject are presented in Figures 12-16 and Tables 4a, 4a', 4b, 4b', 4c and 4c'. High moisture grain refers to grain with 17-18 percent moisture while normal moisture grain is defined as grain having 13-14 per cent moisture content. Only grains having these two moisture levels were tested.

The lower two curves shown in Figure 12 represent what happened to production rate and grinding efficiency when milo of the two different moisture levels wss ground. In all comparisons, the moisture level was the only variable so that true evaluations could be made. Data presented in Figures 13 and 14 point out that these two moisture levels in the grains gave the same results on grinding of corn and oats as was found for grinding milo. For each grain and screen size, high moisture content in the grain reduced production rate and grinding efficiency appreciably when compared to grinding done with normal moisture grain. The actual percentage decreases are shown in Table 4d presented below. (Data taken from Tables 4a, 4a', 4b, 4b', 4c, and 4c'.)

Table 4d. Percentage production rate decrease due to grinding high moisture (17-18%) compared to normal moisture (13-14%) grains.

Screen Size in.	Grain Being Ground					
	Milo		Corn		Oats	
	Gravity reduction %	Fan reduction %	Gravity reduction %	Fan reduction %	Gravity reduction %	Fan reduction %
3/32	16	10.9	30.9	24	31.6	33.4
1/8	15	13.2	31.9	23.4	29	30.1
3/16	8.9	11.7	12.8	12.9	25.3	30.4
1/4	9.8	9.9	14.6	12.9	19.4	17

By referring to the above table, the following statements can be formulated by analysis of these data. (1) The percentage decrease in production rate is greatest for oats and least for milo when grinding high moisture content grains in comparison with normal moisture grains, (2) fine grinding (3/32" screen) suffers more per cent reduction in grinding capacity from grinding high moisture grains than does coarse grinding (1/4" screen) of the same grain, (3) the average decrease in production rate for all four screen sizes due to the grinding of high moisture grains would be approximately:

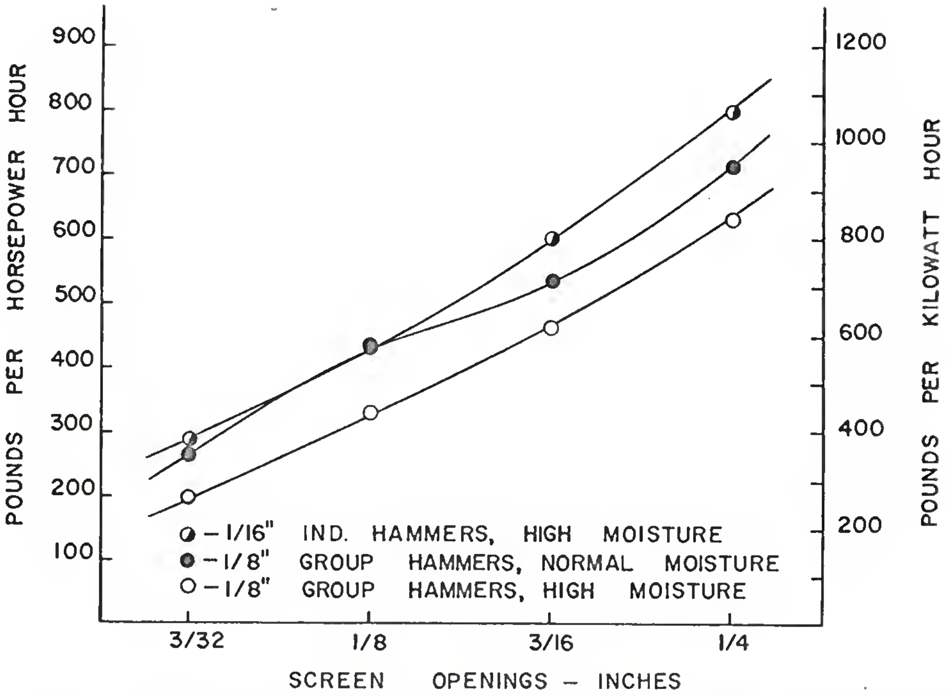


Figure 12. Effect of moisture content of the grain and type of hammers on production rate and grinding efficiency when grinding milo. Hammermill equipped with full screen, fan discharge, and operated at 3600 rpm.

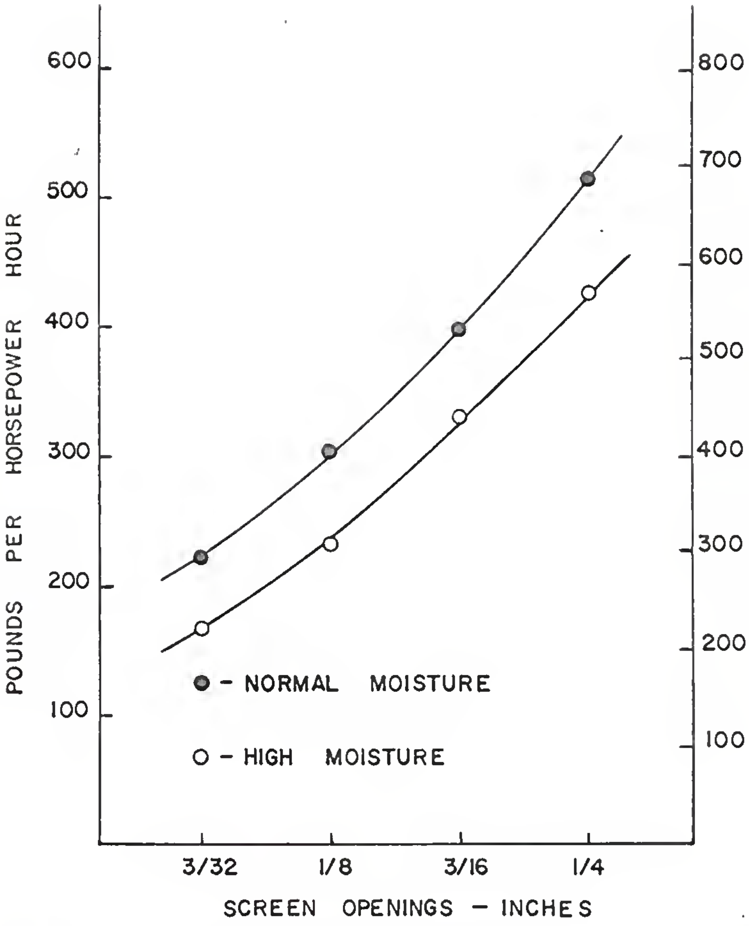


Figure 13. Effect of moisture content of the grain on production rate and grinding efficiency when grinding corn. Hammermill equipped with 1/16" individual hammers, full screen, fan discharge, and operated at 3600 rpm.

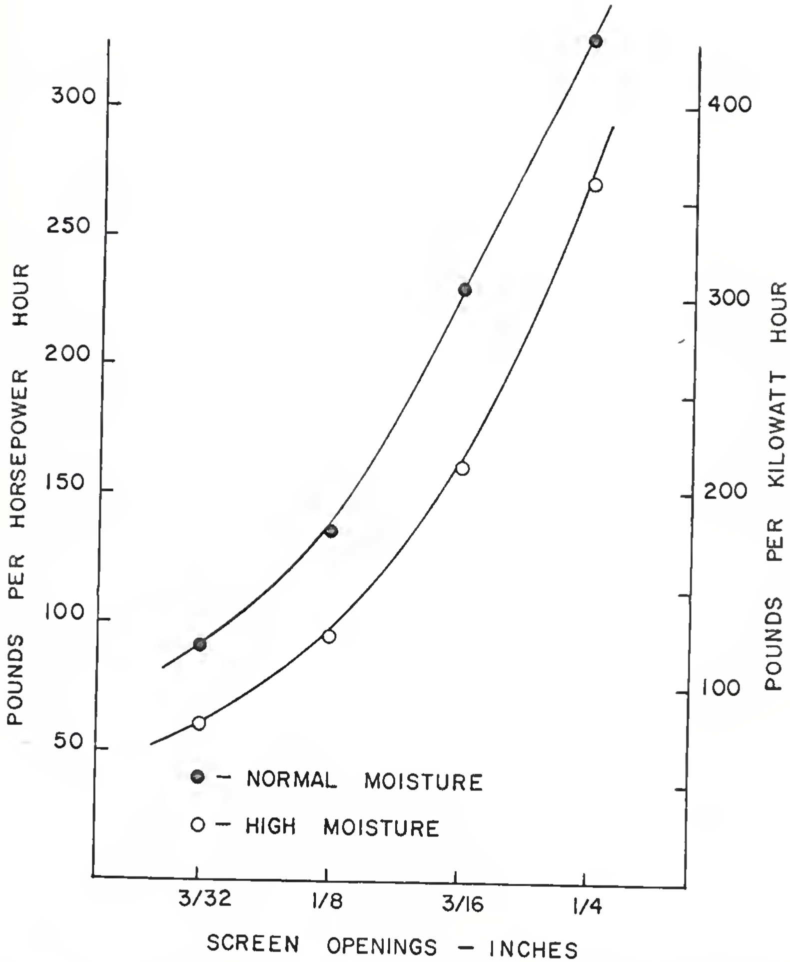


Figure 14. Effect of moisture content of the grain on production rate and grinding efficiency when grinding oats. Hammermill equipped with 1/16" individual hammers, full screen, fan discharge, and operated at 3600 rpm.

Table 4a. Production and granulation in relation to moisture content of the grain in grinding milo.[1]

Test series no.	Screen size in.	Moisture content %	Grinding rate lb/hr.	Grinding efficiency lb/HPhr.	lb/KWH	Tyler sieve analysis Per cent retained on each sieve + 6	+ 9	+ 20	+ 32	pan	F. M. [2]
9	3/32	16.9	2160	288	382	0	0	25	33	42	2.17
2	3/32	13.6	2572	343	452	0	0	22.3	33.9	43.8	2.11
10	1/8	16.9	3230	431	564	0	.5	41.7	26.2	31.6	2.57
4	1/8	13.6	3714	495	648	0	.7	39.5	28.4	31.4	2.52
11	3/16	17.3	4506	601	783	.5	3.0	51.8	20.4	24.3	2.85
6	3/16	13.6	4946	659	878	.5	2.7	49.9	23	23.9	2.79
12	1/4	17.3	6000	800	1041	1	8.4	53.9	15.9	20.8	3.04
8	1/4	13.6	6650	887	1181	.6	6.6	53.7	18.5	20.6	3.01

[1] Composite of three test runs using feed grade milo. The milo used in test series number 9, 10, 11, and 12 had a test weight of 56.6 lbs./bu. Hammermill equipped with 1/16" individual hammers, full screen, fan discharge, and operated at 3600 rpm. The milo used in test series numbers 2, 4, 6, and 8 had a test weight of 58.8 lbs./bu.

[2] Approximate fineness modulus.

Table 4a'. Production and granulation in relation to moisture content of the grain in grinding milo.[1]

Test series no.	Screen size in.	Moisture content %	Grinding rate lb/hr.	Grinding efficiency		Tyler sieve analysis Per cent retained on each sieve					F. M. [2]
				lb/HPhr.	lb/KWH	+ 6	+ 9	+ 20	+ 32	pan	
13	3/32	17.6	1924	257	340	0	0	26.9	33.9	39.2	2.23
1	3/32	13.6	2160	288	378	0	0	25.8	34.8	39.4	2.20
14	1/8	17.6	2908	388	511	0	.9	46.4	25.1	27.6	2.70
3	1/8	13.6	3350	447	590	0	.6	43.4	27.1	28.9	2.60
15	3/16	17.5	4002	537	710	.5	5.1	55	18.6	20.8	2.93
5	3/16	13.6	4532	605	811	0	3.7	52.7	21.8	21.8	2.84
16	1/4	17.5	5565	742	993	2	13.2	53.7	14	17.1	3.19
7	1/4	13.6	6178	824	1112	1.3	12.1	54.7	15.9	16	3.18

[1] Composite of three test runs using feed grade milo. Milo used in test series numbers 13, 14, 15, and 16 had a test weight of 56.6 lbs./bu. while that used in test series numbers 1, 3, 5, and 7 had a test weight of 56.8 lbs./bu. Hammermill equipped with 1/16" individual hammers, full screen, gravity discharge, and operated at 3600 rpm.

[2] Approximate fineness modulus.

Table 4b. Production and granulation in relation to moisture content of the grain in grinding corn.[1]

Test series no.	Screen size in.	Moisture content %	Grinding rate lb/hr.	Grinding efficiency lb/HPhr.	lb/KWH	Tyler sieve analysis Per cent retained on each sieve + 6	+ 9	+ 20	+ 32	pan	F. M. [2]
59	3/32	17.5	1268	169	220	0	0	29.6	30.7	39.7	2.25
52	3/32	13.1	1670	222	290	0	0	25	32.7	42.3	2.17
60	1/8	17.5	1748	233	303	0	.1	43.6	24.1	31.3	2.61
54	1/8	13.1	2282	304	396	0	1	39.6	26.5	32.9	2.54
61	3/16	16.9	2492	332	433	.2	9	48.8	18	24	2.90
56	3/16	13.1	2862	382	505	.4	7.4	45.9	20.9	25.4	2.84
62	1/4	16.9	3214	429	559	1.9	18.6	45.3	14.4	19.8	3.23
58	1/4	13.1	3692	492	642	1.8	14.9	44	17.4	21.9	3.06

[1] Composite of tbree test runs using feed grade corn. Corn used in test series numbers 59, 60, 61, and 62 had a test weight of 53.8 lbs./bu. while that used in test series numbers 52, 54, 56, and 58 had a test weight of 58.2 lbs/bu. Hammermill equipped with 1/16" individual hammers, full screen, fan discharge, and operated at 3600 rpm.

[2] Approximate fineness modulus.

Table 4b'. Production and granulation in relation to moisture content of the grain in grinding corn.[1]

Test series no.	Screen size in.	Moisture content %	Grinding rate lb/hr.	Grinding efficiency		Tyler sieve analysis Per cent retained on each sieve					F.M. [2]
				lb/HPhr.	lb/KWH	+ 6	+ 9	+ 20	+ 32	pan	
63	3/32	17.2	1044	139	181	0	0	31.8	29.8	38.4	2.31
51	3/32	13.1	1512	202	263	0	0	25.4	33.6	41	2.22
64	1/8	17.2	1540	205	268	0	1	45.5	24	29.5	2.66
53	1/8	13.1	2114	282	366	0	.9	40.6	26.6	31.9	2.57
65	3/16	17	2494	333	433	.3	8.9	48.8	18.4	23.6	2.91
55	3/16	13.1	2862	382	505	.4	7.4	45.9	20.9	25.4	2.84
66	1/4	17	3152	420	547	2.1	19.9	45.6	14.3	18.1	3.28
57	1/4	13.1	3692	492	642	1.8	14.9	44	17.4	21.9	3.06

1/ Composite of three test runs using feed grade corn. Corn used in test series numbers 63, 64, 65, and 66 had a test weight of 53.8 lbs./bu. while that used in test series numbers 51, 53, 55, and 57 had a test weight of 58.2 lbs./bu. Hammermill equipped with 1/16" individual hammers, full screen, gravity discharge, and operated at 3600 rpm.

2/ Approximate fineness modulus.

Table 4c. Production and granulation as related to moisture content of grain in grinding oats.[1]

Test series no.	Screen size in.	Moisture content %	Grinding rate lb/hr.	Grinding efficiency lb/HPhr.	lb/KWH	Tyler sieve analysis Per cent retained on each sieve + 6	+ 9	+ 20	+ 32	pan	F. M. [2]
109	3/32	17.9	458	61	79	0	0	31.5	29.8	38.7	2.24
102	3/32	13	688	92	119	0	0	24.6	32.7	42.7	2.10
110	1/8	17.9	710	95	125	0	.1	47.9	21.5	30.5	2.66
104	1/8	13	1016	135	177	0	0	39.7	27.6	32.7	2.49
111	3/16	17.6	1200	160	209	0	5.5	56.6	14.8	23.1	2.92
106	3/16	13	1724	230	298	0	2.8	58.6	17.5	21.1	2.93
112	1/4	17.6	2034	271	351	0	20.1	53.2	10.5	16.2	3.32
108	1/4	13	2450	327	427	0	9.3	60.1	13.8	16.8	3.19

[1] Composite of three test runs using feed grade oats. Oats used in test series numbers 109, 110, 111, and 112 had a test weight of 34.8 lbs./bu. while those used in test series numbers 102, 104, 106, and 108 had a test weight of 35 lbs./bu. Hammermill equipped with 1/16" individual hammers, full screen, fan discharge, and operated at 3600 rpm.

[2] Approximate fineness modulus.

Table 4c'. Production and granulation as related to moisture content of grain in grinding oats.[1]

Test series no.	Screen size in.	Moisture content %	Grinding rate lb/hr.	Grinding efficiency lb/HPhr.	Grinding efficiency lb/KWH	Tyler sieve analysis, Per cent retained on each sieve + 6	+ 9	+ 20	+ 32	pan	F. M. [2]
113	3/32	17.1	386	51	67	0	0	28.5	29.2	42.3	2.13
101	3/32	13	564	75	98	0	0	26.3	32.4	41.3	2.18
114	1/8	17.1	596	79	103	0	.5	48.2	21.2	30.1	2.66
103	1/8	13	840	112	146	0	0	36.2	25.4	29.4	2.61
115	3/16	17.8	1114	149	195	0	5.2	57.1	15.2	22.4	2.94
105	3/16	13	1492	199	258	0	2.6	60.9	17.7	18.8	2.93
116	1/4	17.8	1724	230	302	.2	21	53.7	10.2	14.9	3.42
107	1/4	13	2138	284	372	0	10.1	63.2	12.8	13.9	3.27

[1] Composite of three test runs using feed grade oats. Oats used in test series numbers 101, 103, 105, and 107 had a test weight of 35 lbs./bu. while those used in test series numbers 113, 114, 115, and 116 had a test weight of 34.8 lbs./bu. Hammermill equipped with 1/16" individual hammers, full screen, gravity discharge, and operated at 3600 rpm.

[2] Approximate fineness modulus.

a. Oats 25 per cent

b. Corn 20 per cent

c. Milo 12 per cent

and (4) method of discharge does appear to influence the percentage decrease in production rate but the results are not consistent.

The granulation of the product that resulted from grinding high moisture grains was somewhat variable in behavior. For instance, when grinding milo, very little change in granulation of the grind was found when comparing the ground product of normal moisture grain to that resulting from the grinding of high moisture milo. Tables 4a and 4a' point out this relationship under the heading "Tyler sieve analysis". For each screen size, the variation in amount recovered in the pan for these two moisture levels was very small. Statistically, this difference was not great enough to be significant when grinding milo.

When corn of these two moisture levels was ground a significant difference in the granulation of product was found. Tables 4b and 4b' give measured data for the grinding of corn. The sieve analyses and fineness modulus values point out the apparent differences in the granulation of these grinds. The change found, as shown by Figure 15, was that high moisture content corn gives a coarser grind with a smaller percentage of fines than the product resulting from grinding corn with normal moisture content when ground through the same screen size. This difference in granulation of product was large enough to be statistically significant for both fan and gravity discharge grinding and for most screen sizes.

Oats behaved differently from either corn or milo when grain at these two moisture levels was ground. As shown in Tables 4c and 4c', the gravity and fan discharge also give different granulation results. Figure 16 points out an

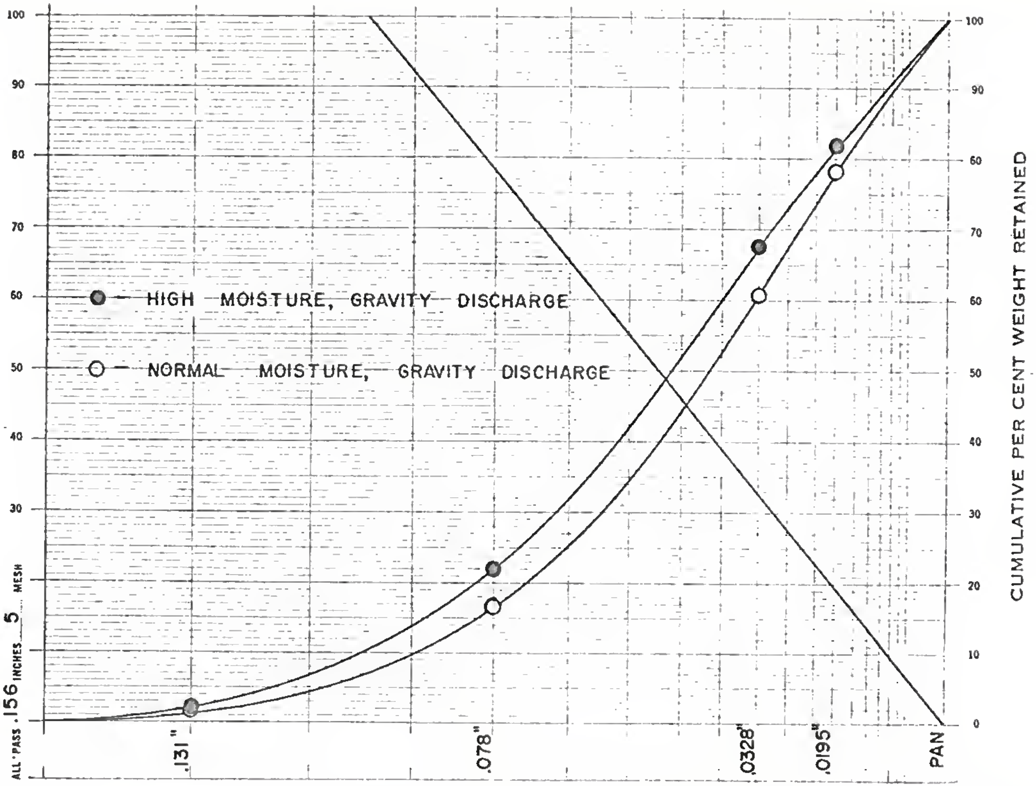


Figure 15. Effect of moisture content of the grain on granulation when grinding corn with a hammermill. Hammermill equipped with 1/16" individual hammers, full screen, gravity discharge, and operated at 3600 rpm.

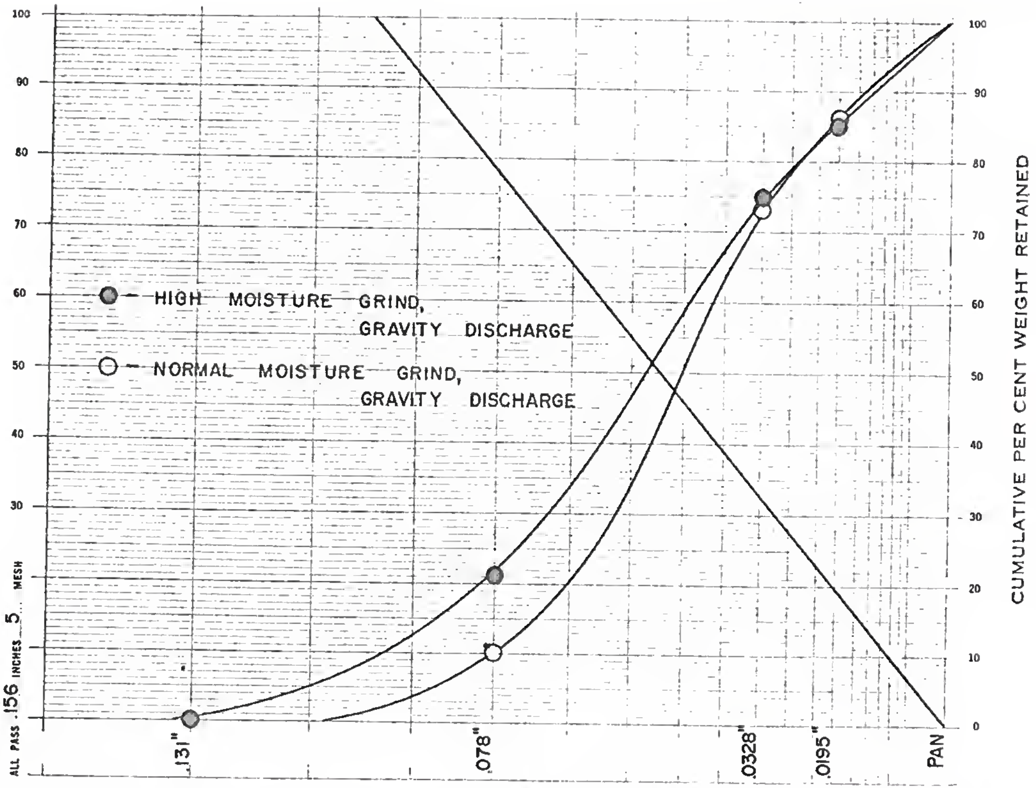


Figure 16. Effect of moisture content of the grain on granulation when grinding oats with a hammermill. Hammermill equipped with 1/16" individual hammers, full screen, gravity discharge, and operated at 3600 rpm.

important relationship. In this graph, it is noticeable that the high moisture content grain gives more coarse particles in the ground product than does grinding of normal moisture content oats. It is also apparent that the percentages of fines is slightly higher when grinding 17-18 per cent moisture oats with gravity discharge. The results are rather inconsistent for grinding oats, and statistical analysis shows the percentage of fines to be significantly different only in a small portion of the tests. There is more change in granulation of product on the two smaller screens than on the two larger ones, resulting from the variable moisture content in the oats. However, it is important to note that although the change in percentages of fines may have been inconsistent, the percentage of coarse particles was always found to be higher in a high moisture ground product compared to that having normal moisture content.

Type of Hammers

Some of the most surprising aspects of this research were encountered while testing the three different hammer designs. Tables 5a, 5a', 5b, 5b', and 5c' give the data taken during this phase of testing.

Figures 17, 18, and 19 show the differences found in the grinding efficiencies when grinding milo, corn, and oats with the different hammer types. Figure 17 points out that a substantial increase in production rate and grinding efficiency results from the use of 1/16" individual hammers as compared to the 1/8" individual or 1/8" group hammers. The production increase resulting from this substitution ranged from 8 to 26 per cent when grinding milo, with the average production rate increase being 15 per cent. The 1/8" group hammers gave slightly less production than grinding done with 1/8" individual hammers. This difference between the two types of 1/8" thick hammers was rather small and was found to be present only when grinding milo.

Figures 18 and 19 also show that the 1/16" individual hammers gave much better production and grinding efficiency than did the 1/8" individual hammers for grinding corn and oats. The production curves for 1/8" group hammers were not placed on these two graphs because they were nearly identical to the 1/8" individual hammer production curves that are shown. In essence, the curves shown for 1/8" individual hammers could also be labeled 1/8" group hammers on Figures 18 and 19. The percentage increase in grinding rate resulting from substituting 1/16" individual hammers for 1/8" individual hammers ranged from 14 to 21 per cent for grinding corn with an average increase of 18 per cent. For grinding oats, a 22 to 30 per cent gain in grinding rate was measured as a result of the change in thickness of the hammers. Increased grinding rates were measured on all screen sizes and for grinding with both gravity and fan discharge when 1/16" individual hammers were used instead of 1/8" group or 1/8" individual hammers.

There was a measurable difference in the no load current (power required to run the hammermill empty) for the different hammer designs. There were 45 hammers in each of the three different hammer sets used for testing. This means only one-half as much hammer surface was available when using the 1/16" individual hammers as when the 1/8" group or individual hammers were used. The no load current requirement was increased by 20.6 per cent when 1/8" individual or 1/8" group hammers were used instead of 1/16" individual hammers. The increased production rates obtained when grinding with 1/16" individual hammers are partially explained by this difference in the no load requirements for the different hammer thicknesses. However, the savings in no load current do not fully compensate for the differential in production rates that was found. Therefore, it is assumed that the 1/16" individual hammers do a more efficient job of

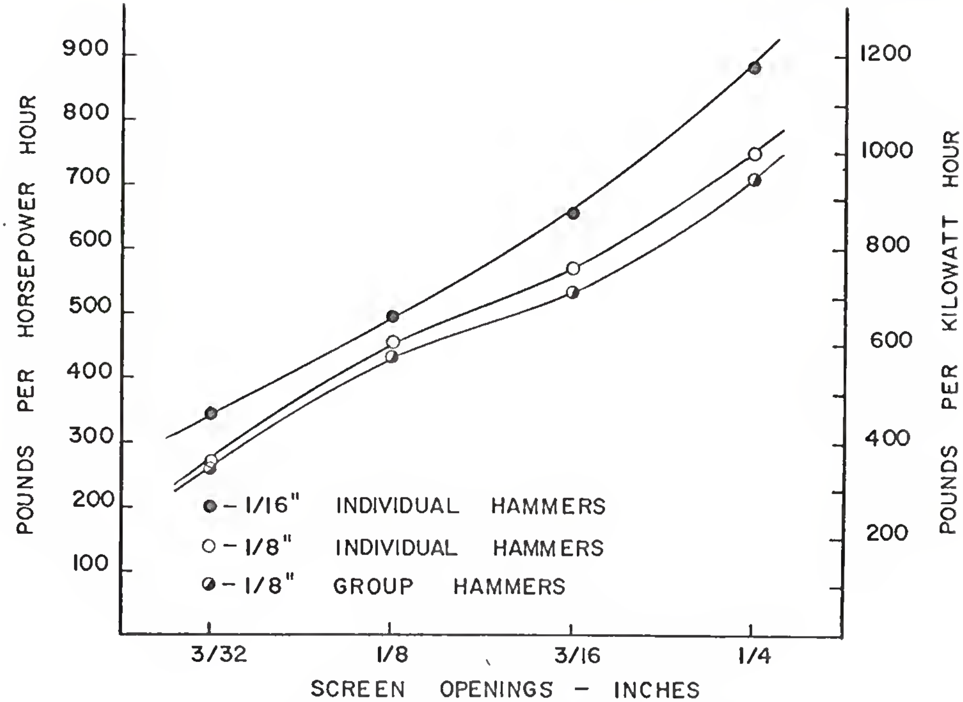


Figure 17. Effect of type of hammers on production rate and grinding efficiency when grinding milo. Hammermill equipped with full screen, fan discharge, and operated at 3600 rpm.

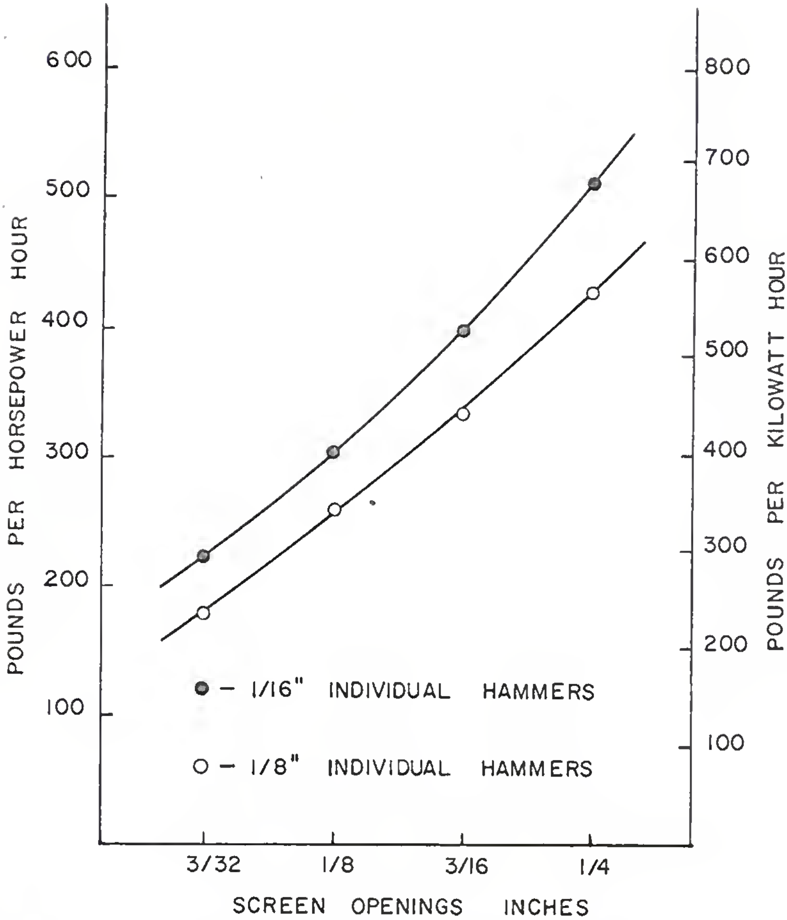


Figure 18. Effect of type of hammers on production rate and grinding efficiency when grinding corn. Hammermill equipped with full screen, fan discharge, and operated at 3600 rpm.

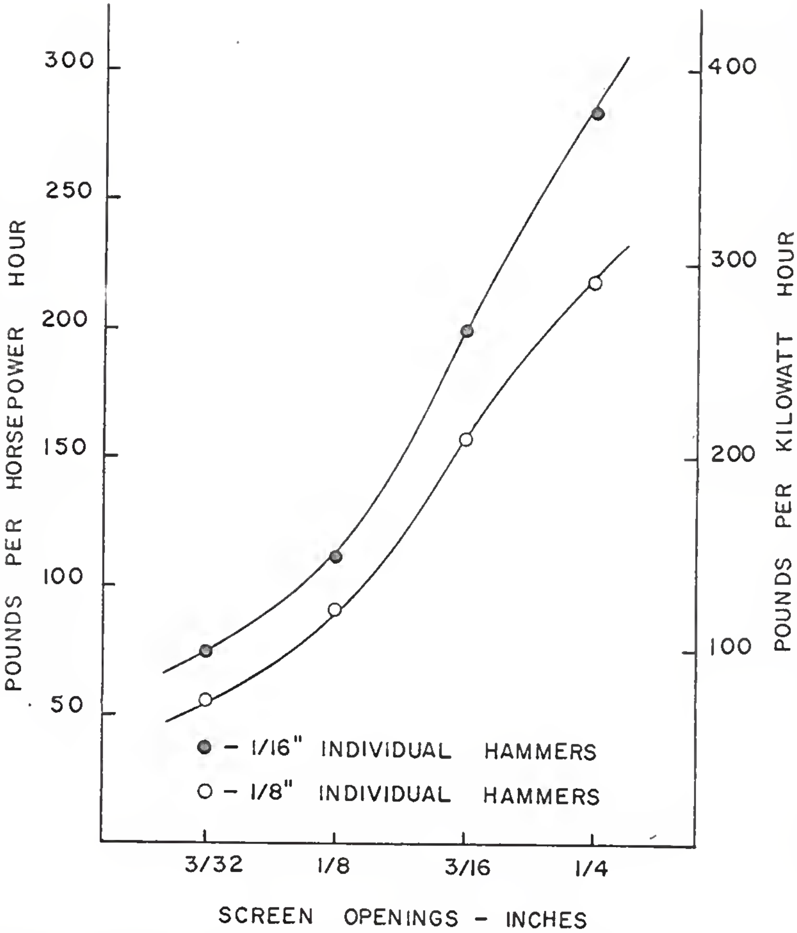


Figure 19. Effect of type of hammers on production rate and grinding efficiency when grinding oats. Hammermill equipped with full screen, gravity discharge, and operated at 3600 rpm.

Table 5a. Production and granulation in relation to type of hammers in grinding milo.[1]

Test series no.	Screen area in.	Type of hammers	Grinding rate lb/hr.	Grinding efficiency lb/HPhr.	Grinding efficiency lb/KWH	Tyler sieve analysis Per cent retained on each sieve + 6	+ 9	+ 20	+ 32	pan	F. M. [2]
17	3/32	1/8" ind.	2034	272	353	0	0	17.3	33.1	49.6	1.97
18	3/32	1/8" group	1978	264	344	0	0	19	33.9	47.1	2.04
2	3/32	1/16" ind.	2572	343	452	0	0	22.3	33.9	43.8	2.11
19	1/8	1/8" ind.	3436	458	579	0	1.1	36.9	27.8	34.2	2.46
20	1/8	1/8" group	3280	437	575	0	1	39.4	27.7	31.9	2.54
4	1/8	1/16" ind.	3714	495	648	0	.7	39.5	28.5	31.4	2.52
21	3/16	1/8" ind.	4270	570	737	0	2	42.5	25.5	30	2.65
22	3/16	1/8" group	4026	537	699	0	1.7	44.8	24.7	28.8	2.62
6	3/16	1/16" ind.	4946	659	878	.5	2.7	49.9	23	23.9	2.79
23	1/4	1/8" ind.	5638	750	968	.5	5	47.5	21.7	25.3	2.82
24	1/4	1/8" group	5352	714	937	.5	5.9	51.8	20.5	21.3	2.92
8	1/4	1/16" ind.	6650	887	1181	.6	6.6	53.7	18.5	20.6	3.01

[1] Composite of three test runs using feed grade milo. The milo used in test series numbers 2, 4, 6, and 8 had a test weight of 58.8 lbs./bu. while the milo used in the other test series in this table had a test weight of 59.4 lbs./bu. Hammermill equipped with full screen, fan discharge, and operated at 3600 rpm.

[2] Approximate fineness modulus.

Table 5a'. Production and granulation as related to type of hammers in grinding milo.[1]

Test series no.	Screen size in.	Type of hammers	Grinding rate lb/hr.	Grinding efficiency lb/HPhr.	Grinding efficiency lb/KWH	Tyler sieve analysis, Per cent retained on each sieve + 6	+ 9	+ 20	+ 32	pan	F. M. [2]
25	3/32	1/8" ind.	1920	256	324	0	0	19.4	34.6	46	2.06
26	3/32	1/8" group	1734	231	304	0	0	21.8	36.4	41.8	2.14
1	3/32	1/16" ind.	2160	288	378	0	0	25.8	34.8	39.4	2.20
27	1/8	1/8" ind.	2978	397	502	0	.7	36.8	29.8	32.7	2.53
28	1/8	1/8" group	2802	374	488	0	1.1	38.5	29.6	30.8	2.56
3	1/8	1/16" ind.	3350	447	590	0	.6	43.4	27.1	28.9	2.60
29	3/16	1/8" ind.	4030	537	667	0	3.3	49.3	23.7	23.7	2.81
30	3/16	1/8" group	3826	510	668	.6	3.7	48.8	23.7	23.2	2.82
5	3/16	1/16" ind.	4532	605	811	0	3.7	52.7	21.8	21.8	2.84
31	1/4	1/8" ind.	5220	696	888	1	8.2	51.2	19.6	20	3.05
32	1/4	1/8" group	5046	673	877	1.5	9.1	53.7	19	16.7	3.12
7	1/4	1/16" ind.	6178	824	1112	1.3	12.1	54.7	15.9	16	3.18

[1] Composite of three test runs using feed grade milo. The milo used in test series numbers 1, 3, 5, and 7 had a test weight of 58.8 lbs./bu. and a moisture content of 13.6 per cent. All other milo used in these tests had a test weight of 59.4 lbs./bu. and 13.5 per cent moisture. Hammermill equipped with full screen, gravity discharge, and operated at 3600 rpm.

[2] Approximate fineness modulus.

Table 5b. Production and granulation in relation to type of hammers in grinding corn.[2]

Test series no.	Screen size in.	Type of hammers	Grinding rate lb/hr.	Grinding efficiency		Tyler sieve analysis Per cent retained on each sieve					F. M. [2]
				lb/HPhr.	lb/KWH	+ 6	+ 9	+ 20	+ 32	pan	
67	3/32	1/8" ind.	1346	179	234	0	0	22.1	32.5	45.4	2.08
68	3/32	1/8" group	1306	174	227	0	0	21.2	32.6	46.2	2.04
52	3/32	1/16" ind.	1670	222	290	0	0	25	32.7	42.3	2.17
69	1/8	1/8" ind.	1946	259	338	0	1.2	35.5	27.7	35.6	2.50
70	1/8	1/8" group	1954	261	339	0	1.1	35.4	26.9	36.6	2.45
54	1/8	1/16" ind.	2282	304	396	0	1	39.6	26.5	32.9	2.54
71	3/16	1/8" ind.	2494	333	433	0	5.2	42.9	22.8	29.1	2.68
72	3/16	1/8" group	2456	327	426	0	6	43.9	22	28.1	2.75
56	3/16	1/16" ind.	2978	398	517	0	6.5	44	21.2	28.3	2.75
73	1/4	1/8" ind.	3208	429	558	1	12.1	43.3	18.8	24.8	2.96
74	1/4	1/8" group	3124	417	548	1	13.1	44.2	18.1	23.6	3.02
58	1/4	1/16" ind.	3852	514	679	1.5	15.9	44.3	16.9	21.4	3.11

[1] Composite of three test runs using feed grade corn. Corn used in test series numbers 52, 54, 56, and 58 had a test weight of 58.2 lbs./bu. and a moisture content of 13.1 per cent. Corn used in all other tests had a test weight of 57 lbs./bu. and 13.4 per cent moisture. Hammermill equipped with full screen, fan discharge, and operated at 3600 rpm.

[2] Approximate fineness modulus.

Table 5b'. Production and granulation in relation to type of hammers in grinding corn.[1]

Test series no.	Screen size in.	Type of hammers	Grinding rate lb/hr.	Grinding efficiency lb/HPhr.	Grinding efficiency lb/KWH	Tyler sieve analysis, Percent retained on each sieve + 6	+ 9	+ 20	+ 32	pan	F. M. [2]
75	3/32	1/8" ind.	1242	166	216	0	0	21.7	34.5	43.8	2.10
76	3/32	1/8" group	1250	167	217	0	0	22.2	33.4	44.4	2.07
51	3/32	1/16" ind.	1512	202	263	0	0	25.4	33.6	41	2.22
77	1/8	1/8" ind.	1848	247	322	0	1.1	38.8	27.9	32.2	2.53
78	1/8	1/8" group	1760	235	306	0	.8	37.5	28.2	33.5	2.52
53	1/8	1/16" ind.	2114	282	366	0	.9	40.6	26.6	31.9	2.57
79	3/16	1/8" ind.	2426	323	421	0	6.3	45.8	22.1	25.8	2.79
80	3/16	1/8" group	2337	312	406	.1	6.2	44.9	21.7	27.9	2.77
55	3/16	1/16" ind.	2862	382	505	.4	7.4	45.9	20.9	25.4	2.84
81	1/4	1/8" ind.	3072	409	534	1.5	14.2	46.6	17.8	19.9	3.12
82	1/4	1/8" group	3082	411	536	1.4	14	45.6	17.5	21.5	3.08
57	1/4	1/16" ind.	3692	492	642	1.8	14.9	44	17.4	21.9	3.06

[1] Composite of three test runs using feed grade corn. Corn used in test series numbers 51, 53, 55, and 57 had a test weight of 58.2 lbs./bu. and a moisture content of 13.1 per cent. Corn used in all other tests had a test weight of 57 lbs./bu. and 13.4 per cent moisture. Hammermill equipped with full screen, gravity discharge, and operated at 3600 rpm.

[2] Approximate fineness modulus.

Table 5c'. Production and granulation as related to type of hammers in grinding oats.[1]

Test series no.	Screen size in.	Type of hammers	Grinding rate lb/hr.	Grinding efficiency lb/HPhr.	Grinding efficiency lb/KWH	Tyler sieve analysis, Per cent retained on each sieve + 6	+ 9	+ 20	+ 32	pan	F. M. [2]
117	3/32	1/8" ind.	416	55	73	0	0	21	33.4	45.6	2.03
118	3/32	1/8" group	416	55	72	0	0	20.2	34.5	45.3	2.06
101	3/32	1/16" ind.	564	75	98	0	0	26.3	32.4	41.3	2.18
119	1/8	1/8" ind.	690	92	119	0	0	39.8	27.4	32.8	2.44
120	1/8	1/8" group	652	87	113	0	0	39.8	27.5	32.7	2.44
103	1/8	1/16" ind.	840	112	146	0	0	46.2	25.4	28.4	2.61
121	3/16	1/8" ind.	1174	157	205	0	2.4	55.9	19.1	22.6	2.91
122	3/16	1/8" group	1180	158	205	0	2.6	56.5	18.5	22.4	2.93
105	3/16	1/16" ind.	1492	199	258	0	2.6	60.9	17.7	18.8	2.98
123	1/4	1/8" ind.	1638	218	285	0	9	59.8	14.3	16.9	3.16
124	1/4	1/8" group	1668	222	289	0	10.3	59.9	13.9	15.9	3.20
107	1/4	1/16" ind.	2138	284	372	0	10.1	63.2	12.8	13.9	3.27

1/ Composite of three tests using feed grade oats with a test weight of 35 lbs./bu. and a moisture content of 13 per cent. Hammermill equipped with full screen, gravity discharge, and operated at 3600 rpm.

2/ Approximate fineness modulus.

grinding with the available power than do the 1/8" thick hammers.

Granulation changes of the ground product are also correlated to the types of hammers used when grinding with this hammermill. Tables 5a, 5a', 5b, 5b', and 5c' give average sieve analyses taken for the different grinds obtained when grinding with these three hammer designs. Figures 20, 21, and 22 show that the 1/16" thick individual hammers gave a coarser grind than did the 1/8" thick individual hammers for grinding of milo, corn, and oats. There was a higher proportion of coarse particles and a smaller percentage of fines (through 32 mesh) produced when grinding through the same size screen with 1/16" individual hammers than when grinding with 1/8" individual hammers. This difference in granulation of product, although small, was statistically significant when grinding corn and oats. Granulation differences for milo resulting from use of the different hammer types were not statistically significant for any screen size. Again, the 1/8" group hammers performed much the same as did the 1/8" individual hammers in that the resulting grinds showed little difference in the granulation of product.

Screen Area

The term, screen area, as used in this paper, is defined as the total screen surface available in the grinding chamber and not the square inches of open area for each screen size. Before discussing the experimental results, something must be said about the unusually great screen area found in this experimental hammermill. There were 424 square inches of screen area for each screen size on this machine. The average hammermill being used in feed mills today has 10 to 12 square inches of screen area per input horsepower. The experimental mill tested has approximately 40 square inches of screen area per

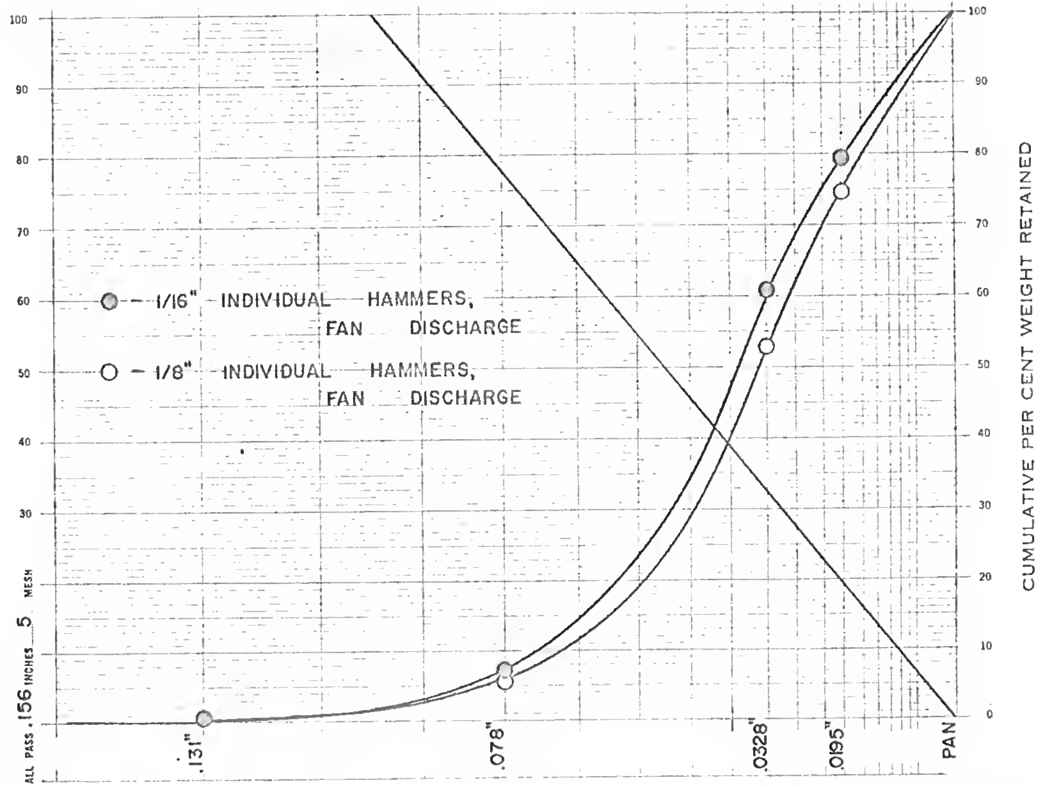


Figure 20. Effect of type of hammers on granulation of product when grinding milo. Hammermill equipped with full screen, fan discharge, and operated at 3600 rpm. Curves shown are for 1/4" (size of screen openings) grinds.

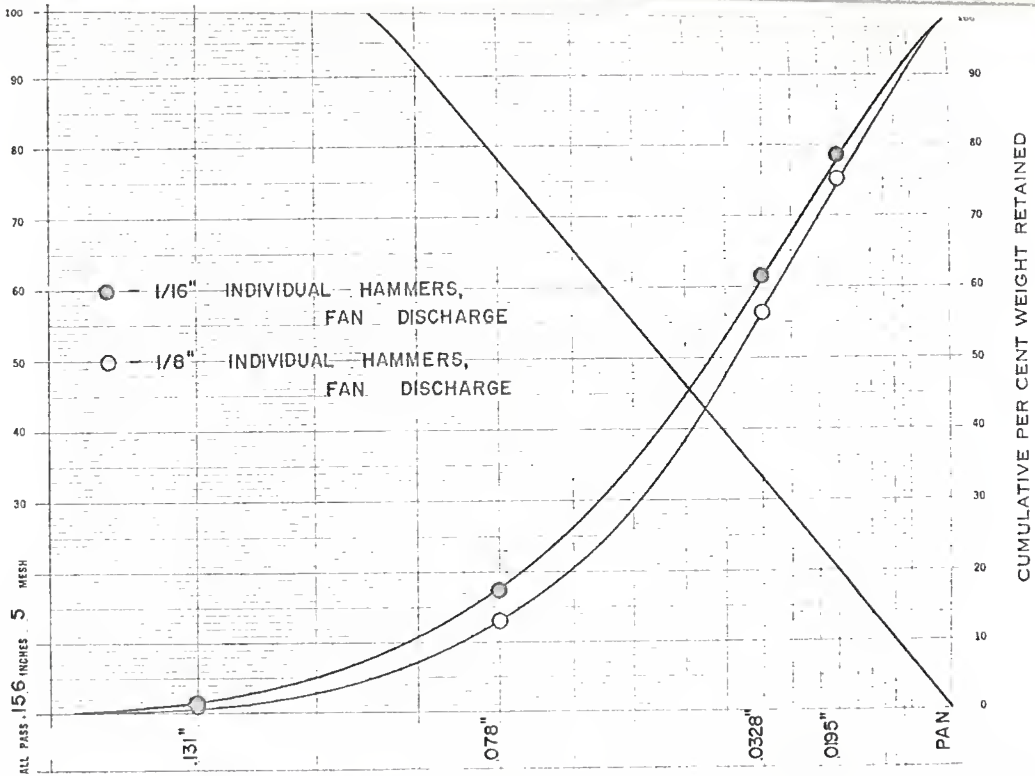


Figure 21. Effect of type of hammers on granulation of product when grinding corn. Hammermill equipped with full screen, fan discharge, and operated at 3600 rpm. Curves shown are for 1/4" (size of screen openings) grinds.

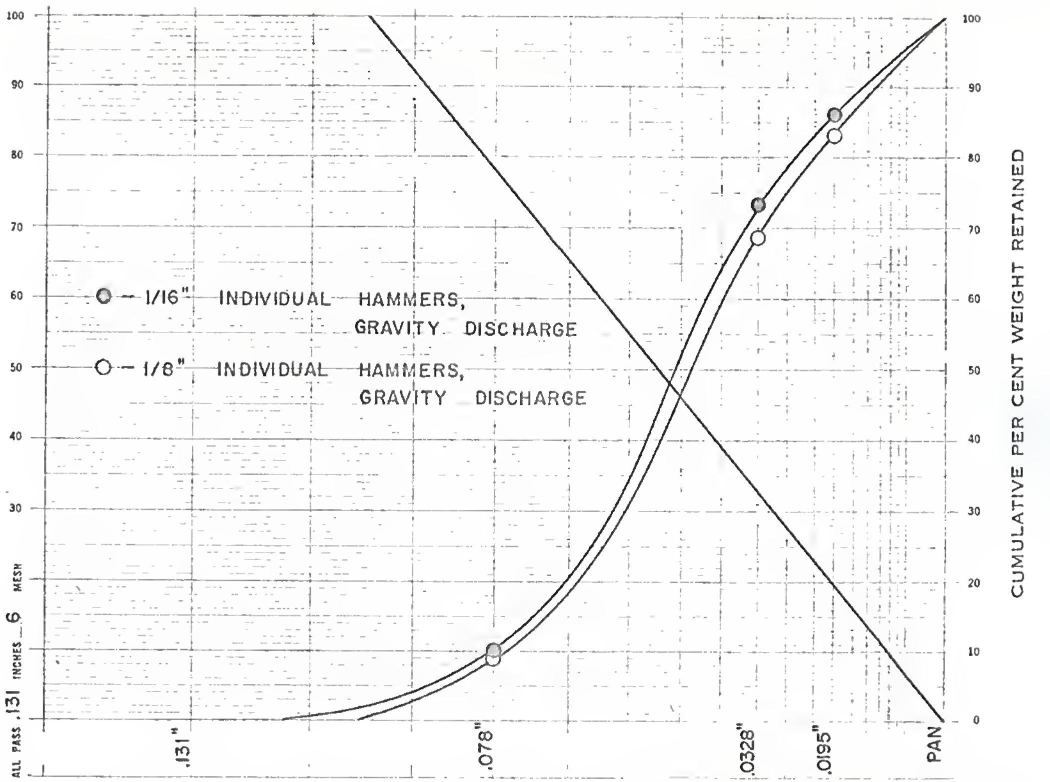


Figure 22. Effect of type of hammers on granulation of product when grinding oats. Hammermill equipped with full screen, gravity discharge, and operated at 3600 rpm. Curves shown are for 1/4" (size of screen openings) grinds.

horsepower as do most production type hammermills. For this reason it is in order to caution the users of larger commercial hammermills that they might not get as good production per input horsepower with their grinders as is reported in this thesis.

The data taken from testing of the full screen versus the half screen when grinding with the hammermill are presented in Tables 6a, 6a', 6b, 6b', 6c, and 6c'. Production and granulation data for all three grains are given in these tables. The term "full" appearing under the heading "Screen area" refers to grinding done with the entire 180° of available screen area in use while the term "½ blanked" refers to grinding done with one-half the screen area blanked off by placing sheet metal on 90° of the 180° screens between the hammer tips and the screen surface.

Figures 23 and 24 show that production rate and grinding efficiency were reduced considerably when the screen area was cut by one-half for grinding of milo and corn through the same size screen. (Diameter of openings.) Figure 26 presents the production curves for grinding oats with these two different screen areas. It can be seen by Figure 25 that the effect of screen area was unimportant on grinding capacity when grinding through the 3/32" size screen. In fact, slightly more production was obtained when grinding with one-half screen blanked than with full screen in this one instance. However, production rates and grinding efficiency were adversely affected by cutting the screen area for the other three screen sizes. The results obtained when grinding with full screen as compared to grinding with one-half of the screen area blanked can be summarized by the following statements:

1. Grinding with one-half screen blanked cut production rate and grinding efficiency an average of:

    a. 23 per cent when grinding milo
    b. 20 per cent when grinding corn
    c. 19 per cent when grinding oats

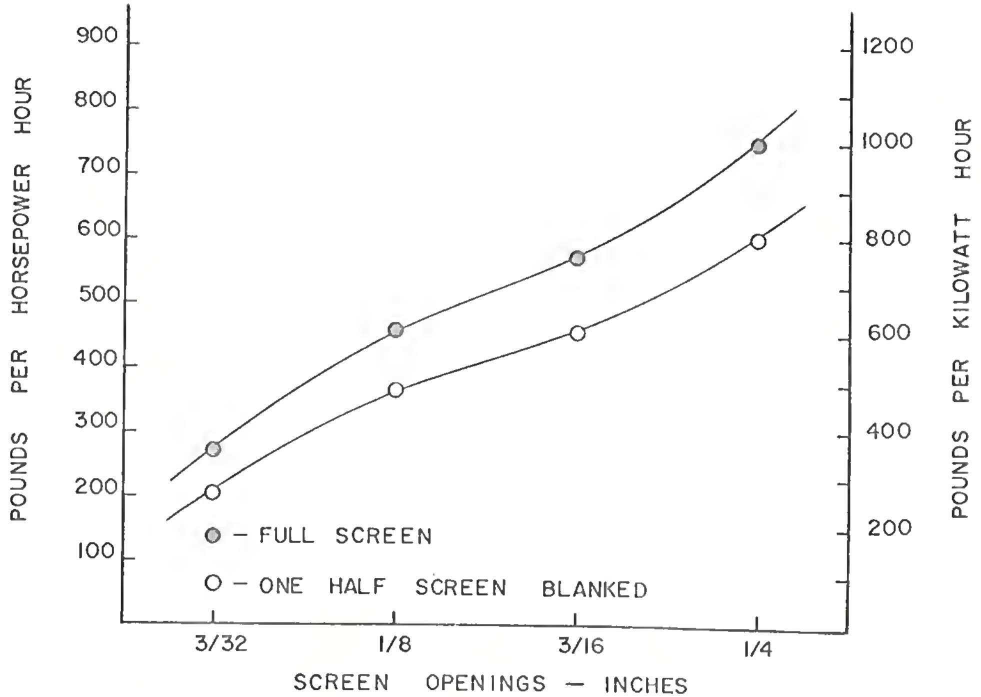


Figure 23. Effect of screen area on production rate and grinding efficiency when grinding milo with a hammermill. Hammermill equipped with 1/8" individual hammers, fan discharge, and operated at 3600 rpm.

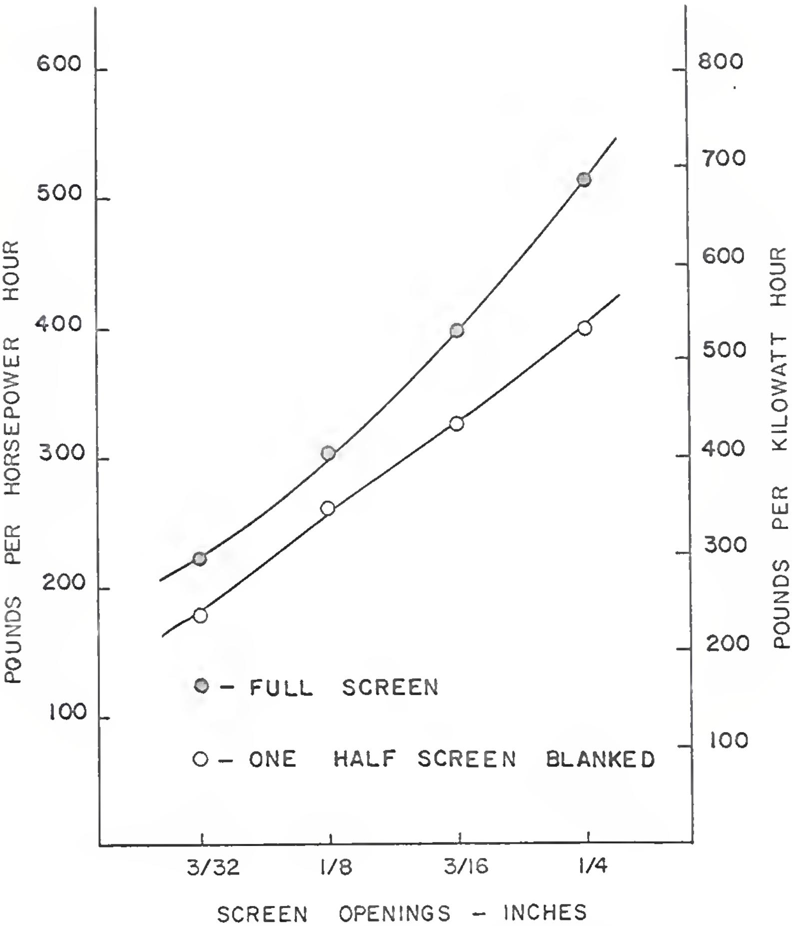


Figure 24. Effect of screen area on production rate and grinding efficiency when grinding corn with a hammermill. Hammermill equipped with 1/16" individual hammers, fan discharge, and operated at 3600 rpm.

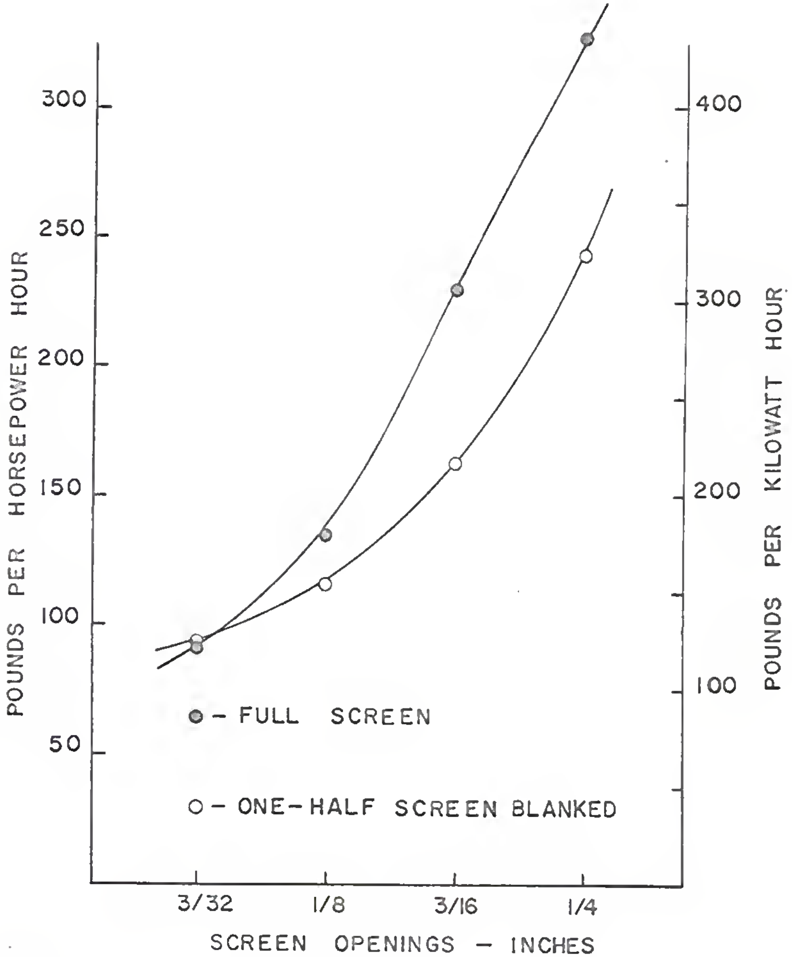


Figure 25. Effect of screen area on production rate and grinding efficiency when grinding oats with a hammermill. Hammermill equipped with 1/16" individual hammers, fan discharge, and operated at 3600 rpm.

Table 6a. Production and granulation as related to screen area in grinding milo.[1]

Test series no.	Screen size in.	Screen area [2]	Grinding rate lb/hr.	Grinding efficiency lb/HPhr.	Grinding efficiency lb/KWH	Tyler sieve analysis Per cent retained on each sieve + 6	+ 9	+ 20	+ 32	pan	F. M. [3]
33	3/32	½ blanked	1533	204	268	0	0	13.7	31.7	54.5	1.84
17	3/32	full	2034	272	353	0	0	17.3	33.1	49.6	1.97
34	1/8	½ blanked	2726	363	474	0	.8	34.3	29	35.9	2.43
19	1/8	full	3436	458	579	0	1.1	36.9	27.8	34.2	2.46
35	3/16	½ blanked	3416	455	584	0	1.5	40.8	27.2	30.5	2.68
21	3/16	full	4270	570	737	0	2	42.5	25.5	30	2.65
36	1/4	½ blanked	4504	601	767	.5	4	46.9	23.2	25.4	2.78
23	1/4	full	5638	750	968	.5	5	47.4	21.8	25.3	2.82

[1] Composite of three test runs using feed grade milo with a test weight of 59.4 lbs./bu. and a moisture content of 13.5 per cent. Hammermill equipped with 1/8" individual hammers, fan discharge, and operated at 3600 rpm.

[2] One-half of the screen blanked off in those tests specified by means of sheet metal on screen surface.

[3] Approximate fineness modulus.

Table 6a'. Production and granulation as related to screen area in grinding milo.[1]

Test series no.	Screen size in.	Screen area [2]	Grinding rate lb/hr.	Grinding efficiency lb/HPhr.	Grinding efficiency lb/KWH	Tyler sieve analysis, Per cent retained on each sieve + 6	+ 9	+ 20	+ 32	pan	F. M. [3]
37	3/32	½ blanked	1406	188	244	0	0	10.6	33.1	56.3	1.83
25	3/32	full	1920	256	324	0	0	19.4	34.6	46	2.06
38	1/8	½ blanked	2288	305	398	0	.6	31.6	31.1	36.7	2.43
27	1/8	full	2978	397	502	0	.7	36.8	29.8	32.7	2.53
39	3/16	½ blanked	2840	378	499	0	1.4	39	27.9	31.7	2.59
29	3/16	full	4030	537	667	0	3.3	49.3	23.7	23.7	2.81
40	1/4	½ blanked	3874	516	685	.9	5.3	44.4	23.5	25.9	2.80
31	1/4	full	5220	696	888	1	8.2	51.2	19.6	20	3.05

[1] Composite of three test runs using feed grade milo with a test weight of 59.4 lbs./bu. and a moisture content of 13.5 per cent. Hammermill equipped with 1/8" individual hammers, gravity discharge, and operated at 3600 rpm.

[2] One-half of the screen blanked off in those tests specified by means of sheet metal on screen surface.

[3] Approximate fineness modulus.

Table 6b. Production and granulation as related to screen area in grinding corn.[1]

Test series no.	Screen size in.	Screen area [2]	Grinding rate lb/hr.	Grinding efficiency lb/HPhr.	Grinding efficiency lb/KWH	Tyler sieve analysis, Per cent retained on each sieve + 6	+ 9	+ 20	+ 32	pan	F. M. [3]
83	3/32	½ blanked	1342	179	233	0	0	19.4	32.7	47.9	2.01
52	3/32	full	1670	222	290	0	0	25	32.7	42.3	2.17
84	1/8	½ blanked	1954	261	340	0	1.5	36	26.8	35.7	2.47
54	1/8	full	2282	304	396	0	1	39.6	26.5	32.9	2.54
85	3/16	½ blanked	2434	325	422	0	4.8	41.9	22.9	30.4	2.66
56	3/16	full	2978	398	517	0	6.5	44	21.2	28.3	2.75
86	1/4	½ blanked	2990	399	522	1	10.9	43.4	19.3	25.4	2.91
58	1/4	full	3852	514	679	1.5	15.9	44.3	16.9	21.4	3.11

[1] Composite of three test runs using feed grade corn. Corn used in test series numbers 83, 84, 85, and 86 had a test weight of 57 lbs./bu. and a moisture content of 13.5 per cent while the corn used in test series numbers 52, 54, 56, and 58 had a test weight of 58.2 lbs./bu. and 13.1 per cent moisture. Hammermill equipped with 1/16" individual hammers, fan discharge, and operated at 3600 rpm.

[2] One-half of the screen blanked off in those tests specified by means of sheet metal on screen surface.

[3] Approximate fineness modulus.

Table 6b'. Production and granulation as related to screen area in grinding corn.[1]

Test series no.	Screen size in.	Screen area [2]	Grinding rate lb/hr.	Grinding efficiency lb/HPhr.	Grinding efficiency lb/KWH	Tyler sieve analysis Per cent retained on each sieve + 6	+ 9	+ 20	+ 32	pan	F. M. [3]
87	3/32	½ blanked	1148	153	199	0	0	18.6	35.5	45.9	2.06
51	3/32	full	1512	202	263	0	0	25.4	33.6	41	2.22
88	1/8	½ blanked	1776	237	309	0	1.5	34.8	28.3	35.4	2.45
53	1/8	full	2114	282	366	0	.9	40.6	26.6	31.9	2.57
89	3/16	½ blanked	2200	293	382	0	4	43.1	23.6	29.3	2.67
55	3/16	full	2862	382	505	.4	7.4	45.9	20.9	25.4	2.84
90	1/4	½ blanked	2820	376	490	.8	10.4	44.8	20.3	23.7	2.94
57	1/4	full	3692	492	642	1.8	14.9	44	17.4	21.9	3.06

[1] Composite of three test runs using feed grade corn. Corn used in test series numbers 87, 88, 89, and 90 had a test weight of 57 lbs./bu. and a moisture content of 13.5 per cent while the corn used in test series numbers 51, 53, 55, and 57 had a test weight of 58.2 lbs./bu. and 13.1 per cent moisture. Hammermill equipped with 1/16" individual hammers, gravity discharge, and operated at 3600 rpm.

[2] One-half of the screen blanked off in those tests specified by means of sheet metal on screen surface.

[3] Approximate fineness modulus.

Table 6c. Production and granulation as related to screen area in grinding oats.[1]

Test series no.	Screen size in.	Screen area [2]	Grinding rate lb/hr.	Grinding efficiency		Tyler sieve analysis Per cent retained on each sieve					F. M. [3]
				lb/HPhr.	lb/KWH	+ 6	+ 9	+ 20	+ 32	pan	
125	3/32	½ blanked	702	94	123	0	0	22.6	33.3	44.1	2.07
102	3/32	full	688	92	119	0	0	24.6	32.7	42.7	2.10
126	1/8	½ blanked	868	116	151	0	0	37.7	29.8	32.5	2.47
104	1/8	full	1016	135	177	0	0	39.6	27.6	32.7	2.49
127	3/16	½ blanked	1224	163	213	0	.5	49.7	23.3	26.5	2.75
106	3/16	full	1724	230	298	0	2.8	58.6	17.5	21.1	2.93
128	1/4	½ blanked	1826	243	322	0	3.2	57.7	17.6	21.5	2.97
108	1/4	full	2450	327	427	0	9.3	60.1	13.8	16.8	3.19

[1] Composite of three test runs using feed grade oats with a test weight of 35 lbs./bu. and moisture content of 13.1 per cent. Hammermill equipped with 1/16" individual hammers, fan discharge, and operated at 3600 rpm.

[2] One-half of the screen blanked off in those tests specified by means of sheet metal on screen surface.

[3] Approximate fineness modulus.

Table 6c'. Production and granulation as related to screen area in grinding oats.[1]

Test series no.	Screen size in.	Screen area [2]	Grinding rate lb/hr.	Grinding efficiency lb/HPhr.	Grinding efficiency lb/KWH	Tyler sieve analysis Per cent retained on each sieve + 6	+ 9	+ 20	+ 32	pan	F.M. [3]
129	3/32	½ blanked	520	69	90	0	0	19	33.5	47.5	2.01
101	3/32	full	564	75	98	0	0	26.3	32.4	41.3	2.18
130	1/8	½ blanked	710	95	123	0	0	36.1	29.3	34.6	2.42
103	1/8	full	840	112	146	0	0	46.2	25.4	28.4	2.61
131	3/16	½ blanked	996	133	173	0	.5	45.9	25.2	28.4	2.71
105	3/16	full	1492	199	258	0	2.6	60.9	17.7	18.8	2.98
132	1/4	½ blanked	1486	198	257	0	2.7	56.2	18.6	22.5	2.92
107	1/4	full	2138	284	372	0	10.1	63.2	12.8	13.9	3.27

[1] Composite of three test runs using feed grade oats with a test weight of 35 lbs./bu. and moisture content of 13.1 per cent. Hammermill equipped with 1/16" individual hammers, gravity discharge and operated at 3600 rpm.

[2] One-half of the screen blanked off in those test specified by means of sheet metal on screen surface.

[3] Approximate fineness modulus.

2. Blanking of one-half the screen area reduced production rates more when grinding with gravity discharge than when grinding with fan discharge.

3. The per cent reduction was much greater for screens with large diameter holes than for screens with small holes.

4. A significantly finer grind was produced when one-half of the screen area was blanked off during grinding than when grinding with full screen exposed.

Some difficulty was experienced in maintaining proper feed rate and load on the hammermill when grinding oats with one-half screen blanked and the smaller screen sizes. The load within the mill had a tendency to build up which would then overload the motor. These were the only production tests during the entire testing period that showed much variation in production results.

Figures 26, 27, and 28 are graphs which show the granulation of the ground products to be much finer when grinding with one-half screen blanked when compared to ground products resulting from grinding with full screen. This statement refers to grinding through screens having the same diameter openings but with different screen areas. Grinding with gravity discharge was more adversely affected by reducing the screen area than grinding discharged by fan for both granulation and production. Statistically, the difference between percentage of fines produced during grinding with full screen and grinding with one-half screen blanked was large enough to be significant for all screen sizes when grinding corn and oats. However, as shown in Table 6a, there was no appreciable difference in the granulation of the product resulting from grinding milo with full screen or one-half screen blanked when the hammermill was discharged by the fan. When the discharge was by gravity, an apparent difference in the amount of fines was found.

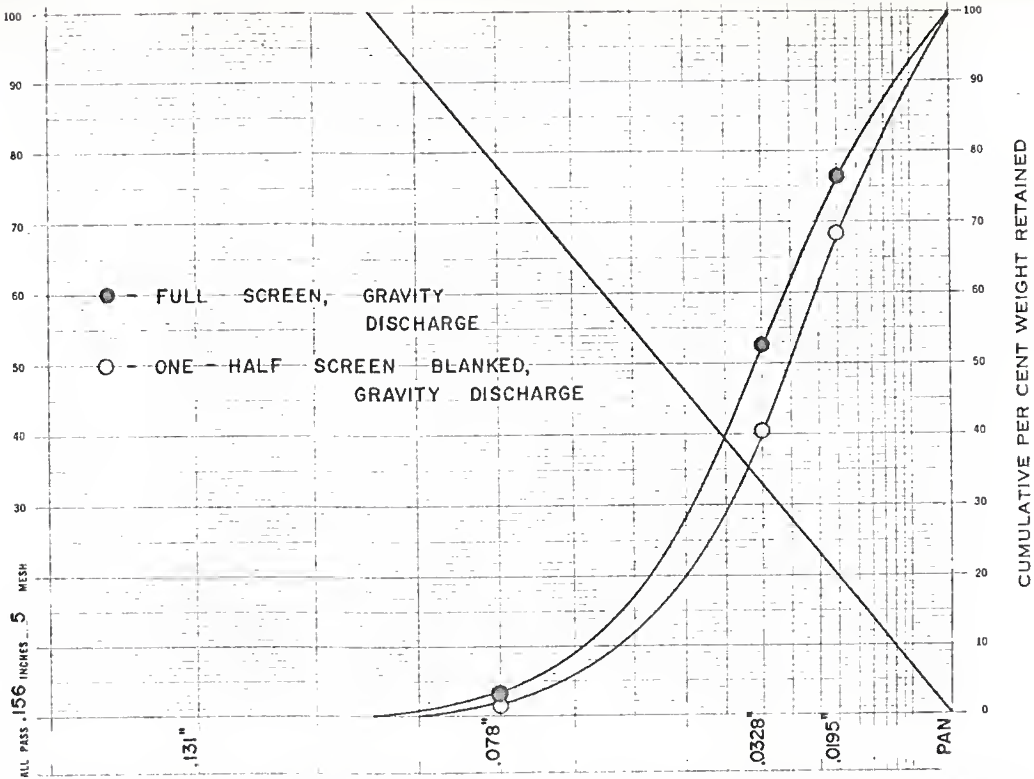


Figure 26. Effect of screen area on granulation of product when grinding milo with a hammermill. Hammermill equipped with 1/8" individual hammers, gravity discharge, and operated at 3600 rpm. Curves shown are for 3/16" (size of screen openings) grinds.

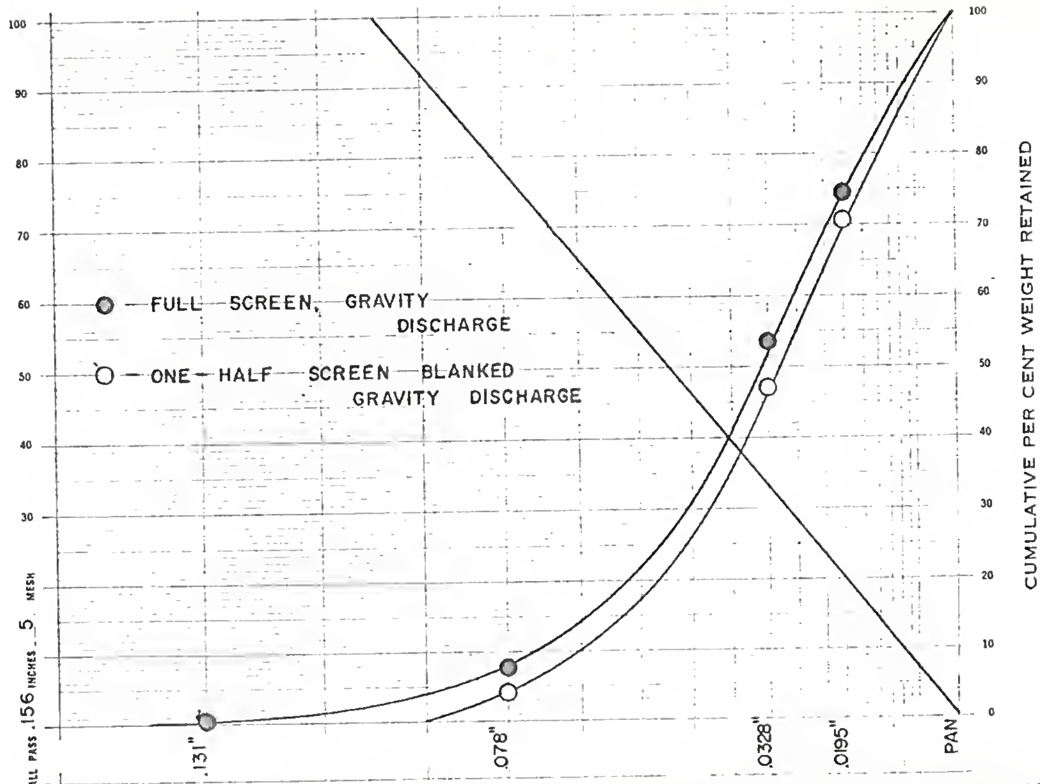


Figure 27. Effect of screen area on granulation of product when grinding corn with a hammermill. Hammermill equipped with 1/16" individual hammers, gravity discharge, and operated at 3600 rpm. Curves shown are for grinds when 3/16" (size of screen openings) grinds.

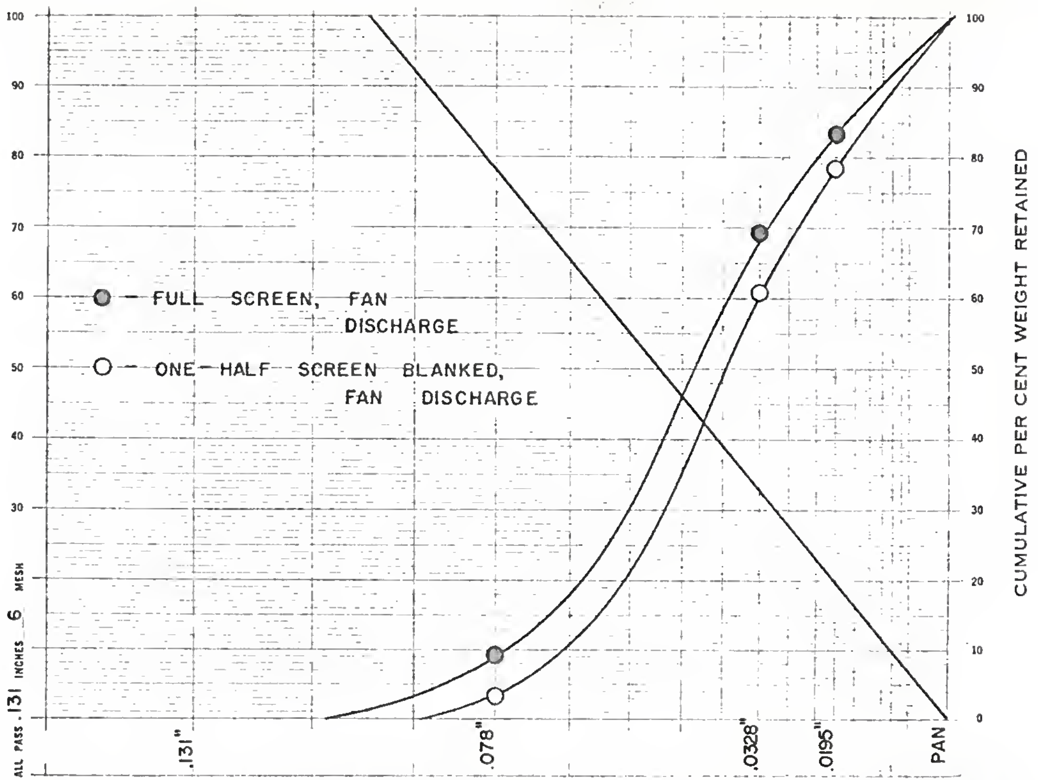


Figure 28. Effect of screen area on granulation of product when grinding oats with a hammermill. Hammermill equipped with 1/16" individual hammers, fan discharge, and operated at 3600 rpm. Curves shown are for 1/4" (size of screen openings) grinds.

Screen Size

The easiest way to make major changes in production rates and granulation when grinding with a hammermill is by changing the size screen used in the machine. Four screen sizes, (3/32", 1/8", 3/16", and 1/4" diameter of openings in screens) were used for testing purposes in this research. Many other screen sizes are available for most hammermills.

The effect of screen size on grinding capacity and efficiency is pointed out by each production curve that has been presented in this paper. By referring to Figures 23, 24, and 25, it is apparent from the slope of the curves that production rate increases rapidly as the size of the screen openings become larger. By starting with the screen having the smallest openings (3/32") and progressing to those screens having larger openings, the following average gains in production rates were measured:

Average of All Three Grains

3/32" to 1/8" --- 42 per cent increase

1/8" to 3/16" --- 42 per cent increase

3/16" to 1/4" --- 35 per cent increase

The hourly production rate for grinding through a 1/4" screen is more than twice that obtained when grinding with 3/32" screens for all three grains tested. These figures very definitely point out the value of grinding only as fine as necessary to meet customer demands.

Figures 29, 30, and 31 give sieve curves for the ground products resulting from grinding milo, corn, and oats with the four different screen sizes. As shown by Figures 29, 30, and 31, there was a definite change in the granulation of product from one screen size to the next.

These reported results were anticipated by the magnitude of the changes

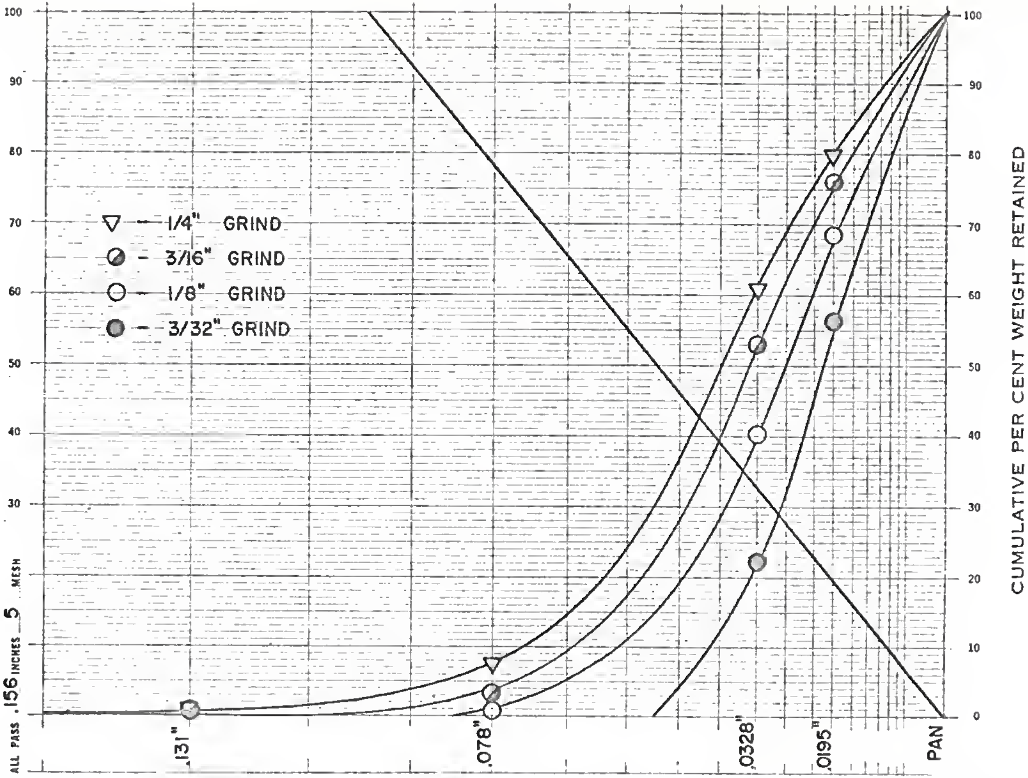


Figure 29. Effect of size of screen openings on granulation of product when grinding milo with a hammermill.

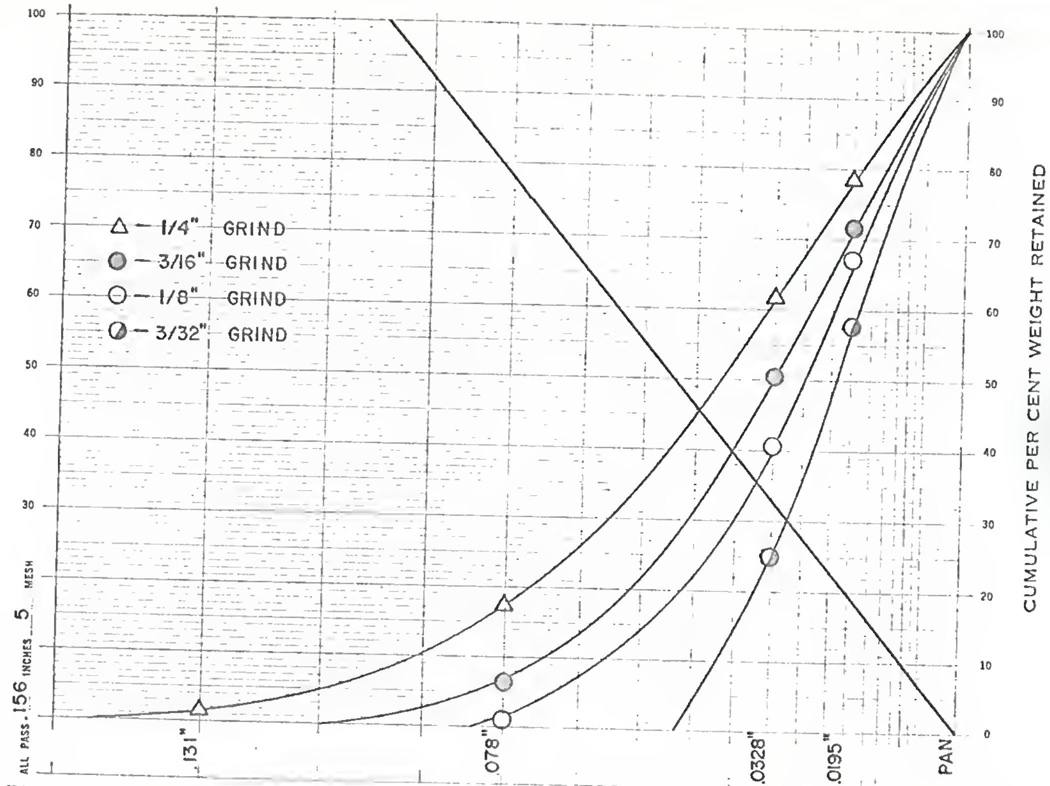


Figure 30. Effect of size of screen openings on granulation of product when grinding corn with a hammermill.

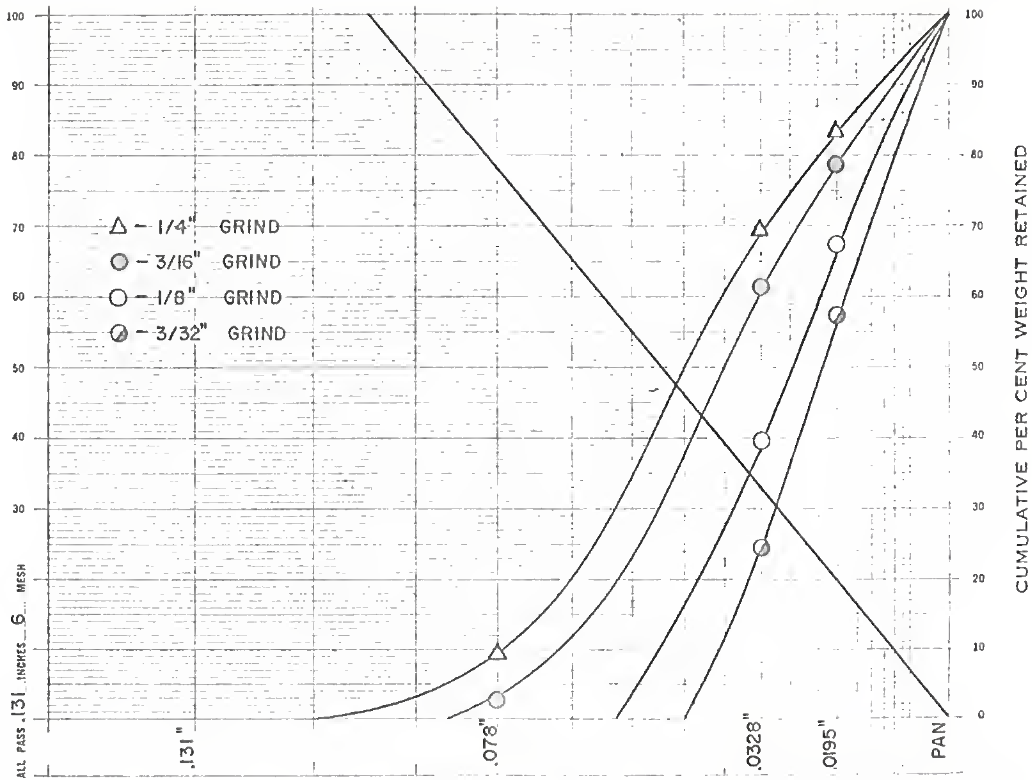


Figure 31. Effect of size of screen openings on granulation of product when grinding oats with a hammermill.

in production rates resulting from the different screen sizes was a little surprising.

DISCUSSION

There is little doubt that the testing work described in this paper has probably been done at some previous time by various hammermill manufacturers and possibly by some of the more progressive feed companies. The makers of hammermills have had to do some experimental work of this kind to develop their machine designs. However, information of this kind is not readily available to the general public.

Part of the real value of this research is that an unbiased study has been made on some of the factors that affect hammermill performance. This thesis will probably have different meanings to different groups of people. To equipment manufacturers, it will be a check on the research they may have already completed and may suggest new areas of research which should be studied; to feed mill managers, it may suggest a possible area in which to increase plant efficiency; to the production men, it may indicate some possible changes that can be made on the hammermill to help keep up with production demands; and to people with a vague understanding of the formula feed industry, it will point out that the hammermill is not just another piece of iron sitting in the basement of the feed mill that automatically makes mash out of whole grains.

The hammermill usually has one of the highest power requirements of any machine in a modern feed mill. Probably the only single unit in the mill that requires as much or more power is the pellet mill. A small percentage change in the grinding efficiency of the hammermill could mean considerable savings or loss in production and power over a period of time. As pointed out in the discussion of experimental results, a number of factors were found that would change production rates 10 per cent or more when grinding these three grains.

How can the findings of this research be used and applied by feed mill management and production personnel? This question can be answered best by discussing the relationship of each testing area to the feed industry and its problems.

Kind of Grain Being Ground

Most production men know that milo and corn grind easier than oats. However, their relative grinding rates as pointed out by this research could help the feed mill manager to more accurately determine actual grinding costs.

Gravity Discharge Versus Fan Discharge

This research area points out that it may be economical to discharge the ground product by gravity from a hammermill. More feed mills may want to investigate this possibility as a means of saving on power requirement. The author has seen some very satisfactory hammermill arrangements in industry using this method of discharge. However, if gravity discharge is used, a small quantity of air must still be pulled through the hammermill to control the fine dust produced when grinding. For those men who still prefer the ease and simplicity of pneumatic handling, one change may also be suggested by this paper. Mill management may want to think about changing to a negative pressure conveying system from the hammermill instead of the conventional positive pressure system now commonly used. The desirability of such a change is implied by the fact that when the ground product was allowed to pass through the fan, more fines were produced than with gravity discharge. This means some power is being wasted in the fan due to the grinding action of the fan. Fan life will also be increased many-fold by changing to a negative pressure conveying system.

Moisture Content of Grain Being Ground

The importance of quality control on incoming ingredients is pointed out by this area of research. Mills which buy high moisture grains should consider that grinding rates will decrease and horsepower per ton will increase when these grains are ground. The storage life of high moisture grain, ground products or feeds made therefrom is poor. Artificial drying might be necessary. For this reason, mills should not buy grains having high moisture content unless these grains can be purchased at a low enough price to pay for artificially drying them to normal moisture levels. The granulation results also point out the importance of proper moisture content in grains. Grains that are over dried will probably produce an excess of fines when ground with the hammermill.

Type of Hammers

The increased grinding efficiency resulting from using the narrower hammers was a surprise to this author. The only reason for not making a change to narrower hammers is the question of hammer life. If the 1/16" thick individual hammers can be sufficiently hardened to maintain their sharp edges for grinding-times equal to those obtainable with the 1/8" thick individual hammers, feed men will definitely want to change to narrower hammers because both production and granulation are better.

Screen Area

The findings in this area of research suggest that hammermill manufacturers might want to try to incorporate more screen area into their machines since blanking of one-half the screen area did have adverse effects on both production and granulation.

Screen Size

The results of testing throughout every phase of this research point out one thing concerning screen size. The feed mill production man should know the particle size requirements for a ration and should grind only fine enough to meet these requirements.

SUMMARY AND CONCLUSIONS

The experimental data gathered seem to indicate that:

1. Oats grind approximately twice as hard as corn and three times as hard as milo when grains of equal moisture content are ground through the same screen sizes with a hammermill.
2. When grinding grains through the same screen sizes with a hammermill, fan discharge will increase production rates over grinding done with gravity discharge. The percentage increase will vary with the grain being ground and the screen size, but will average about 12 per cent for all three grains and four screen sizes.
3. Grinding with fan discharge definitely keeps the ground product cooler than when grinding with gravity discharge.

4. It can be economically feasible to discharge the ground product from a hammermill by gravity instead of by fan discharge.
5. Some particle size reduction occurs when the ground product passes through the fan.
6. Grinding of high moisture grains will decrease production rates approximately 25 per cent for grinding oats, 20 per cent for grinding corn, and 12 per cent for grinding milo when compared to production rates attainable when normal moisture content grains are ground through comparable screen sizes.
7. There is no appreciable change in production rates or granulation of product when grinding these three grains with 1/8" thick individual hammers or with 1/8" thick group hammers.
8. Equal numbers of 1/16" thick individual hammers will grind 15-25 per cent more pounds per hour than 1/8" thick individual or 1/8" thick group hammers when grinding through screens with equal sized openings.
9. The no-load current is lowered 20 per cent by substituting 1/16" thick individual hammers for 1/8" thick group or individual hammers in this machine.
10. Blanking of one-half the available screen area cuts grinding capacity approximately 20 per cent compared to grinding done with the full 180° screen area exposed for these three grains on this hammermill.
11. Only minor changes in granulation can be made when grinding the same grains through screen having equal diameter openings by altering the hammermill design features evaluated by this study.
12. Major changes in both granulation of product and production can be achieved by changing the size of openings in the screen when grinding corn, oats, and milo with a hammermill.

Many different factors which influence the operational characteristics of a hammermill have been investigated in this research. There are still many more that could and should be evaluated. Some of these problem areas are listed below:

a. Effect of worn hammers on granulation and production.

b. Effect of different spacing between hammer tips and screen surface on granulation and production.

c. Effect of number of hammers on granulation and production.

d. Effect of peripheral speed on granulation and production.

Some of these areas are presently being studied by graduate students in feed technology at Kansas State University. It is the hope and the goal of the author that this paper will stimulate more and better research of this kind and that the experimental results of research of this type be made available through subsequent publications.

ACKNOWLEDGMENT

The author wishes to express his sincere appreciation to Prof. E. P. Farrell whose encouragement, counsel, and guidance have had much to do with making this manuscript a reality. To Dr. J. A. Shellenberger, head of the Department of Flour and Feed Milling Industries, and to the entire staff of this department, thank you for making materials and equipment available for use in this experimental work.

Acknowledgment is also given to Prater Pulverizer Co. and to Mr. George Thomas, president of that company, for their cooperation and support in making this research possible.

LITERATURE CITED

(1) Anonymous.
Method of Determining Modulus of Uniformity and Modulus of Fineness of Ground Feed. Agricultural Engineers Yearbook. 1959 Edition. p. 127.

(2) Anonymous.
The Profitable Use of Testing Sieves. The W. S. Tyler Company Catalogue 53. 1957.

(3) Baker, Vernon H.
Feed Processing. Unpublished Manuscript, Rural Electrical Conference, Kansas State University. May 4-5, 1948.

(4) Bohstedt, G.
Feed Grinding. Wisconsin Agricultural Extension Service Circular 286. November 1936.

(5) Brackett, E. E., and E. B. Lewis.
Processing Feeds on Nebraska Farms. Nebraska Agricultural Experiment Station Bulletin 302. August 1936.

(6) Bruhn, H. D.
Importance of Feed Processing Work. Flour and Feed. October 1954, 55:12-13.

(7) Clark, T. F., and E. C. Lathrop.
Dry Grinding of Agricultural Residues, A New Industrial Enterprise. USDA AIC 336, Northern Regional Research Laboratory, Peoria, Illinois. May 1952.

(8) Duffee, F. W.
The Design and Performance of Small Hammer-Type Feed Mills. Agricultural Engineering. May 1930, 11:171-176.

(9) Fairbank, J. P., G. E. Gordon, and L. H. Rochford.
Feed Grinding and Feed Mills. California Agricultural Extension Service, Agricultural Engineering Information Series No. 9. January 1936.

(10) Fenton, F. C., and C. A. Logan.
Farm Grinding of Grain and Forage. Kansas Engineering Experiment Station Bulletin 27. May 1931.

(11) Fitch, J. B., and Wolberg, F. B.
The Utilization of Atlas and Kansas Orange Sorgo Seed by Dairy Cows. Unpublished Manuscript, Department of Dairy Husbandry, Kansas State University. Page 2.

(12) Forth, M. W., R. W. Mowery, and L. S. Foote.
Automatic Feed Grinding and Handling. Agricultural Engineering. November 1951, 32:601-605.

(13) Forth, M. W., and E. W. Lehmann.
Performance and Electrical Load Characteristics of Automatic 5-Horsepower Grinders and Motors. Illinois Agricultural Experiment Station Bulletin 581. September 1954.

(14) Forth, M. W., and E. W. Lehmann.
Feed Grinding with Electric Mortors. Agricultural Engineering. September 1953, 35:648-650.

(15) Hendrix, Andy T.
Design and Performance of a Small Automatic Hammer Mill. Agricultural Engineering. October 1937, 18:445-447, 450.

(16) Hundley, J. C.
Electric Feed Grinding on the Farm. Tennessee Agricultural Extension Publication 253. December 1947.

(17) Kable, Geo. W.
Results of Research in Feed Grinding. Agricultural Engineering. March 1927, 8:53-54.

(18) Klies, R. W., and A. L. Newmann.
Cattle Neutral on Feed Grinding Methods. Agricultural Engineering. August 1956, 17:544.

(19) Krueger, W. C.
Basic Principles Involved in the Design of the Small Feed Grinder. Agricultural Engineering. July 1927, 8:167-171.

(20) Kummer, Wm. R.
Grinding Machinery and Maintenance. Reprint of talk given to Dehydrators Production School, Lincoln, Nebraska. March 26, 1952.

(21) Martin, J. W., and June Roberts.
Feed Grinding with Small Electric Motors. Kansas Extension Service Bulletin 87. September 1941.

(22) Nicholas, John E.
Performance of Small Hammer Mills. Agricultural Engineering. June 1940, 21:207-210.

(23) Shaw, R. S., and H. W. Norton, Jr.
Feeding Whole Grain. Michigan Agricultural Experiment Station Bulletin No. 242:61-62. 1906.

(24) Silver, E. A.
A Simple System for Testing Ground Feeds. Agricultural Engineering. July 1932, 13:183-184.

(25) Silver, E. A.
Characteristics of Feed Mill Performance. Agricultural Engineering. February 1932, 13:31-34.

(26) Silver, E. A.
Feed Grinder Investigations. Ohio Agricultural Experiment Station Bulletin 490. October 1931.

(27) Stroup, Robert L.
Pelleting Dairy Feeds. Proceedings of the 1959 Feed Production School. September 23, 24, and 25. Kansas City, Missouri.

(28) Thomas, George F., G. A. Carlson, and Harold J. Alsted.
Basic Facts in Focus on Grinding, Mixing, Conveying with Air. The Feed Bag. April 1958, 34:88-93.

(29) Wake, Phillip J.
Complete Ration Pellets for Poultry and Swine. Proceedings of the 1959 Feed Production School. September 23, 24, and 25. Kansas City, Missouri.

(30) Vutz, William.
Some Observations on Hammer Type Feed Grinders. Agricultural Engineering. July 1931, 12:271-274.

APPENDICES

APPENDIX A

Recommended Fineness of Grinding by Baker (3).

Feeds	Dairy Cattle: Cows & Heifers	Dairy Cattle: Calves Under 6 months	Beef Cattle: Fattening	Beef Cattle: Breeding	Horses	Swine	Sheep	Lambs	Hens: Scratch	Hens: Mash	Chicks
Shelled Corn	Medium	Med. to whole	Whole[2]	Coarse	Whole	Whole[4]	Whole	Whole	Whole or cracked	Meal	Med. fine meal
Ear Corn	"	*	"	"	"	"	"	"	Coarse to fine	*	Fine
Oats	"	Med. to whole	Coarse	"	"	Fine	"	"	Whole or rolled	Fine	Fine
Barley	"	"	"	"	Coarse	Medium	Coarse	Coarse	Cracked or whole	"	"
Soybeans	"	*	"	"	Whole	Medium[5]	Whole	Whole	*	*	*
Wheat	"	Med. to whole	"	"	Coarse	Coarse	"	"	Cracked or whole	Med.	Med. fine
Rye	"	"	" [3]	" [2]	None fed	"	"	"	Whole	Fine	Fine
Alfalfa Hay	Whole[1]	*	Coarse	"	"	Fine or whole	"	" [6]	*	Med. Fine	Med. to fine
Clover Hay	"	"	"	"	"	Whole	"	" [6]	*	*	*
Soybean Hay	"	"	"	"	"	"	"	"	*	*	*
Corn Stover	"	"	"	"	"	*	"	*	*	*	*
Corn Fodder	"	"	"	"	"	*	"	*	*	*	*

1/ Do not recommend grinding roughages for dairy cattle as a general practice.
2/ Whole only when cattle are followed by hogs, otherwise grind coarse.
3/ Should not exceed 25% of the grain rotation.
4/ Ground medium when fed with other grains and protein added.
5/ Ground medium when used in making up pare of protein supplement.
6/ May be ground or chopped and mixed with coarsely ground grain.
* Not recommended.

APPENDIX B

Modulus of Fineness Determination

The Modulus of Fineness system for measuring and expressing fineness of grind for ground feeds was officially approved and adopted for this purpose by the ASAE in 1930. The Modulus of Uniformity was added to this system by the same group in 1940.

Professor Duff A. Abrams first developed the Modulus of Fineness system for measuring particle size in concrete aggregates in 1918. The system presently in use for measuring fineness of feeds is nearly identical to the original method presented by Professor Abrams.

A series of seven screens (3/8, 4, 8, 14, 48, and 100 mesh) is used for modulus of fineness determination. Starting from the smallest screen and going to the next larger, each succeeding screen has exactly twice as large an opening as the previous screen. A 250 gram oven dried sample is rotapped for 5 minutes to achieve size separation. After rotapping, the per cent of material remaining on each screen is calculated and a fineness modulus value assignad to this grind. A typical screan analysis for a grind is given below.

Screen Mesh	Per cent of Material on each screen x factor
3/8	1.0 x 7 = 7.0
4	2.5 x 6 = 15.0
8	7.0 x 5 = 35.0
14	24.0 x 4 = 96.0
28	35.5 x 3 = 106.5
48	22.5 x 2 = 45.0
100	7.5 x 1 = 7.5
pan	0.0 x 0 = 0.0
Totals	100.0% 312.0

Modulus of Fineness (312 ÷ 100) = 3.12

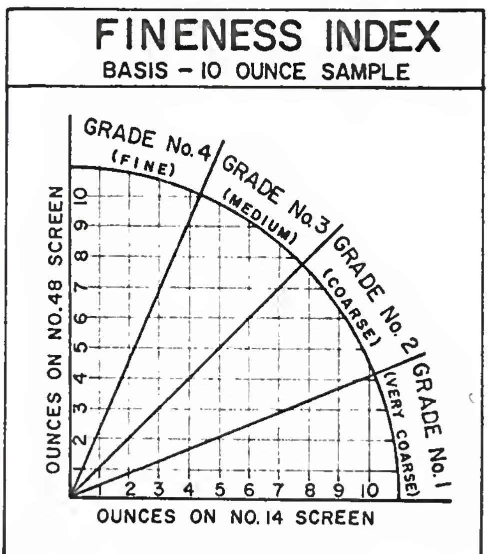
A classification as to coarse, medium, and fine which would correspond to fineness modulus values is given below.

	Corn	Oats	Grain Sorghums
Very fine	1.80	1.40	1.80
Fine	2.40	2.10	2.20
Medium	3.6	2.90	3.00
Coarse	4.8	3.70	4.00
Whole grain	6.00	4.50	5.00

APPENDIX C

Explanation of Fineness Index System for Testing Ground Feeds

The fineness index system for testing ground feeds was first presented by E. A. Silver in June 1932. In this system, a 10 ounce sample is used for determining grades. A No. 14 screen, a No. 48 screen, and the pan are used for sieving. By shaking the 10 ounce sample in the sieve series just mentioned, the weight retained on each screen is determined. These weights retained make up the ratio system which is used to ascertain grade. A typical ratio might be 4:5:1. The first value means 4 ounces retained on the No. 14 screen, the second value refers to 5 ounces retained on No. 48 screen, and the last value means one ounce was collected in the pan. By referring to the figure shown below, a grade of No. 3 (medium) can be assigned to this theoretical grind.



APPENDIX D
Typical Sample Data Sheet

Grain __Corn__, Moisture Content __13.1%__, Test Weight __58.2 lbs/bu.__, Date __June 11, 1959__

Prater $7\frac{1}{2}$ HP Hammermill, __3600__ rpm, __1/16" ind.__ Hammers, Fan ______, Gravity ______, Screen full __X__

Feed Rate Adjusted to 9.6 amps. ± .5 @ 440 volts. Estimated Power Factor .9 Blanked $\frac{1}{2}$ area ______

Test No.	Screen Size	Run Min.	Pounds Ground	Pounds /Min.	Pounds /HR.	Pounds /HPhr.	Disc Rev.	Power Used	Pounds /KWH	Tyler Sieve Analysis (200 gms 3 min) + 6	+ 9	+ 20	+ 32	- 32
										1	13	89	44	53
										1	13	90	43	53
1	3/16	1.52	73	48	2880	384	5	.144KWH	507	1	14	87	43	55
										1	15	88	43	55
										1	18	100	39	42
										1	17	102	39	42
2	3/16	1.53	72	47.1	2826	377	5	.144KWH	500	1	16	93	40	51
										0	14	89	42	54
										1	14	91	43	53
										1	15	94	42	50
3	3/16	1.52	73	48	2880	384	5	.144KWH	507	1	15	92	42	51
										0	13	91	43	53
			Average		2862	382	5	.144KWH	505	.8	14.8	92.2	41.9	51
									Per Cent	.4	7.4	45.9	20.9	25.4
										4	29	88	36	43
										4	30	88	35	43
1	1/4	1.2	72.5	60.4	3624	483	4	.115KWH	630	4	32	89	34	41
										3	32	89	34	42
										3	27	88	36	47
										3	28	87	36	45
2	1/4	1.2	75	62.5	3750	500	4	.115KWH	652	3	28	87	36	46
										4	29	86	35	45
										3	27	90	36	44
										3	32	90	34	41
3	1/4	1.2	74	61.7	3702	494	4	.115KWH	643	4	32	87	34	45
										4	32	88	33	43
			Average		3692	492	4	.115KWH	642	3.5	29.8	88.1	34.9	43.8
									Per Cent	1.8	14.9	44	17.4	21.9

FACTORS THAT AFFECT THE GRANULATION AND CAPACITY IN GRINDING OF CORN, OATS, AND SORGHUM GRAIN WITH A HAMMERMILL

by

RICHARD JAMES BAKER

B. S., Kansas State College
of Agriculture and Applied Science, 1956

AN ABSTRACT OF A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Flour and Feed Milling Industries

KANSAS STATE UNIVERSITY
OF AGRICULTURE AND APPLIED SCIENCE

1960

Corn, oats, and sorghum grain were ground through four different screen size openings with an experimental hammermill. The production rates and granulation of the ground products were studied as they were affected by tha following factors:

a. Kind of grain being ground

b. Method of discharge (pneumatic or gravity)

c. Moisture content of the grain being ground

d. Type of hammers

e. Screen area

f. Screen size (size of openings)

The investigations showed that maximum production rates were obtained when grinding sorghum grain (824 lbs./HPhr. for largest screen) and the lowest production rates were measured when grinding oats. (75 lbs./HPhr. for the smallest screen.)

Experimental results indicate that it may be economical and practical to discharge the ground product from a hammermill by gravity instead of the conventional positive pressure conveying system generally used. The feasibility of such an arrangement varies from mill to mill.

Grinding of high moisture (17-18 per cent) content grains was found to reduce production rates an average of 12-25 per cent lass than those obtainable when grinding normal moisture (13-14 per cent) content grains through equal sized screen openings.

Some of the most startling results for grinding capacity tests were measured when comparing 1/16" thick individual hammers to 1/8" thick individual or group hammers. When grinding the same grains through the same size screen openings, the grinding capacity was increased 15-25 per cent by substituting numbers of 1/16" thick individual hammers for the 1/8" thick hammers. Thia substitution also gave an accompanying improvement in the physical characteristics of the ground product.

When one-half of the available screen area was blanked-off during grinding, an average reduction of 20 per cent in the production rate was measured as compared to grinding the same grain with all the available screen area exposed. A significantly finer grind was produced by blanking one-half of the available screen surface during grinding.

Major changes in granulation and grinding capacity were obtained when size of openings in the screen were changed.