FACTORS AFFECTING HAMMERMILL PERFORMANCE

by

CARL ANDREW STEVENS

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NOMENCLATURE

#/KWH	=	Pounds per kilowatt hour.
Ft./min.	=	Feet per minute.
F.M.	=	Fineness modulus.
M.U.	=	Modulus of uniformity.
S.A./Gm.	=	Surface area in square centimeters per gram.
CFM	=	Cubic feet per minute.
G/cc.	=	Grams per cubic centimeter.
Kh factor	=	A disc constant which indicates the number of watt-hours passing through the meter per disc revolution.

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INTRODUCTION

The hammermill is used throughout the milling industry for size reduction. A conservative estimate is that the hammermill was used to grind over 20 million tons for the feed industry in 1960 (3). Figured on the basis of an average cost of two dollars per ton for grinding, two million dollars could be saved if efficiency could be improved only five per cent.

Results of research to determine the affect of various factors on the performance of a hammermill have not been published extensively. Many of those results published deal only with such things as moisture content and screen size without questioning manufacturer's recommendations on factors such as speed of the mill and hammer width.

There are many factors which affect the performance of a hammermill; some of these are: motor horsepower, screen area, moisture content of the material being reduced, kind of grain, location of feed intake, hammer tip and screen clearance, number of hammers, feed rate, peripheral speed, hammer width, air flow, diameter of screen opening, air flow through the mill, and mechanical condition of the mill.

The peripheral speed refers to the actual tip speed of the hammers. (Revolutions per minute are only an indication of the actual mill speed since peripheral speed is also a function of the diameter of the rotor.) It is this speed that imparts energy to the material being reduced, so it is not unreasonable to assume that the amount of reduction should be some function of the speed.

It is the hammer tips that strike the material being ground and impart energy to it, the design and thickness of the hammers will certainly affect the efficiency and the fineness of grind.

Certain grains will grind more easily than others because of their structure and composition. High fiber grains will not break apart as easily as grains with a high starch content. The diameter of the screen opening has a direct relation to production and coarseness of the product. It is thought that air flow through the mill may effect the efficiency of the mill and the granulation of the product. If a large volume of air is pulled through the mill one might expect to receive greater efficiency and a coarser product.

The purpose of this research was to study the effect of peripheral speed, hammer thickness, diameter of screen opening, kind of grain, and air flow through the mill. These factors were chosen for study because of their importance and the dearth of information concerning this subject.

REVIEW OF LITERATURE

Peripheral Speed

Friedrich (7) states that "impact velocity is one of the most important factors in pulverizing hard and large pieces" and further stated that "for any hammermill there is an important relationship between speed of rotation and capacity." Duffee (5) asserted that correct speed is a matter of prime importance.

There is some disagreement, however, as to the effect of speed on efficiency. Hendrix (8) and Fenton and Logan (6) reported more efficiency at higher speeds, while Krueger (9) shows that efficiency increased as the speed decreased though not in direct proportion. He noted that "a larger screen at higher speeds may produce the same product as smaller screens at slower speeds, and more efficiently."

Silver (11) showed that speeds of 14,000 to 15,000 feet per minute are much above the most critical or economical point. He further indicated that the most efficient peripheral speed is between 7,000 and 9,000 feet per minute while mills do more uniform grinding at slower speeds. Duffee (5) and Fenton and Logan (6) reported that speeds of 13,000 to 14,000 feet per minute are optimum. Bruhn (4) stated, "A tip speed of 12,000 to 15,000 feet per minute may be required and it is doubtful if the speed is too high." Friedrich (7) reported a grinding speed of 12,600 to 19,800 feet per minute was required for feed materials.

All researchers agree that a slower speed produces a coarser product. Thomas (12) stated that "the product fineness is directly proportional to peripheral speed."

It should be noted that most researchers were operating the blower on a direct connection with the hammermill shaft and could not slow the mill down beyond the critical point of conveying the material away from the mill. As stated by Silver (11), "If the speed of the mill is reduced much below its rated rpm, trouble may result from the inability of the fan to elevate the material."

Hammer Thickness

Hammer design is an important factor in the design of a hammer mill. Wear usually occurs at the tip of the hammer, consequently some hammers are manufactured so that the hammers may be turned edge for edge and end to end. This arrangement allows for four wear surfaces and is more economical than acquiring a new hammer when one edge wears out.

There is an advantage to reducing hammer width as far as production and efficiency are concerned. Friedrich (7) reported that, by reducing hammer thickness from 8 mm to 3 mm, capacity and efficiency was increased by 15 per cent. Baker (3) showed that when 1/8 inch wide hammers were substituted for 1/4 inch wide hammers, efficiency increased 23 per cent for grinding corn. When 1/16 inch wide hammers were used instead of 1/8 inch wide hammers, there was an average increase of 19 per cent.

Diameter of Screen Openings

Efficiency increases as the screen openings are enlarged (3), because the mill is doing less work per unit weight of material being reduced.

The fineness of grind can be controlled by the size of screen.

Kind of Grain

Since grain composition varies as to starch and fiber content, there is a difference in the power required to reduce the various grains. In general, the cereal grains with higher starch contents and less fiber are easier to grind. Silver (11) found that oat was harder to grind than barley, and that corn was the easiest. Baker (3) substantiates these results by showing that the easiest to grind is grain sorghum, followed by corn and oat.

Air Flow Through the Mill

The amount of air flowing through the mill may affect the manner in which particles strike impact surfaces. Friedrich (7) indicates an optimim value of about 4,000 cu meters per hour per square meter of screen surface.

MATERIALS AND METHODS

Corn, milo and oats were used in the grinding tests. These grains were of good commercial quality and uniformity. The grains were cleaned in a receiving system to remove large extraneous material. After cleaning, the grains were placed in a large storage bin and transferred to a small holding bin (13.8 cubic feet) above the hammermill for the grinding tests. Samples of all whole grains were taken at intervals throughout the tests. From these samples, test weight, moisture content, and absolute density were determined. The moisture determinations were made by Prof. G. D. Miller of the department according to the official A.O.A.C. air oven method. Absolute density determinations were made by a toluene method to be described later.

Machine Specifications. A Prater G. S. 5 hammermill was used for all grinding tests.

(a) Power Source - 7 1/2 h.p., 220-440 volt, 3 phase, 1760 r.p.m. motor.

(b) Rotor Width - 12 7/8 inches (outside hammer to outside hammer).

(c) Rotor Diameter - 15 3/8 inches (hammer tip to hammer tip).

(d) Rotor Speed (Recommended) - 3525 r.p.m.

(e) Peripheral Speed (Recommended) - 14,165 feet per minute.

(f) Screen Sizes - 3/32", 1/8", 3/16", and 1/4" (diameter of round openings).

(g) Screen Area - 434 square inches.

(h) Number of Openings in Screens - 3/32 inch screen = 19,500; 3/16 inch screen = 5,952; 1/8 inch screen = 13,520; 1/4 inch screen = 3,404.

(i) Screen Location - lower 180 degrees.

(j) Feed Inlet - top-center of machine.

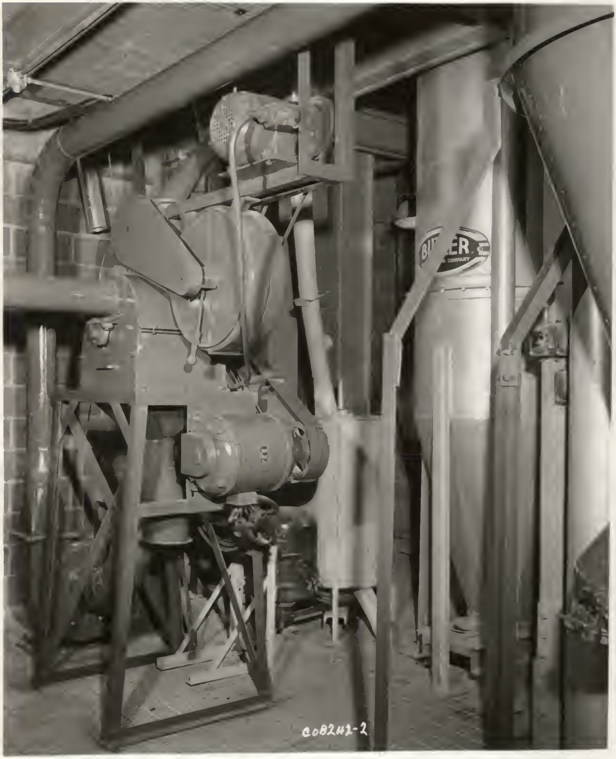
(k) Feed Control - variable speed vane type volumetric feeder--1/2 h.p. motor.

(l) Exhaust Fan - 3 h.p. motor.

EXPLANATION OF PLATE I

View of the Prater G. S. 5 Hammermill

PLATE I



(m) Hammer Designs -

(1) 1/16" x 1 1/4" x 5 11/16" - 3 rows of 15 hammers per row.

(2) 1/8" x 1 1/4" x 5 11/16" - 3 rows of 15 hammers per row.

(3) 1/4" x 1 1/4" x 5 11/16" - 3 rows of 10 hammers per row.

(n) Spacing between Screen and Hammer Tips - 1/8" to 3/16".

A vane-type volumetric feeder controlled the feed going to the hammermill. A 50 ampere scale ammeter and a watt-hour meter were used to measure the current being used by the motor. Full load current for this motor at 220 volts was 9.6 amperes. The ammeter was equipped with a by-pass switch to protect it from initial starting overload. The watt-hour meter was a 15 ampere, 480 volt, 3 phase, 3 wire meter with a 28.8 Kh factor.

The mill was equipped with a two way butterfly valve so the ground material could be sacked off directly below the mill or would be conveyed pneumatically into a cyclone type collector and sacked off. The cyclone was equipped with a butterfly valve and two sack off positions.

The amount of material ground was weighed on a platform scale and recorded after each test. Heavy canvas sacks were used for all ground material to prevent loss of fines during handling.

Peripheral Speed

The feed rate was adjusted so that the motor load was at 9.6 amperes. After a full load current rating had been maintained for sometime with the valve set on fan discharge and the speed of the rotor had been checked, a test was made by diverting the ground material into an empty sack below the mill with the two-way valve. Watt-hour meter revolutions of the disc and time were measured by visual observation and by timing with a stop watch.

The length of a test varied according to the production rate. For a large screen with high production rate, the tests were shorter than those with smaller screens. The test was made until it was estimated that 20 or more pounds of material had been ground. The length of a test ranged from 18 seconds to 3 minutes and 36 seconds. If necessary the feed rate was adjusted during the test to maintain a full load on the motor. At the end of the test, the material was diverted back to the fan discharge. All the tests were made in duplicate. A "series" consisted of four screen sizes at two tests per screen. Before each "series", a "no load" test was taken to determine the power required by the mill when running empty.

The peripheral speed of the hammers was changed by changing pulleys on the motor and mill.

After each test the number of disc revolutions, net weight of material ground during the test, and time were recorded. Knowing that 28.8 watt-hours were used per disc revolution and the weight of material ground from these revolutions, the efficiency in pounds per kilowatt hour were calculated.

The peripheral speeds used and the corresponding rpm of the mill shaft are listed below:

RPM	Peripheral Speed (Feet per minute)
4285	17,200
3525	14,164
2610	10,470
1765	7,080
1395	5,600

Each speed was used with each hammer size and each grain with all four screen sizes.

Air Flow

An inclined tube manometer and pilot tube were used to measure the volume of air through the mill. The air flow rates used were 0, 424 and 582 cubic feet per minute. The air flow was controlled by a valve shown in Plate II.

The air flow tests were conducted in the same manner as the peripheral speed tests except the sack-off below the cyclone was used for collecting samples.

Sampling Procedure

The duplicate tests employed consisted of two canvas sacks each containing 20 to 70 pounds of ground material. Two samples of one gallon each were taken from each canvas sack with a hand scoop in the following manner:

> The canvas sacks were denoted as A and B, and the small cans taken from them as a_1, a_2 and b_1, b_2, respectively. Twelve scoopfuls of material was taken from sack A. The size of the scoopfuls were regulated by the amount of material in the sack so the samples taken were representative of the whole sack. Scoopful numbers three and six were used for sample a_1 and numbers nine and twelve comprised sample a_2. The same procedure was used for B.
>
> Samples a_1, a_2, b_1, and b_2 were used for fineness testing.

Fineness Determination

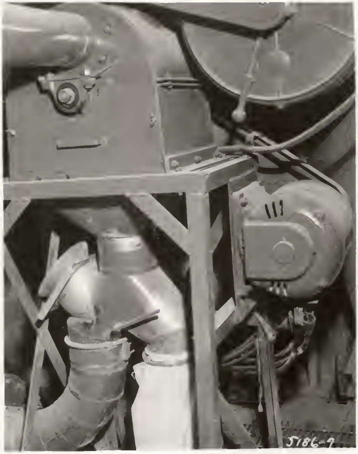
The fineness determinations were made by the "Modulus of Fineness" and the "Modulus of Uniformity" methods adopted in 1940 by the American Society of Agricultural Engineers and by the American Society of Animal Production (1), except that a 200 mesh sieve was added to the recommended standard.

A five-minute test with 500 gram samples, using screens 3/8, 4, 8, 14, 28, 48, 100 and 200 mesh, was sifted on a ro-tap. The overs of the 200 mesh did not enter into the fineness modulus or the modulus of uniformity but were

EXPLANATION OF PLATE II

A close view of the air control valve.

PLATE II



used in the surface area calculations.

All weights under 20 grams were weighed to the nearest one-tenth gram.

Examples of calculations of Modulus of Uniformity, Modulus of Fineness and surface area can be found in Appendix A and B.

Absolute Density Determinations

The procedure used for the determination of absolute density was similar to that used by Sharp (10). Toluene was used to determine the volume displacement of a known weight of grain. A small sample of grain (40 to 50 grams) was put in a 100 milliliter volumetric flask of a known weight and the flask was filled with toluene. The specific gravity and the weight of the toluene used were known so the volume was determined by:

$$V_t = \frac{W_t}{D_t}$$

where V_t = Volume of the toluene.

W_t = Weight of the toluene.

D_t = Density of the toluene.

The volume displacement of the grain was determined by:

$$V_g = 100 - V_t$$

where V_g = Volume of the grain.

100 = Total volume of the flask.

The absolute density of the grain was determined by:

$$D = \frac{W_g}{V_g}$$

where W_g = Weight of the grain.

D_g = Density of the grain.

All weights were accurate to one-hundredth of a gram. Care was taken to remove all air bubbles in the grain mass by gently swirling the grain and toluene mixture before completely filling the flask.

Partial vacuum over the toluene was used when the density of oats were being determined. This was done to aid in the removal of entrapped air between the hull and the groat.

EXPERIMENTAL RESULTS

Effect of Peripheral Speed, Screen Opening and Hammer Width

Milo. The effect of peripheral speed on efficiency and particle size during the grinding of milo, using 1/16 inch wide hammers, is shown in Figures 1 and 2. There was an increase in efficiency with all screen sizes as the peripheral speed was decreased from 17,200 to 10,470 feet per minute (Figure 1). The maximum efficiency of the 1/8 inch screen was at 7,080 feet per minute. The high efficiency rate with the large screens and slow speeds were due to the fact that very little reduction was taking place. The effect of peripheral speed on fineness modulus when grinding milo with 1/16 inch wide hammers is shown in Figure 2. Decreasing the speed resulted in a coarser grind with all screens.

The actual values plotted in Figures 1 and 2 and other data are tabulated in Table 1. Each value of surface area, fineness modulus and modulus of uniformity shown in Table 1 is an average of four tests. The efficiency figures shown in Table 1 are an average of two tests. (The number of these tests used for a given value applies to all data in the thesis.)

Table 1 shows that surface area generally increased as the speed increased for any given screen size.

It can be seen in Table 2 that there was similar particle sizes produced with the 1/4 inch screen at 14,164 feet per minute and the 3/16 inch screen at 10,470 feet per minute. However, the slower speed had an efficiency of 1,057 #/KWH and the faster speed had an efficiency of 893 #/KWH. The results are tabulated as follows:

Milo - 14,164 ft./min. - 1/4 inch screen.

Efficiency (#/KWH)	F.M.	M.U.	S.A./Gm.
893	3.06	1:7:2	94.3

Milo - 10,470 ft./min. - 3/16 inch screen.

Efficiency (#/KWH)	F.M.	M.U.	S.A./Gm.
1057	3.06	0:8:2	91.5

Figures 3 and 4 show the effect of peripheral speed on efficiency and fineness while grinding milo with 1/8 inch wide hammers. There was a definite increase in efficiency with the three larger screen sizes when the speed was decreased from 17,200 feet per minute to 7,080 feet per minute. The trend was very similar to that observed with the 1/16 inch hammers. There was a general increase in particle size through a given screen as the speed was decreased from 17,200 feet per minute to 3,600 feet per minute (Figure 4).

The relationship of peripheral speed to surface area, fineness modulus and efficiency is shown in Table 2. When a given screen size was used there was a decrease in surface area as the speed was decreased.

Figures 5 and 6 summarize the effect of peripheral speed on efficiency

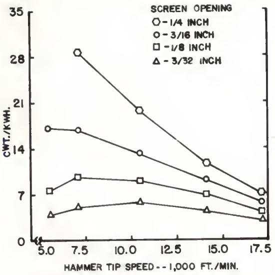


FIGURE 1. EFFECT OF PERIPHERAL SPEED ON EFFICIENCY WHEN GRINDING MILO WITH 1/16 INCH HAMMERS

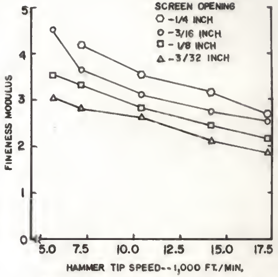


FIGURE 2. EFFECT OF PERIPHERAL SPEED ON FINENESS WHEN GRINDING MILO WITH 1/16 INCH HAMMERS

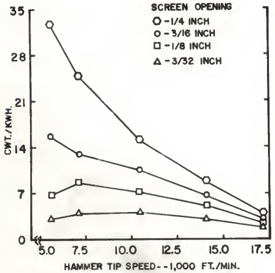


FIGURE 3. EFFECT OF PERIPHERAL SPEED ON EFFICIENCY WHEN GRINDING MILO WITH 1/8 INCH HAMMERS

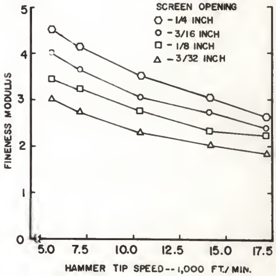


FIGURE 4. EFFECT OF PERIPHERAL SPEED ON FINENESS WHEN GRINDING MILO WITH 1/8 INCH HAMMERS

and fineness when milo was ground with 1/4 inch wide hammers. There was an increase in efficiency with all screens as the speed was decreased from 17,200 feet per minute to 7,080 feet per minute. In general, there was lower efficiency with the 1/4 inch hammers than with the 1/8 inch hammers. A decreased speed gave a coarser product when milo was ground with 1/4 inch hammers (Figure 6).

Table 3 shows the effect of peripheral speed on efficiency, fineness modulus and surface area per gram of material. Surface area shows the same trend when the 1/4 inch hammers are used as when the 1/8 and 1/16 inch are employed.

The relationship of 1/4, 1/8 and 1/16 inch hammers during the grinding of milo isshown in Figure 7. The wider hammers were less efficient at all speeds.

Corn. The effect of peripheral speed on efficiency and particle size when corn is ground with 1/16 inch hammers is hown in Figures 8 and 9. The peak efficiency for the three smaller screens was at 10,470 feet per minute (Figure 8). The peak efficiency of the 1/4 inch screen was at 7,080 feet per minute. There was an increase in particle size with all screens as peripheral speed was decreased (Figure 9).

The effect of peripheral speed on efficiency, fineness modulus and surface area per gram when corn is ground with 1/16 inch hammers is shown in Table 4. With the exception of the two higher speeds, there was a decrease in surface area with a decreased peripheral speed. There was greater efficiency during the grinding of milo with 1/16 inch hammers than when corn was ground with 1/16 inch hammers at the same speed and the same screen size.

The effect of peripheral speed on efficiency and particle size during the grinding of corn with 1/8 inch hammers is shown in Figures 10 and 11. The peak efficiency was at 10,470 feet per minute with the three smaller screens. The

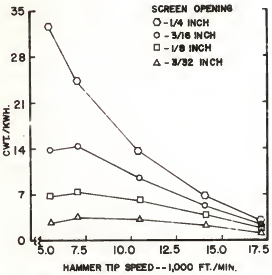


FIGURE 5. EFFECT OF PERIPHERAL SPEED ON EFFICIENCY WHEN GRINDING MILO WITH 1/4 INCH HAMMERS

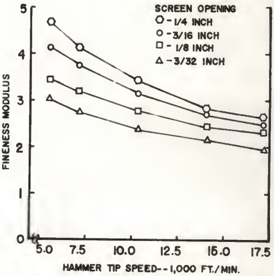


FIGURE 6. EFFECT OF PERIPHERAL SPEED ON FINENESS WHEN GRINDING MILO WITH 1/4 INCH HAMMERS

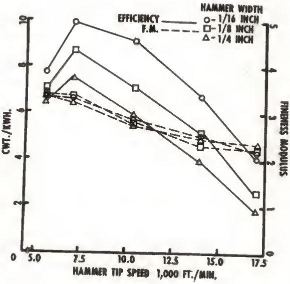


FIG. 7. EFFECT OF PERIPHERAL SPEED AND HAMMER WIDTH ON HAMMERMILL PERFORMANCE. (MILO—1/8 INCH SCREEN)

most efficient peripheral speed involving the use of the 1/4 inch screen was at 7,080 feet per minute. The efficiency when corn was ground with the 1/8 inch hammers was not so great as during the grinding of milo with 1/8 inch hammers. There was a gradual increase in fineness with a higher peripheral speed (Figure 11).

Table 5 shows the effect of peripheral speed on the efficiency, fineness modulus and surface area per gram when corn is ground with 1/8 inch hammers. Without exception, the surface area decreased with a given screen opening as the speed was decreased.

The effect of peripheral speed on efficiency and granulation during corn grinding with 1/4 inch hammers is shown by Figures 12 and 13. The peak efficiency of the two smaller screens was at 10,470 feet per minute, and the peak efficiency of the two larger screens was at 7,080 feet per minute (Figure 12).

There was an increase in particle size with a decrease in speed (Figure 13).

Table 6 shows that surface area per gram increased as the speed was increased.

The relationship of three different hammer widths when corn was ground through a 3/16 inch screen is shown in Figure 14. At the two higher speeds the 1/16 inch hammer was the most efficient, while the three lower speeds the 1/8 inch hammer was the most efficient.

Oats. The effect of peripheral speed on particle size and efficiency during the grinding of oats with 1/16 inch hammers is shown in Figures 15 and 16. The highest efficiency with the three smaller screens was at 10,470 feet per minute. The highest efficiency with the 1/4 inch screen was at 7,080 feet per minute. There was a decrease in particle size with an increased speed

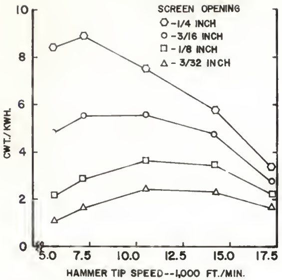


FIGURE 8. EFFECT OF PERIPHERAL SPEED ON EFFICIENCY WHEN GRINDING CORN WITH 1/16 INCH HAMMERS

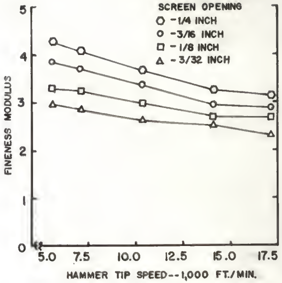


FIGURE 9. EFFECT OF PERIPHERAL SPEED ON FINENESS WHEN GRINDING CORN WITH 1/16 INCH HAMMERS

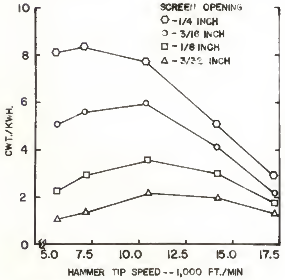


FIGURE 10. EFFECT OF PERIPHERAL SPEED ON EFFICIENCY WHEN GRINDING CORN WITH 1/8 INCH HAMMERS

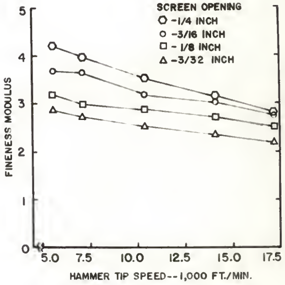


FIGURE 11. EFFECT OF PERIPHERAL SPEED ON FINENESS WHEN GRINDING CORN WITH 1/8 INCH HAMMERS

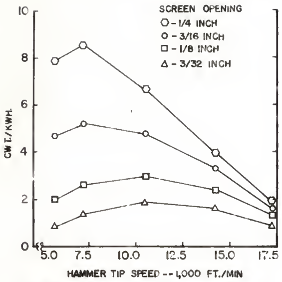


FIGURE 12. EFFECT OF PERIPHERAL SPEED ON EFFICIENCY WHEN GRINDING CORN WITH 1/4 INCH HAMMERS

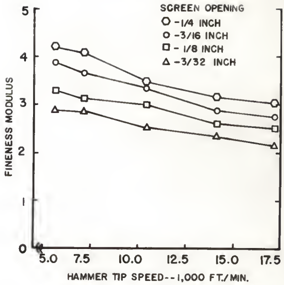


FIGURE 13. EFFECT OF PERIPHERAL SPEED ON FINENESS WHEN GRINDING CORN WITH 1/4 INCH HAMMERS

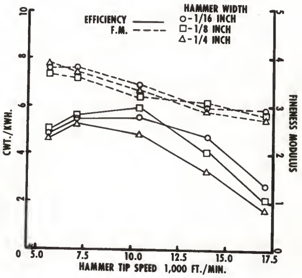


FIG. 14. EFFECT OF PERIPHERAL SPEED AND HAMMER WIDTH ON HAMMERMILL PERFORMANCE. (CORN—3/16 INCH SCREEN)

(Figure 16).

The relationship of modulus of uniformity, fineness modulus, surface area and efficiency in grinding oats with 1/16 inch hammers is shown in Table 7.

The effect of peripheral speed on efficiency and particle size when oats were ground with 1/8 inch hammers is shown in Figures 17 and 18. The highest efficiency when the three smaller screens were used was at 10,470 feet per minute. The highest efficiency with the 1/4 inch screen was at 5,600 feet per minute (Figure 17). Particle size decreased as the speed increased (Figure 18).

The surface area increased as the speed is increased when using 1/8 inch hammers (Table 8).

The effect of peripheral speed on particle size and efficiency during the grinding of oats with 1/4 inch hammers is shown in Figures 19 and 20. The highest efficiency with the two smaller screens was at 10,470 feet per minute. The highest efficiency with the 3/16 inch screen was at 7,080 feet per minute. The highest efficiency with the 1/4 inch screen was at 5,600 feet per minute (Figure 19).

There was a decrease in particle size with an increased speed (Figure 20).

The relationship of surface area and modulus of uniformity to peripheral speed when oats were ground with 1/4 inch hammers is shown in Table 9.

The effect of hammer width on grinding efficiency and particle size is shown in Figure 21. The 1/16 inch hammers were the most efficient followed by the 1/8 inch and the 1/4 inch. There was less difference in efficiencies at slow speeds than at high speeds.

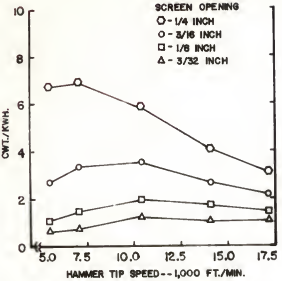


FIGURE 15. EFFECT OF PERIPHERAL SPEED ON EFFICIENCY WHEN GRINDING OATS WITH 1/16 INCH HAMMERS

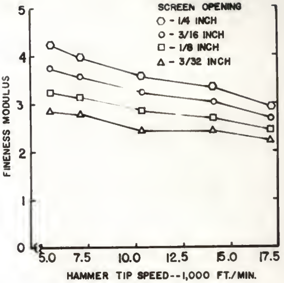


FIGURE 16. EFFECT OF PERIPHERAL SPEED ON FINENESS WHEN GRINDING OATS WITH 1/16 INCH HAMMERS

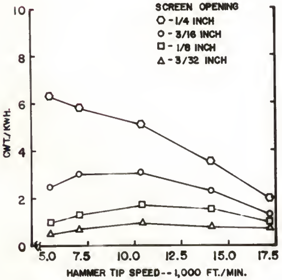


FIGURE 17. EFFECT OF PERIPHERAL SPEED ON EFFICIENCY WHEN GRINDING OATS WITH 1/8 INCH HAMMERS

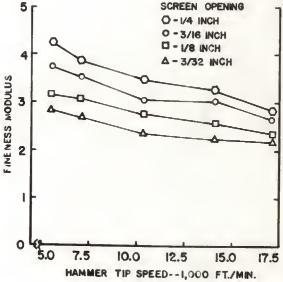


FIGURE 18. EFFECT OF PERIPHERAL SPEED ON FINENESS WHEN GRINDING OATS WITH 1/8 INCH HAMMERS

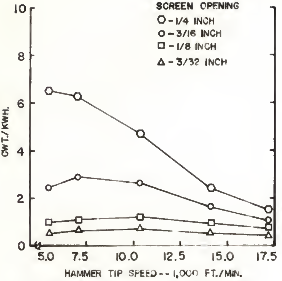


FIGURE 19. EFFECT OF PERIPHERAL SPEED ON EFFICIENCY WHEN GRINDING OATS WITH 1/4 INCH HAMMERS

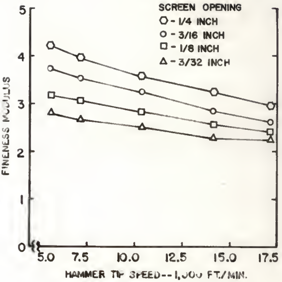


FIGURE 20. EFFECT OF PERIPHERAL SPEED ON FINENESS WHEN GRINDING OATS WITH 1/4 INCH HAMMERS

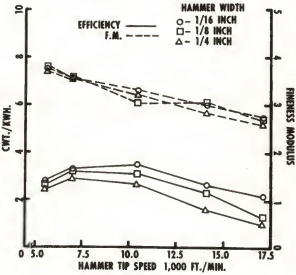


FIG. 21. EFFECT OF PERIPHERAL SPEED AND HAMMER WIDTH ON HAMMERMILL PERFORMANCE. (OATS—3/16 INCH SCREEN)

Table 1. Effect of peripheral speed on hammermill performance.
(Milo - 1/16 inch hammers)

Speed (Ft./min.)	3/32 inch screen #/KWH	F.M.	M.U.	S.A./Gm.	1/8 inch screen #/KWH	F.M.	M.U.	S.A./Gm.
17,200	314	1.87	0:3:7	176.9	419	2.18	0:5:5	143.5
14,164	466	2.10	0:5:5	145.6	678	2.44	0:6:4	122.0
10,470	579	2.61	0:7:3	100.4	910	2.83	0:7:3	113.4
7,080	511	2.81	0:7:3	113.1	984	3.33	0:9:1	73.4
5,600	399	3.03	0:8:2	89.5	776	3.52	0:9:1	61.5
	3/16 inch screen #/KWH	F.M.	M.U.	S.A./Gm.	**1/4 inch screen** #/KWH	F.M.	M.U.	S.A./Gm.
17,200	572	2.51	0:6:4	118.8	712	2.74	1:6:3	111.4
14,164	916	2.76	0:7:3	103.0	1175	3.16	1:7:2	79.4
10,470	1324	3.11	0:8:2	99.0	1948	3.58	2:7:1	47.5
7,080	1693	3.66	1:8:1	62.4	2873	4.19	4:6:0	36.5
5,600	1722	4.49	6:4:0	25.2			[1]	

[1]Test omitted because of a large per cent of whole milo.

Table 1a. Analysis of the grains used in Table 1.

	Average	Range
Moisture	13.7%	13.3 - 14.0%
Protein	8.8%	8.6 - 8.9%
Test Weight	58.3 #/bu.	57.9 - 58.9 #/bu.
Absolute Density	1.227 g./cc.	1.206 - 1.237 g./cc.

Table 2. Effect of peripheral speed on hammermill performance. (Milo - 1/8 inch hammers)

Speed (Ft./min.)	3/32 inch screen #/KWH	F.M.	M.U.	S.A./Gm.	1/8 inch screen #/KWH	F.M.	M.U.	S.A./Gm.
17,200	193	1.85	0:3:7	158.5	265	2.21	0:5:5	142.7
14,164	322	2.04	0:4:6	154.2	502	2.31	0:5:5	137.6
10,470	427	2.29	0:6:4	143.9	710	2.76	0:7:3	109.8
7,080	414	2.73	0:7:3	105.7	862	3.23	0:8:2	82.9
5,600	324	3.01	0:8:2	89.3	693	3.45	0:9:1	64.2
	3/16 inch screen #/KWH	F.M.	M.U.	S.A./Gm.	**1/4 inch screen** #/KWH	F.M.	M.U.	S.A./Gm.
17,200	326	2.40	0:6:4	135.6	396	2.62	0:6:4	130.6
14,164	653	2.72	0:7:3	115.1	893	3.06	1:7:2	94.3
10,470	1057	3.06	0:8:2	91.5	1530	3.52	1:8:1	65.6
7,080	1307	3.65	1:8:1	60.2	2467	4.16	4:6:0	34.4
5,600	1480	4.01	3:6:1	48.3	3263	4.52	6:4:0	29.5

Table 2a. Analysis of the grains used in Table 2.

	Average	Range
Moisture	14.1%	13.6 - 14.3%
Protein	8.0%	8.6 - 8.9%
Test Weight	57.0 #/bu.	57.0 - 58.4 #/bu.
Absolute Density	1.230 g./cc.	1.207 - 1.248 g./cc.

Table 3. Effect of peripheral speed on hammermill performance. (Milo - 1/4 inch hammers)

Speed (Ft./min.)	3/32 inch screen #/KWH	F.M.	M.U.	S.A./Gm.	1/8 inch screen #/KWH	F.M.	M.U.	S.A./Gm.
17,200	124	1.94	0:7:3	151.1	186	2.32	0:5:5	128.4
14,164	252	2.16	0:5:5	126.4	395	2.46	0:6:4	117.7
10,470	331	2.38	0:6:4	107.6	594	2.77	0:7:3	95.7
7,080	351	2.76	0:7:3	94.2	749	3.20	0:8:2	73.9
5,600	279	3.01	0:8:2	71.1	645	3.44	0:9:1	55.3
	3/16 inch screen #/KWH	**F.M.**	**M.U.**	**S.A./Gm.**	**1/4 inch screen #/KWH**	**F.M.**	**M.U.**	**S.A./Gm.**
17,200	230	2.48	0:5:5	118.7	282	2.65	0:6:4	108.1
14,164	544	2.70	0:7:3	107.2	668	2.82	0:7:3	93.3
10,470	955	3.16	0:8:2	78.2	1340	3.44	1:7:2	65.6
7,080	1448	3.76	1:8:1	48.6	2423	4.14	3:6:1	36.0
5,600	1373	4.14	4:6:0	35.5	3279	4.69	7:3:0	22.5

Table 3a. Analysis of the grains used in Table 3.

	Average	Range
Moisture	14.6%	14.4 - 14.7%
Protein	8.8%	8.4 - 8.9%
Test Weight	59.8 #/bu.	59.6 - 60.1 #/bu.
Absolute Density	1.263 g/cc	1.260 - 1.270 g/cc

Table 4. Effect of peripheral speed on hammermill performance.
(Corn - 1/16 inch hammers)

Speed	3/32 inch screen				1/8 inch screen			
(Ft./min.)	#/KWH	F.M.	M.U.	S.A./Gm.	#/KWH	F.M.	M.U.	S.A./Gm.
17,200	161	2.32	0:4:6	102.3	220	2.69	0:5:5	85.7
14,164	232	2.52	0:5:5	103.6	345	2.71	0:6:4	91.8
10,470	245	2.62	0:6:4	90.0	366	3.00	0:7:3	75.2
7,080	163	2.86	0:7:3	77.0	287	3.25	0:8:2	64.9
5,600	111	2.96	0:7:3	72.8	219	3.31	0:7:3	60.4
	3/16 inch screen				1/4 inch screen			
	#/KWH	F.M.	M.U.	S.A./Gm.	#/KWH	F.M.	M.U.	S.A./Gm.
17,200	275	2.88	0:6:4	76.1	338	3.14	1:6:3	66.8
14,164	475	2.95	0:7:3	80.7	578	3.26	1:7:2	69.5
10,470	558	3.37	1:7:2	59.2	753	3.69	3:6:1	49.2
7,080	555	3.71	2:6:2	47.3	892	4.09	4:5:1	36.5
5,600	482	3.85	3:5:2	46.7	840	4.27	5:4:1	27.1

Table 4a. Analysis of the grains used in Table 4.

	Average	Range
Moisture	13.4%	13.2 - 13.8%
Protein	8.7%	8.6 - 8.9%
Test Weight	57.4 #/bu.	56.9 - 57.8 #/bu.
Absolute Density	1.229 g/cc	1.225 - 1.232 g/cc

Table 5. Effect of peripheral speed on hammermill performance.
(Corn - 1/8 inch hammers)

Speed (Ft./min.)	3/32 inch screen #/KWH	F.M.	M.U.	S.A./Gm.	1/8 inch screen #/KWH	F.M.	M.U.	S.A./Gm.
17,200	122	2.20	0:7:3	120.1	174	2.52	0:5:5	101.3
14,164	192	2.35	0:6:4	111.4	297	2.72	0:6:4	91.5
10,470	217	2.52	0:6:4	101.8	353	2.88	0:7:3	82.8
7,080	139	2.72	0:6:4	91.6	288	2.99	0:7:3	74.0
5,600	110	2.87	0:7:3	79.9	224	3.19	0:7:3	67.5
	3/16 inch screen #/KWH	**F.M.**	**M.U.**	**S.A./Gm.**	**1/4 inch screen #/KWH**	**F.M.**	**M.U.**	**S.A./Gm.**
17,200	211	2.74	0:6:4	92.4	282	2.80	0:6:4	87.1
14,164	405	3.04	0:7:3	84.7	501	3.16	1:6:3	74.2
10,470	590	3.19	0:7:3	69.6	772	3.52	2:6:2	59.5
7,080	560	3.64	2:6:2	53.6	835	3.98	4:5:1	44.4
5,600	504	3.68	3:5:2	51.4	810	4.22	5:4:1	37.2

Table 5a. Analysis of the grains used in Table 5.

	Average	Range
Moisture	13.4%	13.2 - 13.6%
Protein	8.1%	8.6 - 8.9%
Test Weight	58.2 #/bu.	57.4 - 59.3 #/bu.
Absolute Density	1.229 g/cc	1.225 - 1.232 g/cc

Table 6. Effect of peripheral speed on hammermill performance. (Corn - 1/4 inch hammers)

Speed (Ft./min.)	3/32 inch screen #/KWH	F.M.	M.U.	S.A./Gm.	1/8 inch screen #/KWH	F.M.	M.U.	S.A./Gm.
17,200	89	2.14	0:3:7	118.8	138	2.52	0:5:5	103.5
14,164	161	2.34	0:6:4	112.3	240	2.60	0:5:5	100.0
10,470	187	2.54	0:6:4	93.7	300	2.99	0:7:3	76.1
7,080	134	2.85	0:6:4	78.7	265	3.14	0:7:3	63.3
5,600	87	2.89	0:6:4	71.2	202	3.30	0:7:3	58.4
	3/16 inch screen #/KWH	F.M.	M.U.	S.A./Gm.	**1/4 inch screen** #/KWH	F.M.	M.U.	S.A./Gm.
17,200	164	2.75	0:6:4	89.0	198	3.04	1:6:3	79.4
14,164	332	2.88	0:6:4	81.4	398	3.17	1:6:3	84.5
10,470	480	3.33	1:7:2	58.4	667	3.47	2:6:2	55.4
7,080	522	3.68	2:6:2	45.9	850	4.09	4:5:1	39.4
5,600	469	3.89	3:5:2	43.5	790	4.22	5:4:1	33.6

Table 6a. Analysis of the grains used in Table 6.

	Average	Range
Moisture	13.4%	13.2 - 13.6%
Protein	8.8%	8.4 - 8.9%
Test Weight	58.0 #/bu.	57.5 - 58.4 #/bu.
Absolute Density	1.229 g/cc	1.225 - 1.232 g/cc

Table 7. Effect of peripheral speed on hammermill performance.
(Oats - 1/16 inch hammers)

Speed	3/32 inch screen				1/8 inch screen			
(Ft./min.)	#/KWH	F.M.	M.U.	S.A./Gm.	#/KWH	F.M.	M.U.	S.A./Gm.
17,200	114	2.22	0:5:5	122.1	153	2.43	0:6:4	111.7
14,164	103	2.42	0:5:5	99.2	177	2.69	0:7:3	83.9
10,470	121	2.44	0:6:4	104.5	199	2.86	0:7:3	84.7
7,080	77	2.78	0:7:3	83.4	143	3.13	0:8:2	70.5
5,600	62	2.86	0:7:3	77.6	108	3.24	0:8:2	61.2

Speed	3/16 inch screen				1/4 inch screen			
(Ft./min.)	#/KWH	F.M.	M.U.	S.A./Gm.	#/KWH	F.M.	M.U.	S.A./Gm.
17,200	220	2.68	0:7:3	98.4	312	2.94	0:7:3	87.1
14,164	263	3.03	0:7:3	64.3	407	3.32	0:8:2	55.9
10,470	356	3.24	0:8:2	67.6	581	3.58	1:8:1	51.2
7,080	336	3.56	1:8:1	50.6	689	3.99	2:7:1	34.5
5,600	272	3.76	1:8:1	43.2	671	4.24	4:6:0	29.8

Table 7a. Analysis of the grains used in Table 7.

	Average	Range
Moisture	11.3%	11.2 - 11.7%
Protein	12.9%	12.7 - 13.2%
Test Weight	42.7 #/bu.	42.3 - 42.9 #/bu.
Absolute Density	1.310 g/cc	1.299 - 1.322 g/cc

Table 8. Effect of peripheral speed on hammermill performance.
(Oats - 1/8 inch hammers)

Speed (Ft./min.)	3/32 inch screen #/KWH	F.M.	M.U.	S.A./Gm.	1/8 inch screen #/KWH	F.M.	M.U.	S.A./Gm.
17,200	69	2.19	0:5:5	126.3	98	2.34	0:5:5	117.9
14,164	75	2.23	0:5:5	109.3	154	2.56	0:6:4	106.2
10,470	98	2.34	0:6:4	112.9	170	2.79	0:7:3	92.4
7,080	74	2.69	0:6:4	88.4	128	3.07	0:8:2	74.5
5,600	55	2.81	0:7:3	84.4	100	3.14	0:8:2	72.1
	3/16 inch screen #/KWH	F.M.	M.U.	S.A./Gm.	**1/4 inch screen** #/KWH	F.M.	M.U.	S.A./Gm.
17,200	132	2.66	0:6:4	98.4	197	2.82	0:7:3	86.5
14,164	237	3.07	0:7:3	94.0	356	3.26	0:8:2	75.8
10,470	308	3.02	0:8:2	74.6	511	3.49	1:8:1	59.0
7,080	302	3.51	0:8:2	60.0	584	3.86	2:7:1	39.7
5,600	251	3.73	1:8:1	46.8	630	4.23	4:6:0	30.4

Table 8a. Analysis of the grains used in Table 8.

	Average	Range
Moisture	10.8%	9.6 - 11.9%
Protein	13.4%	13.1 - 13.9%
Test Weight	42.9 #/bu.	42.4 - 43.1 #/bu.
Absolute Density	1.304 g/cc	1.298 - 1.310 g/cc

Table 9. Effect of peripheral speed on hammermill performance.
(Oats @ 1/4 inch hammers)

Speed (Ft./min.)	3/32 inch screen #/KWH	F.M.	M.U.	S.A./Gm.	1/8 inch screen #/KWH	F.M.	M.U.	S.A./Gm.
17,200	45	2.24	0:4:6	111.8	74	2.40	0:5:5	106.2
14,164	58	2.26	0:5:5	98.5	96	2.55	0:6:4	86.1
10,470	69	2.50	0:6:4	96.3	126	2.81	0:7:3	85.4
7,080	62	2.67	0:6:4	87.3	117	3.07	0:8:2	72.4
5,600	55	2.80	0:7:3	78.2	100	3.19	0:8:2	62.4
	3/16 inch screen #/KWH	**F.M.**	**M.U.**	**S.A./Gm.**	**1/4 inch screen #/KWH**	**F.M.**	**M.U.**	**S.A./Gm.**
17,200	107	2.61	0:6:4	100.9	152	2.92	0:7:3	92.7
14,164	161	2.84	0:7:3	75.1	247	3.24	0:8:2	62.3
10,470	270	3.24	0:8:2	66.6	470	3.54	1:8:1	54.6
7,080	290	3.54	1:8:1	51.3	628	3.96	2:7:1	38.0
5,600	243	3.73	1:8:1	44.7	650	4.21	4:6:0	30.9

Table 9a. Analysis of the grains used in Table 9.

	Average	Range
Moisture	11.4%	11.1 - 11.7%
Protein	13.0%	12.6 - 13.2%
Test Weight	43.1 #/bu.	42.6 - 43.3 #/bu.
Absolute Density	1.303 g/cc	1.294 - 1.310 g/cc

Effect of Air Flow

Corn. The effect of air flow on hammermill performance in corn grinding is shown in Tables 10, 11, 12 and 13. The effect of air flow on efficiency is shown in Figures 22, 23, 24 and 25. Air flow had very little affect on particle size and efficiency within the ranges tested. There was always an increase in efficiency when the air flow was increased from zero to 424 C.F.M. In some cases there was an increase in efficiency from 424 to 582 C.F.M.

Oats. The effect of air flow on hammermill performance in oats grinding is shown in Tables 14, 15, 16 and 17. The effect of air flow on efficiency is shown in Figures 26, 27, 28 and 29. In general there was an increased efficiency when the air flow was increased from zero C.F.M. to 424 C.F.M. In some cases there was an additional increase in efficiency when the air flow was increased from 424 CFM to 582 C.F.M.

DISCUSSION

Peripheral Speed

The results show that slower hammermill speeds are generally more efficient than higher speeds. This confirms the work of Silver (11) and re-emphasizes Friedrich's (7) statement that "impact velocity is one of the most important factors in pulverizing hard and large pieces."

The speed at which a hammermill is operated seems to be dependent upon the particle size and particle size distribution desired. If the prime objective in a grinding operation is efficiency and a slight difference in particle size and distribution can be neglected, slower speeds (7,080 - 10,470 feet per minute) are the most desirable.

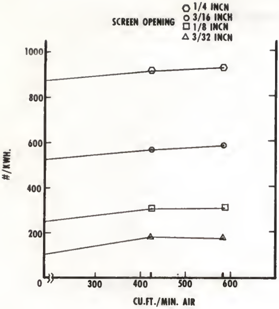


FIG. 22 EFFECT OF AIR FLOW ON EFFICIENCY WNEN GRINDING CORN AT 7,080 FT./MIN., USING 1/16 IN. NAMMERS

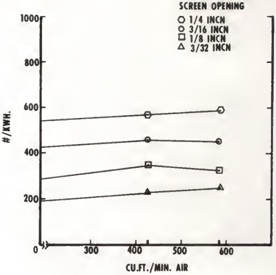


FIG. 23 EFFECT OF AIR FLOW ON EFFICIENCY WNEN GRINDING CORN AT 14,164 FT./MIN., USING 1/16 IN. NAMMERS

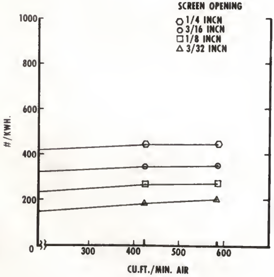


FIG. 25 EFFECT OF AIR FLOW ON EFFICIENCY WNEN GRINDING CORN AT 14,164 FT./MIN., USING 1/4 IN. NAMMERS

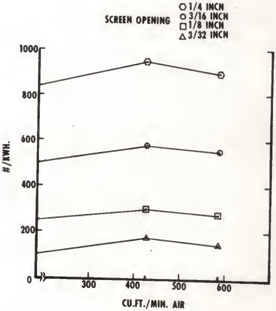


FIG. 24 EFFECT OF AIR FLOW ON EFFICIENCY WNEN GRINDING CORN AT 7,080 FT./MIN., USING 1/4 IN. HAMMERS

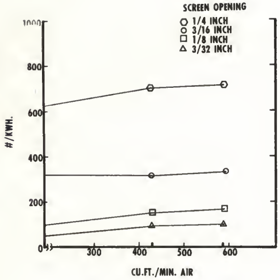


FIG. 26 EFFECT OF AIR FLOW ON EFFICIENCY WHEN GRINDING OATS AT 7,080 FT./MIN., USING 1/16 IN. HAMMERS

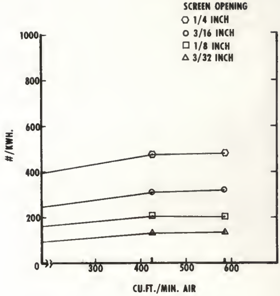


FIG. 27 EFFECT OF AIR FLOW ON EFFICIENCY WHEN GRINDING OATS AT 14,164 FT./MIN., USING 1/16 IN. HAMMERS

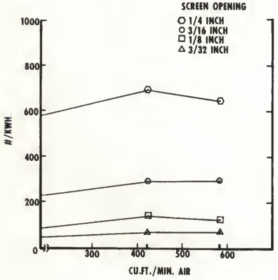


FIG. 28 EFFECT OF AIR FLOW ON EFFICIENCY WHEN GRINDING OATS AT 7,080 FT./MIN., USING 1/4 IN. HAMMERS

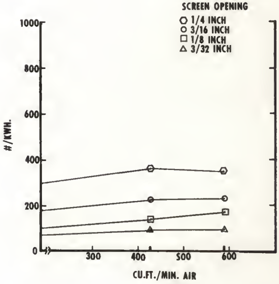


FIG. 29 EFFECT OF AIR FLOW ON EFFICIENCY WHEN GRINDING OATS AT 14,164 FT./MIN. USING 1/4 IN. HAMMERS

Table 10. Effect of air flow on hammermill performance.
(Corn - 7,080 ft./min. - 1/16 inch hammers.)

Air flow:	3/32 inch screen			1/8 inch screen			3/16 inch screen			1/4 inch screen		
(C.F.M.)	#/KWH	F.M.	M.U.	#/KWH	F.M.	M.U.	#/KWH	F.M.	M.U.	#/KWH	F.M.	M.U.
0	101	3.01	0:7:3	242	3.24	1:7:2	521	3.67	2:6:2	870	4.04	4:5:1
424	180	2.91	0:6:4	302	3.22	0:7:3	565	3.73	2:6:2	914	3.89	3:5:2
582	176	2.82	0:6:4	306	3.17	0:7:3	582	3.61	2:6:2	925	3.95	4:5:1

Table 10a. Analysis of the grains used in Table 10.

Moisture	14.4%
Protein	8.5%
Test Weight	56.9 #/bu.
Absolute Density	1.232 g/cc

Table 11. Effect of air flow on hammermill performance.
(Corn - 14,164 ft./min. - 1/16 inch hammers.)

Air flow:	3/32 inch screen			1/8 inch screen			3/16 inch screen			1/4 inch screen		
(C.F.M.)	#/KWH	F.M.	M.U.	#/KWH	F.M.	M.U.	#/KWH	F.M.	M.U.	#/KWH	F.M.	M.U.
0	195	2.56	0:6:4	287	2.83	0:6:4	428	3.19	0:7:3	540	3.38	1:7:2
424	237	2.53	0:5:5	348	2.71	0:6:4	460	3.05	0:7:3	570	3.38	1:7:2
582	248	2.51	0:5:5	328	2.81	0:6:4	458	3.06	0:7:3	589	3.26	1:6:3

Table 11a. Analysis of the grains used in Table 11.

Moisture	14.4%
Protein	8.5%
Test Weight	56.9 #/bu.
Absolute Density	1.232 g/cc

Table 12. Effect of air flow on hammermill performance.
(Corn - 7,080 ft./min. - 1/4 inch hammers.)

Air flow:	3/32 inch screen			1/8 inch screen			3/16 inch screen			1/4 inch screen		
(C.F.M.)	#/KWH	F.M.	M.U.	#/KWH	F.M.	M.U.	#/KWH	F.M.	M.U.	#/KWH	F.M.	M.U.
0	108	2.88	0:6:4	251	3.21	0:7:3	507	3.65	2:6:2	840	3.88	4:5:1
424	181	2.78	0:6:4	303	3.16	0:7:3	581	3.56	2:6:2	954	3.85	4:5:1
582	155	2.96	0:7:3	280	3.18	0:7:3	557	3.65	2:6:2	898	3.88	4:5:1

Table 12a. Analysis of the grains used in Table 12.

Moisture	14.4%
Protein	8.3%
Test Weight	57.0 #/bu.
Absolute Density	1.222 g/cc

Table 13. Effect of air flow on hammermill performance.
(Corn - 14,164 ft./min. - 1/4 inch hammers.)

Air flow:	3/32 inch screen			1/8 inch screen			3/16 inch screen			1/4 inch screen		
(C.F.M.):	#/KWH	F.M.	M.U.	#/KWH	F.M.	M.U.	#/KWH	F.M.	M.U.	#/KWH	F.M.	M.U.
0	148	2.46	0:5:5	234	2.77	0:6:4	320	3.04	0:7:3	419	3.07	1:6:3
424	186	2.43	0:5:5	269	2.72	0:6:4	346	2.92	0:6:4	443	3.09	1:6:3
582	203	2.43	0:5:5	275	2.68	0:6:4	353	2.92	0:6:4	445	2.98	1:6:3

Table 13a. Analysis of the grains used in Table 13.

Moisture	14.4%
Protein	8.3%
Test Weight	57.0 #/bu.
Absolute Density	1.222 g/cc

Table 14. Effect of air flow on hammermill performance.
(Oats - 7,080 ft./min. - 1/16 inch hammers.)

Air flow:	3/32 inch screen			1/8 inch screen			3/16 inch screen			1/4 inch screen		
(C.F.M.):	#/KWH	F.M.	M.U.	#/KWH	F.M.	M.U.	#/KWH	F.M.	M.U.	#/KWH	F.M.	M.U.
0	55	2.94	0:7:3	96	3.22	0:8:2	320	3.35	1:7:2	623	4.03	2:7:1
424	86	2.78	0:7:3	146	3.15	0:8:2	315	3.59	1:8:1	701	4.01	2:7:1
582	93	2.81	0:7:3	168	3.14	0:8:2	335	3.56	1:8:1	719	4:05	2:7:1

Table 14a. Analysis of the grains used in Table 14.

Moisture	11.9%
Protein	13.5%
Test Weight	39.8 #/bu.
Absolute Density	1.264 g/cc

Table 15. Effect of air flow on hammermill performance.
(Oats - 14,164 ft./ min. - 1/16 inch hammers)

Air flow:	3/32 inch screen			1/8 inch screen			3/16 inch screen			1/4 inch screen		
(C.F.M.)	#/KWH	F.M.	M.U.	#/KWH	F.M.	M.U.	#/KWH	F.M.	M.U.	#/KWH	F.M.	M.U.
0	99	2.45	0:6:4	161	2.68	0:7:3	252	2.99	0:8:2	397	3.32	0:8:2
424	135	2.40	0:6:4	202	2.63	0:7:3	309	2.99	0:7:3	473	3.33	0:8:2
582	136	2.42	0:6:4	201	2.69	0:7:3	318	3.00	0:7:3	477	3.33	0:8:2

Table 15a. Analysis of the grains used in Table 15.

Moisture	12.2%
Protein	13.7%
Test Weight	42.1 #/bu.
Absolute Density	1.264 g/cc

Table 16. Effect of air flow on hammermill performance.
(Oats - 7,080 ft./min. - 1/4 inch hammers.)

Air flow:	3/32 inch screen			1/8 inch screen			3/16 inch screen			1/4 inch screen		
(C.F.M.)	#/KWH	F.M.	M.U.	#/KWH	F.M.	M.U.	#/KWH	F.M.	M.U.	#/KWH	F.M.	M.U.
0	47	2.88	0:7:3	88	3.18	0:8:2	235	3.52	1:8:1	582	3.98	2:7:1
424	74	2.76	0:7:3	143	3.05	0:8:2	297	3.56	1:8:1	695	4.00	2:7:1
582	78	2.79	0:7:3	130	3.15	0:8:2	298	3.53	1:8:1	649	3.99	2:7:1

Table 16a. Analysis of the grains used in Table 16.

Moisture	11.9%
Protein	13.5%
Test Weight	39.8 #/bu.
Absolute Density	1.265 g/cc

Table 17. Effect of air flow on hammermill performance.
(Oats - 14,164 ft./min. - 1/4 inch hammers.)

Air flow	3/32 inch screen			1/8 inch screen			3/16 inch screen			1/4 inch screen		
(C.F.M.)	#/KWH	F.M.	M.U.	#/KWH	F.M.	M.U.	#/KWH	F.M.	M.U.	#/KWH	F.M.	M.U.
0	65	2.54	0:6:4	99	2.81	0:7:3	176	3.02	0:7:3	287	3.28	0:8:2
424	87	2.64	0:6:4	137	2.64	0:6:4	220	2.87	0:7:3	359	3.20	0:8:2
582	95	2.53	0:6:4	174	2.71	0:6:4	225	2.90	0:7:3	346	3.24	0:8:2

Table 17a. Analysis of the grains used in Table 17.

Moisture	12.0%
Protein	13.8%
Test Weight	39.8 #/bu.
Absolute Density	1.265 g/cc

Hammer Thickness

Baker (3) and Friedrich (7) have indicated that a thinner hammer gives greater efficiency. The results presented here are in agreement with these previous works. It should be pointed out, however, that the number of hammers may have a significant effect.

No attempt was made to maintain a constant total striking area. There were thirty 1/4 inch hammers and 45 each of the 1/8 and 1/16 inch hammers used in all tests.

Kind of Grain

Oats were the most difficult to reduce, followed by corn and milo; these results are in agreement with those of Baker (3) and Silver (11).

Screen Opening

In all cases as might be expected, there was greater efficiency as the particle size increased with larger screen openings.

Air Flow through the Mill

There was no appreciable effect of air flow on efficiency and particle size within the ranges of air flow used.

Need for Further Study

There are still many factors affecting hammermill performance which would merit further study; some of these are: hammer tip and screen clearance, number of hammers, and the shape and number of screen openings. Additional research on hammer width may be rewarding.

Another area of importance is the flow of particles through the mill and the effect of interparticle collision. Work with high speed films in this aspect may suggest many design features which will improve hammermill performance.

CONCLUSION

Peripheral Speed

1. In all cases peripheral speeds less than the normal recommended speeds for hammermills gave most efficient reduction.

2. Particle size increased as the peripheral speed decreased.

3. In most cases, when the particle size was maintained uniform, there was greater efficiency in the reduction, if the peripheral speed was reduced and the diameter of the screen opening decreased.

4. It was found that a peripheral speed greater than the recommended speed for this mill gave a smaller particle size, and reduction was less efficient for a given screen opening.

5. Peripheral speed affected efficiency more with the larger than with the smaller screens.

Hammer Thickness

1. In general, the most efficient hammer was the 1/16 inch, followed by the 1/8 and the 1/4. There were some exceptions

2. Hammer width differences did not result in a large variation in particle size.

Kind of Grain

It was found that milo reduced the most efficiently, followed by corn and oats.

Screen Opening

In all cases there was greater efficiency as the particle size increased with a larger screen opening.

Air Flow through the Mill

It was found that air flow through the mill had no great effect on hammermill performance within the limits tested.

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APPENDICES

APPENDIX A

Examples of "Modulus of Fineness" and "Modulus of Uniformity"

The following Tables show examples of calculations of "Modulus of Fineness" and "Modulus of Uniformity". The methods were adopted by the American Society of Agricultural Engineers and by The American Society of Animal Production, (1) except that a 200 mesh sieve was added to the recommended standard. This alteration, however, did not affect the "Modulus of Fineness" or the "Modulus of Uniformity".

Table 18. Sample calculation of Fineness Modulus.

Screen Mesh (Tyler Number)	Per cent of material on each screen		Factor	Product
3/8	0.0	x	7	0.0
4	0.0	x	6	0.0
8	4.0	x	5	20.0
14	7.0	x	4	28.0
28	52.0	x	3	156.0
48	19.0	x	2	38.0
100	7.6	x	1	7.6
200	7.0	x	0	0.0
Pan	3.4	x	0	0.0
Totals	100.0			249.6

Modulus of Fineness = 249.6 ÷ 100 = 2.50

Table 19. Sample calculation of Modulus of Uniformity.

(A) Screen mesh (Tyler number)	(B) Per cent material on each screen	(C) Totals from (B)	(D)	(E) Figures from (D) rounded to nearest whole number
	Coarse			
3/8	0.0			
4	0.0			
8	4.0	4.0 ÷ 10	= .4	0
	Medium			
14	7.0			
28	52.0	59.0 ÷ 10	= 5.9	6
	Fine			
48	19.0			
100	7.6			
200	7.0			
Pan	3.4	37.0 ÷ 10	= 3.7	4

The figures 0 : 6 : 4 express the Modulus of Uniformity.

APPENDIX B

Surface Area Determination

The surface area was determined by sieve analysis. A Tyler Ro-Tap was used with the following series of screens: 3/8, 4, 8, 14, 28, 48, 100, 200 mesh and pan. The particles were considered to be cubes. Therefore, the surface area of a given number of particles with diameter (d) would be:

Surface area = $6d^2$ times the number of particles.

The number of particles over a given screen would be equal to the total weight over the screen divided by the weight per particle. The weight per particle is equal to its true density times volume. Therefore, the surface area over a given screen is:

$$\text{Surface area} = \frac{6 \text{ (Weight over a given screen)}}{\text{Density (Particle Diameter)}}$$

Percentage of material over each screen was used in the formula instead of weight. The surface areas of all the screens were totaled and surface area was expressed as square centimeters per gram.

The diameter of the particles over a given screen was considered to be a logarithmic average of the diameter of the openings of the screen the material had passed over and the diameter of the screen from which the particles had passed through.

Screen openings used in the calculations are shown in the following table. The values for the screen openings were taken from The W.S. Tyler Catalogue No. 53 (2).

Table 20. Screen openings used in the calculation of surface area.

Sieve (Tyler Mesh)	Actual opening (Millimeters)	Opening used in calculation of S.A./Gm. (mm)
3/8	9.423	13.33
4	4.699	6.680
8	2.362	3.327
14	1.168	1.651
28	.589	.833
48	.295	.417
100	.417	.208
200	.074	.104
Pan	----	.053

Table 21. Sample calculation of Surface Area.[1]

Screen mesh (Tyler Number)	6 (Per cent over a given screen) / (Density) (Particle Diameter) (Cm.)	Surface area
3/8	$\frac{6 \times 0}{1.3 \times 1.333}$	0.0
4	$\frac{6 \times 0}{1.3 \times .6680}$	0.0
8	$\frac{6 \times .04}{1.3 \times .3327}$	.55
14	$\frac{6 \times .07}{1.3 \times .1651}$	1.96
28	$\frac{6 \times .52}{1.3 \times .0833}$	28.81
48	$\frac{6 \times .19}{1.3 \times .0417}$	21.03
100	$\frac{6 \times .076}{1.3 \times .0208}$	16.86
200	$\frac{6 \times .07}{1.3 \times .0104}$	31.07
Pan	$\frac{6 \times .034}{1.3 \times .0053}$	29.61
	Total Surface Area (cc/gm.) =	129.89

[1]The percentages used are the same as those used in Tables 18 and 19, except they are expressed as decimals. The density was assumed to be 1.3 for this example.

APPENDIX C

Typical Data Sheet

Grain Corn Moisture Content 12.1% Test Weight 56.1 Date January 4, 1962

Prater 7 1/2 HP Hammermill, 17 sec/1000 rev. 14,164 RPM

Feed Rate Adjusted to 9.6 amps ± .5. 440 volts. Hammer Width 1/4 inch

Fan ______ Gravity X

Test No.	Screen Size	Run Min.	Pounds Ground	Pounds Per Min.	Disc Rev.	Power Used	Pounds Per KWH.	Test Weight of Reduced	Product
1	3/32	1m,30s	28.75	19.2	5	.1440	199.6	42.8 42.1	41.3 41.3
3	3/32	1m,30s	29.50	19.7	5	.1440	204.8	41.7 41.8	41.7 41.6
		Average	29.12	19.5	5	.1440	202.2		

Tyler Sieve Analysis, 500 g., 5 min.

Test No.	3/8	8	14	28	48	100	200	Pan
1	---	---	27	207	234	31.	.10	---
2	---	---	24	191	248	36.	.60	---
3	---	---	26	208	209	56.	.70	---
4	---	---	26	204	253	16.30	.50	---

FACTORS AFFECTING HAMMERMILL PERFORMANCE

by

CARL ANDREW STEVENS

B. S., Kansas State University, 1960

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Flour and Feed Milling Industries

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1962

Corn, oats and milo were reduced with a 7 1/2 horsepower experimental hammermill. The particle size of the product and the efficiency of production were studied as they were affected by the following factors:

(a) Peripheral speed

(b) Hammer thickness

(c) Kind of grain

(d) Screen opening

(e) Air flow through the mill

It was found that the reduction of the peripheral speed from the recommended gave an increase in particle size and that most slower speeds were more efficient.

In some cases the same particle size could be obtained by a reduction in peripheral speed and a decrease in the screen openings.

Peripheral speeds greater than the recommended gave a decreased particle size and the reduction was less efficient for a given screen opening.

The peripheral speed affected efficiency to a greater degree with larger screens than with smaller ones.

It was found that in most cases the 1/16 inch wide hammers were more efficient than 1/8 inch, and the 1/8 inch more efficient than the 1/4 inch.

The investigations showed that milo was reduced the most efficiently, followed by corn and oats.

The air flow through the mill had no great effect on particle size and efficiency.

There was always greater efficiency as the screen openings were enlarged.