GRINDING PERFORMANCE AS AFFECTED BY HAMMERMILL SCREEN DESIGN

by

VANCE E. WESTHUSIN

B.S., Kansas State University, 1981

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Grain Science and Industry

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1983

Approved by:

Major Professor

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

The hammermill is widely used in the formula feed industry for particle size reduction of cereal grains and forages. It is commonly found on farms and in feed mills. Not only is the hammermill one of the most frequently used pieces of equipment, but it is also one of the highest energy consuming machines used by the industry. Given the historical increase in energy costs, steps must constantly be taken to improve hammermill performance and to utilize energy more efficiently.

Numerous factors influence hammermill performance. Among these are: the physical characteristics of the material to be ground, peripheral speed, hammer width, hammer tip and screen clearance, air flow through the mill, the diameter of screen opening and the screen open area. Although hammermill performance has been studied in some detail, further investigation and improvements are needed to keep the costs of grinding from increasing.

One major area of investigation needed is that of hammermill screen design. The Ahlstrom Machinery Inc. has introduced a method of manufacturing hammermill screens in an attempt to improve the hammermills performance. The technique involves drilling the holes in the screen instead of using the standard method of punching The result is an increased screen open area and more holes to be utilized in grinding. Drilling also allows for a wider selection of metals to be utilized in the screen manufacture.

Holes can also be drilled in harder metals than by punching, therefore increasing screen life. A drilled hole is also reported to have a sharper edge than a punched hole, which should aid in grinding and produce a slightly smaller particle by providing more shearing action.

This study investigated the performance of drilled hammermill screens by comparing them with semilar standard punched screens. The following variables were used to measure performance:

1. Mean particle diameter produced, dgw (μ).
2. Log-normal standard deviation of the sample.
3. Exposed surface area, (cm^2/g).
4. Grinding efficiency, (Kg/Kwh).
5. True efficiency, (m^2/Kwh).

Another area of study was to determine whether a linear relationship existed between the screen open area and three other variables; mean particle diameter, grinding efficiency and true efficiency. It was hoped to determine if screen open area had an influence on hammermill performance.

REVIEW OF LITERATURE

The hammermill is generally classified as an impact grinder. Rumpf (1959) stated that particle size reduction occurs in an impact grinder as a result of particles meeting the milling surface at high velocities. The particle will rupture if the kinetic energy of the impact is greater than the stress the particle is able to withstand. He also stated that the energy requirement is very important in all grinding processes because over 90 percent of the required energy is lost in friction.

Several factors have been shown to influence hammermill performance. Early studies indicated that the physical characteristics of a grain has an influence on grinding energy requirements. Silver (1932) found that, when comparing the grinding characteristics of corn, oats and barley, the energy requirements of the grain were different. Corn required less energy than barley, and barley required less energy than oats. Baker (1960) later found that grain sorghum was easier to grind than corn, and corn was easier to grind than oats. Several studies have shown that, as the moisture content of grain rises above 12 to 13 percent, the energy requirement for grinding increases and the grinder capacity decreases (Silver 1932, Friedrich 1959). Baker (1960) concluded that, in general, cereal grains with high levels of fiber or moisture require more energy to grind than grain with a lower fiber and moisture content.

The revolving hammer tips supply the energy that is consumed in hammermill grinding. The factors that influence the amount of energy produced are important in determining hammermill performance.

Peripheral speeds of 4200 to 6600 meters per minute are most suitable for grinding feed ingredients and problem materials (Friedrich 1959). Speeds above 15,000 feet per minute (4572 meters per minute) are inefficient for grinding cereals (Silver 1932). Stevens (1962) showed that slower hammermill speeds, 7080 - 10,470 feet per minute (2158 - 3191 meters per minute), are generally more efficient than higher speeds.

Thinner hammers provide an advantage in hammermill performance. Friedrich (1959) found that by reducing hammer thickness from 8mm to 3mm, capacity and efficiency were increased by 15 percent. When substituting 1/16 inch (1.6mm) wide hammers for 1/8 inch (3.2mm) wide hammers, an average increase in efficiency of 18 percent was noted (Baker 1960). Stevens (1962) noted that hammer width had a greater effect on efficiency when grinding oats than when grinding corn or grain sorghum. As hammer width was increased, efficiency decreased at all speeds. He also noted that hammer width had little effect on average particle size.

Research has shown that hammer tip and screen clearance affect both particle size and grinding efficiency. Friedrich (1959) found that a clearance of 8mm was best for grinding rye. In other research, it was found that, as the clearance increased, the specific power requirement decreased and a larger average particle size was produced (O'Callaghan et al., 1963).

Stevens (1962) examined the influence of air flow through the hammermill screen. As air flow was provided, some improvement in grinding capacity was noticed, however the effect was not significant at the air flows tested.

The amount of screen surface area has also been shown to influence hammermill performance. Baker (1960) found that, by blanking one-half of a 180 degree hammermill screen, capacity was reduced by approximately 20 percent and a smaller average particle size resulted. Similar studies showed a sharp increase in the specific power required to grind after one half of the holes in a 3/32 inch (2.38mm) screen had been blocked (O'Callaghan et al., 1963). They also found that, when the hammermill screen was removed, less than 10 percent of the grains were broken by the initial impact of the hammers alone.

The Ahlstrom Machinery Inc. (1983) conducted a field study with the assistance of Riceland Foods, located in Stuttgart, Arkansas. The grinding performances of a punched 2.78mm hammermill screen, with 25.8 percent open area, and a drilled 2.4mm hammermill screen, with 54.8 percent open area, were compared when grinding rice hulls through a Champion hammermill. The 2.4mm drilled screen produced a 6.2% larger mean particle size, a 4% smaller log-normal mean standard deviation and exposed an average of 8.3% less surface area. The 2.4mm drilled screen produced a 36.6% higher apparent efficiency and a 25.6% higher true efficiency when compared to the 2. 78mm punched screen. The larger mean particle size, efficiency and true efficiency, produced by the 2.4mm drilled screen, may be related to the 112 percent increase in open area with the drilled screen. The punched screen was constructed from mild steel with chrome plating and the drilled screen was constructed from stainless steel with chrome plating. The punched screen had an average life span of 5000 tons compared to 22,100 tons for the drilled screen. This is an increase in life span of 342 % (Appendix 1).

Particle Size Determination

Early researchers reported fineness of grind (particle size) in terms of how the grain appeared to them. The terms used to define Particle size were coarse, medium and fine. The Modulus of Uniformity and Fineness Modulus was the first standard method of quantatively reporting particle size and was adopted by the American Society of Agricultural Engineers and the American Society of Animal Science (Headley and Pfost, 1966). The Modulus of Uniformity and Fineness Molulus technique was limited in its application and became obsolete when the log-normal method of determining particle size was adopted. (Pfost and Headley, 1971).

Techniques previously used in classifying minerals in the mining and glass manufacturing industries were applied to certain ground feeds to describe their particle size distribution (Headley and Pfost, 1966). Although the particle size distributions of cereal grains ground by a hammermill were non-normal, the logrithm of the particle size closely resembled a normal distribution. The geometric mean particle size (measured in microns) and the geometric log-normal standard deviation (a measure of distribution variability) can be determined with the log-normal method.

The total surface area per gram (Appendix 2) and the total number of particles per gram of a sample can be estimated by using the information obtained from the log-normal method. Computer programs can be used to perform the calculations and report the information quickly and accurately.

Using the total surface area per gram and the energy used in grinding, Pfost and Headley (1971) calculated an efficiency rating in terms of square meters of new surface area produced per watt hour of grinding energy input. This figure was referred to as true efficiency.

PURPOSE

The purpose of this study was to determine performances of several different hammermill screens. The variables used to measure screen performance were mean particle size, log-normal standard deviation, exposed surface area, efficiency (measured in kilograms of throughput per kilowatt hour) and true efficiency (measured in square meters of exposed surface area per kilowatt hour).

The initial comparison was between a standard, punched hole screen, and a screen that was manufactured by drilling. The screens were similar except that the drilled screen had more open area. The comparison determined which screen resulted in better grinding performance.

The second comparison was among drilled screens with various open areas. The screens were the same in every respect except for the open area. Four different open areas were used for comparison.

The third comparison was between a punched hole and a drilled hole screen with the same open area. The effect of hole design on grinding performance was determined by comparing the two types.

MATERIALS AND METHODS

Good quality Grade #2 grain sorghum, corn and oats were used in the grinding tests. The grains were isolated in storage bins above the hammermill prior to use. Samples of the whole grains were collected at different intervals during the tests. The test weight and moisture content were determined. The moisture content was determined by using the official A.O.A.C. air oven method. The test weight was determined by using standard test weight equipment.

A Jacobson P-240 full circle hammermill was used in all the grinding tests. The machine specifications were:

a) Power Source - 30 H.P., 220-44- V., 3 phase, 3515 rpm motor.

b) Rotor Width - 152.4mm (outside hammer to outside hammer).

c) Rotor Diameter - 603.25mm (hammer tip to hammer tip).

d) Rotor Speed - 3515 rpm.

e) Peripheral Speed - 6661.51 mpm.

f) Screen Design - Full circle, tear drop shape.

g) Feed Inlet - Top side feed.

h) Feed Control - 152.4mm variable speed screw conveyor.

i) Number of Hammers - 28.

j) Hammer Design: (See Figure 1)

   1. 6.35 mm x 50.8 mm x 190.5 mm - 2 rows of 4 hammers, 2 rows of 6 hammers.

   2. 6.35 mm x 50.8 mm x 190.5 mm - 4 rows of 1 hammer per row.

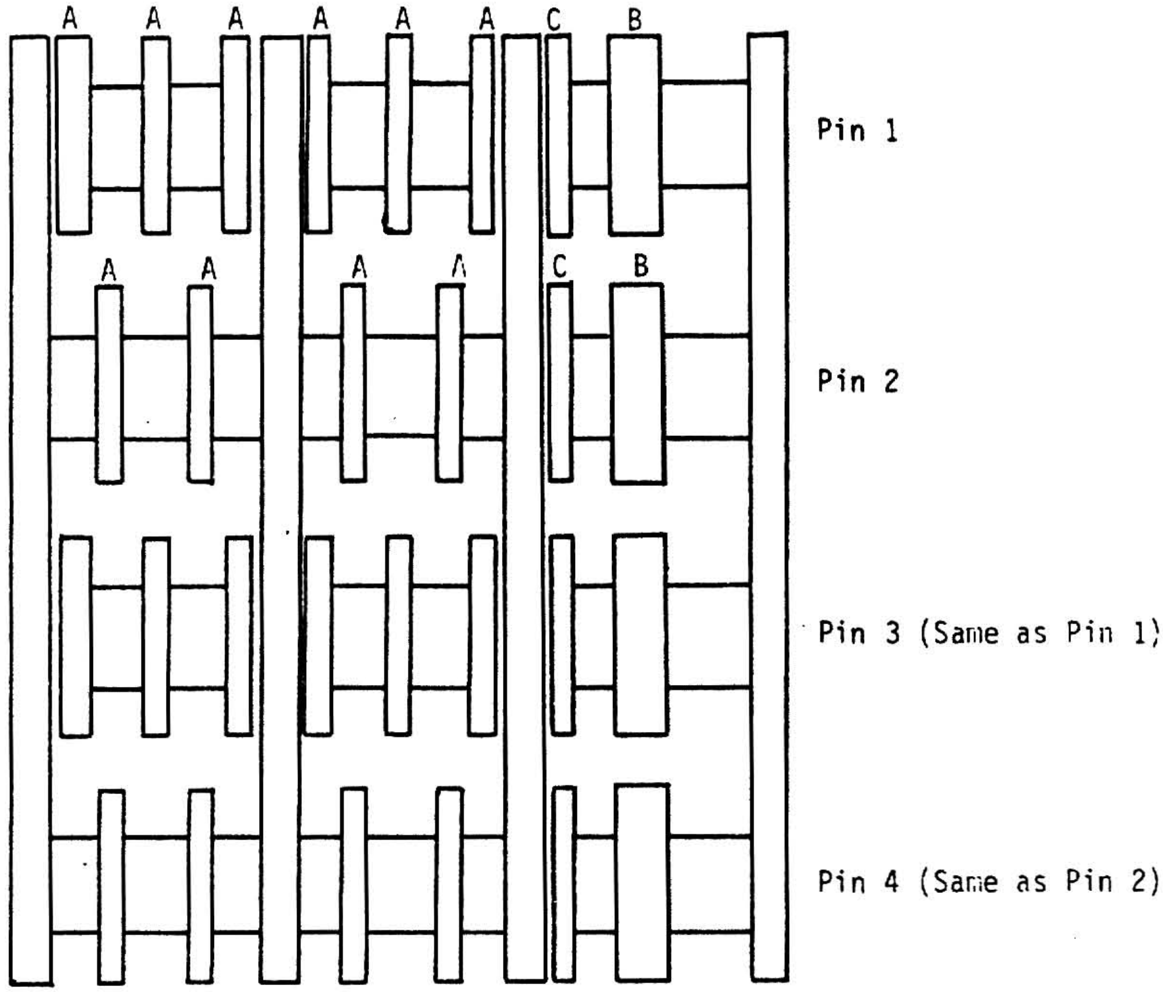
   3. 1.27 mm x 50.8 mm x 177.8 mm - 4 rows of 1 hammer per row.

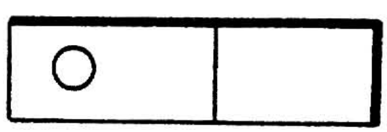
1) Screen and tip clearance - range 2-19 mm.

THIS BOOK CONTAINS NUMEROUS PAGES WITH DIAGRAMS THAT ARE CROOKED COMPARED TO THE REST OF THE INFORMATION ON THE PAGE.

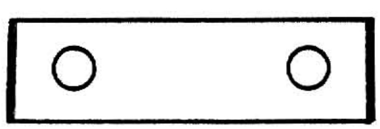
THIS IS AS RECEIVED FROM CUSTOMER.

Figure 1. Hammermill Arrangement

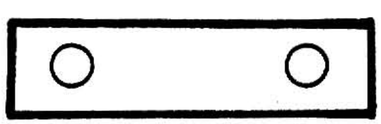




Style "B"



Style "A"



Style "C"

Punched and Drilled Screen Comparison

Grain sorghum, corn and oats were used in comparing the grinding performance of the punched screens with the drilled screens. The tests were made in triplicate for each grain, screen design and hole size. Each grain was tested separately using random screen selection. The order of progression was grain sorghum, corn and oats. The screens used in these tests are shown in table 1.

Open Area Comparison

Tests were conducted to determine the effect of open area on grinding performance. Corn was the only grain tested in this study. Open area tests were conducted in triplicate for each screen. The order of the screens was randomly selected. The screens used in the tests are shown in table 2.

Punched and Drilled Hole Comparison

Corn was used in comparing the grinding performance of punched hole and drilled hole screens. The tests were conducted in triplicate for each hole design. The order of the screens was randomly selected. The screens used in the test are shown in table 3.

Grinding tests were conducted in triplicate for each grain, screen design and hole size. The grain was metered into the hammermill by means of a 152.4mm (six inch) variable speed screw conveyor. The feed rate was adjusted so the hammermill was operating at a full load, or approximately 37 amps, as measured by a recording ammeter. After a full load was achieved and maintained, a test was conducted by diverting the flow of the ground product into an empty bin, located directly above the scale hopper, for a specific period of time. The test was stopped by

Table 1. Screens Used in the Punched and Drilled Screen Comparison Study

Design	Hole Dia. (mm)	Screen Material	Thickness (mm)	Open Area (%)
Punched	3.2	1018 mild steel	2.7	39.1
Drilled	3.2	AR 225 mild steel	3.2	58.1
Punched	1.7	1018 mild steel	1.7	24.1
Drilled	1.7	AR 225 mild steel	1.7	36.96

Table 2. Screens Used in the Open Area Comparison Study

Design	Hole Dia. (mm)	Screen Material	Thickness (mm)	Open Area (%)
Drilled	3.2	AISI 316 S.S.	3.0	18
Drilled	3.2	AISI 316 S.S.	3.0	27.3
Drilled	3.2	AISI 316 S.S.	3.0	41
Drilled	3.2	AISI 316 S.S.	3.0	60.9

Table 3. Screens Used in the Punched and Drilled Hole Comparison Study

Design	Hole Dia. (mm)	Screen Material	Thickness (mm)	Open Area (%)
Punched	3.2	1018 mild steel	3.4	40.2
Drilled	3.2	AR 225 mild steel	3.4	40.2

diverting the flow of the ground product away from the test bin. The ground product from each test was placed in the scale hopper and the weight was recorded. Three random samples of the ground product were collected from each test to be used for particle size analysis.

A stop watch was used to obtain the exact time of each test. The stop watch was started when the ground product was diverted into the test bin and stopped precisely as the ground product was diverted away from the test bin. The length of each test was held at approximately five minutes to make the tests as similar as possible.

A recording ammeter was used to record the power usage during each test. Average amperage and voltage readings were determined from recording ammeter charts and used to calculate power usage for each test. The following formula was used to calculate the electrical power used.

$$\text{Power usage} = \frac{(\text{Amp})\ (\text{Volt})\ (\text{Power Factor})\ (\text{Motor Efficiency})\ \sqrt{3}}{1000}$$

A power factor of .90, an efficiency factor of .90 and 420 volts were used for all calculations.

The production rate for each test was calculated using the kilograms of ground product produced for the time of each test expressed in kilograms per hour. The production rate was divided by the kilowatts used during the test period to yield an efficiency measurement in kilograms of ground product produced per kilowatt hour.

Sampling

Samples of the ground product were collected after each test for particle size analysis. Three samples of each test were collected to provide representative samples. Each sample weighed approximately 2000 grams. The samples were collected by probing the ground product in several different places with a single tube probe. These samples were reduced to 100 grams by the official A.O.A.C. (1955) coning-and-quartering method. The 100 gram sample was then used for the particle size analysis.

Particle Size Determination

Particle size determination was made by using the A.S.A.E. standard method of determining and expressing fineness of feed materials by sieving.[1] The 100 gram sample was sifted for ten minutes with a Ro-tap[2] sifter. The screens used were standard Tyler Screen numbers 4, 6, 8, 10, 14, 20, 28, 35, 48, 65, 100, 150, 200, 270 and a pan. The geometric mean particle size (d_{gw}), expressed in microns, and the geometric log-normal standard deviation (Sgw) of the samples were calculated by using the amount of ground product collected on each screen. These values were then used to calculate the total surface area of one gram of each sample. Example calculations are shown in Appendix 2. Surface area is expressed in square centimeters per gram of sample, cm^2/g.

[1]A.S.A.E. Standard S319, Agricultural Engineers Yearbook, 1982

[2]W.S. Tyler, Inc., Mentor, Ohio

The total surface area exposed per unit of energy used was calculated for each test. This measurement is referred to as true efficiency. True efficiency is measured according to the square meters of surface area exposed for each unit of energy used as measured in kilowatt hours. True efficiency is expressed in terms of m^2/Kwh using surface area and energy calculations as described earlier.

Experimental Design

The statistical design of the punched and drilled screen comparison was a randomized block design with four treatments in three blocks. The open area comparisons were arranged in a randomized design with four treatments and three replications. Linear regressions analysis was conducted on the open area data with the open area being the independent variable and the particle size, efficiency and true efficiency each being dependent variables. The punched hole and drilled hole comparisons were arranged in a randomized design with two treatments and three replications.

EXPERIMENTAL RESULTS

Punched and Drilled Screen Comparison

The punched 3.2mm screen had an open area of 39.1 percent and the drilled 3.2mm screen had an open area of 58.1 percent representing an increase of 48.6 percent for the drilled screen. The 1.7mm punched screen had an open area of 24.1 percent and the drilled 1.7mm screen had an open area of 36.9 percent, representing a 67.9 percent increase for the drilled screen.

Grain Sorghum. Grain sorghum used in these tests had an average moisture content of 12.1 percent with a range of 11.5 - 12.3 percent. The average test weight of the grain sorghum was 72.3 Kg/hl with a range of 71.2 - 74.2 Kg/hl. The grinding performance of the punched and drilled screens is shown in table 4. The efficiency figures are an average of three tests. Each value of mean particle size, log-normal standard deviation, surface area and true efficiency are an average of nine tests. (The number of tests used for a given value applies to all of the data in this document).

The 3.2mm punched screen and the 3.2mm drilled screen produced the same log-normal standard deviation when grinding grain sorghum ($P > .05$). (table 4) The 3.2mm drilled screen gave a better performance than the 3.2mm punched screen. The 3.2mm drilled screen produced a 4% smaller particle ($P < .05$) and exposed 5.5% more surface area ($P < .05$). The 3.2mm drilled screen was also 4.8% higher in efficiency ($P < .10$) and 10.7% greater in true efficiency ($P < .05$) (table 4).

The 1.7mm punched screen and the 1.7mm drilled screen both produced the same particle size, had the same log-normal standard deviation and the same amount of surface area exposed when grinding grain sorghum ($P > .05$). (table 4) The 1.7mm drilled screen resulted in improved grinding performance compared to the 1.7mm punched screen, producing a 25.9% higher efficiency ($P < .05$). The 1.7mm drilled screen also gave a 25.9% higher true efficiency ($P < .05$). (table 4) The ranges of the data for grain sorghum are in Appendix 3.

Table 4. Results of grinding grain sorghum in the punched and drilled screen comparison

Screen Size	Screen Type	Particle Dia. (dgw)	Geometric Std. Deviation (Sgw)	Surface Area (cm^2/g)	Grinding Efficiency (Kg/Kwh)	True Efficiency (m^2/Kwh)
3.2mm	Drilled	587.55 a	1.84 a	91.09 a	232.99 a	2122.90 a
3.2mm	Punched	612.10 b	1.79 a	86.37 b	222.22 a	1918.10 b
Difference (%)[1] (Drilled vs Punched)		-4.0	+2.7	+5.5	+4.8 [2]	+10.7
1.7mm	Drilled	430.18 a	1.59 a	115.11 a	123.18 a	1417.70 a
1.7mm	Punched	435.32 a	1.63 a	115.08 a	97.86 b	1126.00 b
Difference (%)[1] (Drilled vs Punched)		-1.2	-2.5	.00	+25.9	+25.9

1. Percentage difference in mean values. Mean values in the same column with the same letter are not significantly different . α = .05.

2. Significantly different. α = .10.

Corn. Corn used in these tests had an average moisture content of 13.5 percent with a range of 12.8 - 13.7 percent. The average test weight was 73.7 Kg/hl with a range of 71.9 - 74.6 Kg/hl. The grinding performances of the punched and drilled screens is shown in table 5. The 3.2mm drilled screen had a better grinding performance than the 3.2mm punched screen. The 3.2mm drilled screen produced 2.2% smaller particle size ($P < .05$) and exposed 5.6% more surface area ($P < .05$). The drilled screen also produced 9.3% higher efficiency ($P < .05$) and was 15.4% higher in true efficiency ($P < .05$). The differences in the amount of increase between the efficiency and the true efficiency are the result of more surface area being exposed by the 3.2mm drilled screen.

The 1.7mm punched screen and the 1.7mm drilled screen produced the same particle size, log-normal standard deviation and exposed the same amount of surface area when grinding corn ($P > .05$) (table 5). The 1.7mm drilled screen gave a better performance than the 1.7mm punched screen in that it was 22.5% higher in efficiency ($P < .05$) and 23.1% higher in true efficiency ($P < .05$). The ranges of the data for corn are shown in Appendix 4.

Oats. The oats used in these tests had an average moisture content of 11.5 percent with a range of 11.2 - 11.8 percent. The average test weight was 55.1 Kg/hl with a range of 54.1 - 55.7 Kg/hl. The grinding performance data of the punched vs. drilled screen studies when grinding oats can be found in table 3. The 3.2mm punched screen and the 3.2mm drilled screen produced the same particle size, log-normal standard deviation and exposed the same amount of surface area when grinding oats ($P > .05$). The 3.2mm drilled screen had a 7.9%

higher average efficiency but the improvement was not significant (P< .05) due to the variability of the results. The 3.2mm drilled screen resulted in an 11.4% increase in true efficiency (P< .05).

The 1.7mm punched screen and the 1.7mm drilled screen produced the same particle size when grinding oats (P> .05). (table 6) The 1.7mm drilled screen, with 67.9 % more open area, resulting in improved grinding performance over the 1.7mm punched screen. The 1.7mm drilled screen produced a 7.1% larger log-normal standard deviation (P< .05) and exposed 6.4% more surface area (P< .05). The drilled screen also had 27.2% higher efficiency (P< .05) and 35.6% higher true efficiency (P< .05). The ranges of data for oats are shown in Appendix 5.

Table 5. Results of grinding corn in the punched and drilled screen comparison

Screen Size	Screen Type	Particle Dia. (dgw)	Geometric Std. Deviation (Sgw)	Surface Area (cm^2/g)	Grinding Efficiency (Kg/Kwh)	True Efficiency (m^2/Kwh)
3.2mm	Drilled	562.28 a	2.20 a	109.94 a	147.11 a	1616.90 a
3.2mm	Punched	574.70 b	2.09 a	104.15 a	134.54 b	1401.33 b
Difference (%)[1] (Drilled vs Punched)		-2.2	+5.5	+5.6	+9.3	+15.4
1.7mm	Drilled	394.08 a	1.98 a	145.89 a	75.05 a	1094.91 a
1.7mm	Punched	399.03 a	1.98 a	145.20 a	61.25 b	889.73 b
Difference (%)[1] (Drilled vs Punched)		-1.2	.00	.00	+22.5	+23.1

1. Percentage difference in mean value. Mean values in the same column with the same letter are not significantly different. $\alpha = .05$.

Table 6. Results of grinding oats in the punched and drilled screen comparison

Screen Size	Screen Type	Particle Dia. (dgw)	Geometric Std. Deviation (Sgw)	Surface Area (cm^2/g)	Grinding Efficiency (Kg/Kwh)	True Efficiency (m^2/Kwh)
3.2mm	Drilled	530.24 a	1.92 a	103.78 a	73.88 a	767.65 a
3.2mm	Punched	540.17 a	1.87 a	100.53 a	68.48 a	689.20 b
Difference (%)[1] (Drilled vs Punched)		-1.8	-2.6	+3.2	+7.9	+11.4
1.7mm	Drilled	371.06 a	1.67 a	136.90 a	37.21 a	509.51 a
1.7mm	Punched	382.06 a	1.56 b	128.61 b	29.25 b	375.88 b
Difference (%)[1] (Drilled vs Punched)		-2.9	+7.1	+6.4	+27.2	+35.6

1. Percentage difference in mean values. Mean values in the same column with the same letter are not significantly different. $\alpha = .05$.

Open Area Comparison

Corn used in these tests had an average moisture content of 13.2 percent with a range of 12.6 - 13.6 percent. The average test weight was 74.1 Kg/hl with a range of 73.3 - 74.5 Kg/hl. Data on the performance of the four drilled screens with different open areas is shown in table 7. Linear regression analysis were conducted on the data using the percentage of open area as the independent variable and particle size, efficiency and true efficiency as dependent variables. This was to determine if a linear relation existed between the open area and any of the other three variables. Each regression conducted resulted in a highly significant linear ($P < .001$).

Figure 2 represents the linear relationship between open area and particle size produced when grinding corn. The regression analysis gave the following linear equation: $Y = (574.36) + (.933) (X)$. For each one unit change in open area, a corresponding .933 unit change in particle size was found.

Figure 3 represents the linear relationship between open area and efficiency produced when grinding corn. The regression analysis gave the following equation: $Y = (100.04) + (1.15) (X)$. This indicates a 1.15 unit change in efficiency for each unit change in open area.

Figure 4 represents the linear relationship between open area and true efficiency when grinding corn. The regression analysis resulted in a linear relationship with the equation: $Y = (887.2) + (9.46) (X)$. For each one unit change in open area there was a 9.46 unit change in true efficiency.

Table 7. Results of grinding corn in the screen open area percentage comparison

Screen Size	Screen Open Area Percentage	Particle Dia. (dgw)	Geometric Std. Deviation (Sgw)	Surface Area (cm^2/g)	Grinding Efficiency (Kg/Kwh)	True Efficiency (m^2/Kwh)
3.2mm	18	588.01	1.62	86.86	117.82	1021.6
3.2mm	27.3	600.26	1.75	88.41	136.53	1207.2
3.2mm	41	619.85	1.79	86.81	145.23	1260.7
3.2mm	60.9	627.23	1.78	85.57	170.27	1457.3

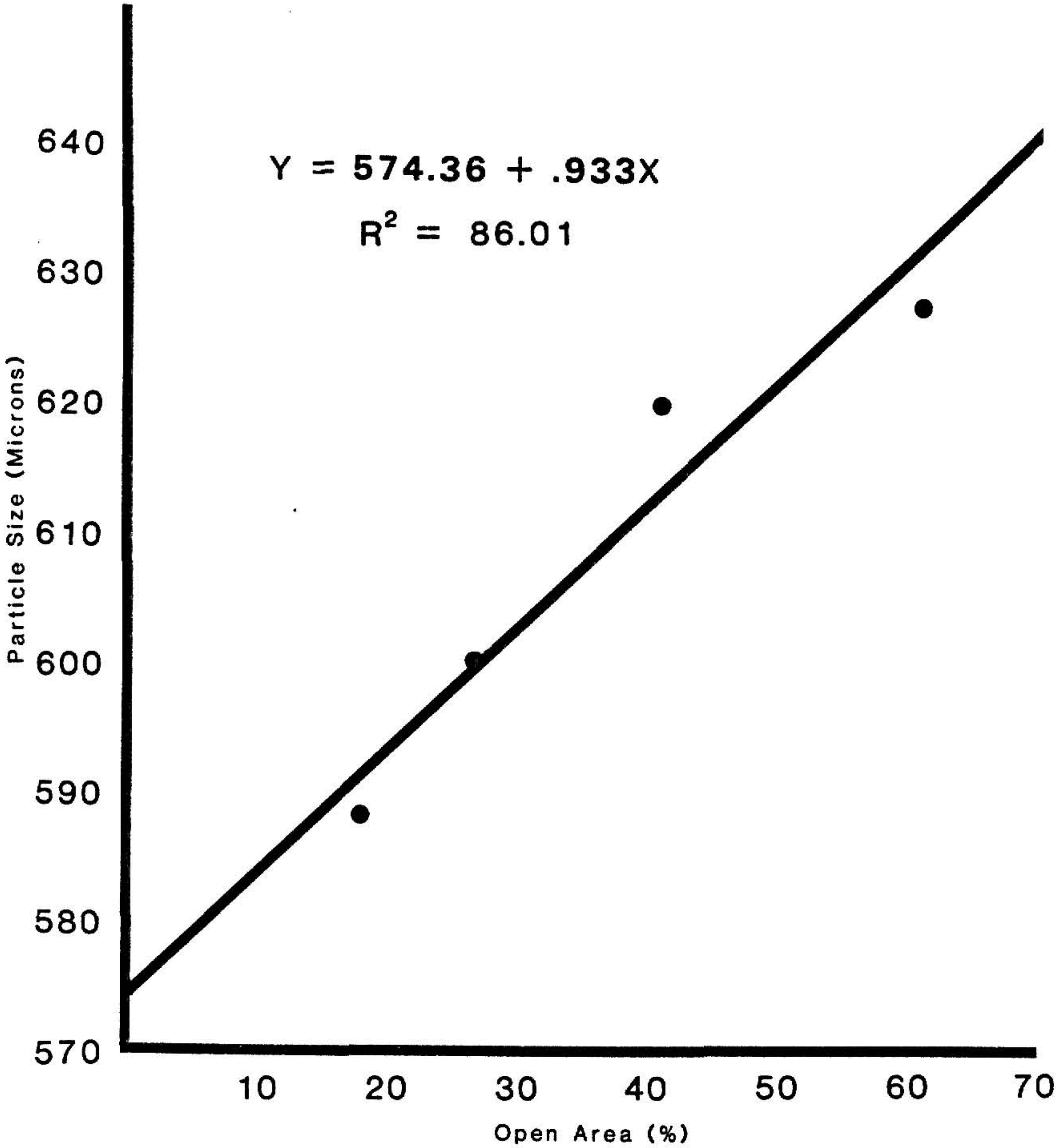


FIGURE 2-RELATIONSHIP BETWEEN SCREEN OPEN AREA AND PARTICLE SIZE (MICRONS) -CORN

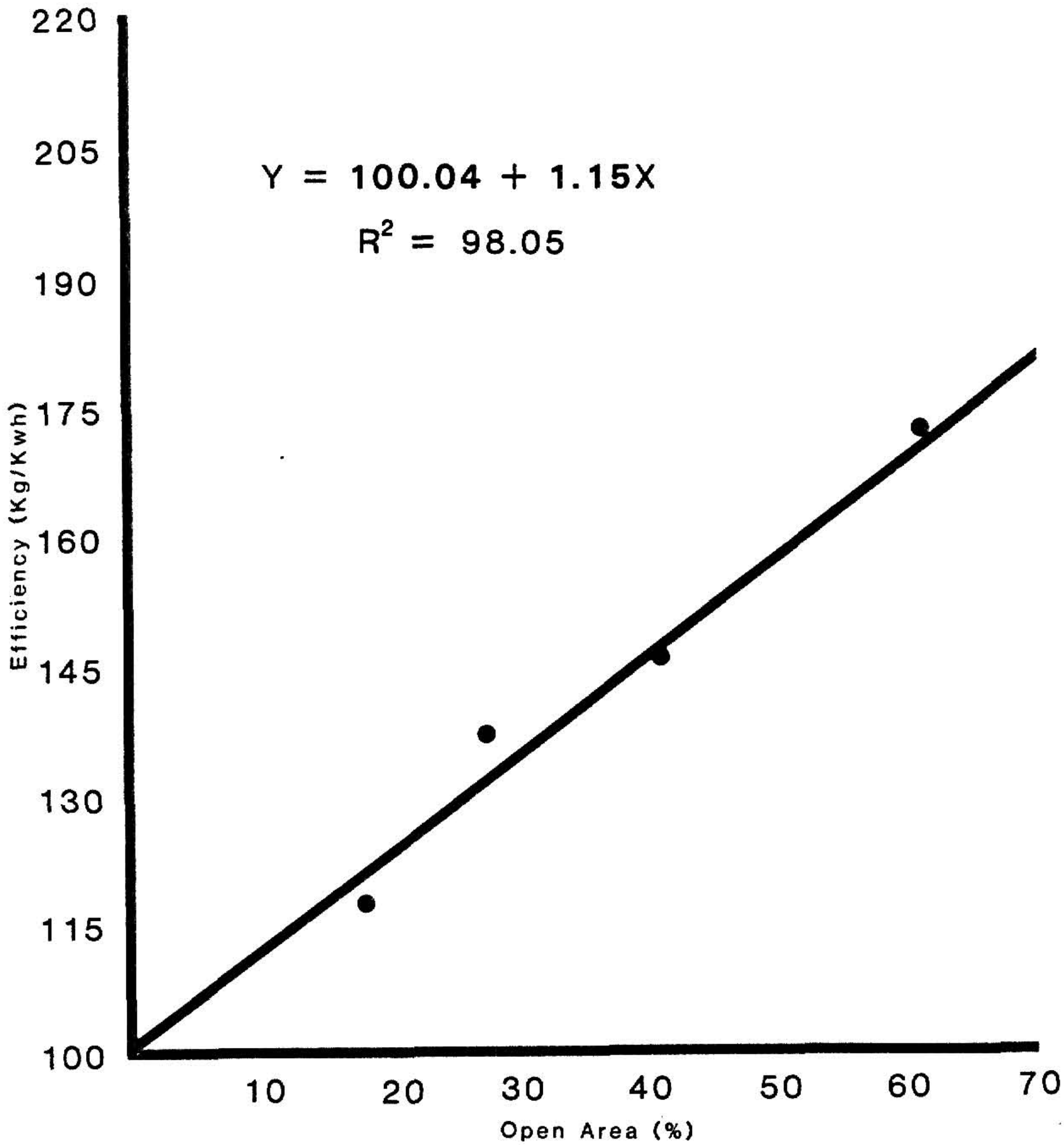


FIGURE 3-RELATIONSHIP BETWEEN SCREEN OPEN AREA AND EFFICIENCY (Kg/Kwh) -CORN

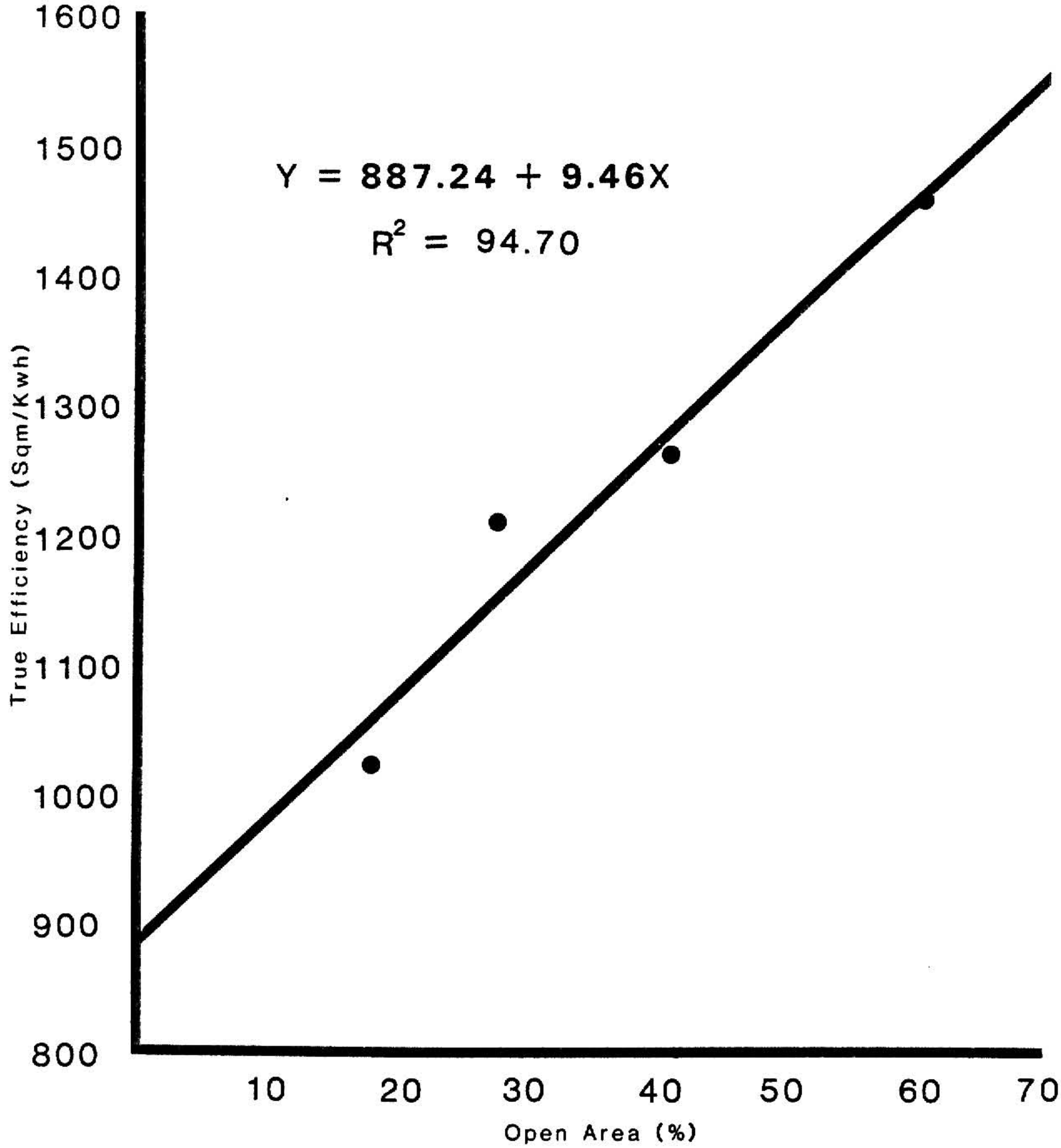


FIGURE 4- RELATIONSHIP BETWEEN SCREEN OPEN AREA AND TRUE EFFICIENCY (Sqm/Kwh) -CORN

Punched and Drilled Hole Comparison

Corn used in these tests had an average moisture content of 13.1 % with a range of 12.7 - 13.3 %. The average test weight was 74.0 Kg/hl with a range of 73.2 - 74.3 Kg/hl. The grinding data for the screens used in these tests is shown in table 8. Both screens had a 3.2mm hole diameter and 40.2 percent screen open area.

The drilled hole produced a 4% smaller mean particle size ($P < .05$) and exposed 3.5% more surface area ($P < .05$) than the punched hole. The drilled hole also produced a 3.5% higher true efficiency ($P < .05$). These differences may be due to the drilled holes having sharper edges. The drilled hole and the punched hole produced the same log-normal standard deviation and the same efficiency. Screens with the same open area percentage produced similar efficiencies, even though the hole design was different. The ranges of the data for these tests is shown in Appendix 7.

DISCUSSION

Punched and Drilled Screen Comparison

Drilled screens with greater open area had a better grinding performance than the punched screens in all tests. This result agrees with work of Baker (1960) and O'Callaghan et al. (1963). This also agrees with a field study conducted by Ahlstrom Machinery Inc. (1983) with the assistance of Riceland Foods, located in Stuttgart, Arkansas.

Table 8. Results of grinding corn in the punched and drilled hole comparison

Screen Size	Hole Type	Particle Dia. (dgw)	Geometric Std. Deviation (Sgw)	Surface Area (cm^2/g)	Grinding Efficiency (Kg/Kwh)	True Efficiency (m^2/Kwh)
3.2mm	Drilled	557.62 a	2.06 a	106.07 a	137.35 a	1456.93 a
3.2mm	Punched	581.22 b	2.08 a	102.40 b	137.66 a	1409.58 b
Difference (%)[1] (Drilled vs Punched)		-4.0	-.01	+3.5	.00	+3.5

1. Percentage difference in mean values. Mean values in the same column with the same letter are not significantly different. α = .05.

The differences in performance varied with the hole size and the grain being ground.

The 3.2mm drilled screen produced a small or mean particle size and exposed more surface area than did the 3.2mm punched screen. These differences may be due to the drilled screens having sharper hole edge. A sharper edge may produce a shearing action which aids in particle reduction. In order to confirm this, more tests would be needed. The 3.2mm drilled screen also produced a higher efficiency and true efficiency than the 3.2mm punched screen. The 1.7mm drilled screen gave higher efficiency and true efficiency than did the 1.7mm punched screen. It also produced a slightly smaller mean particle size.

The increase in open area resulted in a much improved grinding performance. In some cases, the efficiency and true efficiency were increased by over 25 percent. This improvement in performance could result in a substantial reduction in grinding costs for the formula feed industry.

Open Area Comparison

The amount of open area a screen contains directly influences its grinding performance. The tests showed as open area was increased, the mean particle size, efficiency and true efficiency also increased. This suggests that a screen with more open area would have a better grinding performance than one with less open area percentage of open area should be manufactured and used to improve grinding performance. The percent of open area to be used is dependent on the particle size desired and the cost of increasing the open area, as compared to the reduction in costs associated with the increased efficiency and true efficiency. It should be noted however, that increasing the percentage of open area may reduce the strength of the screen. This may lead to a reduced screen life and increased costs for screen replacement.

Punched and Drilled Hole Comparison

The punched and drilled hole comparison with open area constant, suggests that the hole design has some influence on grinding performance. The drilled hole produced a smaller mean particle size, exposed more surface area and had a higher true efficiency. The log-normal standard deviation and the efficiency of the two screens were equal. Since the open areas were the same, it was concluded that, hole design difference were responsible for the difference in grinding performance. The drilled holes sharper edge may produce a combination of grinding and shearing action in the particle reduction, leading to a smaller particle size. Additional tests are needed to determine how long the drilled edge remains sharp and the results after it is worn down.

Both hole design and the amount of open area influenced the mean particle size produced. A drilled hole produces a smaller mean particle size and a increase in open area produces a larger mean particle size. The mean particle size produced will be the result of a combination of these two factors.

CONCLUSION

Punched and Drilled Screen Comparison

In all cases, the drilled screens, with more open area, had a better grinding performance than the punched screens. The drilled screens produced a smaller mean particle size and exposed more surface area. They also produced a higher efficiency and a higher true efficiency.

Open Area Comparison

The open area of a screen has a direct influence on grinding performance. As the open area increases, the mean particle size, efficiency and true efficiency all increase.

Punched and Drilled Hole Comparison

The hole design has some influence on grinding performance, when all other factors are held constant. The drilled hole produced a smaller mean particle size, exposed more surface area and produced a higher true efficiency.

Need For Further Study

Although several areas were examined in this study, there are many factors that merit further investigation in dealing with the drilled hammermill screen. Some of these areas are:

1. The wear characteristics of a drilled edge.
2. The effect of hole shape on grinding performance.
3. The reduction in screen strength caused by increasing the open area percentage.
4. Metals that will increase screen life.
5. The effect of wear on results of this study.

ACKNOWLEDGMENT

The author wishes to express his sincere appreciation to Mr. Carl Stevens whose encouragement, counsel and guidance helped make this thesis a reality; to Dr. C. W. Deyoe, Head of the Department of Grain Science and Industry, and other members of the Department.

Acknowledgment is also given to the Ahlstrom Machinery Inc. for support of this project and donation of the drilled screens and the Jacobson Machinery Works, Inc. for donating the punched screens.

LITERATURE CITED

Anonymous: 1983. Unpublished field study conducted by Ahlstrom Machinery Inc. with the assistance of Riceland Foods, Stuttgard, Arkansas.

American Society of Agricultural Engineers: 1982. Method of Determining and Expressing Fineness of Feed Materials by Sieving. Agricultural Engineers Yearbook. ASAE S319, pp. 342-343.

Baker, R.J.: 1960. Factors that Affect the Granulation and Capacity in Grinding Corn, Oats, and Sorghum Grain with a Hammermill. Master Thesis. Kansas State University, Manhattan, Kansas.

Friederich, Ing.: 1959. Factors Affecting the Particle Reduction Process in Hammermills. translated from Die Muhle, Heft 48, pp. 648-651, 1959 and Heft 49, pp. 660-661.

Headley, V. E. and H. B. Pfost: 1966. Describing Particle Size Distribution of Feedstuffs Statistically. Feedstuffs, Vol. 38, No. 40, p. 50.

Headley, V. E. and H. B. Pfost: 1968. A Comminution Equation Relating Energy to Surface Area by the log-Probability Method. ASAE Trans. 11:3, pp. 331-338.

O'Callaghan, J. R., M. E. O'Hagan, and B. G. Rice: 1963. Performance of Hammermills. Journal of Agricultural Engineering Research, Vol. 3, No. 1, pp. 92-104.

Pfost, H. B. and V. E. Headley: 1971. Use of Logarithmic Normal Distribution to Describe Hammermill Performance. ASAE Trans., Vol. 14, No. 3, pp. 531-535.

Rumpf, H.: 1959. Stress Theory of Impact Grinding. Chemic-Ing-Tech., Vol. 31, No. 5, pp. 357.

Silver, E. R.: 1932. Characteristics of Feed Mill Performance. Agricultural Engineering, 13: 31-34.

Stevens, C. A.: 1960. Factors Affecting Hammermill Performance. Masters Thesis. Kansas State University, Manhattan, Kansas.

APPENDICES

APPENDIX 1

Mean results of grinding rice hulls in the punched and drilled screen comparison conducted by the Ahlstrom Machinery Inc. with the assistance of Riceland Foods.

Screen Size	Screen Type	Particle Dia. (dgw)	Geometric Std. Deviation (Sgw)	Surface Area (cm^2/g)	Grinding Efficiency (Kg/Kwh)	True Efficiency (m^2/Kwh)
2.4mm	Drilled	537.51 a	1.62 a	96.06 a	139.89 a	1353.03 a
2.78mm	Punched	506.27 b	1.70 b	104.81 b	102.38 b	1069.33 b
Difference (%)[1] (Drilled vs Punched)		+6.2	-4.7	-8.3	+36.6	+26.5

1. Percentage difference in mean values (average of 36 tests). Differences in mean values with the same letter are not significantly different. $\alpha = .05$.

APPENDIX 2

Surface Area Calculation

The exposed surface area was calculated using the equation found on pages 514 - 517 in the 1976 Feed Manufacturing Technology. The equation used was:

$$Ast = \frac{Bs\ Wt}{Bvp}\ \text{Exp}\quad 0.5\ (\text{In}\ Sgw)^2 - \text{In}\ dgw$$

Where:

Ast	=	total surface are of particles.
B_s	=	shape factor for calculating surface area of particles.
B_v	=	shape factor for calculating volume of particles.
Sgw	=	geometric log-normal standard deviation of sample estimate by weight distribution.
dgw	=	geometric mean particle size or diameter by weight distribution of sample.
Wt	=	weight of sample (1g).
p	=	specific weight of the material.

For the calculations contained in this thesis, it was assumed that the particles were cubical so $B_v = 1$ and $B_s = 6$.

APPENDIX 3

Ranges of the results when grinding grain sorghum in the punched and drilled screen comparison

Screen Size	Screen Type	Particle Dia. (dgw)	Geometric Std. Deviation (Sgw)	Surface Area (cm^2/g)	Grinding Efficiency (Kg/Kwh)	True Efficiency (m^2/Kwh)
3.2mm	Drilled					
	High	602.49	1.89	94.85	237.17	2241.00
	Low	573.62	1.81	89.33	225.40	2017.50
	MEAN	587.55	1.84	91.09	232.99	2122.90
3.2mm	Punched					
	High	663.14	1.90	98.28	227.31	2014.50
	Low	598.25	1.36	76.40	217.49	1738.90
	MEAN	612.10	1.79	86.37	222.23	1918.10
1.7mm	Drilled					
	High	462.70	1.64	122.64	127.01	1519.20
	Low	409.17	1.55	105.71	119.35	1302.10
	MEAN	430.18	1.59	115.11	123.18	1417.70
1.7mm	Punched					
	High	454.00	1.72	130.10	99.51	1256.50
	Low	395.15	1.55	109.60	96.58	1058.30
	MEAN	435.32	1.63	115.08	97.87	1126.00

APPENDIX 4

Ranges of the results when grinding corn in the punched and drilled screen comparison

Screen Size	Screen Type	Particle Dia. (dgw)	Geometric Std. Deviation (Sgw)	Surface Area (cm^2/g)	Grinding Efficiency (Kg/Kwh)	True Efficiency (m^2/Kwh)
3.2mm	Drilled					
	High	584.52	2.34	120.13	151.20	1816.31
	Low	543.42	2.05	100.56	141.17	1520.42
	MEAN	562.28	2.20	109.94	147.11	1616.90
3.2mm	Punched					
	High	593.11	2.29	116.57	135.24	1576.47
	Low	549.43	2.01	97.91	134.00	1320.57
	MEAN	574.70	2.09	104.15	134.54	1401.33
1.7mm	Drilled					
	High	403.16	2.09	161.38	77.20	1220.69
	Low	368.66	1.87	137.43	72.29	1021.29
	MEAN	394.08	1.98	145.89	75.05	1094.91
1.7mm	Punched					
	High	433.89	2.06	174.94	62.98	1088.30
	Low	337.71	1.75	122.64	58.55	718.05
	MEAN	399.03	1.98	145.20	61.25	889.73

APPENDIX 5

Ranges of the results when grinding oats in the punched and drilled screen comparison

Screen Size	Screen Type	Particle Dia. (dgw)	Geometric Std. Deviation (Sgw)	Surface Area (cm^2/g)	Grinding Efficiency (Kg/Kwh)	True Efficiency (m^2/Kwh)
3.2mm	Drilled					
	High	562.24	1.97	107.38	81.53	875.45
	Low	519.18	1.86	95.83	69.29	678.57
	MEAN	530.24	1.92	103.78	73.88	767.65
3.2mm	Punched					
	High	585.01	1.98	109.67	73.50	777.23
	Low	511.22	1.73	88.31	65.49	578.30
	MEAN	540.17	1.87	100.53	68.48	689.20
1.7mm	Drilled					
	High	387.21	1.72	144.01	40.32	580.64
	Low	357.21	1.60	125.07	34.24	463.60
	MEAN	371.06	1.67	136.90	37.21	509.51
1.7mm	Punched					
	High	405.96	1.64	143.50	31.10	446.32
	Low	349.92	1.49	118.46	27.94	340.18
	MEAN	382.06	1.56	128.61	29.25	375.88

APPENDIX 6

Ranges of the results when grinding corn in the open area comparison

Screen Size	Screen Open Area Percentage	Particle Dia. (dgw)	Geometric Std. Deviation (Sgw)	Surface Area (cm^2/g)	Grinding Efficiency (Kg/Kwh)	True Efficiency (m^2/Kwh)
3.2mm	18					
	High	597.85	1.65	88.77	119.52	1039.20
	Low	579.93	1.60	84.99	116.44	996.80
	MEAN	588.01	1.62	86.86	117.82	1021.60
3.2mm	27.3					
	High	605.49	1.78	90.83	140.32	1274.60
	Low	590.79	1.73	87.91	133.91	1178.20
	MEAN	600.26	1.75	88.41	136.53	1207.20
3.2mm	41					
	High	623.34	1.81	87.35	147.00	1279.00
	Low	615.55	1.78	86.06	142.27	1224.40
	MEAN	619.11	1.79	86.81	145.23	1260.70
3.2mm	60.9					
	High	644.88	1.89	93.24	172.48	1590.40
	Low	596.40	1.72	82.96	167.77	1412.30
	MEAN	627.23	1.78	85.57	170.27	1457.30

APPENDIX 7

Ranges of the results when grinding corn in the punched and drilled hole comparison

Screen Size	Hole Type	Particle Dia. (dgw)	Geometric Std. Deviation (Sgw)	Surface Area (cm^2/g)	Grinding Efficiency (Kg/Kwh)	True Efficiency (m^2/Kwh)
3.2mm	Drilled					
	High	569.46	2.09	110.46	137.83	1528.55
	Low	541.85	2.04	103.43	135.84	1432.16
	MEAN	557.62	2.06	106.07	137.35	1456.93
3.2mm	Punched					
	High	587.71	2.09	103.43	138.33	1422.58
	Low	574.83	2.07	101.24	137.10	1388.00
	MEAN	581.22	2.08	102.40	137.66	1409.58

GRINDING PERFORMANCE AS AFFECTED BY HAMMERMILL SCREEN DESIGN

by

VANCE E. WESTHUSIN

B.S., Kansas State University, 1981

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Grain Science and Industry

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1983

Studies were conducted to determine the effect of hammermill screen design on grinding performance. Grain sorghum, corn and oats were ground through several punched and drilled hammermill screens. The grinding performances of the screens were determined and compared.

The screen open area and hole design had an influence on grinding performance. With this in mind, the following comparisons were conducted:

1. Punched and Drilled Screen Comparisons
2. Open Area Comparisons
3. Punched and Drilled Hole Comparisons

The results showed that the drilled screens had a better grinding performance than punched screens. The amount of improvement in grinding performance varied with the hole size and the grain.

The screen open area was found to have a direct influence on grinding performance. As open area was increased by one unit, the mean particle size increased by .933 units, the efficiency increased by 1.15 units and the true efficiency increased by 9.46 units.

The investigations also showed that hole design influenced grinding performance. The drilled hole had a better grinding performance than the punched. It produced a 4.0% smaller mean particle size, exposed an average of 3.5% more surface area and was 3.5% higher in true efficiency.