THE EFFECTS OF PREBREAKING ON THE EFFICIENCY OF HAMMERMILL PARTICLE SIZE REDUCTION SYSTEMS IN FEED MANUFACTURING

by

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INTRODUCTION

Grain processing is as old as man. Stone mills were the earliest form of grinding machines. In its most primitive form, particle size reduction was accomplished by pounding cereal grains between two stones using human power. That process was followed by the use of a pair of circular stones rotated by human power and, later by animal power. As civilization progressed, water power, wind power, and steam power made possible the use of larger and more powerful grinding machines. During this time, energy efficiency was not an important factor and millers concentrated on maximizing the available power and its accessibility.

In recent generations, electrically driven motors have become universally applied within the grain processing industry. The formula feed industry today has turned to almost exclusive use of the hammermill for particle size reduction. There are many reasons for the hammermill's wide acceptance, but its greatest inherent advantage lies in its versatility. The hammermill can produce a "finer" grind from a greater variety of raw materials than any other machine. It must be mentioned, however, that there is some argument for the use of a roller mill to more efficiently produce a "coarser" grind of certain ingredients (Martin, 1983; Heimann, 1983).

The hammermill is also known to be one of the highest energy consuming machines used within the feed industry. Electrical energy at one time was inexpensive and little attention was paid to energy costs and efficiency. The Arab oil embargo of 1973 changed that forever. Energy costs, including electricity, skyrocketed dramatically and, since then, have continued to increase and, are forecasted to continue to increase. According to Energy Users News (1984), the price per million BTU's for industrial electrical users averaged, in 1983 dollars, $10.94 in 1978, $16.20 in 1983, and is projected to rise to $17.15 by 1995.

Particle size reduction, in general, is not an efficient operation. How efficiently the processing system performs its function is of vital importance in saving limited resources. The objective of the industry must be to minimize the amount of energy usage per unit processed, which also makes good economical sense through the lowering of production costs. That objective calls for an increased effort by machinery designers, machinery manufacturers, and feed manufacturers to improve hammermill performance through more efficient systems design and efficient energy management.

Numerous variables affect hammermill performance and efficiency. The variables include: raw material characteristics, hammer design and tip speed relationship factors, screen design factors, air flow factors, and various other design and relationship variables. These variables have been studied in some detail, especially by equipment manufacturers, but further research is needed in each area.

Most of the published studies focus on the hammermill as an entity and not as part of a particle size reduction system. The utilization of a hammermill within a grain processing <u>system</u> is a major area needing unbiased scientific research.

PURPOSE OF THESIS

This study will focus on three particle size reduction systems (See Appendix D).The systems investigated include the utilization of:

A. A prebreaking device to do the initial particle size reduction.

B. A sieving device to remove the particles not needing further reduction.

C. A hammermill to perform the final particle size reduction.

Performance of the systems and their separate components was evaluated through the use of the following dependent variables:

1. Geometric mean particle diameter produced, (dgw).
2. Log-normal standard deviation of the sample, (Sgw).
3. Exposed surface area, (cm^2/g).
4. Grinding Efficiency, (Kwh/Mton).
5. True Efficiency, (m^2/Kwh).
6. System throughput capacity, (Mton/H)

Another performance area of this study included temperature and moisture content changes within the raw materials during processing. These factors relate to another manufacturing cost item - shrink.

REVIEW OF LITERATURE

REASONS FOR GRINDING

Silver (1932), Stevens (1961), and Larson (1983) provide the major reasons for particle size reduction of ingredients in the feed industry. The reasons include:

- Exposing greater surface area for digestion.
- Improving the ease of handling certain ingredients.
- Aiding homogeneous mixing and balancing of rations.
- Increasing pelleting efficiency and pellet quality.
- Reducing feed wastage, by minimizing selective eating.
- Aiding mastication for animals with poor teeth (young and old).
- Increasing consumption of feed per unit of time.
- Satisfying customer preferences.

Behnke (1983) stated that, of the above, the most important reasons are to improve digestibility, improve homogeneity during mixing, and to aid further processing such as pelleting. Animal nutritionists, however, have not established an optimum particle size for maximum rate and efficiency of gain (Allee, 1983). Customers have a wide difference of opinion as to a desired particle size and its definition. There is, however, widespread agreement by nutritionists and customers that they want a uniform particle size (Elliot, 1983; Silver, 1932).

THE HAMMERMILL GRINDER

Hammermills consist of either fixed or free swinging hammers mounted on a rotating shaft. Outside of and fully, or partially, enclosing the hammers, is a perforated screen controlling the maximum particle size to exit from the chamber. The perforations in the screen may vary anywhere from .79 mm (1/32 in.) to 50.8 or more millimeters (two or more inches).

According to Thomas (1960), reduction by the hammermill is accomplished by a combination of impact, sheer, and attrition. The greatest proportion of particle size reduction is generally recognized to be the result of particle impact. Impact takes place between the hammers and the grain particles; and, subsequently, after the particle has been accelerated by the hammers, impact occurs through striking the screen, another stationary surface, or another particle.

MECHANICS AND THEORY OF IMPACT GRINDING

Rotating hammers and accelerated particles possess kinetic energy as a result of their mass and velocity. The transfer of that energy into breaking molecular bonds in materials with diverse physical properties and the creation of new surface area is an extremely complex process. As Beke (1964) explained, it is hardly surprising, under the circumstances, that there should exist no law or formula of absolute accuracy and reliability to define the mechanism of the process.

Various physical laws describing pulverization have been proposed by Rittinger, Kick, Griffith and Bond (none specifically cited). Aspects of these theoretical works have been discussed in the literature by Austin et al. (1964), Beke (1964), Lowrison (1974), and Pfost (1976). Rumf (1959) probably best described the kinetic energy transfer into breaking bonds through his treatise: Stress Theory of Impact Grinding.

Rumf (ibid) discussed the various impacts that occur, the resulting stresses, and energy relationships. As explained by Lowrison (1974), when two bodies impact, they compress each other until they have the same velocity and remain in that state until restitution of compression begins. The bodies, then, push each other apart and go their separate ways. The restitution of compression takes an extremely short period of time to complete; and, during that time, the particle is internally stressed with a small portion of the original kinetic energy converted into strain energy. The strain energy is released in the form of elastic restitution, plastic deformation, crack formation and propagation, and ideally into new surface area through surface rupture and particle fracture.

Friedrich (1959) described fracture as occuring when the localized strain energy exceeds a critical surface energy limit which is a function of the material. Rupture points requiring the least amount of energy occur along lines of weaknesses. Those points consist of cracks, pores, stratifications, and along cleavage planes.

The efficiency of generating new surface area through impact is extremely low. Beke (1964) and Friedrich (1959) asserted that less than one per cent of the input energy is used to create new surfaces. Austin et al. (1964) stated that a maximum of less than three per cent is converted.

Thermal energy created by friction accounts for the greatest proportion of energy output. Rumf (1959) and Beke (1964) estimated the proportion of kinetic energy converted into thermal energy to be in excess of 90 per cent, whereas, Friedrich (1959) quoted a figure of 99 per cent. The thermal energy output occurs as heat absorbed by the machine, by the air circulation, and by the product.

Impact grinding efficiencies also suffer from additional theoretical and physical difficulties. Lowrison (1974) stated that, as particles become smaller, there are fewer lines of weaknesses to attack and, also, that there is a difficulty in isolating the smaller particles for impaction. Austin et al. (1964) provided insight into the latter through their mechanistic approach.

Ideally, during impact grinding, material would cease to be reduced as soon as it reaches the desired particle size. Overgrinding takes place because some material stays in the mill undergoing additional impacts which results in a double problem of expending power needlessly and of reducing material particles smaller than required. Another factor relating to these problems is the possiblity of violent impacts with resulting fracture into much smaller particles than is desirable. The creation of fines is a recognized problem with impact grinding by the hammermill.

INDEPENDENT VARIABLES AFFECTING HAMMERMILL PERFORMANCE

There are many variables which affect the particle sizes generated, their distribution, and overall grinding efficiency. The factors can be catagorized as: raw material characteristics, hammer design and relationships, screen design features, an air flow characteristic, and various other design and relationship factors.

Material Characteristic Factors: Early studies have shown, and it is generally recognized, that grinding energy requirements vary for the different grains because of their wide variation in starch and fiber composition. Silver (1932) found that corn (high relative starch content) required less energy than barley, and barley required less energy than oats (high relative fiber content). Baker (1960), confirmed by Stevens (1962), found that sorghum was easier to grind than corn which, again, was easier to grind than oats. Grains, therefore, can be placed into a grinding efficiency spectrum based upon their starch to fiber composition. The spectrum can be bounded by starchy, easy-to-grind, "nonfibrous and friable" materials at one end, and the tough-to-grind, "fibrous and nonfriable" materials at the other .

Grain moisture content also plays a vital role in grinding capacity and efficiency. Friedrich (1959) and Silver (1932) reported that capacity and efficiency are inversely related to moisture content. Baker (1960) confirmed that relationship and further stated that the magnitude of the decrease in efficiency through an increasing moisture content varies directly with grain fiber content.

Hammer Design and Relationship Factors: Increased numbers of hammers and total hammer surface (width) will obviously cause an increase in the no-load energy requirement and can ultimately affect net efficiency. Fifteen hammers (3mm width) per 100 mm of rotor width was found by Friedrich (1959) to be most desirable. That number can vary with hammer width but not directly proportional to width. He also stated that the arrangement of the hammers must allow a great enough time period between hammers (also peripheral speed related) so that entering material impacts on the hammer strike surface. Otherwise, a much less efficient glancing blow with abrasion and slow impaction on stationary parts results. He further stated that, if more than four groups of hammers are used, the number of hammers per group must be reduced and the hammer arrangement should be staggered.

A number of studies have dealt with hammer width. Friedrich (1959) found a 15 % improvement in efficiency and capacity by going from an 8 mm (.31 in.) to a 3 mm (.118 in.) width hammer. Reducing the width from 3.2 mm (1/8 in.) to 1.6 mm (1/16 in.) results in an increase in efficiency of 18 % for corn and 22 % for oats as reported by Baker (1960). Stevens (1962) confirmed that, by going from 6.4 mm (1/4 in.) to 3.2 mm (1/8 in.) to 1.6 mm (1/16 in.), an increase in grinding efficiency occurs at each step. The magnitude of the increase was also found to be grain and peripheral speed dependent. Neither of those two studies attempted to keep the total hammer surface area equivalent, nor at all times, the number of hammers equivalent. It must also be noted that the magnitude of the results are partially explained by the reduction in no-load requirements.

The first major independent variable affecting "fineness" of grind, power requirements, efficiency, and capacity is the peripheral speed of the hammer tips. The revolving hammer provides the kinetic energy for impact grinding. According to Friedrich (1959), there is an important relationship between speed of rotation and capacity, efficiency, and fineness of grind. Over the years, there has been a difference of opinion as to ideal peripheral speed. Friedrich (1959) found that feed material required a speed range of 4200 to 6600 meters per minute (13,780 to 21,653 ft/min). Speeds above 4572 m/min (15,000 ft/min) are sufficient according to Silver (1932), with an ideal range of 2134 to 2743 m/min (7000 to 9000 ft/min). Stevens (1962) reported that, if the objective is grinding efficiency, peripheral speeds of 2158 to 3191 m/min (7080 to 10,470 ft/min) are the most desirable. Later analysis by Stevens, et al, (1983) revealed that the optimum speed was 3200 m/min (10,500 ft/min) based upon a "true efficiency" calculation. He further stated that an optimum peripheral speed, as measured by "true efficiency", can be determined and depends on the grain and screen perforation size.

All researchers agree that a slower speed produces a "coarser" particle size.

The clearance between the hammer tip and the screen affects both particle size and efficiency. An 8mm (.315 in.) gap was found by Friedrich (1959) to be the optimum clearance for the various types of grain.

Screen Design Factors: The screen is the second major variable affecting particle size and performance. It will control the maximum final particle size of the product exiting from the grinding chamber. It is understood that efficiency and capacity will increase as the screen openings are enlarged.

Research by Friedrich (1959) initially showed this relationship. Baker (1960) reported an average gain in production rate of 42 % when going from a screen containing 2.38 mm (3/32 in.) to one containing 3.18 mm (1/8 in.) openings. He further found an increase of 42 % going from 3.18 mm (1/8 in.) to 4.76 mm (3/16 in.), and a 35 % gain going from 4.76 mm (3/16 in.) to 6.35 mm (1/4 in.). Stevens confirmed that general relationship, in a reanalysis of his original studies using "true efficiency" as a measure (Stevens, et al; 1983).

The percentage of open area within the screen has a direct effect on capacity and efficiency. An initial study by Baker (1960) showed that, by blanking one half of an 180^0 screen, grinding capacity and efficiency decreased by 20 %. Westhusin (1983) provided greater insight during his analysis using screens containing 18%, 27.3%, 41%, and 60.9% open areas. He found direct linear relationships between the independent variable per cent open area and the dependent variables of particle size, efficiency (measured in Kg/Kwh) and true efficiency (measured in m^2/Kwh).

Air Flow Factors: Air flow through the hammermill has been found to be advantageous for optimum results. Air flow aids in controlling the environment of the grinding chamber by reducing heat buildup and moisture accumulations. It also provides a means of breaking the rotational pull on materials by the rotating hammers. Finally, it assists particle movement through the screen, thus reducing overgrinding and maintaining a more uniform particle size.

Air flow can be the result of two independent actions. "Inherent" air flow is created by the rotating hammers. "Induced" air flow is created by external air moving devices, such as a separate motor driven fan, a pnuematic conveying system, or a dust control exhaust system.

Friedrich (1959) reported an optimum air volume of about 4000 cubic meters per hour per square meter of screen surface (equivalent to 1.52 cubic feet per minute per square inch of screen surface [cfm/in^2]).

Fan-aided product discharge was found by Baker (1960) to increase production by an average of 12 % over non-assisted gravity discharge.

An examination of data generated by Stevens (1962) shows even greater results. He compared a non-assisted system versus an air-assisted system consisting of an induced air flow of 424 cfm (0.977 cfm/in^2) measured at the fan. His analysis showed that the increase in efficiency (measured in lbs/kwh) averaged 49 % using a 2.38 mm (3/32 in.) screen, 33 % using a 3.18 mm (1/8 in.) screen, 12.4 % using a 4.76 mm (3/16 in.) screen, and a 12.5 % increase using a 6.35 mm (1/4 in.) screen. His research showed a negligible gain, to a loss, in efficiency when the induced air flow was further increased to 582 cfm (1.34 cfm/in^2) . Particle size was not found to be affected by the different air flows in his research.

Olson (1983) stated that 1.25 cfm/in^2 is optimal for maximum production with a resulting improvement in capacity of 15 to 40 per cent. According to Larson (1983), experience indicates that an air flow of 500 cfm per square foot of screen surface area (3.47 cfm/in^2) should provide the most efficient performance.

<u>Various Other Design and Relationship Factors:</u> Research by Friedrich (1959) showed that tangential feeding into the hammer tips, which as a zone possesses the highest kinetic energy level, provides 20 % greater capacity and efficiency when compared to central feeding. The feed rate should be as consistent as posssible and at, or near, the maximum capacity of the machine. It is generally recognized that machinery running at or near capacity performs its function most efficiently.

Westhusin (1983) found that screen hole design influences hammermill performance. He found that a drilled hole, when compared to the more commonly produced punched hole, produced a smaller mean particle size, exposed more surface area, and produced a higher "true efficiency".

It must be noted that one highly controllable factor affecting efficiency is the mechanical condition of the hammermill and its wear surfaces. Wear can be detected through lowered capacities and efficiencies and, also, through the increased temperature of surfaces and products.

TEMPERATURE DIFFERENTIALS AND SHRINK

As stated earlier, thermal energy is the main energy output of the system. Heat generation increases moisture losses during grinding which results in shrink. Overheated, moist products also present major problems in both storage (condensation, mold, and freezing), and the flowability from storage bins.

Temperature Differentials: Research conducted by Baker (1960) showed that product temperature rise is related to the material being ground, the screen hole size, and the availability of air assistance. Grinding oats through a 2.38 mm (3/32 in.) screen, non-fan-assisted, resulted in a temperature rise of 13.3 ^{0}C (24 ^{0}F), while corn experienced a temperature rise of 8.9 ^{0}C (16 ^{0}F). Air assistance resulted in temperature rises of 0 ^{0}C (0 ^{0}F) and 2.2 ^{0}C (4 ^{0}F), respectively. Using a larger screen hole size, 6.35 mm (1/4 in.), corn showed a 2.2 ^{0}C (4 ^{0}F) for air-assisted and a 2.2 ^{0}C (4 ^{0}F) to a 8.3 ^{0}C (10 ^{0}F) range (moisture content dependent) for non-air-assisted.

Other reported temperature differential ranges include: Pfeiffer, et el, (1983) with a normal rise of 5.6 to 8.3 ^{0}C (10 to 15 ^{0}F), Moy (date unknown) with a range of 5 to 10 ^{0}C (9 to 18 ^{0}F), and Silver (1932) with a range of 2.2 to 12.8 ^{0}C (4 to 23 ^{0}F).

Shrink: Shrink caused by moisture losses has been attributed to heat buildup (moisture bearing capacity of air doubles for every 11.2 ^{0}C (20 ^{0}F) rise) and the method of conveying the material away. McEllhiney (1983) discussed the results of studies conducted by Remen and Wolfe. They reported moisture losses of .95 % to 1.10 % when grinding and pnuematically conveying the ground corn. Remen also reported that the system design (gravity drop into a bin, versus mechanical handling of ground material, versus pneumatic handling of materials) makes a wide difference in total per cent moisture loss. He also noted that an average moisture loss of 1.20 % occurs when starting with greater than 15% moisture corn and an .81 percentage loss occurs for less than 15% moisture corn. Wolfe reported that shrink varies only slightly with screen size (1.10% for 3.18 mm [1/8"] and 1.05% for 4.76 mm [3/16"]).

PARTICLE SIZE MEASUREMENT

Researchers, producers, and customers historically have reported fineness of grind based on appearance to them. Designations of "fine", "medium", and "coarse" based on appearance are not precise and leave much to personal judgement. More sophisticated techniques have been developed using sieving on standard sieve sets. The simplest designation was stating the upper and lower limits containing the material, e.g. -20 +80, or stating the sieve through which the material will pass, e.g. -200 mesh.

The first standardized method of expressing particle size was approved in 1940 by the American Society of Agricultural Engineers (ASAE). The method was called the Method of Determining Modulus of Uniformity and Modulus of Fineness of Ground Feed. The procedure involved using a specified sieve set to separate the material into eight size categories. Through calculation, a number based upon the per cent in each category designated the Modulus of Fineness (relative particle size) and three proportions described the Modulus of Uniformity (relative particle size distribution).

That technique was limited in its applications and did not facilitate the calculation of a number of more revealing parameters. Using sophisticated mathematical analysis, Headley and Pfost (1966 and 1968) developed performance parameters based upon a logarithmic normal distribution. That analysis, again, was based upon the percentages retained on specified screens. The method produces the geometric mean particle size (measured in microns), the geometric log normal standard deviation (a measure of size distribution variability), total surface area per gram (cm^2/gm), and the number of particles per gram. (See Appendix A & B). The A.S.A.E. adopted this procedure in 1968 and entitled it: "Methods of Determining and Expressing Fineness of Feed Materials by Sieving" (ASAE 1983) (ASAE Standard - S319). The calculations are fairly simple and straight forward, but quite lengthy; so computer programs have been developed to perform them.

EFFICIENCY DESIGNATIONS

Efficiency, as expressed by Stevens (1981), is any method of relating the amount of work output to input. One method commonly used in the feed industry is pounds or kilograms of ground material produced per horsepower hour. It is a convenient way to express capacity, since it can easily be related to a given hammermill motor.

Other efficiency expressions are based upon kilowatt hours of power consumed. Reported descriptions include: lbs/kwh, Kg/kwh, kwh/ton, kwh/Mton (Appendix C), lbs/HPH, and Kg/HPH. Values for Kwh are easily calculated by knowing amps consumed, voltage, the applicable power factor, and motor efficiency. The formula is:

$$Kwh=[(amp)(volts)(power\ factor)(motor\ efficiency)(1.73)]/1000$$

An efficiency rating in terms of square meters of new surface area produced per watt hour was developed by Pfost and Headley (1971). They used the total surface area previously calculated and the calculated energy used in grinding to more accurately reflect the efficiency of the reduction process. Their rating is referred to as "true efficiency", since it relates both production and quality (fineness) to energy consumed (Appendix C).

MATERIALS AND METHODS

RAW MATERIALS AND EQUIPMENT

Grain: Good quality Grade #2 corn was used in these grinding tests. The corn was isolated in a storage bin above the prebreaker prior to use. Samples of the whole grain were collected at different intervals during the tests for moisture analyses.

Hammermill: A Jacobson[1] P-240, full circle hammermill was used for the hammermill portions of the study. The machine specifications were:

A. Power Source - 30 H.P., 220-440 V., 3 Phase, 3515 rpm motor

B. Rotor Width - hammer to hammer - 152.4 mm (6")

C. Rotor Diameter - tip to tip - 603.25 mm (23.75")

D. Rotor Speed - 3515 rpm

E. Peripheral Speed - 6661.51 mpm (21,880 ft/min)

F. Screen Design - Full circle, tear drop shape

G. Feed Inlet - Top side feed

H. Feed Control - 152.4 mm (6 inch) variable speed screw conveyor

I. Number of Hammers - 28

(1) Jacobson Machine Works, Minneapolis, Minnesota

J. Hammer Design - Four Rows

Outside to Inside

1. 6.35 mm x 50.8 mm x 190.5 mm (.25" x 2" x 7.5")

a. 2 rows of 5 hammers

b. 2 rows of 7 hammers

2. 11.17 mm x 50.8 mm x 177.8 mm (.44" x 2" x 7")

a. 4 rows of 1 hammer

K. Screen to Tip Clearance - range of 2 to 19 mm (.08" to .75")

L. Air Assist - none

Prebreaker: A CPM[1] Model 1612H Ripple Mill was used for the prebreaking portion of the tests. The design basis of the Ripple Mill is a squirrel cage rotor consisting of hardened tubes carried by support discs. It uses the rotational speed of the rotor to accelerate the incoming grain for impaction against the rippled surface in the housing. Repeated impacts between the rotor and rippled surfaced housing further reduce the particle size until the material is discharged. Control over particle size is achieved through rotor rotational speed and the clearance between rotor and the rippled surface.

The machine specifications were:

A. Power Source - 15 H.P., 230-460 V, 3 Phase, 1760 rpm motor

B. Rotor Width - disc to disc - 304.8 mm (12 inches)

C. Rotor Diameter - tube to tube - 406.4 mm (16 inches)

D. Rotor Speed - Variable (Set at recommended speed: 2000 rpm)

(1) California Pellet Mill Co., San Francisco, California

E. Peripheral Speed - 2554 mpm (8379 ft/min)

F. Screen - None

G. Feed Inlet Size - Top - 317.5 mm x 127 mm (12 1/4" x 5")

H. Feed Control - Slide Gate - Max opening - 88.9 mm (3.5")

I. Discharge - Horizontal - 317.5 mm x 127 mm (12 1/4" x 5")

J. Number of Tubes in Rotor - 30

K. Rotor Design - Squirrel Cage with every other tube indented 9.5 mm (3/8")

L. Rotor to Ripple Surface Clearance - Variable (Set at recommended distance: 3.2 mm [1/8"])

M. Ripple Plate Condition - New

<u>Sieve:</u> A Rotex model 202CP Series 20 Screener was used for the sieving portions of the study. The machine specifications were:

A. Power Source - 1.5 H.P., 230-460 V., 3 Phase, 1730 rpm motor

B. Screen Surface Size - 762 mm x 1524 mm (30" x 60")

C. Number of Screens - Two

D. Upper Screen Opening Size -25.4 mm (1")

E. Lower Screen Opening Size - 2.24 mm (.088")

During pretesting, a 3.35 mm screen was tested in the Rotex Screener. This screen produced unacceptably coarse particle sizes by both visual and analytical examination. The hammermill system products were analyzed for particle size distribution. The data indicated an approximately 9 to10 Tyler mesh sifter screen (2.24 to 2.03 mm respectively) would provide a more appropriate distribution of particle sizes within the prebreak-sieve-hammermill system.

Mixer: A Sprout-Waldron(1) horizontal double ribbon mixer was used for mixing the "throughs" and the hammermilled "overs". The mixer specifications were:

A. Power Source - 10 H.P., 230-460 V., 3 Phase, 1760 rpm motor

B. Capacity - 1 m^3 (35 ft^3)

- 453.6 Kg. (1000 lbs)

C. Ribbon rpm - 34 rpm

D. Inside Dimensions - 2 m x .8 m (6' 7" x 32")

ANALYSIS PROCEDURES

Sampling: Samples of the ground product were collected for temperature determinations, moisture analysis, and particle size analysis. One sample of approximately 4.5 Kg. was collected for the temperature analysis. Three samples were collected at each of the two other indicated sampling points to provide representative samples. Where possible, the samples were collected by probing the ground product in several different places with a single probe. The other samples were taken in-line by taking representative cross sections of the flows. Each of the three samples for moisture analysis weighed approximately 200 grams and were placed into coded, air tight polyethylene containers. These samples were stored in a freezer to safeguard the integrity of the samples until analysis. Each of the three samples for particle size analysis weighed approximately 500 grams and were stored in coded polyethylene bags until analysis.

(1) Sprout-Waldron Div., Koppers Inc., Muncy, Pennsylvania

Temperature Analysis: The sample collected was immediately placed into a styrofoam bucket. A styrofoam lid was placed on top and a centigrade thermometer was inserted through the lid into the center of the material. The maximum temperature attained was recorded. That sample was returned to the batch.

Moisture Analysis: The sealed samples were removed from the storage freezer and were allowed to equilibrate to room temperature. The equilibration period averaged approximately five hours, with room temperature at approximately 25 ^{0}C. The samples were then mixed by tumbling the sealed sample containers. The whole grain samples were analyzed by the official ASAE (1983) procedure (See Appendix F). The ground samples were analyzed by the official AOAC (1980) procedure 7.007 air oven method (See Appendix G). The moisture loss (%) was recorded for data analysis.

Particle Size Analysis: The approximately 500 gram samples were reduced to 100 grams by the official AOAC (1955) riffling method. Particle size analysis was made by using the ASAE (1983, Standard S319) standard method of determining and expressing fineness of feed material by sieving. Each of the 100 gram samples were sifted for ten minutes with a Ro-tap[1] sifter. The screens used were standard Tyler Screen numbers 4, 6, 10, 14, 20, 28, 35, 48, 65, 100, 150, 200, 270, and a pan. The weight of the product collected on each screen was recorded for data analysis.

1. W.S. Tyler, Inc., Mentor, Ohio

PROCEDURAL METHODS

Tests were conducted to evaluate the performance of three grain particle size reduction systems. The three processing systems consisted of a non altered hammermilling system, a prebreaking-hammermilling system, and a prebreaking-sieving-hammermilling "overs" system (See Appendix D for systems description and Appendix E for the system flow diagram). The length of each test was held to approximately five minutes to make the tests as similar as possible. The tests were timed using a hand held stop watch, and the amperage and voltage were recorded on a recording ammeter.

Hammermill Procedure: The grain temperature was determined and samples taken for moisture analysis. The grain was then metered into the hammermill by means of a 152.4 mm (six inch) variable speed conveyor. The feed rate was adjusted so that the hammermill was operating at full load, or approximately 39 amps, as measured by the recording ammeter. The test time was initiated when the load reached 50 % of the maximum level and stopped when the load dropped off to the 50 % level. Samples were collected during the test run above the pneumatic conveyor air lock for product temperature determination and moisture analysis. The ground product was pneumatically conveyed to the scale hopper and the weight recorded. Samples were then taken for particle size determinations and additional moisture analysis.

Prebreaking Procedure: The ingoing grain temperature was determined and samples collected for moisture analysis. The feed rate to the prebreaker was controlled by the use of the slide gate at the throat opening. The slide gate position was adjusted so that the prebreaker was operating at full load or approximately 19 amps as measured by the recording ammeter. The time was started when the load at the start reached the 50 % level and stopped when the load dropped to the 50 % level. The material was discharged into and collected in a bin hopper located at the side and below the prebreaker. Immediately upon completion of the test run, the product temperature was determined; and the samples for moisture analysis were taken. Additional samples were then taken for particle size determination.

Sieving Procedure: The prebroken grain was metered into the sieve by means of a 152.4 mm (six inch) variable speed screw conveyor. The test time was initiated when the product first entered the sieve and stopped when the last product entered the sieve. The "overs" from the 2.24 mm (.088 inch) screen were pneumatically conveyed to a bin above the hammermill. The "throughs" were pneumatically conveyed to the scale hopper, the weight recorded, and discharged into the mixer. Samples of the "overs" and "throughs" were taken in-line, prior to conveying, for moisture analysis and particle size determination.

Composite: The "throughs" from the sieve and the hammermilled "overs" were mixed for three minutes in a ribbon mixer. Samples were then taken for moisture analysis and particle size determination.

DATA ANALYSIS

The raw data were collated and the calculations performed using a spreadsheet software program. Generated data included:

A. Particle Size Analysis:

1. Geometric mean particle size - dgw (Appendix A)
2. Geometric log-normal standard deviation - Sgw (Appendix A)
3. Total surface area per gram - cm^2/g (Appendix B)
4. Number of particles per gram (Appendix B)

B. Grinding Efficiencies :

1. Kilowatt hours per metric ton Kwh/Mton (Appendix C)
2. Kilograms produced per horsepower hour - Kg/HPH
5. True Efficiency - m^2/Kwh (Appendix C)

C. Production Rates:

1. Capacities in tons produced per hour - T/H
2. Capacities in metric tons produced per hour - Mton/H

D. Temperature Differentials:

1. Prebreaker product in degrees centigrade - ^0C
2. Hammermill product in degrees centigrade - ^0C

E. Moisture Analysis Data:

1. Per cent changes - % (Appendix F & G)

An average amperage and voltage reading was determined from the recording ammeter and used for the calculations. A power factor of .90 and a motor efficiency factor of .90 was used for all calculations. (See Appendix H for examples of computer generated output)

Aspects of the generated data were then analyzed using a Statistical Analysis System (SAS)[1].

EXPERIMENTAL DESIGN

The statistical design of the system comparisons was a randomized design consisting of three treatments and three replications.

RESULTS AND DISCUSSION

PARTICLE SIZES PRODUCED

The particle size analysis results of the individual system processes are shown in table 1. The prebreaker-hammermill system results indicate that the prebreaker produces a significantly larger geometric mean particle size, a smaller generated surface area per gram, and a smaller number of generated particles per gram than the hammermill produces. Similar geometric log-normal standard deviations were produced by these systems.

Significant differences were observed when comparing the products from the four processing steps within the prebreaker-sieve-hammermill sytem. The overs from sieving the prebreaker product possess a significantly larger average mean diameter and the throughs possess a significantly smaller mean diameter when compared to the prebreaker product. The weight ratio of overs to throughs produced from the sieving

(1) SAS Institute, 1979)

Table 1. Particle Size Analysis Results of the System Processes and Their Comparisons within each System(1)

System Process	Geometric Mean Particle Dia. (dgw)	Geometric Log-Normal Std. Deviation (Sgw)	Surface Area (cm^2/g)	Number of Particles/gm
--------------------System No. 1 - HAMMERMILL--------------------				
Hammermill	681	1.87	81.4	14400
--------------System No. 2 - PREBREAK - HAMMERMILL--------------				
Prebreaker	2310^{a}	1.88^{a}	23.7^{b}	350^{b}
Hammermill	680^{b}	1.88^{a}	81.2^{a}	14000^{a}
------------System No. 3 - PREBREAK - SIEVE-HAMMERMILL-----------				
Prebreaker	2180^{b}	1.90^{a}	25.7^{b}	500^{b}
Sieved (Overs)	2984^{a}	1.36^{c}	16.0^{c}	50^{c}
Sieved (Throughs)	838^{c}	1.85^{ab}	66.8^{a}	7700^{a}
Hammermill (Overs)	753^{c}	1.81^{b}	72.1^{a}	8550^{a}

Note: Mean values in the same column and system with the same superscript letter are not significantly different. $P<.05$

(1) Each system was analyzed separately.

process (2.24 mm screen) was approximately 2:1. The sieved throughs and the product from hammermilling the sieved overs were statistically ($P<.05$) equivalent across the four particle size analysis parameters shown in the table. There was an indication, however, by visually comparing the product retained on the upper sieves during sieve analysis and by comparing the two averages in the table, that the throughs were slightly coarser and have a slightly larger calculated mean diameter than the hammermilled overs.

The particle size comparisons of the products produced by the hammermill within each system is shown in table 2. The results indicate that the product produced by straight hammermilling and the product produced by prebreaking and then hammermilling are equivalent across the particle size parameters. When the overs from the sieve were ground, a significantly larger particle size was produced, a smaller total surface area and a reduced total number of particles per gram were produced than were generated by hammermilling whole or prebroken corn. This result may be due to the removal of the soft endosperm through prebreaking and sieving, thus producing overs with a high percentage of the "harder to grind" horny endosperm remaining to be milled.

The particle size analysis results and the comparisons of the products produced by each system are shown in table 3. There were no significant differences in analytical results between the products produced by the hammermill system and the prebreaker-hammermill system. The prebreaker-sieve-hammermill system did result in significant differences in the data when compared to the other two systems. There

Table 2. Comparisons of the Hammermilling Process Particle Size Analysis Results

System Design	Geometric Mean Particle Dia. (dgw)	Geometric Log-Normal Std. Deviation (Sgw)	Surface Area (cm^2/g)	Number of Particles/gm
Hamm	681^{b}	1.87^{a}	81.4^{a}	14400^{a}
Pre-Ham	680^{b}	1.88^{a}	81.2^{a}	14000^{a}
Pre-Siv-Ham	753^{a}	1.81^{a}	72.1^{b}	8550^{b}

Note: Mean values in the same column with the same superscript letter are not significantly different. P<.05

Table 3. System Comparisons of the Particle Size Analysis Results

System Design	Geometric Mean Particle Dia. (dgw)	Geometric Log-Normal Std. Deviation (Sgw)	Surface Area (cm^2/g)	Number of Particles/gm
Hamm	681^{b}	1.87^{a}	81.4^{a}	14400^{a}
Pre-Hamm	680^{b}	1.86^{a}	81.1^{a}	14000^{a}
Pre-Siv-Hamm	764^{a}	1.90^{a}	72.9^{b}	10750^{b}

Note: Mean values in the same column with the same superscript letter are not significantly different. P<.05

was a higher average mean particle diameter, a lower generated surface area, and a reduced number of particles produced per gram in this system. The higher mean particle size was due to compositing the throughs and the hammermill overs, which both have relatively higher mean particle diameters than produced from hammermilling the whole or prebroken corn.

Grinding Efficiency

The grinding efficiency results of the individual reduction processes are shown in table 4. Comparing the efficiency results between the prebreaker and the hammermill within the prebreak-hammermill system and the prebreak-sieve-hammermill system, shows that the prebreaker was significantly more efficient in both kilowatt hours consumed per metric ton produced and in kilograms of product produced per horsepower hour. The

kg/hph results for the two systems containing the prebreaker are useful for the designing of balanced systems, so that each piece of processing equipment is running under full load where it performs most efficiently.

The kwh/Mton comparisons of the hammermill processing steps indicate trends between the systems but not statistically significant ($P<.05$) differences. The trends indicate that it takes more energy (kwh) per metric ton to grind the sieved overs (7.70 kwh), than whole corn (7.49 kwh), or than prebroken corn (6.86 kwh).

The three systems' efficiency data, calculated through accumulating all processing energy consumed within the particular system, and the comparisons between each system are shown in table 5. The hammermill system and the prebreak-sieve-hammermill system are equivalent in efficiency when measured by kwh/Mton.

Table 4. Comparisons of the Grinding Efficiency Results between the System Reduction Processes and Type of Material

System	System Process	Type of Material	Kwh/ Mton	Kg/ HpH
Pre-Hamm	Prebreaker	Whole	2.37^{b}	332^{a}
Pre-Siv-Hamm	Prebreaker	Whole	2.35^{b}	325^{a}
Hamm	Hammermill	Whole	7.49^{a}	122^{bc}
Pre-Hamm	Hammermill	Prebroken	6.86^{a}	123^{b}
Pre-Siv-Hamm	Hammermill	Overs	7.70^{a}	97^{c}

Note: Mean values in the same with the same superscript letter are not significantly different. P<.05

Table 5. System Comparisons of the Grinding Efficiency Results

System	(Kwh/Mton)	True Efficiency (m^2/Kwh)
Hamm	7.49^{b}	1089^{a}
Pre-Hamm	9.22^{a}	881^{c}
Pre-Siv-Hamm	7.45^{b}	984^{b}

Note: Mean values in the same column and system with the same superscript letter are not significantly different. P<.05

The prebreak-hammermill system consumed significantly more energy by almost two kwh per metric ton (a 23% difference) than the other two systems. The energy consumed by the prebreaker is not overcome in this system by the slight reduction of the energy consumed by the hammermill when compared to straight hammermilling.

When the particle size produced by each system was factored into a true efficiency measurement, all three sytems have significantly different efficiency ratings. The hammermill system had the highest true efficiency rating. Though the prebreak-sieve-hammermill system was equivalent in energy consumed per metric ton, this system had a lower true efficiency; since, it produces a significantly larger average mean diameter particle size. This difference in the true efficiency measurements between these two systems may not be relevant in feed manufacturing if the higher average diameter particle size is acceptable.

The prebreak-hammermill system had the lowest true efficiency rating. This system produces equivalent average mean particle sizes when compared to the hammermill system, but consumes significantly more energy as previously discussed.

Production Rates

The production rates in metric tons per hour for the milling equipment utilized thoughout the tests and the equipment comparisons are shown in table 6. The prebreaker gave a significantly higher production rate when compared to the hammermill in each of the three systems. A through-put trend was indicated when comparing the hammermill

Table 6. Comparisons of the Production Rate Results between the Systems and Type of Material

System	System Process	Type of Material	Tons/Hr	Metric Tons/Hr
Pre-Hamm	Prebreaker	Whole	5.48^{a}	4.99^{a}
Pre-Siv-Hamm	Prebreaker	Whole	5.36^{a}	4.88^{a}
Hamm	Hammermill	Whole	4.03^{bc}	3.66^{bc}
Pre-Hamm	Hammermill	Prebroken	4.08^{b}	3.71^{b}
Pre-Siv-Hamm	Hammermill	Overs	3.21^{c}	2.92^{c}

Note: Mean values in the same column with the same superscript letter are not significantly different. $P<.05$

production rates between the three systems. The rate of output from hammermilling prebroken corn was slightly higher (3.71 Mton/Hr) than hammermilling whole corn (3.66 Mton/Hr) which, in turn, was higher than hammermilling overs (2.92 Mton/Hr). However, the data shows an insignificant improvement in the production rate of the hammermill by prebreaking the corn prior to hammermilling.

Temperature Differentials

The product temperature rises during grinding with the particle size reduction equipment are shown in table 7. The prebreaker showed only a one degree (C) rise in this installation. This low temperature rise is due to a significantly larger average diameter particle size produced by the prebreaker and considering that there is a lack of a screening/sizing device to entrap particles for repeated impacts and subsequent heat generation. The prebreaker product temperature rise may also have been affected by the installation design. The product was thrust by the prebreaker into a large collecting/holding bin. This factor may have allowed the heat to be dissipated immediately after grinding, lowering product temperature prior to temperature sample collection.

The hammermill consistently produced a product temperature differential of nine degrees centigrade. The data indicate that there was no effect on the temperature differentials by the form of material being milled by the hammermill. The temperature differential produced by the hammermill in these systems is consistent with the data previously reported in the literature review (Moy, date unknown; and Silver, 1932).

Table 7. Product Temperature Rise Across Individual Grinding Steps

System	System Process	Type of Material	TEMP (^0C)
Pre-Hamm	Prebreaker	Whole	1.0^b
Pre-Siv-Hamm	Prebreaker	Whole	1.0^b
Hamm	Hammermill	Whole	9.3^a
Pre-Hamm	Hammermill	Prebroken	9.0^a
Pre-Siv-Hamm	Hammermill	Overs	9.0^a

Note: Mean values in the same column with the same superscript letter are not significantly different. $P<.05$

Moisture Analysis

The analytical moisture results and the comparisons within each system are shown in table 8. The first significant feature noted was that, in each system, the greatest loss of moisture occured at the first milling step. This result was true whether prebreaking or hammermilling was the first reduction process. Each system, also, showed a moisture loss trend continuing after the initial loss, but not significant (P>.05) losses between the steps. As expected, in most cases, loss of moisture occurred during pneumatic conveying of the products.

The total moisture loss by the processing systems and the moisture loss comparisons between systems are shown in table 9. The differentials between the three systems showed a definite trend, though not a significant (P>.05) difference in these experiments. Additional data would be needed to confirm significant differences between the systems. The prebreak-sieve-hammermill system showed the greatest loss of moisture (1.38%). This may be due to the number of processing and conveying steps within the system. The hammermill systems relatively higher loss (1.18%), compared to the prebreak-hammermill system (1.00%), may be due to the higher temperatures generated at the first milling step where the greatest moisture losses take place in each system.

Table 8. Comparison of Moisture Analysis Results within each System

System	Component/Step	Moisture (%)	Differential
No. 1 HAMM	Whole Corn	15.11^a	
			-1.14
	Hammermill	13.97^b	
			-.04
	Conveying	13.93^b	
No. 2 PRE-HAMM	Whole	15.09^a	
			-.95
	Prebreaker	14.14^b	
			-.01
	Hammermill	14.13^b	
			-.04
	Conveying	14.09^b	
No. 3 PRE-SIV-HAMM	Whole	14.99^a	
			-1.07
	Prebreaker	13.92^b	
	Sieved (Overs)	13.64^b	
			+.02
	Conveyed (Overs)	13.66^b	
			+.12
	Hammermill (Overs)	13.78^b	
			-.12
	Conveyed (Hamm)	13.66^b	
	Sieved (Throughs)	14.07^b	
			-.16
	Conveyed (Throughs)	13.91^b	
	Composite (Thru&Hamm)	13.62^b	

Note: Mean values in the same column and system with the same superscript letter are not significantly different. $P<.05$

Table 9. Comparisons of the Moisture Content Results and Losses within and between the Systems

System	Moisture Before (%)	Moisture After (%)	Differential
Hamm	15.11^{a}	13.93^{ab}	1.18^{a}
Pre-Hamm	15.09^{a}	14.09^{a}	1.00^{a}
Pre-Siv-Hamm	14.99^{a}	13.62^{b}	1.38^{a}

Note: The first two mean values within each row are significantly different from each other. Mean values in the same column with the same superscript letter are not significantly different. $P<.05$

Conclusion

This study indicates that there is no performance advantage at this stage of Ripple Mill development to design a particle size reduction system that includes this particular prebreaker. The hammermill system produces an equivalent, or slightly smaller, average diameter particle size when compared to the two systems containing the prebreaker. The hammermill system performs equivalently or better than the other two systems when comparing system efficiencies in both Kwh/Mton and true efficiency.

The prebreaker did not increase the production rate of the hammermill in this system enough to sufficiently warrant a prebreaker installation directly prior to the hammermill, even if energy efficiencies are ignored. Installing a properly sized prebreaker and sieve system prior to an already installed hammermill could provide a system that produces at a higher production rate for the given sized hammermill. This type of system would produce product at a slightly higher mean diameter particle size and would perform equivalently in energy efficiency. There were no prebreaker effects on the product temperature rises during hammermilling nor were there significant improvements in moisture retention, providing for a reduction in shrink losses during manufacturing.

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APPENDIX A

Calculated Geometric Mean Particle Size and Geometric Log-Normal Standard Deviation

The method of analysis, ASAE S319, covers in detail the sieve selections and a description of the procedure with formulas. Calculated values were obtained using the following spreadsheet format and formulas.

	1	2	3	4	5	6	7
1	Screen	Diameter	log	Weight	W(i)*	log D(i) –	W(i) *
2	Sizes	microns	D(i)	W(i)	log D(i)	log dgw	[(log D(i)–
3	(Tyler)	D(i)					log dgw)**2]
4	--------------------		-------	------	----------	----------	---------------
5	3	6730	3.903				
6	4	4760	3.753				
7	6	3360	3.602				
8	8	2380	3.452				
9	10	1680	3.301				
10	14	1190	3.149				
11	20	841	3				
12	28	595	2.849				
13	35	420	2.699				
14	48	297	2.549				
15	65	210	2.398				
16	100	149	2.248				
17	150	105	2.097				
18	200	74	1.944				
19	270	53	1.799				
20	pan		1.643				
21	Summs:	XXXXXXX	XXXXXX	A	B	XXXXXXXXXX	C

$$dgw = \log^{-1} (\text{Summation B}/\text{Summation A})$$
$$Sgw = \log^{-1} [(\text{Summation C}/\text{Summation A})^{1/2}]$$

where:

dgw = Geometric Mean Particle Size or Diameter
Sgw = Geometric Log-Normal Standard Deviation

APPENDIX B

The following formulas were used to calculate the surface area produced per gram and the number of particles per gram. For mathematical derivation of the formulas, see Pfost & Headley (1976).

Surface Area Calculation:

$$Ast = [(B_s Wt)/(B_v p)] \, Exp\, [0.5\, (\ln Sgw)^2 - \ln dgw]$$

Where:

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

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

Number of Particles Per Gram Calculation:

$$N_t = (Wt/\, pB_v)\, Exp\, [4.5(\ln Sgw)^2 - 3(\ln dgw)]$$

where:

N_t = number of particles per gram
Wt = weight of sample (1 gm)
p = specific weight of material.
B_v = shape factor for calculating volume of particles.
Sgw = geometric log-normal standard deviation.
dgw = geometric mean particle size or diameter.

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

APPENDIX C

Efficiency Calculations

The following formulas were used to calculate electrical energy efficiencies and "true efficiency".

Kilowatt Hours per Metric Ton:

$$Kwh/Mton = [(I)(E)(PF)(EFF)(1.73)]/[(1000)(Mton/hr)]$$

Where:

Kwh/Mton	= kilowatt hours per metric ton
I	= amperage
E	= voltage
EFF	= efficiency factor
PF	= power factor
1.73	= correction factor for three phase motor
Mton/hr	= metric tons per hour
1000	= number of wats per kilowatt

For the calculation contained in this thesis, it was asssumed that EFF= .90 and PF = .90.

True Efficiency:

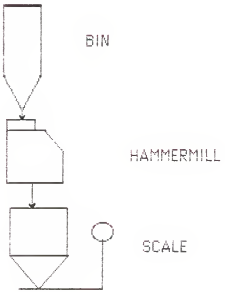
$$m^2/Kwh = [(cm^2/gm)(m^2/10{,}000\ cm^2)(1{,}000{,}000g/MT)]/(Kwh/MT)$$

Where:

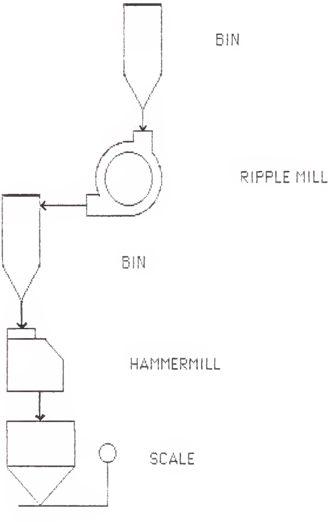
m^2/Kwh	= square meters of surface area per kilowatt hour
cm^2/gm	= surface area per gram
Kwh/MT	= kilowatt hours per metric ton

APPENDIX D

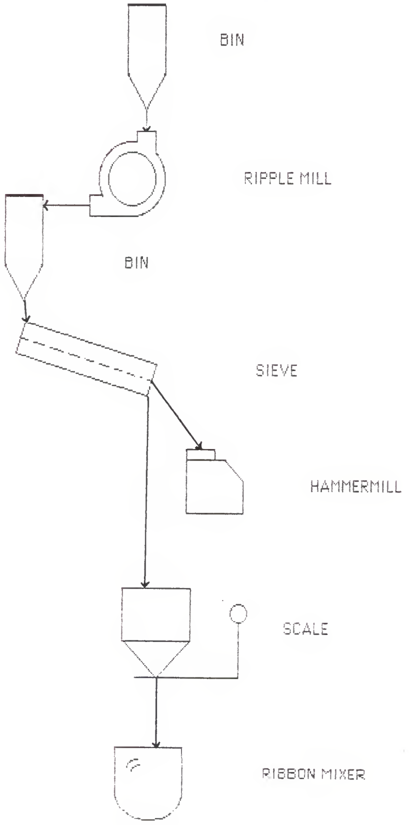
SYSTEM NO. 1 NON-ALTERED HAMMERMILL SYSTEM



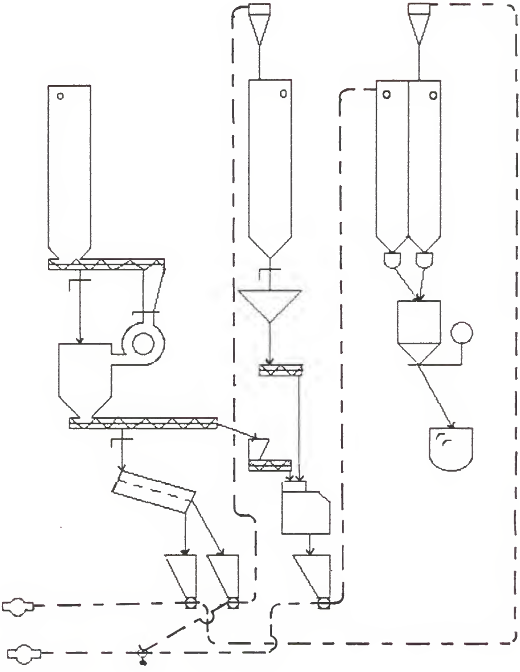
SYSTEM NO. 2 PREBREAKER-HAMMERMILL SYSTEM



System No. 3 PREBREAKER-SIEVE-HAMMERMILL SYSTEM



APPENDIX E



APPENDIX F

Method for determining oven moisture of whole kernel corn.

1. 15 grams of sample weighed into tared moisture dishes in duplicate. All weights recorded to the nearest milligram.
2. Moisture dishes with covers beneath placed on central shelf of oven.
3. Oven was set at 103 ^{0}C and drying time was 72 hours.
4. Upon termination of drying time, dishes were removed and covers put in place.
5. Covered moisture dishes were allowed to equilibrate to room temperature within a desiccator.
6. Covered moisture dishes were weighed to the nearest milligram and the results recorded.
7. Moisture was determined as loss of weight:

   Moisture % = A/B x 100

   where A = moisture loss in grams.

   B = original weight of sample.
8. Duplicates of same sample must check within plus or minus .2% moisture; otherwise repeat determination.

APPENDIX G

Method for determining oven moisture of ground corn.

1. All samples were ground prior to weighing.
2. Approximately two grams of sample weighed into tared moisture dishes in duplicate. All weights recorded to the nearest milligram.
3. Moisture dishes with covers beneath placed on central shelf of oven.
4. Oven was set at 135 ^{0}C and drying time was two hours.
5. Upon termination of drying time, dishes were removed and covers put in place.
6. Covered dishes were allowed to equilibrate to room temperature within a desiccator.
7. Covered moisture dishes were weighed to the nearest milligram and the results recorded.
8. Moisture was determined as loss of weight:

   Moisture % = A/B x 100

   where A = moisture loss in grams.

   B = original weight of sample.
9. Duplicates of same sample must check within plus or minus .2% moisture; otherwise repeat determination.

APPENDIX H

	1	2	3	4	5	6
1	Test Variation:	Pr-S-H		Screen	Grams on	
2	Step Number:	CM		Sizes	Screen	Percent
3	Sample Number:	R16CMPS1		(Tyler)	(weight)	
4	Date Milled:	10/25		---------	----------	---------
5	Ingredient:	Corn		3		0.00%
6	Specific Wt. (gms):	1.32		4		0.00%
7	********************	***********		6	0.00	0.00%
8	Experiment Data:	%%%%%%%%%%		8	0.20	0.20%
9	Prebreaker Time:	----------		10	9.70	9.84%
10	Minutes:	4		14	20.80	21.10%
11	Seconds:	0		20	17.30	17.55%
12	Sieve Time:	----------		28	15.80	16.02%
13	Minutes:	3		35	14.30	14.50%
14	Seconds:	25		48	10.90	11.05%
15	Hammermill Time:	----------		65	7.80	7.91%
16	Minutes:	4		100	1.70	1.72%
17	Seconds:	25		150	0.10	0.10%
18	Weight (lbs):	----------		200	0.00	0.00%
19	Prebreaker:	723		270	0.00	0.00%
20	Sieve Overs:	464		pan	0.00	0.00%
21	Sieve Unders:	256		Summation:	98.60	100.00%
22	Hammermill:	460		*************	*************	************
23	Amps:	----------				
24	Prebreaker:	18				
25	Sieve:	2.25				
26	Hammermill:	37				
27	Volts:	----------				
28	Prebreaker:	420				
29	Sieve:	420				
30	Hammermill:	420				
31	Horsepower:	----------				
32	Prebreaker:	15				
33	Sieve:	1.5				
34	Hammermill:	30				
35	Ambient Conditions:	----------				
36	Dry Bulb Temp.:	72				
37	Wet Bulb Temp.:	62				
38	Rel Humidity:	58				
39						

	1	2	3	4	5	6
40	Test Variation:	Pr-S-H				
41	Step Number:	CM		Screen	Grams on	
42	Sample Number:	R16CMPS1		Sizes	Screen	Percent
43	********************	************		(Tyler)	(weight)	
44	Calculated Data:	%%%%%%%%%%		---------	----------	---------
45	Average Diameter	----------		3	0.00	0.00%
46	Particle Size:	763.39354		4	0.00	0.00%
47	Standard Deviation	----------		6	0.00	0.00%
48	of Particle Size:	1.9084993		8	0.20	0.20%
49	Surface Area in	----------		10	9.70	9.84%
50	sq cm per gram:	73.373101		14	20.80	21.10%
51	Number of Particles	----------		20	17.30	17.55%
52	per gram:	11157.141		28	15.80	16.02%
53	Grinding Efficiencies	----------		35	14.30	14.50%
54	in kwh per Ton:	----------		48	10.90	11.05%
55	Prebreaker:	2.0501577		65	7.80	7.91%
56	Hammermill:	7.3136063		100	1.70	1.72%
57	in kwh per MTon:	----------		150	0.10	0.10%
58	Prebreaker:	2.2627718		200	0.00	0.00%
59	Hammermill:	8.0720728		270	0.00	0.00%
60	Sieve Efficiency:	----------		pan	0.00	0.00%
61	in kwh per ton:	0.2198091		Summation:	98.60	100.00%
62	in kwh per MTon:	0.2426047		*************	************	***********
63						
64	Total Efficiency:	----------				
65	in kwh per ton:	6.9231603				
66	in kwh per MTon:	7.6411351				
67						
68	True Efficiency in	----------				
69	sq meters per kwh:	962.31739				
70						
71	Efficiency/HPH:	lbs/HPH		Kg/HPH		
72	Prebreaker:	723		328.63636		
73	Hammermill:	208.30189		94.682676		
74						
75	Production Rates:	T/H		MT/H		
76	Prebreaker:	5.4225		4.9295455		
77	Hammermill:	3.1245283		2.8404803		
78						

THE EFFECTS OF PREBREAKING ON THE EFFICIENCY OF HAMMERMILL PARTICLE SIZE REDUCTION SYSTEMS IN FEED MANUFACTURING

by

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AN ABSTRACT OF A MASTER'S THEISIS

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Studies were conducted to evaluate the effect of prebreaking on the performance of hammermill grinding systems. The systems consisted of a straight hammermilling system, a prebreaker-hammermill system, and a prebreaker-sieve-hammermill system. The grinding performances of each system on corn were determined and compared.

The hammermill system and the prebreaker-hammermill system produced equivalent mean particle sizes and exposed equivalent surface areas. The prebreaker-sieve-hammermill system produced a 12% higher mean particle size and exposed 10% less surface area.

The hammermill system and the prebreaker-sieve-hammermill system performed equivalently in grinding efficiency, as measured by kwh/metric ton. The prebreaker-hammermill system consumed 23% more energy per metric ton. True efficiency ratings showed system performances to be in the following efficiency order: hammermill system (1089 m^2/Kwh) > prebreaker-sieve-hammermill system (984 m^2/Kwh) > prebreaker-hammermill system (881 m^2/Kwh).

Prebreaking did not improve hammermill production rates, as measured by metric tons/hour. As a system, the prebreaker-sieve-hammermill system produced at a higher rate. Its' rate was based on the production rate of the prebreaker instead of the hammermill, which occured in the other systems tested.

The investigation showed prebreaking had no effect on product temperature rises during the hammermilling process.

The moisture analysis results showed that the greatest moisture loss occurs at the initial particle reduction step. Total system moisture losses ranged from 1.00 to 1.38%. A moisture loss trend was indicated for the systems in the following order: prebreaker-sieve-hammermill system > hammermill system > prebreaker-hammermill system.