THEORY AND APPLICATION OF IMPACT GRINDING

by

ARTHUR NATHAN HIBBS

B. S., Kansas State College of Agriculture
and Applied Science, 1943

A THESIS

submitted in partial fulfillment of the

requirements for the degree of

MASTER OF SCIENCE

Department of Milling Industry

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1947

TABLE OF CONTENTS

TABLE OF CONTENTS (concl.)

INTRODUCTION

The process of milling wheat into flour consists of grinding the wheat and separating the resulting fragments. The major end products of this process are flour, bran and germ. Flour is the finely divided particles of endosperm, bran is the outer seed coat made up of cellulose tissue, while the germ is the embryonic tissue of the wheat kernel. The germ is usually put into the feed products.

The milling system can be divided into two parts or sequences: the break system and the reduction system. The break system is that process that initially crushes the wheat kernel.

The normal grinding machines for the break system are corrugated rolls. These corrugated rolls tear the kernel open by a shearing and crushing action. This process flattens the bran coat and releases the endosperm and germ. The endosperm is fractured into fragments called sizings or middlings. The bran, containing some endosperm, is again passed through corrugated rolls and the resulting stock is again sifted. The process is repeated until almost all of the endosperm is removed from the bran. The small amount of flour produced by this process is called break flour.

The reduction system utilizing smooth rolls further reduces the fragments of endosperm called sizing or middlings. The endosperm is reduced and classified into particle sizes by means of sieves and appears finally as flour in this process. The small bran particles and germ are removed by means of sieves and air currents. Germ, or pieces of germ, are undesirable in flour since they contain considerable fat which causes rancidity in flour.

Although technical improvements have been made, the milling industry has been using this basic system for over 50 years.

In the search for more efficient grinding machines, attention has been given to the principle of impact grinding. This principle is not new, since an impact grinder was demonstrated at Paris in 1878. Kozmin (1921) discussed impact machines and concluded that they were inefficient and produced endosperm which contained too much fine bran.

Impact grinders have not been accepted by the flour milling industry, although they are used in other industries. The chief problem of grinding wheat in the milling process is to reduce the kernel in such a way as to facilitate the separation of the bran, endosperm and germ. Impact grinders complicated this problem by producing fine bran fragments.

The hammer mill is an example of an impact grinder. Smith (1945) describes a new impact grinder, the "W. S. Barron Impact Grinder". No infirmation is available concerning its effectiveness in reducing wheat to flour.

The purpose of this investigation was to study the theory of impact grinding and determine in what way an impact grinder may be used to the best advantage in the milling process.

THEORY OF IMPACT GRINDING

Classification of Impact Grinders

Impact grinders can be classified into three groups with reference to the number of impacts received by the material as it passes through the machine.

1. Single-Stage Grinders. In this type of machine the material is given sufficient velocity so that on striking a stationary surface, breakage or crushing occurs. The only impact received by the material occurs when it strikes the stationary surface. Velocity may be imparted to the material by revolving impellers or other mechanical means, or by air, steam, or other fluids.

2. Two-Stage Grinders. The working parts of this type of machine are a set of revolving beaters or impactors and a stationary surface. The material receives impact upon contact with the surfaces of both working parts. The hammer mill is an example of this type of machine, in which the stationary surface is a screen which retains the material within the impact zone until it is reduced sufficiently to pass through the openings of the screen. This process produces a mixture of fine bran, middlings, and flour. The separation and classification of this material is practically impossible.

3. Multi-Stage Impact Grinders. These machines have alternate concentric rings of rotating and stationary impactors. After

the material is subjected to several impacts, it is rejected from the machine and purified before receiving additional reduction. The theory of the grinding principle of this type of machine is the subject of this paper.

The machine investigated was a multi-stage impact grinder whose working parts consist of two rows of rotating impactors (28 in each row), set in concentric circles on a horizontal rotating disc. The disc is rotated at approximately 3,450 r.p.m. by an electric motor. The two rows of impactors rotate on either side of a row of stationary impactors set in the liner of the housing. The impact machines investigated were loaned and installed by the Entoleter Division, Safety Car Heating and Lighting Co., Inc., New Haven, Connecticut. A photograph of the machine and its working parts is shown in Plate I.

The material enters the machine at the center of the disc and strikes a conical hub attached to the shaft rotating the disc. It is then forced through the three sets of impactors before striking the outer case, and is discharged through a hopper below.

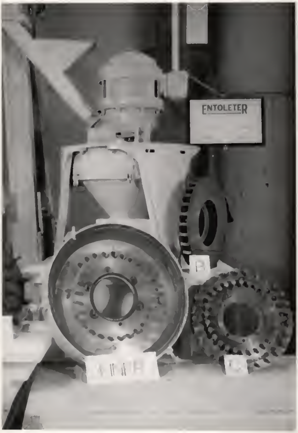
Theory

The forces causing the breaking action produced by this machine are difficult to fit into any one mathematical formula. The reason for this is the undefined particle path and the manner in which forces act on it. The usual formulae used to study the strength of materials are not applicable because they

EXPLANATION OF PLATE I

Photograph of the impact machine (Entoleter).

PLATE I



assume that the elastic limits of the material will never be exceeded. In this machine the elastic limit of the material must be exceeded for breakage to occur.

In general, two types of impact may occur: first, direct impact and second, oblique impact. The following assumptions have been made in considering impact action.

Direct Impact

1. The velocity paths of the particles are in line with the center of gravity of the particles.

2. The surfaces of contact (particle surface relative to wheat surface) are perpendicular to each other.

3. The particles do not rotate about their own axes.

Oblique Impact

1. The tangential components of the particles' velocity are unchanged during contact, i.e., the surfaces are frictionless.

2. The normal components of the velocity of the particles are treated as in direct impact.

3. The particles are not rotating about their own axes.

If the particle is not spherical in shape then it can be assumed that the surfaces of contact will seldom be perpendicular to the line of centers. This being true, the formulae for impact can not be used in this case. Furthermore, the particles will probably be spinning or rotating about their own axes.

For this type of problem the loss of kinetic energy during impact can be a measure of the unrecoverable work. This means that destructive work has been done.

Consider now the forces acting upon the material as it travels through the machine.

Distribution of Stock. As the material strikes the cone-shaped hub, the particles will be deflected toward the circumference of the disc. Each particle will be deflected from the cone in a different path from that which it had when it struck the cone. Only a few particles will be reflected directly back into the entrance spout. Those that are will be resisted by additional material flowing into the machine. Thus, it is assumed that the stock is distributed quite evenly over approximately one-half the area of the disc.

Loss of Kinetic Energy. The equation for calculating the linear velocity of the impactors (V) is:

(1) $V = Wr$

V = linear velocity

W = angular velocity = $2 \times \frac{3450}{60}$ = 361 radians per sec.

r_1 and r_2 = radii of impactors

(2) $V_1 = Wr_1 = 361 \times 0.41 = 148$ ft./sec.

(3) $V_2 = Wr_2 = 361 \times 0.554 = 200$ ft./sec.

The loss of kinetic energy is a measure of the crushing action, provided the force is great enough to press the material beyond its elastic limits. The loss of kinetic energy due to impact is given in the following equation:

(4) $$E = 1/2 \frac{M_2 M_1 (V_2 - V_1)^2}{M_w + M_1}$$

E = loss of kinetic energy due to impact

M_w = mass of wheat particle

M_i = mass of impactors

V_w = velocity of wheat particle

V_i = velocity of impactors (from equations 2 and 3).

If the following assumptions can be made -

M_i is constant and relatively large,

M_w is relatively small,

V_i is constant and known,

V_w is variable and probably small,

then the equation can be simplified to -

(5) $E = 1/2\, M_w (V_i)^2$.

The loss of kinetic energy, or crushing effect, varies directly with the mass of the particle to be reduced and directly with the square of the velocity of the impactors. If 0.04 gm. can be considered the average weight of a kernel of wheat, then the loss of kinetic energy will be:

(6) $E_1 = 1/2 \frac{0.04}{454 \times 32.2} (148)^2 = 0.033$ ft. lbs.

(7) $E = 1/2 \frac{0.04}{454 \times 32.2} (200)^2 = 0.06$ ft. lbs.

Kozmin (1921) assumes that the velocity required to crush a kernel of wheat is 487.5 ft./sec. This assumption is based on Professor Afanasyeff's studies which were conducted in 1883. This is more than twice the velocity attained by the impactors under observation. Therefore, it is doubtful if the loss of kinetic energy would be large enough to exceed the elastic limit of the material and produce crushing action.

Breaking Action Produced by Impact. Reduction by crushing action would imply that the force was entirely compression. However, when the kernel is struck by the impactor the center of impact is a relatively small part of the entire area of the particle. Consequently, it may be assumed that only the contact area will receive sufficient compression or crushing force to pulverize the outer coating of material. Throughout the kernel, lines of compression and tension will be created. It is a well known fact that in general less force is required to break materials by bending than by compression. Consequently, less force will break the kernel of wheat than might appear at first thought, since forces of both compression and tension are brought to bear on the kernel by impact grinding. However, as the area of the particle approaches in size the area of impact there will be less breaking action as a result of the decreasing moment arm between compression and tension. For small particles the reduction will have to be accomplished by compression alone, and consequently more power will be required.

Consider a theoretical path of the wheat particle. The particle strikes the center of the rotating disc and is deflected toward the rotating impactors. When struck by the impactors, the center of impact is a relatively small portion of the entire wheat particle. Therefore, lines of compression and tension will be formed and the particle will break, if force is great enough, along lines of least resistance. The structural strength of the bran and endosperm will affect the nature of the breakage. The bran, being tough and composed of long flexible cells, will tend to hold together, while the starchy endosperm cells will separate more readily. The bond holding the bran layers to the endosperm is weaker than the forces which cause bran cells to adhere; therefore sudden impact can be expected to cause a separation of the endosperm from the bran. After striking the rotating impactors the particles are thrown from them and strike the stationary impactors, where similar effects again occur.

Centrifugal force is that force tending to pull the particle from the axis of rotation. The flour particle can be assumed to be free to respond to the centrifugal force applied in a centrifugal machine.

(8) Centrifugal force $= \frac{MV^2}{r}$

M = mass of particle - for wheat 0.0000027

V = velocity of particle (from equation 2)

r = radius of curvature of path at the instant centrifugal force is considered (0.41 ft.).

Force impelling the particle after it has been acted on by the first set of impactors:

(9) $F = \frac{0.0000027}{0.41}(148)^2 = 0.145$ lbs.

The force necessary to move the unattached wheat kernel is approximately 0.00009 pounds. This force is about 1/1,600 of the force which would act on the particle if it were attached to the impactors. If this assumption is correct the particle will be forced from the impactor immediately upon being struck.

The particle probably will not attain the velocity of the impactors but will travel at some lower velocity.

There will be no centrifugal force acting upon the free particle. If the particle travels in a path non-intersecting with any other particle, it can be assumed that the only forces acting upon it are the forces received from the impactor, plus the force of gravity; therefore, the free particle will travel in straight lines. However, it may be spinning or rotating around its own axis.

The action of the stationary impactors will depend upon the velocity of the particle. The particles will break if its velocity is sufficient; however, the chief function of the stationary impactors is to stop the material so that it will not rotate with the revolving impactors. The stationary impactors also afford more opportunities for the particle to be struck by the high velocity impactor.

When the particle loses its velocity, it is pushed by the flow of stock to the outer rotating impactors or it will fall by force of gravity to the rotating disc and be thrown to the outer impactors. These impactors strike the particle with a high velocity, thus reducing it in the same manner as before. After the material leaves the outer set of rotating impactors, it will strike the outer case of the machine. Breakage will occur if the velocity normal to the contact surfaces is sufficient. It is assumed that the largest component of the velocities of the particle will be tangential to the surface of the case. If this is true, only a small amount of reduction will take place when the material strikes the case. The velocity of the material will be expended on the sides of the case and hopper before being discharged from the machine.

Internal Air Turbulence. An additional force to be considered is the effect of the velocity of the air in the machine. The rotating impactors are traveling in a medium of air, water vapor, and wheat particles. The particles are solid and the velocities they receive can be calculated. On the other hand, air and water vapor are being displaced and disturbed by the rotating impactors, and these motions and speeds are more difficult to calculate. There will be shock waves produced by the impactors, and eddy currents formed by both sets of impactors. Thus, a very high turbulence will result. Associated with this turbulence will be a pumping action; that is, air will be forced through the machine.

These air currents and turbulence effects cannot be calculated accurately. Neither can the effect of this air disturbance upon the material passing through the machine be determined satisfactorily. However, the following deductions can be made:

1. Air currents will offer resistance to particle movement.

(a) This would slow the velocity of the particles and possibly its rate of movement through the machine.

(b) It will not change materially the crushing effect of the impactors upon the particle.

(c) The probability of striking an impactor will be increased.

2. Air currents will facilitate particle movement.

(a) This will increase the velocity of the particles and rate of movement.

(b) It will not change materially the crushing effect of the impactors upon the particle.

(c) The probability of a particle's being struck by an impactor will be decreased.

(d) There is a possibility that small particles of large specific gravity will be carried through without being struck by the impactors.

The total effect is probably a combination of items 1 and 2. The effects of the air turbulence on the grinding action of the machine are indeterminate factors characteristic of the machine.

Theoretical Factors Affecting Reduction of Material by Impact Grinder

The rate of feed would affect the amount of reduction indirectly. If the machine were overloaded the rotating parts would be slowed and less energy imparted to the material. If the rate of feed is such that the speed of the impactors is not decreased no change in reduction should occur. However, if the rate of feed is slowed to such an extent that the material remains in the machine a greater period of time and receives more impacts, then the reduction should be increased.

The nature of the material will affect the reduction. Various types of grains will be reduced to a different extent, and the characteristics of the product obtained will vary, so that within even one kernel of grain, differences can be expected. For example, wheat will be reduced to different degrees, depending upon the hardness or other physical characteristics of the kernel. Thus the amount of reduction accomplished as the kernel passes through this machine will be affected. The size of the particle to be reduced is also an important factor.

Preparation of the wheat by toughening the bran coats and softening the endosperm will affect the reduction. In impact breakage the more brittle the material, the more susceptible it is to breaking. When the material is moistened, it becomes tough and the breakage will be decreased. Within certain limits one can expect the reduction to vary inversely with the moisture content.

In "conditioning" grains, the purpose of a "rest period" is to allow enough time for the moisture to be absorbed into the interior of the kernel, thus softening the endosperm. However, during a long "rest period" the bran coat will lose moisture and will become brittle again. At some combination of moisture content and "rest period", the kernel will be at its best condition for reduction. This condition implies a tough bran coat to prevent excess breakage, and a soft endosperm to increase its reduction.

The working parts of the machine will affect the reduction obtained.

The linear velocity of the impactors affect the amount of reduction produced. The higher the linear velocity the more breakage.

The number of impactors, or working parts, will affect the reduction. The reduction will vary directly with the number of impactors if they exert sufficient force to exceed the elastic limit of the material.

The position of the impactors will affect the reduction if the position of the impactor will affect their velocities or the velocities of the material. The nature of the surfaces of the impactors will affect the reduction. This will change the area of contact and the friction of the surfaces.

OBJECTIVES

The object of this investigation was to determine the factors that affect the reduction of material by impact machines and how these machines may be used to the best advantage in the milling process. Experiments were conducted to determine the effects of rate of feed, types of material, condition of the material, and the type of machine upon the reduction obtained. After determining the factors affecting the reduction of material by an impact machine, tests were conducted to determine how to integrate these machines into the milling process. This was studied by conducting experiments to determine the physical characteristics and the quality of the products produced by impact machines compared to products produced by rolls.

MATERIALS AND METHODS

The wheat used in this work was a No. 1 hard red winter wheat purchased from a commercial mill. The wheat analysis was as follows: test weight, 60.5 pounds per bushel; moisture content, 11.6 percent; protein, 13.2 percent; and ash, 1.76 percent. This one lot of wheat was used throughout the experiments.

The samples were milled on the 130-sack college mill. The wheat received identical treatment in cleaning before milling. The cleaning equipment used included a milling separator and an Iron Printz scourer. The wheat was tempered to various moisture levels by the Thomas, Stone and French wheat conditioner.

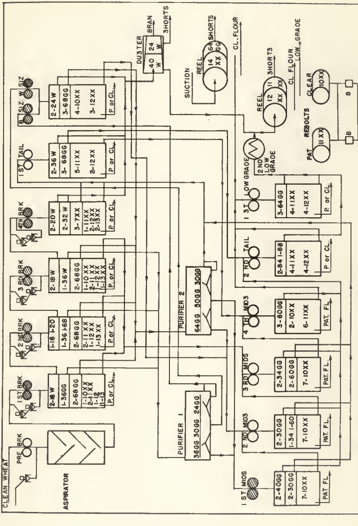
A flow of the mill is shown in Plate II. Samples were obtained for analysis below each grinding machine in the break system while the mill was in operation. Individual flour streams were sampled. This permitted a study to be made of the effect which each individual machine had upon its product.

In all cases the mill was allowed to "warm up" and obtain normal adjustment before sampling. To mill efficiently each

EXPLANATION OF PLATE II

The flow sheet of the Kansas State College mill.

PLATE II



130 SACK MILL WITH ENTOLETER INSTALLATIONS
KANSAS STATE COLLEGE 1946

piece of equipment in the mill must be correctly adjusted so that all machines are properly loaded. This being a continuous process, not only a change in the grinding, but also a change in the size opening or the amount of sifting surface will affect the quantity and quality of the material going to other equipment.

In normal milling practice the rolls are set to reduce the material to satisfy sifting and classifying conditions. In the break system the object is to separate the bran from the endosperm and make a minimum amount of flour. The rolls are set to obtain a maximum amount of middlings and a minimum amount of break flour without excessive cutting of the bran, so that the bran is removed in large flat pieces. The granular middlings are cleaned and classified by means of sieves and air currents before they are reduced by smooth rolls.

No valuable information can be obtained until the mill is in balance and the amount of material going to each operation can be determined.

The sifting and purifying equipment in the college mill is somewhat inefficient and rather inflexible. For this reason changes from the normal milling procedure could not be accomplished readily to treat properly the material obtained by different grinding methods.

In the first phase of the problem studies were conducted to determine the effect of certain variables on the grinding ability of impact grinders. Experiments were conducted to determine how the rate of feed, the types of material, the condition of the material and the working parts of the machine affected the amount of reduction obtained. The amount of reduction was measured by the percent of the sample retained over an 18 wire sieve.

In the second phase of the problem a study was made to determine the utility of impact machines in the milling process. Experiments were conducted enabling the use of all break rolls, all impact machines, or any combination of break rolls or impact machines in the break system. This permitted a comparative study of impact grinding and roll grinding in the break system.

Tests were made to determine reduction and the particle size distribution of the material treated with impact grinders and break rolls. However, no measurement was made of the physical nature of the product other than size. The relative amounts of small bran fragments in some fractions could not be measured except by particle counts.

A granulation study was made on break flour produced by rolls and impact machines. The Roller particle-size analyzer was employed for the study. The particle sizes were separated by employing air velocities which exert sufficient force on the area of a particle of specified size to lift it out of the sample, thereby obtaining particle size fractions. To function accurately all particles must have the same specific gravity and physical characteristics. This is not the case with break flour samples because the bran chips are flat and narrow, thus exposing more area than the chunks of endosperm. The differences obtained from this source of error are probably negligible in a comparative study.

The air had a tendency to dry the material, thus a weight loss was noted in recovery of the fractions. The percent fractions obtained were calculated from the total sample recovered.

Tests were made to determine the quality of the material produced by impact grinders. Various streams were sampled, analyzed, and percentage of those streams of the original wheat was determined. The ash, moisture, protein, and crude fiber determinations were determined in the usual manner and the results converted to 14 percent moisture basis. To determine the location of the germ, crude fat extractions were made on various streams. The crude fat was extracted with anhydrous ether for a period of 16 hours.

Straight grade flour from each process was baked, using the formula and baking procedure reported by Johnson, Swanson and Bayfield (1943).

Further tests were conducted with different types of impact machines. These machines were examined to determine their desirability in the milling process.

EXPERIMENTAL DATA

Influence of Material on Reduction by Impact Machines

In processing cereals a grinding machine must be capable of adjustment in order to provide optimum treatment of the product. In milling wheat, for instance, the hardness of the wheat varies over a wide range, thus the grinding machine must be flexible in order to process the product efficiently. Adjustment in the amount of reduction was not a feature of the impact machine investigated, but it was found that the amount, type and condition of the material affected the degree of reduction.

Rate of Feed. To determine the effect of the rate of feed on reduction, wheat tempered to different moisture levels was fed into the machine at various rates. The reduced product was then sifted over an 18W sieve. It is shown in Table 1 that when the rate of feed is sufficient to overload the machine and slow the moving impactors the extraction is reduced. However, when the rate of feed is from three to 20 pounds per minute the amount of reduction remains nearly constant. The rate of feed used in subsequent experiments was approximately 10.6 pounds per minute at the head of the mill.

Type of Material. To determine the effect of different types of material on reduction by an impact machine, whole wheat, second break stock, sorghums, and soy beans were reduced and sifting tests were made. The results are shown in Table 2. Whole wheat is reduced less in one operation than is second break stock. The size of the material determines the amount of reduction. This is shown by the difference in overs of 12W between soy beans and sorghums. For this investigation the type of wheat was not a variable since the same lot was used through-

Table 1. Effect of rate of feed on the reduction of wheat. One passage through the impact machine.

Moisture content percent	Rate of feed lbs/min.	Throughs of 18W percent	Overs of 18W percent
18.0	43.0	2.4	97.6
18.0	11.0	7.5	92.2
18.0	9.8	6.3	93.1
18.0	8.9	7.5	92.5
18.0	8.1	7.0	93.0
18.0	3.0	8.0	92.0
16.2	30.0	8.0	92.0
16.2	25.0	7.5	92.5
16.2	20.0	9.0	91.0
16.2	15.0	9.5	90.5
16.2	10.0	11.0	89.0
16.0	43.0	7.0	93.0
16.0	13.0	10.0	90.0
16.0	10.1	12.0	88.0
16.0	7.5	12.0	88.0

Table 2. The effect of type of material upon the reduction of different grains by impact machines.

Type of material*	Percent of sample				
	Overs of 12W	Overs of 18W	Overs of 24W	Overs of 56GG	Throughs 11XX
Wheat	-	86.0	-	10.2	0.8
2nd break stock	-	42.0	-	39.5	7.4
Sorghums	31.9	-	49.8	11.8	1.1
Soybeans	69.4	-	17.1	8.8	1.3

* Moisture content 16 percent.

out this work.

Moisture Content and Tempering Time. Wheat is normally conditioned before processing to toughen the bran coat and mellow the endosperm. The influence of moisture content and tempering time on the amount of reduction by impact machine was studied. The reduced material was sifted and the percent overs 18W was calculated. Table 3 indicates that the extraction varies inversely with the moisture content of the wheat. The results for a four-hour and 22-hour tempering time were similar. The tempering time, as shown in Table 4, had little effect on the reduction when varied from two hours to 25 hours.

Utility of Impact Machines in the Break System

Reduction Obtained. To compare the grinding effect of impact machines to that of break rolls, each break roll was replaced by one impact machine (E), and the material obtained following each reduction was sifted. The results shown in Table 5 indicate that after four operations, 46 percent of the material was retained over an 18 wire sieve. The scalp sieves used in these millings were 16W, 20W, 16W and 18W.

To increase the reduction, two impact machines (EE) were substituted for each break roll. The results are shown in Table 6. The impact machines in series nearly duplicated the break rolls in the amount of reduction produced, but the appearance of the middlings separations indicated that the impact

Table 3. Effect of moisture content of the wheat upon reduction by impact machines.

Moisture content percent	Percent of sample over 18 wire Tempering time 4 hours	22 hours
11.3	73.0	74.8
12.0	75.7	-
14.0	84.6	85.2
16.0	87.0	87.5
17.0	88.8	89.2
18.0	90.4	90.0
19.0	91.1	91.6
20.0	91.6	91.6
22.0	92.8	93.7
24.0	93.9	95.3

Table 4. The effect of tempering time upon reduction by impact machines. Wheat tempered to 18 percent moisture.

Tempering time hours	Overs 18W percent
1	89.1
2	90.2
4	90.2
6	90.6
8	92.0
9	91.0
12	91.3
16	91.6
20	90.8
22	90.3
25	90.2

Table 5. Percentage reduction of wheat* after each operation with single impact machine**.

Treatment	Percent				
	Overs	Coarse midds	Medium midds	Fine midds	Flour
1st operation 1E	84.2	11	2	2	1
2nd operation 2E	68.0	22	4	4	2
3rd operation 3E	56.0	29	6	5	3
4th operation 4E	46.0	37	7	6	3

* Moisture content 15.5 percent.

** Results reported as percent of total original sample.

Table 6. Comparison of average particle size distribution of stock from rolls and double impact machines. Moisture content of original wheat 16 percent.

Treatment	Percent of total original wheat				
	Overs	Coarse midds	Medium midds	Fine midds	Flour
Rolls					
1st Break	65	26	4.0	2.0	2.0
2nd Break	39	44	6.5	4.5	5.5
3rd Break	16	58	10.0	7.5	8.0
4th Break	9	62	11.0	8.0	9.0
Impact machines					
1EE	64	25.5	3.5	2.5	4.5
2EE	33	44.0	6.0	5.0	11.0
3EE	11	63.0	7.0	6.0	12.0
4EE	5	66.0	8.0	7.0	12.0

machine produced more fine bran fragments than did the rolls. The distribution of mill fractions produced by each grinding method in the break system is shown in Fig. 1. It is noted that one impact machine in each operation did not reduce the material sufficiently if the action of the roll system is taken as a standard of comparison. However, when two impact machines were operated in series, the extraction approached that obtained by regular rolls. More break flour and coarse midds were obtained when using the impact machines, and the fine fractions contained considerable bran which is highly undesirable. The coarse scalp sieves used allowed large particles of endosperm to pass through the purifiers and at the same time, small fragments of bran passed through the coarse sieve openings. The impact machines did not clean up the bran sufficiently and thus a considerable amount of endosperm was scalped off into bran.

Chemical Analyses of Break Flours Produced. Chemical analysis of the various break flours obtained are shown in Table 7 and Fig. 2 which represents graphically the relation between the number of grinding operations and the ash content of the flour produced. This indicates that an excess of bran in the break flour was produced by impact machines.

Granulation of Break Flour Produced. To detect any noticeable differences in the granulation of the break flour produced by rolls and impact machines, the Roller Air Analyzer was used, employing 10-gram samples. The results shown in Table 8 indicate that the flours produced were of about the same granulation.

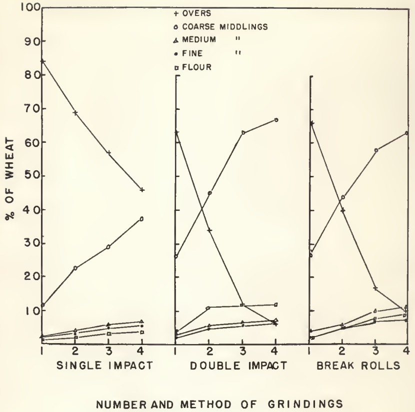


Fig. 1. A comparison of the results obtained in grinding by impact machine and break rolls in terms of yield of mill fractions.

Table 7. Average ash, moisture and protein content of break flour produced by roll and impact grinders.

Flour obtained from:	Percent of sample		
	Moisture content	Ash content	Protein content
Rolls			
1st Break	12.8	0.63	13.1
2nd Break	13.0	0.64	12.9
3rd Break	12.8	0.64	14.7
4th Break	12.6	0.72	17.4
Impact machines			
1EE	13.3	0.95	14.8
2EE	13.4	1.00	15.3
3EE	12.8	1.07	15.7
4EE	11.0	0.94	18.2

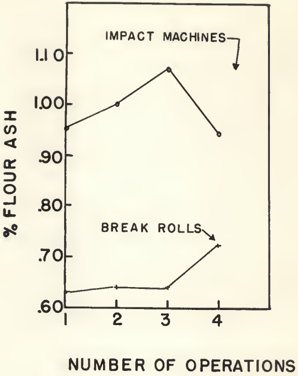


Fig. 2. Effect of impact and break roll grinding on the ash content of the flour fraction produced.

Table 8. Particle size distribution of break flour, determined by roller air analyzer.

Description of sample	Fraction particle size range microns	Time min.	Fraction Weight grams	Fraction Percent
1st Break roll flour	0-36	50	4.10	43.3
	36-56	30	4.09	43.1
	56-72	60	1.16	12.3
	72-115	-	0.13	1.0
Impact flour	0-36	60	3.61	39.3
1BE	36-56	50	4.40	48.0
	56-72	40	0.71	7.7
	72-115	-	0.46	5.0
2nd Break roll flour	0-36	60	4.49	47.2
	36-56	40	4.12	43.3
	56-88	10	0.90	9.5
	88-115	-	-	-
Impact flour	0-36	80	4.27	45.0
2BE	36-56	40	4.24	44.6
	56-88	10	1.00	10.5
	88-115	-	-	-

The impact machines may produce a more granular product as shown by this data.

Utility of Impact Machines to Supplement the Break System

Among the undesirable features in using impact machines throughout the break system were the incomplete reduction of large pieces of endosperm, as well as the incomplete separation of the endosperm from the bran, resulting in large amounts of endosperm passing over the sieves into bran. To alleviate this situation, the fourth break roll was used after the fourth impact operation.

The mill was operated using an alternating break system. After sufficient time had been allowed to insure normal operation, samples were obtained when break rolls were in use, and then when impact machines plus fourth break rolls were used in the break system. The fourth break rolls were used following the fourth impact operation. This resulted in cleaner bran and large amounts of middlings in the last operation. This was undesirable because the fourth break roll is essentially a clean-up roll and most of the endosperm should have been removed in the previous operations.

Chemical Analyses. Chemical analyses were made on these various stocks and are shown in Table 9. Figure 3 shows the ash and crude fat content of various classified mill streams produced by impact grinders and break rolls. The flour produced by

Table 9. Average chemical analysis of mill streams obtained from rolls and impact machines in the break system.

Sample no.	Treatment	Percent of sample: Moisture content	Ash content	Fat content	Fiber content	Protein content
Wheat	Wheat	16.0	1.50	1.17	4.12	10.85
1	1st break stock	15.9	1.63	1.16	3.50	11.0
2	Thru 1st break roll	16.6	1.56	1.21	3.09	10.7
3	2nd break stock	15.4	2.02	1.68	3.35	12.5
4	Thru 2nd break roll	15.4	2.46	1.72	3.61	12.8
5	3rd break stock	15.4	3.74	3.35	5.14	14.5
6	Thru 3rd break roll	15.0	3.08	3.53	5.47	14.4
7	4th break stock	13.5	5.76	4.54	6.66	14.9
8	Thru 4th break roll	13.5	6.05	4.83	8.47	15.0
9	Sizings stock	15.1	0.39	0.15	1.57	10.1
10	Thru sizing	15.4	0.39	0.42	1.62	10.1
11	1st tailings stock	14.1	1.66	2.93	3.58	11.6
12	Thru 1st tailing	14.2	2.01	1.90	3.00	11.7
13	1st midds stock	14.4	0.45	0.48	1.38	9.9
14	Thru 1st midds	14.7	0.45	0.53	1.35	9.9
15	Bran (rolls)	13.6	4.28	5.08	8.00	14.6
16	Shorts	11.6	2.38	5.07	5.54	15.6
17	Flour	13.5	0.48	0.63	1.23	10.3
20	1st Ent.1/ stock	15.9	1.51	0.67	2.49	10.8
21	Thru 1EE	15.9	1.54	0.84	2.56	10.8
22	2nd Ent. stock	15.8	1.68	0.96	2.76	11.2
23	Thru 2EE	15.4	1.73	1.51	2.84	11.2
24	3rd Ent. stock	15.1	1.76	1.54	2.89	11.8
25	Thru 3EE	15.2	2.24	1.44	3.28	11.5
26	4th Ent. stock	15.0	2.16	1.21	3.01	11.5
27	Thru 4EE	14.6	2.82	1.97	4.28	12.1
28	Thru 4th break roll	14.7	3.18	2.05	4.28	12.2
29	Sizings stock	15.4	0.46	0.34	1.19	9.9
30	Thru sizings	15.1	0.38	0.32	1.58	9.9
31	1st tailing stock	14.4	1.43	1.39	3.34	11.2
32	Thru 1st tailing	13.7	1.45	1.41	2.88	11.0
33	1st midds stock	14.6	0.43	0.37	1.28	10.0
34	Thru 1st midds	14.7	0.47	0.41	1.71	10.1
35	Bran	13.8	5.56	5.27	9.17	15.7
36	Shorts	11.6	6.29	3.93	5.84	13.6
37	Flour	13.3	0.53	0.44	1.97	10.2

1/ Impact machine

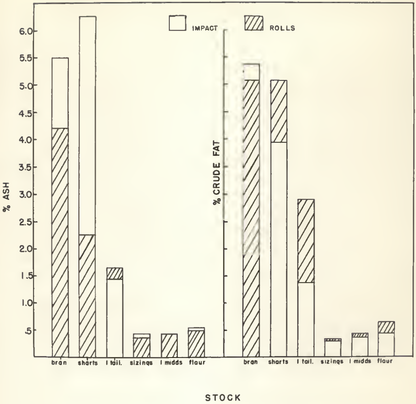


Fig. 3. Ash and crude fat contents of mill streams produced by (1) impact grinders and (2) break rolls in the break system.

using impact machines in the break system is higher in ash content and lower in fat content than flour produced by the normal method.

Baking Quality. The straight grade flours produced from these experiments were baked and the results are shown in Table 10. All flours show similar baking characteristics. The bread obtained from the impact method produced a slightly higher volume, but in general the baking quality was the same.

Utility of Other Types of Multi-Stage Impact Machines to Supplement the Break System

Other multi-stage impact grinders were tested. Type A was a machine containing 40 stationary impactors instead of 28. Type B machine was designed for higher extraction. It consisted of an additional row of stationary impactors on the inside of the first set of rotating impactors.

Reduction Produced. Grinding operations performed by different impact machines and rolls were tested by grinding wheat and separating the products by sifting.

The performance of these machines in terms of grinding efficiency, as estimated by separation of the ground wheat products, is shown in Table 11. The 40 stationary impactor machines (A) produced about the same extraction as the normal first break rolls. The machine that employed two rows of stationary impactors (B) produced about the same extraction as two standard impact machines in series. Using the impact grinders there

Table 10. Comparison of baking results of flour* produced by usual roll milling system with flour* produced when impact machines are used in the system.

Flour sample milled with	Absorption** percent	Mixing time min.	Loaf volume cc	Crumb color	Grain texture	Handling characteristics
Roll	57	4.5	658	88-cw	90-c	Bucky
Roll	58	4.5	650	90-cw	87-c	Bucky
Impact	58	4.5	670	88-cw	89-c	Bucky
Impact	60	4.5	695	86-cw	90-c	Bucky

* Chemical analysis as follows: ash, 1.50 percent; protein, 10.8 percent.

** 14 percent moisture basis.

Table 11. The effect of different type break machines on wheat at 16 percent moisture content.

Treatment	Percent of sample				
	Overs: 16W	Overs: 560G	Overs: 700G	Overs: 11XX	Throughs 11XX
Break rolls	71.6	20	3.8	2.3	1.7
8 standard milling impact machine in series	64.0	25.5	3.5	2.5	4.5
1 Impact machine A	70.0	17.1	2.1	1.8	2.2
1 Impact machine B	60.9	28.8	4.0	3.0	2.7

appeared to be too much good stock at the tail of the break system. Normally it is good milling practice to remove most of the middlings from the bran before it reaches the fourth break rolls. If the theory of breaking by bending action is correct the impact machine is more efficient on whole wheat and large particles due to the great lever arm produced. To get the maximum impact breaking effect and to remove most of the endosperm from the bran before it reaches the fourth break, a combination of impact machines and rolls was used in the break system. Two impact machines, BE (type B together with the standard type) were used in the first break. Two impact machines, AE (Type A and standard) were used in the second break. The normal third and fourth break rolls were used to reduce the large pieces of endosperm and clean up the bran before it reached the tail of the break system. This resulted in a very high extraction as shown in Table 12. Figure 4 shows the reduction graphically and indicates that most of the endosperm is removed by the time the stock reached the fourth break rolls. For these operations the following scalp sieves were employed: 18W, 26W, 30W, and 18W. This resulted in cleaner fractions and a better balance of the mill.

Chemical Analyses. The chemical analyses of the flour streams produced with the combination break system are shown in Table 13. Figure 5 shows a comparison of the quantities of different stocks produced by the two grinding systems, while in Fig. 6 the ash content of these various streams are compared. Figure 6 suggests

Table 12. Combination of impact machines and rolls in break system at 16 percent moisture content.

Type of grinder for each operation	Percent of total original wheat: Overs	Coarse middS	Medium midds	Fine midds	Flour	Percent* Flour ash
1 impact machine, Type B, 1 standard impact machine in series	62.0	24.4	4.9	3.9	4.5	1.12
1 impact machine, Type A, 1 standard impact machine in series	46.8	32.7	7.4	5.9	6.2	1.11
3rd break rolls	15.8	53.0	14.0	8.3	7.6	0.89
4th break rolls	9.7	56.3	15.7	8.8	8.0	0.70

* Percent of sample.

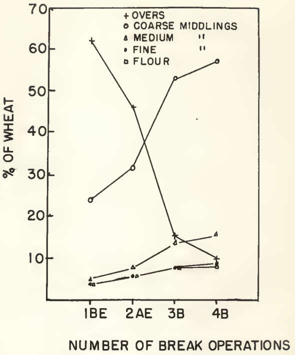


Fig. 4. Influence of a combination of impact grinders and rolls on the stock produced in the break system. The first break 1BE was a combination of two impact grinders (Type B and standard type). The second break 2AE employed Type A and standard type. The third and fourth break, 3B and 4B, were the conventional third and fourth break rolls respectively.

Table 13. Characteristics of flour streams obtained using break rolls in comparison with those produced by a combination of impact machines and break rolls in the break system. Wheat tempered to 16 percent moisture.

Break system: rolls only					Break system: impact machines and rolls				
	Percent of original wheat	Percent of sample				Percent of total original wheat	Percent of sample		
Mill stream		Moisture	Ash	Protein	Mill stream		Moisture	Ash	Protein
1st break	0.4	13.7	0.58	11.0	Impact 1BE	1.3	14.0	1.09	14.7
2nd break	1.0	14.7	0.53	12.0	Impact 2AE	1.2	14.1	1.15	14.7
3rd break	0.9	14.4	0.50	13.8	3rd break	0.8	13.5	0.70	12.6
4th break	0.7	13.6	0.86	16.0	4th break	0.6	13.2	0.85	15.6
1st tailings	2.6	13.2	0.65	13.3	1st tailings	3.0	13.4	0.67	14.0
2nd tailings	2.7	12.4	0.63	11.5	2nd tailings	1.8	12.8	0.58	11.7
Sizings	4.1	14.7	0.48	11.1	Sizings	8.2	14.1	0.49	11.8
1st midds	11.3	14.3	0.43	11.4	1st midds	11.2	14.0	0.46	11.5
2nd midds	13.2	14.1	0.38	11.3	2nd midds	16.5	13.8	0.39	11.2
3rd midds	7.0	13.6	0.41	12.2	3rd midds	9.1	13.5	0.53	13.0
4th midds	5.8	12.8	0.42	12.1	4th midds	7.5	13.0	0.44	12.0
5th midds	6.3	12.2	0.55	12.2	5th midds	5.8	12.7	0.53	12.3
Rebolt roll	7.6	12.7	0.68	12.5	Rebolt roll	7.7	12.4	0.75	12.7

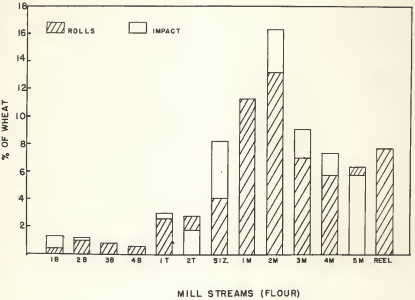


Fig. 5. Comparative quantities of various mill stream flours produced by conventional break rolls and with a combination of impact machines and break rolls in the break system.

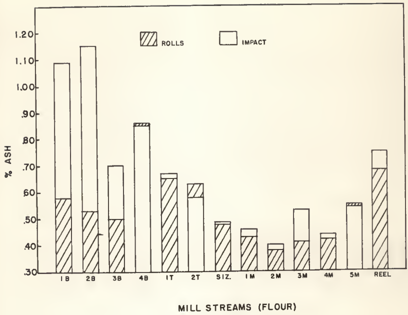


Fig. 6. Comparative ash content of various mill stream flours produced by conventional break rolls and with a combination of impact machines and break rolls in the break system.

that impact machines yield stocks with somewhat higher ash contents than those produced with the conventional break roll system.

Crude Fat of Mill Streams as an Index of Germ Content. Differences in mill streams at the tail end of the mill due to type of grinding in the break system were studied with particular reference to germ separation. The relative amounts of various mill streams at the reduction and tail end of the mill, produced with (1) conventional break rolls, (2) with impact grinders in the break system as well as with (3) a combination of both impact grinders and break rolls, are shown in Table 14, which also presents data for the moisture, ash, protein and crude fat contents of the various streams. Figure 7 shows graphically the relative amounts of these stocks produced by the various systems and Fig. 8 shows their crude fat content which is an index of the amount of germ present. These data indicate that better removal and recovery of the germ is obtained when using a combination of impact machines and rolls in the break system. The wheat should be tempered to 17 percent moisture content to obtain the best germ removal when using impact grinding.

DISCUSSION

Factors Affecting Reduction of the Material by Impact Grinders

It has been shown that the size, hardness, or the extent of injury to the particle affects the reduction obtained from an

Table 14. Comparison of stock in the reduction system when using different grinders in break system.

Break system	Mill stream	Percent of original wheat	Percent of sample: Moisture	Ash	Protein	Crude fat
Rolls	1st midds	25.2	14.9	0.51	11.5	1.09
	2nd midds	31.8	14.6	0.46	11.6	1.04
(16%	3rd midds	19.3	14.4	0.49	12.1	1.12
moisture	Sizings	29.0	15.3	0.52	11.9	0.81
wheat)	Brown sizings	14.2	15.1	1.42	12.1	1.77
	1st tailings	11.3	14.2	1.24	13.4	1.80
	2nd tailings	9.3	13.4	1.06	12.3	1.83
Impact	1st midds	35.2	14.0	0.55	11.4	0.92
machines	2nd midds	33.2	14.3	0.49	11.7	1.03
	3rd midds	23.8	14.3	0.62	12.8	0.92
(16%	Sizings	26.5	15.3	0.75	11.9	0.89
moisture	Brown sizings	30.8	15.5	1.71	12.5	1.98
wheat)	1st tailings	20.8	14.0	1.55	12.8	1.94
	2nd tailings	19.0	13.5	1.18	12.7	1.67
Combination						
impact ma-	1st midds	34.5	15.1	0.64	11.8	0.84
chines &	2nd midds	37.7	14.7	0.52	11.6	0.76
rolls	3rd midds	22.3	14.6	0.66	12.7	0.93
	Sizings	40.3	15.6	0.64	11.4	0.38
(17.4%	Brown sizings	24.8	15.6	1.98	12.4	2.00
moisture	1st tailings	16.4	14.3	1.87	13.4	2.42
wheat)	2nd tailings	10.2	13.5	1.54	12.9	2.03

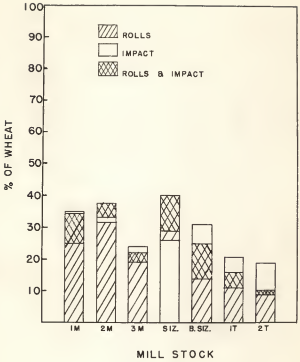


Fig. 7. Comparative quantities of mill stock produced by (1) break rolls, (2) impact machines, and (3) combination of impact machines and break rolls in the break system.

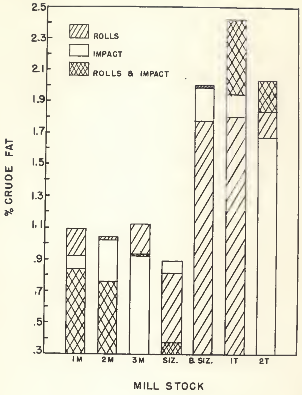


Fig. 8. Comparative crude fat content of mill stock produced by (1) break rolls, (2) impact machines, and (3) combination of impact machines and break rolls in the break system.

impact machine. The amount of reduction varied inversely with the moisture content of the material. Hard red winter wheat should be tempered to about 17 percent moisture content for satisfactory reduction by the impact grinder used in this study. The tempering time, however, (two to 25 hours), did not affect the amount of reduction obtained at an 18 percent moisture level.

Definite changes in extraction were obtained when the working parts of the machine are altered. The impact machine (Type B), which employed two sets of stationary impactors, reduced the wheat as much in one operation as did the standard impact grinder in two operations. The desired reduction is therefore best accomplished by such changes in the working parts of the machine, since the rate of feed has been shown to have very little effect upon the amount of reduction.

Performance of Impact Machines in the Break System

In judging the performance of the impact grinder in the break system it is essential to study the physical characteristics of the reduced material. The classification of the ground material is done by sieves and air currents and depends on difference in particle size and particle shape. Evaluation of a grinding process must therefore take into account particle size distribution and the shape of the particle. These factors directly influence the quality of the product. In the present studies, the classification system was fairly constant, and only a few changes were made in the scalp sieves in the break sifters normally used in roll grinding. The sifting and classification system was essentially that designed for material reduced by rolls, and therefore it is not known what further improvements in the products from impact grinding could have been affected, if this important factor had also been studied.

Effect on Physical Characteristics. The standard impact machines, operating two in series, reduced the bran more than did the rolls. This resulted in smaller pieces and greater quantities of bran in the sizings, middlings, and flour separations. On the other hand, the impact machines did not reduce the endosperm as much as did the rolls. As a result, large portions of endosperm were carried over to the tail of the break system. This is undesirable because material from the tail of the break system usually goes to streams of inferior quality. A series of photographs were taken of the different separations produced by rolls and impact machines.

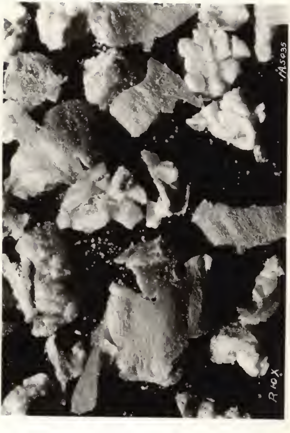
The action of first break rolls upon the wheat is demonstrated by Plate III, the photograph shown being of the scalp stock of first break rolls. The bran coat appears to be torn apart and the endosperm fractured into small pieces. The wheat product of impact machines is shown in Plate IV. There is little fracture of the endosperm, while the bran appears rounded, indicating that the endosperm is freed from the bran coats by a blow or impact. The sizing stock produced by break rolls is shown in Plate V. This fraction is composed chiefly of

EXPLANATION OF PLATE III

The scalp stock of first break rolls.

Magnified 10 times.

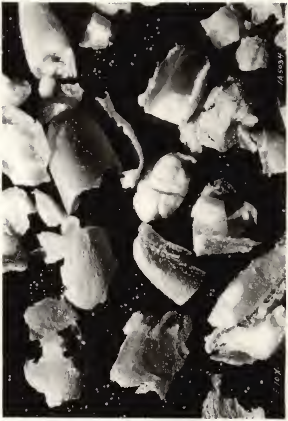
PLATE III



EXPLANATION OF PLATE IV

The scalp stock of the first impact operation. Magnified 10 times.

PLATE IV



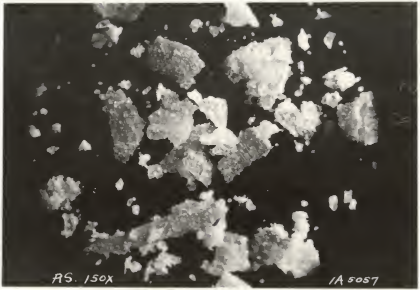
EXPLANATION OF PLATE V

The sizings stock produced by break rolls.

Magnified 10 times.

150

PLATE V



large portions of endosperm and some bran not removed by the purifiers. The sizings produced by the impact machines, as shown in Plate VI, is similar to the roll stock. However, more bran fragments appear in this separation than that from rolls.

A comparison of the middlings produced by impact and rolls is shown in Plates VII and VIII. Not much difference is evident from the photograph, although the middlings produced by impact machines do contain more bran fragments.

A comparison of the flour produced by roll and impact machines is shown in Plates IX and X. These photographs are magnified 600 times and no difference is evident. These flours are shown magnified 1,500 times in Plates XI and XII. Again no difference is apparent. Analysis of the break flours for granulation also showed no differences.

The bran obtained from break rolls is shown in Plate XIII. It is evident that the bran is flattened and that the endosperm had been removed from it by a scraping action. Bran obtained from impact machines is shown in Plate XIV. Here the bran is rounded and the endosperm is still attached to a great extent. There appears to be insufficient separation of the endosperm from the bran by this method.

Increased extraction was produced by the use of Type A and B impact machines in series with the standard impact machine. Type B and the standard machine were used in the first operation and Type A and the standard machine were used in the second break operation. Type A machine was employed in the third break

EXPLANATION OF PLATE VI

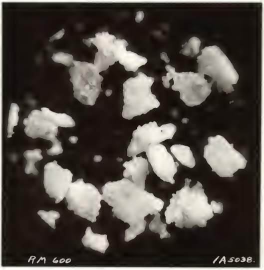
The sizings stock produced by impact machines. Magnified 150 times.

PLATE VI

EXPLANATION OF PLATE VII

The middlings stock produced by break rolls. Magnified 600 times.

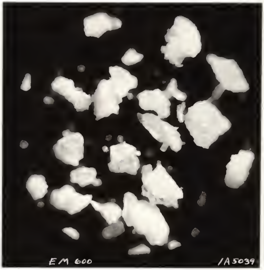
PLATE VII



EXPLANATION OF PLATE VIII

Middling stock produced by impact machines
Magnified 600 times.

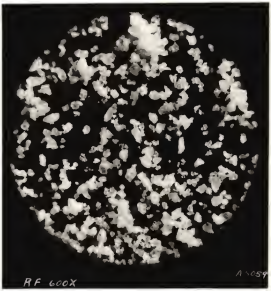
PLATE VIII



EXPLANATION OF PLATE IX

Break flour produced by rolls. Magnified 600 times.

PLATE IX



EXPLANATION OF PLATE X

Break flour produced by impact machines.

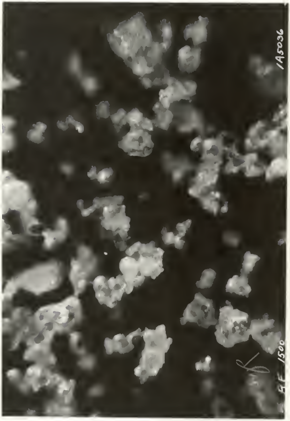
Magnified 600 times.

PLATE X

EXPLANATION OF PLATE XI

Break flour produced by rolls. Magnified 1500 times.

PLATE XI



EXPLANATION OF PLATE XII

Break flour produced by impact machines

Magnified 1500 times.

PLATE XII

EXPLANATION OF PLATE XIII

Bran produced by break rolls. Magnified 10 times.

PLATE XIII

EXPLANATION OF PLATE XIV

Bran produced from impact machines

Magnified 10 times.

PLATE XIV

operation while two standard impact machines were used in the fourth break operation. The bran was reduced to about the same extent as before and more endosperm reduction was obtained. The bran produced by this combination of impact machines is shown in Plate XV, and is shell-like in appearance, with some endosperm still attached to the bran.

To obtain a better balanced mill and to remove most of the endosperm before the fourth break operation, rolls were used in the third and fourth break operation. A photograph of the bran obtained from this combination of impact machines and rolls in the break system is shown in Plate XVI. There appears to be a small amount of endosperm attached to the bran. Some of the flat pieces of bran have been cut and scraped by rolls, but the shell-shaped pieces of bran appear to be the products of impact action.

It would be desirable to remove the free bran from the system after each reduction, but in the impact process the bran remained in the system and was continually subjected to further grinding action. This could account for some of the small bran fragments.

Effect of Impact Grinding on Product Quality. Whenever impact machines were employed in the break system a break flour high in ash was obtained. This also caused a straight grade flour to be slightly higher in ash. This indicates that more fine bran fragments are produced by impact machines than by rolls and that the separation system used for roll grinding cannot remove them.

EXPLANATION OF PLATE XV

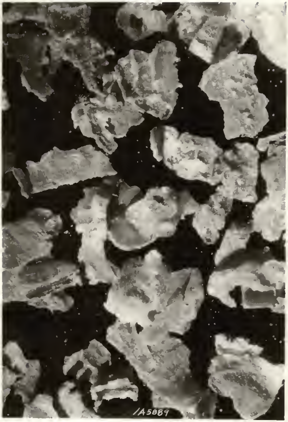
Bran produced with impact machines in the break system. BE, AE, A, EE. Magnified 10 times.

PLATE XV

EXPLANATION OF PLATE XVI

Bran produced by a combination of impact machines and rolls in the break system. BE, AE, 3B, 4B. Magnified 10 times.

PLATE XVI



There was no important difference in the protein content of flours produced by the two methods. The baking quality of the flours from either method was similar.

The impact machine excelled the rolls in germ removal. Crude fat analysis indicated flour produced by using impact machines in the break system contained less fat than flour produced by the normal process. The impact action evidently freed the germ in larger portions than did roll grinding and consequently, the germ was classified into fractions of large size and was scalped off into the brown sizings and tailings stocks. This is a distinct advantage over the conventional process.

SUMMARY AND CONCLUSIONS

In impact breaking the total force received by the particle to be reduced will be sufficient to press it beyond its elastic limit when it is rapidly decelerated or accelerated. When the particle is struck by a high velocity impactor, force will be exerted on the contact area of the particle. This will produce moments and create lines of compression and tension in the particle. If the force is sufficient, the material will break. As the particle becomes smaller the moment arm decreases, and it will take more force to break the material.

The bran layers composed of long flexible cells, if properly conditioned, will tend to hold together and bend. The starchy endosperm granules are more spherical and will fracture more easily. The bond holding the bran layers to the endosperm is less than the forces which cause the bran layers to adhere. Thus an impact action may cause the two to separate.

The experimental work has shown that several factors affect the reduction of the material. The type of material will affect the amount of reduction obtained. The amount of reduction varies inversely with the moisture content, but length of tempering time has little effect (two hours to 25 hours). The working parts of the machine affect the reduction of the material. An increase in the amount of reduction obtained by a grinder does not necessarily make it a better machine, since the reduction must also be accomplished in a manner which will facilitate the separation and classification of the reduced material. The use of impact machines in the break system complicated the separation and classification problem. The classification equipment used in these experiments was not adapted to impact grinding, thus fine bran particles were distributed throughout the separations. This resulted in flour of higher ash when impact machines were employed in the break system.

The action of the impact machines released more whole germ as indicated in an increase of crude fat content of the brown sizings stream. The flour produced when using impact machines in the break system was lower in fat content, indicating more germ removal.

The baking quality of flour produced using impact machines in the break system compared favorably with that observed with break rolls.

In view of the present work the following recommendations are made for the most efficient use of these impact machines in the break system:

1. The wheat should be tempered to approximately 17 percent moisture content. This will result in less fracture of the bran coat and is helpful in releasing the germ.

2. The clean bran fragments should be taken out of the system after each operation. It is desirable to remove the bran as soon as it has been freed of endosperm.

3. The classification of middlings must be more efficient than can be obtained on the separation system of a conventional

mill. The middlings that contain bran fragments should be separated into different fraction sizes, which can be cleaned by employing the principle of the difference in the physical shape of bran tissue and endosperm chunks. Thus, the bran fragments could be removed before the middlings are reduced to flour.

4. The break flour must be kept at a minimum. The break flour could be cleaned by the use of air to remove bran fragments which differ from the flour particles in size and shape, but this would be a costly process. Perhaps a static charge could be put on bran fragments that differed from that on endosperm particles, thus making separation by magnetism possible.

An impact machine, to be used efficiently, should be provided with a means of varying the amount of reduction. Thus, the amount of reduction in a single operation could be controlled to obtain the most efficient processing of the material. In the break system this would mean the reduction would be set to obtain maximum coarse middlings and a minimum of break flour without excessive breaking of the bran. Different mill stocks vary in their grinding requirements for satisfactory reduction.

It is possible that a number of the impacts received by the material as it passes through a multi-stage grinder do not break the material but cause only bruising, fracture, or chipping of the bran coat. This action would tend to produce fine bran fragments and energy would be used unproductively.

Perhaps the single stage impact grinder would be the most efficient machine, since if a machine produced a single impact with sufficient force to yield the required reduction, less energy would be wasted and less bran fragments would be produced.

ACKNOWLEDGMENTS

The author wishes to thank Dr. J. A. Shellenberger, Head of the Department of Milling Industry, not only for direction and supervision of this investigation, but also for helpful suggestions in the preparation of this thesis. The author is also grateful to Professor R. O. Pence, Department of Milling Industry, for cooperation and assistance in the sampling and operation of the mill, to Donald C. Abbott who was responsible for most of the chemical analyses, to Professor J. H. Robert, Department of Applied Mechanics, for helpful suggestions in presenting the theory, to Dr. Max Milner for helpful suggestions in the final preparation of this thesis, and to the Safety Car Heating and Lighting Company, Inc., New Haven Connecticut, for equipment and financial assistance which made this work possible.

LITERATURE CITED

Johnson, John A., C. O. Swanson and E. G. Bayfield.
The correlation of mixograms with baking results.
Cereal Chem. 20:625. 1943.

Kozmin, Peter A.
Flour milling. Translated from the Russian by M. Falkner and Theodor Fjelstrup. London. George Routledge & Sons., Ltd. pp. 582. 1921.

Smith, Leslie.
Flour milling technology. Liverpool, England. Northern Pub. Co., Ltd. pp. 568. 1945.