10

# ROLL DIAMETER AND SPEED - THEIR EFFECTS ON FIRST BREAK GRINDING OF WHEAT

by

FLOYD FRANCIS NIERNBERGER

B. S., Kansas State University, 1955

914

---

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Flour and Feed Milling Industries

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1966

Approved by:

E. J. Farrell
Major Professor

TABLE OF CONTENTS

# INTRODUCTION

The objective of this experiment was to find the influence of certain variables on first break grinding of wheat, measured in terms of milling results.

The initial selection of a procedure for first break grinding is a logical approach to flour mill break roll grinding investigations. The milling process is such that interdependency of the entire system exists. The first break roll grinding action is the first process in the milling flow and its effect upon the product obtained is spread throughout the system. In this regard, removal of the product from the first break rolls for critical analysis requires careful evaluation. Results cannot be considered as either positive or negative in totality, without regard for the arrangement it occupies in the flow. The functioning of the first break rolls as a part of the total manufacturing process of flour from wheat must be the final criteria. However, it is valid to isolate and investigate the various factors applicable to improvement of break roll grinding operations through selective testing procedures, if results are presented within the system's boundaries.

In modern milling, the manufacture of acceptable white flour requires the separation of the bran and germ from the endosperm. The extent to which this can be done is usually measured by the ash content of the final flour. The usefulness of the ash content test as an indication of the degree of product separation, lies in the knowledge that the outer layer of the wheat kernel (bran and germ) contains significantly more ash than the interior (endosperm) of the kernel.

The break roll grinding process in milling is designed to open the wheat kernel with a minimum of shattering of the outer layers and to scrape out the endosperm. The position of the first break rolls in this system of normally five breaks, is that of the rolls first coming in contact with the relatively whole kernel. Modern mills today, use a prebreak impact machine arrangement to facilitate insect infestation removal and the wheat kernel may be somewhat altered upon arrival at the first break rolls. However, the first break designation is still applicable to the rolls in regard to opening up the wheat kernel to permit separation of the outer layer or skin from the endosperm.

The variable factors in first break roll grinding that were tested in this research were: (a) wheat class, (b) roll diameter, (c) roll speed. Three levels of each factor were tested. All other known variables were held constant or contained within the experimental error design of the experiment. The development of methods and techniques to evaluate the research data in terms applicable to milling results is described under the section titled Materials and Methods.

## REVIEW OF LITERATURE

The function of the first break rolls in the milling of wheat into flour is primarily directed toward opening the wheat kernel. A prerequisite to experimentation in this area is a knowledge of the structure of the grain. Detailed descriptions and pictures of the botanical structure of the wheat kernel and parts of the wheat kernel were presented in articles by Bradbury et al. (7). A complete summary of current knowledge on the subject was covered by MacMasters et al. (20, Chap. III). The authors listed the major parts of the wheat kernel as follows: Pericarp (outer and inner); Seed coat and pigment strand; Nucellar epidermis; Aleurone layer; Starchy endosperm; and Germ.

The aleurone cell layer is the primary division point when separating bran (composed of all outer structures of the kernel inward to, and including this layer) from starchy endosperm in the break roll process. Senti and Maclay (36) have observed:

> Because the aleurone layer is the outermost layer of the endosperm as well as the innermost layer of the bran, there is no natural line of cleavage between starchy endosperm and bran. Irregularities in the junction between the aleurone layer and starchy endosperm contribute to the difficulty of a clean separation of the two. Moreover, cell walls must be broken to accomplish the separation.

Measurement of the thickness of the aleurone cell layer has been the subject of several investigations. Crewe and Jones (10) reported that the range of thickness was 32 to 55 microns, with an average of 46 microns for 3 English and Canadian wheats. Larkin et al. (26) found a thickness range of 46.0 to 56.8 microns for 3 Pacific Northwest wheats. Bradbury et al. (7) reported a range of 37 to 65 microns in thickness, with an average of 46.9 microns for Pawnee wheat.

It was stated that the proportion of bran in a kernel of wheat is more affected by variety than environment (20, p. 67). It was further noted that the effect of bran thickness is negligible on the amount of flour extraction from the kernel. No correlation was found between thickness of either the entire bran or of any one of its layers and the milling quality of 7 varieties of Pacific Northwest wheat (26).

Additional difficulties in separating bran from endosperm are evident when viewing the pictures Hanssen (33, pp. 11-17) made using micro-photograph techniques. The oval form of the kernel in combination with the depth and length of the crease does not permit easy removal of the outer layers of the bran. The crease and hairs on the brush end form a barrier to ready cleansing of dust and fine debris from the kernel. Natural endosperm cell formation growth develops thicker cell walls in the aleurone layer area than in cells closer toward the kernel's interior.

Knowledge of the chemical composition of wheat kernel structure permits evaluation of flour milling techniques by various methods. Comparison of the ash content of different mill streams has been used as one method of determining efficiency of separation between bran and endosperm in the milling process (14,47). The Mohs' curve or cumulative ash curve is the most popular of the ash index methods and its history and use is described by Will (33, pp. 39-46). The development of the cumulative ash curve was made possible by the variation in the ash content of various parts of the wheat kernel. Ash content analysis of the interior of the endosperm has been reported to be in the range of 0.27 to 0.42 percent (19,20,23,33). The ash content of bran was found to range from 7.9 to 8.6 percent (23) and from 5.3 to 9.5 percent (20). The wide difference in ash content of the bran and endosperm (approximately 25 times) allows the detection of small portions of bran in endosperm samples from the various mill streams.

## Factors Affecting First Break Roll Grinding

Class and Variety of Wheat. It has been reported that different classes and varieties of wheat vary considerably in both physical and chemical composition (7,10,19,20,23,26).

Swanson (41) stated that ash content variation in wheat kernels is due primarily to the type of growing season, type of soil used during growth, and wheat variety.

This composition variation of the wheat kernel between classes and varieties can affect the comparison of milling results when using ash content percentages as means of evaluation.

Conditioning or Tempering. Conditioning of wheat is an important aid in the removal of endosperm from bran. Basically, the purpose of conditioning in this regard has been twofold. First, moisture is applied to toughen the bran in order for it to resist abrasion and attrition in the milling process. Second, it allows the outer layers of the kernel to be removed in large pieces and mellows the endosperm pieces for easy reduction into flour in later processes.

Bradbury *et al*. (8) in a comprehensive survey of literature on the subject, defined the various types of wheat conditioning. These were as follows: cold conditioning (commonly called tempering, in which the effects of moisture and time are accomplished without heat addition), warm conditioning (the effects are accomplished in conjunction with heat at grain temperatures not exceeding 46 degrees Centigrade), and hot conditioning (where the effects are reached in conjunction with heat at grain temperatures in excess of 46 degrees Centigrade). There are numerous methods in each of the 3 classifications.

The method of conditioning depends on the properties of the wheat to be conditioned, on the type of mill, and the capabilities of the mill operator. Recommendations as to the desirability of a specific conditioning method are conflicting.

Recent research by Eustace (13) indicated that a method of cold conditioning was the safest way to lower ash content of the flour without affecting flour yield or quality. The selection of a tempering or cold conditioning method for investigating grinding effects is in general agreement with the conditioning review literature (8).

Temperature and Humidity. To some extent, the effect of elevated temperatures on the physical properties of wheat can replace those of moisture (20, p. 168). An increase in the period of temper of Hard Winter wheat caused an increase in the amount of first break release. When, however, the tempered wheat was warmed and fed to the break rolls at 100 degrees F., 3 hours' wait between tempering and milling produced the same level of break release that followed 24 hours' wait at ordinary temperatures. The normal and more economical procedure would be adjustment of break release through roll clearance movement.

Swanson (42) in a review of atmospheric control in flour mills, states that a controlled humidity is essential to the best conditions of milling.

The optimum level of atmospheric control is not indicated for the break roll process, but Anderson (2) reports that controlled relative humidity and temperature would reduce the effects of various climatic factors on the milling process.

## Technical Details of First Break Rolls

Descriptions of break roller mills are given in various milling textbooks (24,27,35,37). The arrangement of the rolls is quite diverse. However, 2 styles are prevalent (24,37) in modern flour mills: American (two pairs of rolls arranged in a horizontal plane), and European (each of two pairs of rolls arranged in a diagonal plane at an angle of 45 degrees from the horizontal).

The roll factors considered important in affecting operation of break rolls are: diameter, speed, differential, clearance between facing rolls, corrugation, and feed rate (4). Additional factors such as roll temperature, roll hardness, roll pressure, heat dissipation, tramming, and dynamic balancing are related to the primary factors and are usually controlled by adjustments or equipment design.

Roll Diameter. Roll diameters vary from 6 to 10 inches in the United States with 9 inch diameter rolls being the most popular size (5,51).

European roll diameters are usually 10 inches (35,50). A diameter of approximately the same size may be designated as 250 millimeters (mm) in some of the literature (4,25).

Kozmin (25) developed a series of mathematical equations that when solved for roll diameter indicates that the diameter of break rolls affects the number of grinding actions performed on a particle passing through the rolls. With all other factors held constant, a larger diameter roll would permit more grinding actions by the roll corrugation than a smaller diameter roll. In actual processing methods, the number of grinding actions is usually increased through use of other factors that are less expensive than increasing roll diameter, which requires use of a greater amount of metal, increased roll support strength, and higher cost of shipping and installation.

Roll Speed. Roll speed or velocity is expressed in revolutions per minute (rpm) of the fast roll in milling literature. However, differences in roll diameter will affect the velocity of a point on the periphery of the rolls at a constant rpm. The rapidity of movement of this point on the surface of the roll is called the peripheral or circumferential speed. It is a method of expressing speed where roll diameter is not designated or for comparison purposes. A common unit used for peripheral speed is feet per minute (fpm).

Investigators (5,21,51) report break roll speed in the United States as generally standardized for 9 inch diameter rolls at 500 rpm (1,178 fpm). But, variations in break roll speed have been mentioned that include speeds that range from 1,060 to 2,093 fpm (3,35,46). European textbooks (27,34,37) list normal break roll speed for 10 inch diameter rolls as 350 rpm (916 fpm). Youdale (50) in a recent summary of equipment design, indicated speeds of 450 rpm for 10 inch diameter rolls were presently being used in England.

Kozmin (25) used mathematical equations to express the view that the absolute speed of the rolls will not affect the number of grinding actions of the corrugations on the material passing through the rolls, provided diameter, corrugation design, differential, and clearance remain the same.

Wolff (49) has published information which states that increasing the roll speed with all other factors held constant, will have no milling value benefit as long as rolls are above effective maximum capacity.

Roll Differential. The normal roll differential for break rolls is generally accepted as being 2.5 to 1 (5,22,27,35,46,51). Wolff (49) stated that mathematical analysis of roll factors shows that the optimum differential is 2.5 to 1.

A comprehensive study of 5 roll differentials was conducted by Pence (31). The 1.5 to 1 roll differential on first break grinding released stock of the lowest ash content but the quantity of release was small. It appeared that the 2.5 to 1 roll differential was the most satisfactory in all aspects, but the author did not indicate any specific conclusions as to preference for a specific roll differential.

The data in the report of the experiment conducted by Pence was evaluated by Kozmin (25). Kozmin stated that only general conclusions could be drawn from the study due to methodology faults in the experiment design. Pence had kept the speed of the fast roll constant and obtained differential changes using varying slow roll speeds. Thus a greater numerical force effect by the corrugation design on the grain occurred at the higher differentials when compared to the lowest differential, using Kozmin's equations. The difference in corrugation effect force led Kozmin to suspect higher ash content of the break flour at higher roll differentials because of bran pulverization (25).

Roll Clearance. Roll clearance or gap is the opening between paired break rolls. The distance of this opening influences the grinding action that will occur on passage of wheat kernels between the rolls.

Recommended settings for roll clearance are determined by the quality of the product after roll passage rather than a specific distance (5,27,30). The reason for this type of recommendation is that the variation in wheat structure, hardness, and size do not permit a constant distance as a guide to ordinary break roll operation. These settings are called break extractions and noted in percentage of product passing through a specified sieve. The means of determination involves placing a sample of known amount of the product on a selected size sieve and through use of a circular motion on the sieve for a period of time separating the product into two portions. The portion of product passing through the sieve is referred to as the percentage of break extraction. The conventional number of meshes used on the sieve cloth for the first break roll clearance setting ranges from 16 to 22 (5).

The amount of break release desired at the first break roll for an individual mill should be analyzed through the method outlined by Roethe (33). With the amount of break release obtained through the method described, the rolls are adjusted inward or outward, changing the roll clearance to yield the amount of break release desired.

Roll Corrugation. The milling term, roll corrugation, consists of many factors that contribute to the cutting operation performed by the break rolls. These factors are: (a) angle of cut, (b) depth of cut, (c) shape of cut, (d) hardness, (e) angle of spiral, (f) number of corrugations.

The first 3 factors are usually specified through use of the name of a particular corrugation (5), although variation will occur due to the type of cutting die in use at different machine shops. In break roll grinding, there are in general use, 2 main types of shape of cut. One, is a straight line cut with variation in the forward and rear angle according to differing specifications. The second, is a cut of unsymmetrical shape with either a blunted or rounded leading angle (5). It was reported by several authors (5,32) that the rounded lead angle type of cut had a less severe action on the wheat kernel with a resulting decrease in the ash content of the product through the first break scalp sieve. Dedrick (11) states it is difficult to theoretically design a universally correct corrugation style due to the variation in size of the wheat berry and its position when feeding into the roll gap.

The hardness of the corrugation on break rolls is not always uniform according to studies by Essmueller (12). This apparently was due to roll manufacturing difficulties, but new processes have corrected this variation.

Break roll corrugations are cut on an angle of spiral ranging from 0.375 to 0.875 inch per linear foot (5). One half inch per foot is the accepted standard in the United States for milling of hard wheats (21). European angle of spiral on the first break roll will range from 0.8 to 1.2 inches per linear foot (4). The degree of spiral influences the grinding or cutting action of the rolls similar to the differential effects (25).

The number of corrugations on a first break roll are normally 10 to 12 per inch (5,21,27,35,51). The average size of the wheat kernel to be ground seems to be the determining factor in the selection of the number of corrugations (21).

The majority of the types of corrugations used on break rolls are unsymmetrical (5). Thereby, the use of paired rolls actually permits 4 kinds of grinding operation with differing action by the corrugation. These methods of operation are identified according to the position of the corrugation lead angle and the designation of which roll is the fast roll. The four methods are: (a) dull to dull, (b) sharp to dull, (c) dull to sharp, (d) sharp to sharp (5). Break roll operation in the United States is usually dull to dull (5,22,51).

Heide (18) reports that the grinding force is greater for sharp to sharp facing than dull to dull at the same speed and differential. This grinding force effect is usually referred to as severity of action.

Dedrick (11) recommended running break rolls dull to dull for most hard wheats. This recommendation was based on results of tests that used short pieces of soft metal passed through the rolls. As the function of the break rolls is thought to consist of gently opening and folding back the exterior of the wheat kernel, undue shattering of the metal pieces inserted prior to the rolls into small particles after passage indicated too severe an action. Using the number and size of the metal particles as a criteria of proper roll corrugation resulted in the dull to dull advice.

Roll Feed Rate. The capacity of a roller mill is in effect characterized by the amount and quality of the stock produced.

Theoretical physical amounts of throughput attainable by roller mills have been computed by several authors. Scott (35) reported that for 10 inch rolls with 2.5 to 1 differential and a fast roll speed of 350 rpm, the amount of wheat handled could be as much as 4.45 pounds per minute per inch of contact roll surface. Speight (39) states a figure of 4.77 for similar conditions, with a maximum of 10.94 pounds per minute per inch of contact roll surfact at the fast roll speed of 800 rpm.

European mills report actual operating capacities that range from 0.5 to 1.5 pounds per minute per inch of first break roll contact surface (27,35,50).

Capacity of mills in the United States is greater, ranging from 1 to 2.5 pounds per minute per inch of first break roll contact surface (5,29,43, 51). The larger capacity is due primarily to better quality of wheat, its type of conditioning, higher roll speeds, and the position of roll mounting

(24,35).

Much larger roller mill capacities which ranged from 7.0 to 8.11 pounds per minute per inch of first break roll contact surface were reported by Speight (39) as occurring in Russia and Czechoslovakia. Better feeding arrangements of wheat to the rolls and high roll speeds are said to be responsible for this capacity.

Pratique has developed a system of feeding the rolls that is reported to increase the capacity to 8.02 pounds per minute per inch of roll contact surface (39). Wolff (48) reports that although the Pratique system is attempting to reach the theoretical load of 10.1 pounds per minute per inch of roll contact surface, available information indicated actual effective rates near normal United States roller mill capacity.

Gehle (16) published photographs showing wheat feed rates of 1.85 and 4.6 pounds per minute per inch of roll contact surface on first break rolls. Visual appearance indicates a large amount of roll space clear from wheat kernels even at the largest load. Quality results of the products are not given for either of the feed rates nor are conclusions as to effectiveness of the rolls at these capacities stated.

Moog reportedly has stated (48) that high feed rates increase the temperature problem in milling, due to rolls' heating. Water cooling of rolls is a means to reduce this difficulty. Little information is available on the actual use of water cooled break rolls, although it was reported that the early Bellera process (3) involved water cooled rolls.

# MATERIALS AND METHODS

The wheats used in this research study were selected from wheats available in storage facilities at the Kansas State University Pilot Flour Mill. Three classes of wheat were obtained and consisted of the following: Hard Red Winter, Hard Red Spring, and Soft Red Winter. The wheats were analyzed and evaluated prior to experimentation. Standard measurements were used to indicate the characteristics of each class of wheat. The results from this testing is shown in Table 1 below.

Table 1. Analyses of the wheats used in the research study.

| | Class of wheat | | |
|---|---|---|---|
| | Hard red winter | Hard red spring | Soft red winter |
| Test weight (lbs./bu.) | 61.9 | 61.9 | 62.2 |
| Pearling value (%) | 75.0 | 68.5 | 51.5 |
| 1000 kernel weight (gms.) | 22.6 | 32.6 | 27.0 |
| Wheat size | | | |
| Over 7 W (%) | 31.5 | 75.0 | 66.0 |
| Over 9 W (%) | 66.0 | 24.0 | 31.5 |
| Over 12 W (%) | 2.5 | 1.0 | 2.5 |
| Moisture (%) | 11.7 | 11.8 | 11.8 |
| Ash (%)* | 1.7 | 1.7 | 1.6 |
| Protein (%)* | 12.5 | 12.7 | 10.0 |

* 14.0 % moisture basis.

## Cleaning and Sample Preparation

Cleaning of wheats preparatory to analysis and sample make-up were done by passing the wheats through the cleaning facilities of the Kansas State University Pilot Flour Mill cleaning house (Fig. 1). The wheat cleaning equipment of the Pilot Flour Mill consisted of a permanent magnet, pneumatic lift aspirator, milling separator, dry stoner and gravity separator, disc separators for oat and cockle, Entoleter scourer aspirator, and duo-aspirator. The flow rate through the cleaning operation was 60 pounds per minute with the equipment adjusted for optimum performance at that rate.

## Schematic Flow of Kansas State's Grain Cleaning Facilities

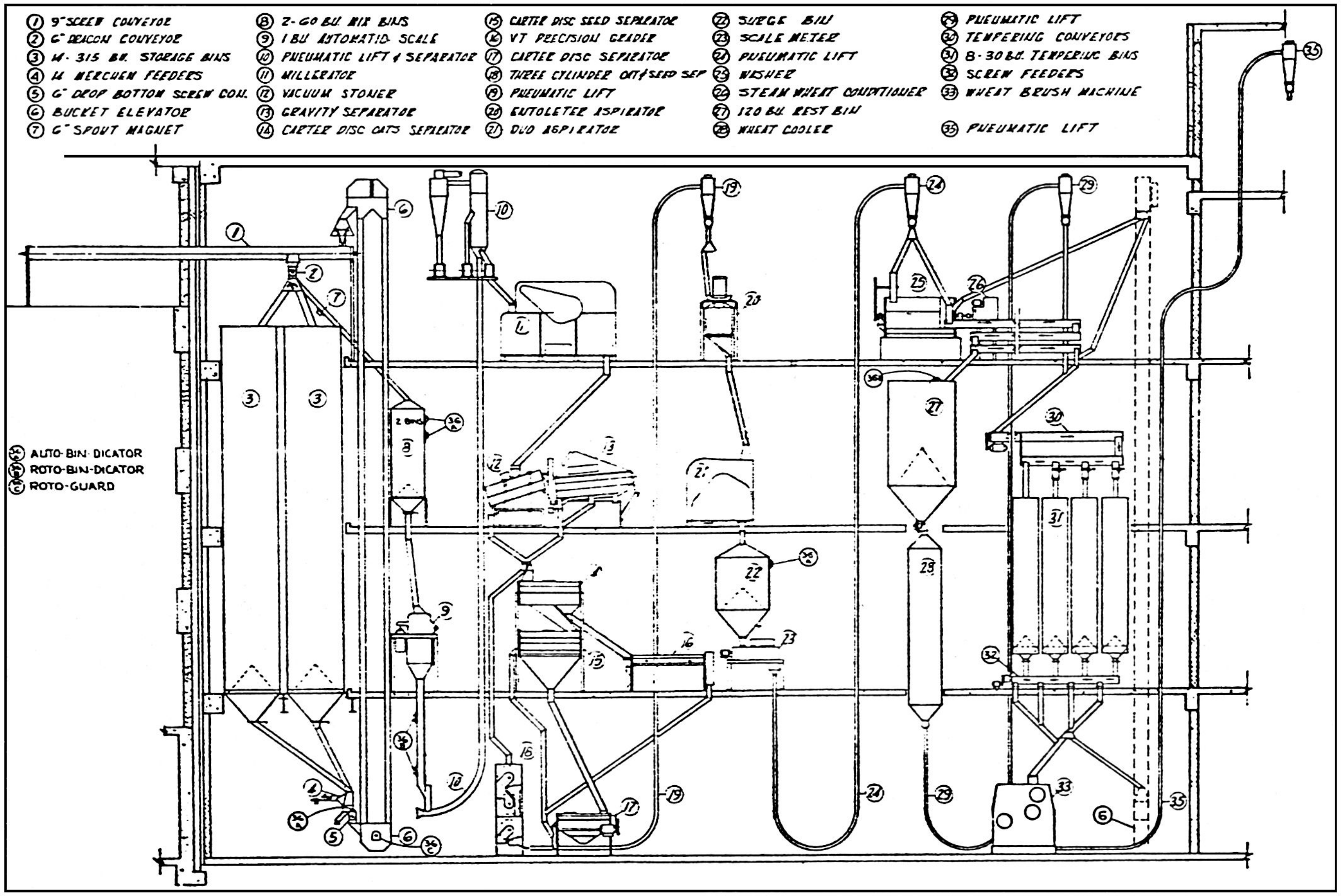



Figure 1. Wheat cleaning flow.

Movement of the wheat between the various operations was accomplished by gravity flow or pneumatic conveying.

The cleaned wheat of each class was distributed into the proper amount and number of samples required for testing through use of a sample splitter. Each sample was packaged in a plastic bag to prevent moisture fluctuation prior to tempering. Random procedures were followed in the preparation of samples.

## Conditioning or Tempering

All wheat samples were conditioned in the same manner prior to milling, by raising the moisture content to 15.5 percent and letting the samples remain undisturbed in sealed metal cans for 18 hours at room temperature.

Samples were tempered by adding the necessary amount of water in the form of a fine mist to the sample of wheat rotating in a metal blending drum. The amount of water to be added to the sample was determined by using the following formula:

$$\frac{100 - M_1}{100 - M_2} \times W_1 = W_1 + H$$

$M_1$ = percent moisture in the untempered wheat sample.

$M_2$ = percent moisture desired in wheat sample.

$W_1$ = weight of untempered wheat sample.

$H$ = weight of water to be added.

## Grinding Procedure

A milling machine consisting of a pair of adjustable rolls arranged in a horizontal position was used for the grinding tests. See Plates I and II. The unit was constructed to allow independent roll speeds from 50 to 1,000 revolutions per minute using hydraulic power driven rolls. The machine allowed test use of pairs of rolls of various diameters. The roll clearance was adjustable and could be locked in a selected fixed position without movement during testing.

The diameters of the rolls tested were 6, 9, and 12 inches. Roll length used during all tests consisted of the center 2 inches of the rolls.

The 3 diameters of rolls used had the same number and type of corrugations. The specifications were 10 corrugations per inch of Minneapolis 19 configuration (40) with 0.375 inch spiral per linear foot. The corrugations of the rolls were run dull to dull throughout testing. The rolls were driven so that a constant differential of 2.5 to 1 was maintained at all times. In all cases, speeds shown or designated in this report refer to the speed of the fastest roll of a pair. The slow roll of a pair would always revolve at a speed 0.4 times the fast roll speed.

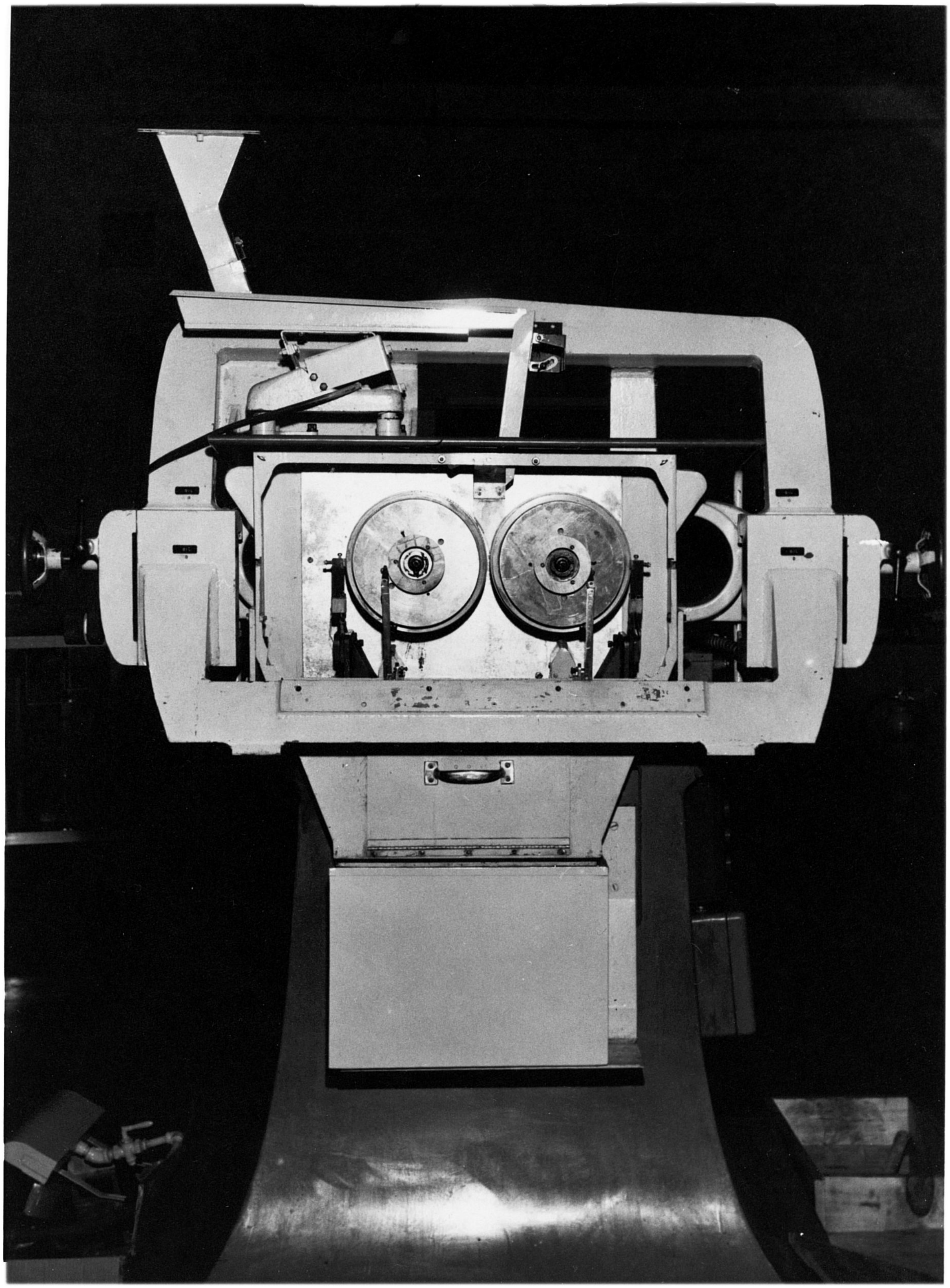
The different fast roll speeds used for testing were selected to give the same peripheral speed within types of wheat, regardless of the diameter of the particular pair of rolls being used. Three speeds of rolls were tested. For ease of notation, these speeds were designated as slow (942 fpm), normal (1178 fpm), and fast (1414 fpm). Actual speeds of the various diameter of rolls in revolutions per minute, are shown in Table 2.

The path or flow of the wheat samples during the tests is shown in Fig. 2. Tempered wheat was placed in a small hopper above a volumetric feeder, which was set to deliver 1.5 pounds of wheat per minute per inch of contact roll surface on the test rolls. As previously mentioned, 2 inches of roll

EXPLANATION OF PLATE I

Front view of the experimental milling machine showing 9 inch diameter rolls installed for first break grinding.

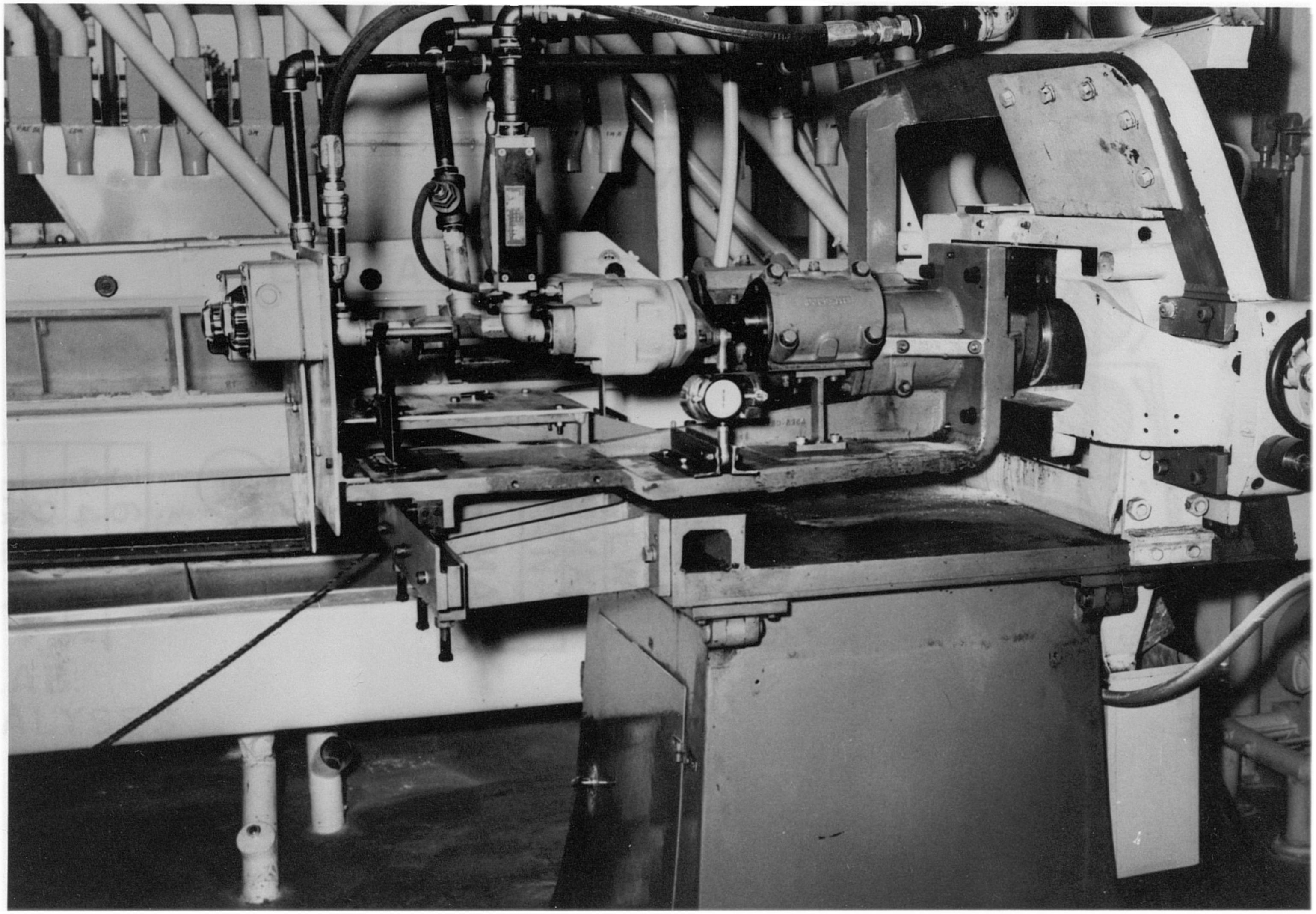
PLATE I



## EXPLANATION OF PLATE II

Rear view of the experimental milling machine showing individual hydraulic drive for each break roll.

PLATE II



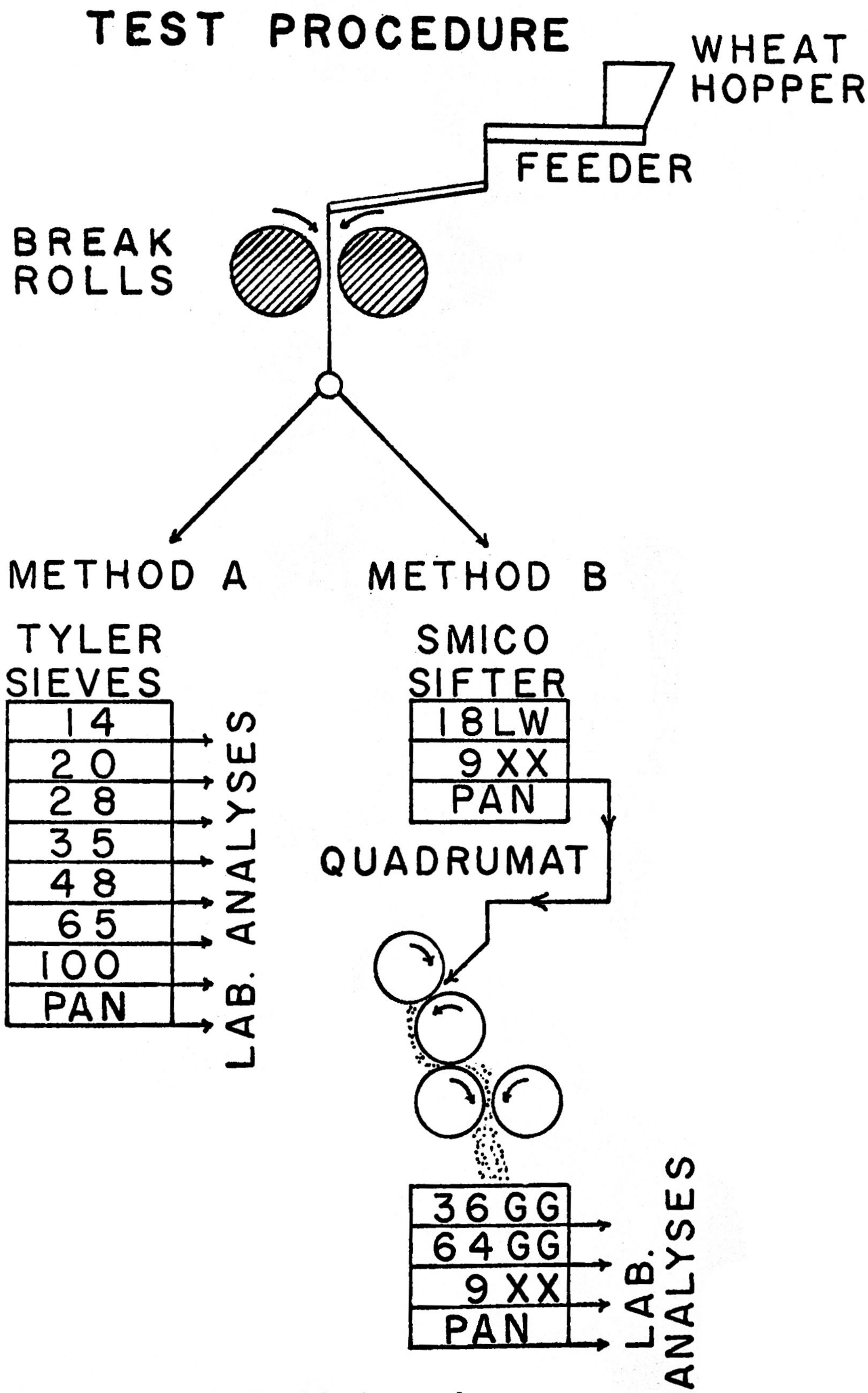



Figure 2. Flowsheet of test procedure.

Table 2. Roll speeds.

| Roll diameter | Roll speeds: Slow (942 fpm)* | Normal (1178 fpm) | Fast (1414 fpm) |
|---|---|---|---|
| 6 inches | 600 rpm | 750 rpm | 900 rpm |
| 9 inches | 400 rpm | 500 rpm | 600 rpm |
| 12 inches | 300 rpm | 375 rpm | 450 rpm |

* Feet per minute.

length was used which required a feed rate of 3 pounds per minute of wheat. The wheat was fed onto a vibratory feeder in order to distribute the load equally along the entire roll length and finally guided through a device designed to deliver the wheat at the entry point of the roll clearance. After an initial roll warm-up period of time, the roll gap was set to the opening that would produce 30 percent of the roll product through a number 18 light wire (1190 micron opening) sieve. This was accomplished by screening a sample for 30 seconds in a standard break release sifter using the 18 LW sieve and adjusting the roll clearance until a sample analysis of 30 percent break release was obtained.

When the wheat flow through the operation was functioning smoothly, 2 samples were collected at the discharge of the break rolls.

Sample A consisted of approximately 500 grams of total throughput of the ground wheat. This sample was used for both particle size analysis and cumulative ash curve analysis. To obtain this information, Tyler sieve tests for percentage of total product on 7 different sieves was calculated. Also, moisture and ash analyses were run on samples of each sieve material.

Sample B was taken at the time Sample A was taken, although a larger amount consisting of approximately 2,000 grams was obtained. This sample was screened on a Smico laboratory sifter with the following sieve sizes: number 18 light wire (1190 micron opening) and number 9 XX cloth (153 micron opening). The amount of ground material passing the number 18 LW sieve and retained on the number 9 XX sieve was further milled through the reduction side of a standard Quadrumat Senior experimental mill (see Plate III). The selection of this type of experimental mill and data for its proper operation was based on information written by Schafer (34). A schematic diagram of the Quadrumat Senior mill with the product flow indication, roll corrugations, and sieve sizes used for the experiment is shown in Fig. 3. A volumetric feeder was used to accurately deliver the material to the Quadrumat Senior roll hopper at a uniform rate of 70 grams a minute. As indicated in the flowsheet (Fig. 3), 4 streams of product were obtained from the Quadrumat Senior mill: (a) bran, which was the product over the 36 GG sieve (571 micron opening); (b) shorts, which was the product through the 36 GG sieve and over the 64 GG sieve (282 micron opening); middlings, which was the product through the 64 GG and over the 9 XX sieve (153 micron opening); flour, the product through the 9 XX sieve. Each stream was analyzed for moisture, ash, protein, and percentage of total product. Additional tests on the flour for average particle size and color were performed.

## Physical Methods of Determination

The moisture, ash, and protein of the samples were determined by procedures 44-15, 08-01, and 46-11, respectively in Cereal Laboratory Methods (1).

Fisher Sub-Sieve average particle size measurements were determined on flour samples according to procedures outlined by the Fisher Scientific Company (15).

Agtron color readings were performed on flour samples using the green

## EXPLANATION OF PLATE III

Photograph of the Quadrumat Senior experimental mill used for Method B tests.

PLATE III


UNIT 1
BREAK SYSTEM
UNIT 2
REDUCTION SYSTEM
PLANSIFTER
SCREW
C.W. BRABENDER INSTRUMENTS INC.
SOUTH HACKENSACK N.J.
UNIT 1
UNIT 2
REVERSAL
REVERSAL
OFF
OFF
GRINDING
GRINDING
QUADRUMAT
SENIOR
EXPERIMENTAL MILL

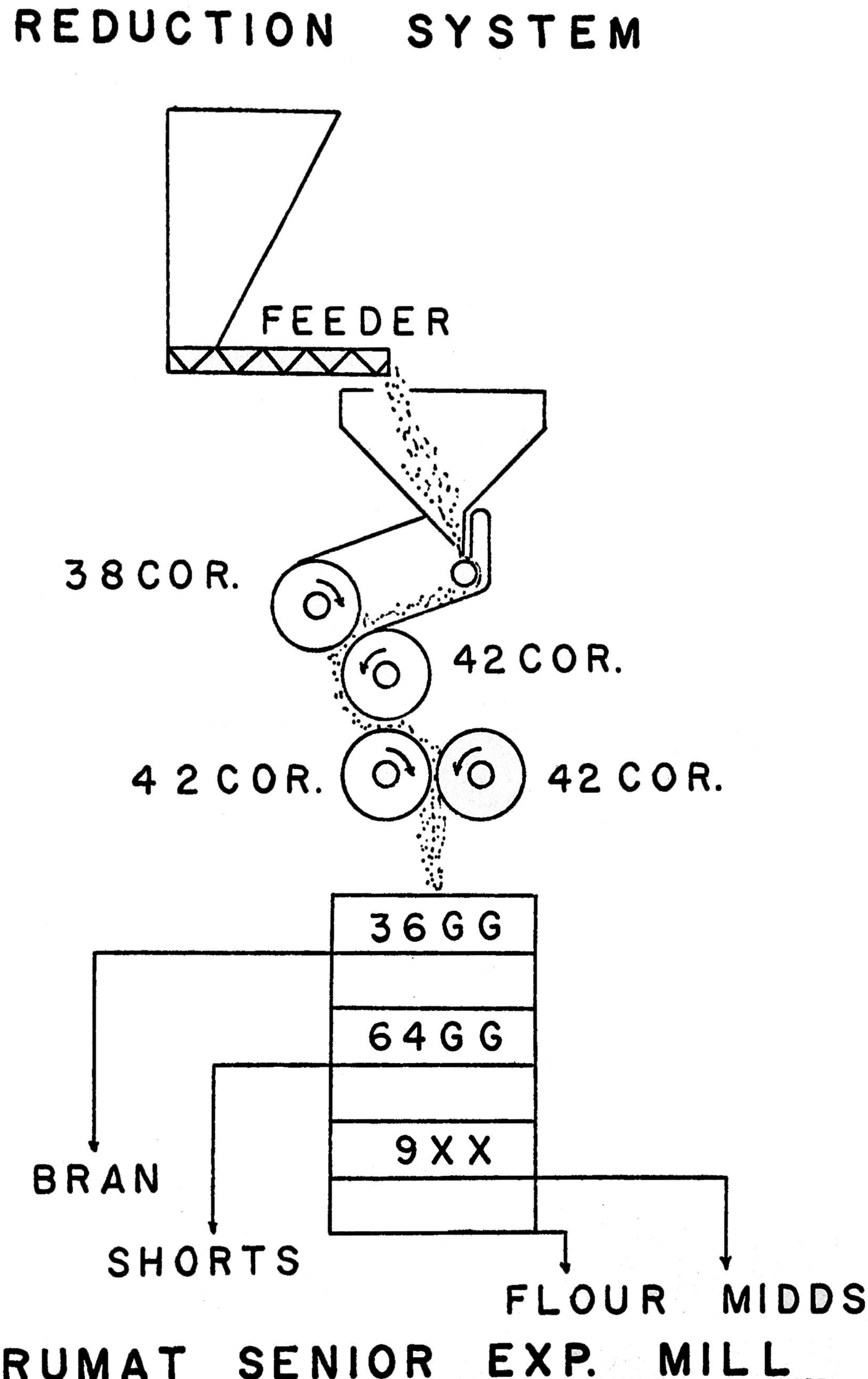



Figure 3. Flowsheet of Method B product through the Quadrumat Senior mill.

filter and following methods listed by Gillis (17).

The test weight determinations were made with a quart kettle using a beam scale according to the standard method outlined by the U.S. Department of Agriculture (45).

The pearling value test was performed as outlined by McCluggage (28), by using 20 grams of sample wheat for the test. The wheat was pearled in a Strong-Scott barley pearling machine for 60 seconds. The product that was removed was sifted on a number 20 wire sieve in a Smico laboratory sifter for 30 seconds to separate the product. The wheat remaining on the number 20 sieve was weighed and recorded as a percentage of the original sample.

The wheat size test was performed according to the following method. Two hundred grams of wheat were placed on the top sieve of a stack of 3 Tyler standard sieves (numbers 7, 9, 12). This stack was then inserted in a Tyler Ro-Tap testing sieve shaker and the machine run for a 60 second time period. The amount retained on each sieve was recorded as a percentage of the total sample weight. The purpose of the test was to assign a universal size designation to the wheat used in the experiment.

The 1,000 kernel count weight was determined with an electronic seed counter using 40 grams of wheat, and using the count of this weight to determine the weight of 1,000 kernels.

Particle size tests on the ground material from the wheat passed through the first break rolls was determined using the Tyler Ro-Tap testing sieve shaker and the following Tyler number sieves: 14, 20, 28, 35, 48, 65, and 100 wire mesh. The sequence of sieves follows the standard square root of 2 ratio between openings on adjacent sieves. The results obtained from use of the sieves were divided into a uniform proportion since they were separated on a fixed scale and the results could be represented by a plotted curve to much better advantage. The ground product was sifted for 3 minutes on the sieves placed in the Tyler shaker. Procedures were followed according to directions in the manufacturer's manual (44).

The cumulative ash curves of the first break roll product were developed from ash and particle size results from each test. The method of plotting the data points was described in an article by Farrell and Ward (14).

## Statistical Analyses

Preliminary experiments were performed to develop a basis for expectations of experimental error and procedural replication. After the development of methods and techniques, the final experiment was designed to be a completely randomized 3 factorial experiment. The 3 factors tested were: (a) class of wheat, (b) diameter of rolls, (c) speed of rolls, while holding all other known factors constant. The testing was done with 3 levels of variation with 2 replicates of each variation.

Classes of wheat used for the test were: Hard Red Spring, Hard Red Winter, and Soft Red Winter.

Diameter of rolls that were tested consisted of 6, 9, and 12 inches.

The peripheral speeds of the fast rolls tested were 942, 1,178, and 1,414 feet per minute.

The data obtained from the tests was transferred into an analysis of variance computer program, compiled, and executed on the University IBM 1410 computer. The output of this program was tested for significance at the 0.05 level using the F test. Further statistical testing for indications of advantage was done using the least significant determination (LSD) method of mean comparisons. All analyses were determined by procedures outlined by Snedecor (38).

# RESULTS AND DISCUSSION

## Method A

Wheat Class. The statistical analyses of the experimental results (see Appendix A for test results) are shown in the analysis of variance Tables 3 through 9. It is evident from the tables that there was a significant variation in particle size distribution and cumulative ash content between samples of the 3 wheat classes. The variation was expected to be significant and was in accord with observations from the literature (20).

One reason for including the 3 classes of wheat as a test factor was to evaluate the avility of the test equipment to accurately determine variations in particle size distributions and ash content of samples known to give variations.

In addition to employing wheat class as a gauge to evaluate the accuracy of the experimental procedure, wheat class provided a means to simultaneously test the effects of the other 2 factors when using 3 kinds of milling types of wheat. The possibility of erroneous conclusions about the effects of roll diameter and roll speed due to the use of a single milling type of wheat class were thereby eliminated.

Specific wheat class desirability in terms of milling quality, which is indicated by the cumulative ash curves shown in Figs. 4 to 12, cannot be evaluated because of inherent wheat class characteristics. This observation was noted in the discussion in the Review of Literature section and was the reason why the least significant difference test was not performed on the wheat class results.

Table 3. Method A. Analysis of variance of the cumulative ash percentage in the product through the Tyler 100 mesh sieve and on the pan.

| Source of variation | d.f. | S.S. | M.S. | |
|---|---|---|---|---|
| Roll diameter | 2 | 0.020639 | 0.010320 | * |
| Roll speed | 2 | 0.000217 | 0.000108 | n.s. |
| Wheat class | 2 | 0.721646 | 0.360823 | * |
| Speed & diameter interaction | 4 | 0.000762 | 0.000190 | n.s. |
| Speed & class interaction | 4 | 0.000271 | 0.000068 | n.s. |
| Class & diameter interaction | 4 | 0.001332 | 0.000333 | n.s. |
| Class, speed, & diameter interaction | 8 | 0.002068 | 0.000258 | n.s. |
| Error | 27 | 0.027503 | 0.001019 | |
| Total | 53 | 0.774438 | | |

Table 4. Method A. Analysis of variance of the cumulative ash percentage in the product through the Tyler 65 mesh sieve and on the 100 mesh.

| Source of variation | d.f. | S.S. | M.S. | |
|---|---|---|---|---|
| Roll diameter | 2 | 0.015876 | 0.007938 | * |
| Roll speed | 2 | 0.000282 | 0.000141 | n.s. |
| Wheat class | 2 | 0.686462 | 0.343231 | * |
| Speed & diameter interaction | 4 | 0.000915 | 0.000229 | n.s. |
| Speed & class interaction | 4 | 0.000385 | 0.000096 | n.s. |
| Class & diameter interaction | 4 | 0.000925 | 0.000231 | n.s. |
| Class, speed, & diameter interaction | 8 | 0.001553 | 0.000194 | n.s. |
| Error | 27 | 0.017352 | 0.000643 | |
| Total | 53 | 0.723750 | | |

Table 5. Method A. Analysis of variance of the cumulative ash percentage in the product through the Tyler 48 mesh sieve and on the 65 mesh.

| Source of variation | d.f. | S.S. | M.S. | |
|---|---|---|---|---|
| Roll diameter | 2 | 0.014345 | 0.007172 | * |
| Roll speed | 2 | 0.000556 | 0.000278 | n.s. |
| Wheat class | 2 | 0.755440 | 0.377720 | * |
| Speed & diameter interaction | 4 | 0.001714 | 0.000428 | n.s. |
| Speed & class interaction | 4 | 0.000223 | 0.000056 | n.s. |
| Class & diameter interaction | 4 | 0.000541 | 0.000135 | n.s. |
| Class, speed, & diameter interaction | 8 | 0.002012 | 0.000252 | n.s. |
| Error | 27 | 0.013156 | 0.000487 | |
| Total | 53 | 0.787987 | | |

n.s. Non-significant

* Significant at the 0.05 level

Table 6. Method A. Analysis of variance of the cumulative ash percentage in the product through the Tyler 35 mesh sieve and on the 48 mesh.

| Source of variation | d.f. | S.S. | M.S. | |
|---|---|---|---|---|
| Roll diameter | 2 | 0.020089 | 0.010044 | * |
| Roll speed | 2 | 0.001321 | 0.000660 | n.s. |
| Wheat class | 2 | 0.738290 | 0.369145 | * |
| Speed & diameter interaction | 4 | 0.002323 | 0.000581 | n.s. |
| Speed & class interaction | 4 | 0.000626 | 0.000156 | n.s.. |
| Class & diameter interaction | 4 | 0.000907 | 0.000227 | n.s. |
| Class, speed, & diameter interaction | 8 | 0.001622 | 0.000203 | n.s. |
| Error | 27 | 0.015383 | 0.000570 | |
| Total | 53 | 0.780561 | | |

Table 7. Method A. Analysis of variance of the cumulative ash percentage in the product through the Tyler 28 mesh sieve and on the 35 mesh.

| Source of variation | d.f. | S.S. | M.S. | |
|---|---|---|---|---|
| Roll diameter | 2 | 0.026085 | 0.013042 | * |
| Roll speed | 2 | 0.001341 | 0.000670 | n.s. |
| Wheat class | 2 | 0.709239 | 0.354620 | * |
| Speed & diameter interaction | 4 | 0.002690 | 0.000672 | n.s. |
| Speed & class interaction | 4 | 0.001018 | 0.000254 | n.s. |
| Class & diameter interaction | 4 | 0.001963 | 0.000491 | n.s. |
| Class, speed, & diameter interaction | 8 | 0.002152 | 0.000269 | n.s. |
| Error | 27 | 0.014343 | 0.000531 | |
| Total | 53 | 0.758831 | | |

Table 8. Method A. Analysis of variance of the cumulative ash percentage in the product through the Tyler 20 mesh sieve and on the 28 mesh.

| Source of variation | d.f. | S.S. | M.S. | |
|---|---|---|---|---|
| Roll diameter | 2 | 0.018882 | 0.009441 | * |
| Roll speed | 2 | 0.001909 | 0.000954 | n.s. |
| Wheat class | 2 | 0.677002 | 0.338501 | * |
| Speed & diameter interaction | 4 | 0.003721 | 0.000930 | n.s. |
| Speed & class interaction | 4 | 0.004136 | 0.001034 | n.s. |
| Class & diameter interaction | 4 | 0.000847 | 0.000212 | n.s. |
| Class, speed, & diameter interaction | 8 | 0.001388 | 0.000174 | n.s. |
| Error | 27 | 0.016419 | 0.000608 | |
| Total | 53 | 0.724304 | | |

n.s. Non-significant

* Significant at the 0.05 level

Table 9. Method A. Analysis of variance of the cumulative ash percentage in the product through the Tyler 14 mesh sieve and on the 20 mesh.

| Source of variation | d.f. | S.S. | M.S. | |
|---|---|---|---|---|
| Roll diameter | 2 | 0.004350 | 0.002175 | n.s. |
| Roll speed | 2 | 0.007487 | 0.003744 | n.s. |
| Wheat class | 2 | 0.668801 | 0.334400 | * |
| Speed & diameter interaction | 4 | 0.008697 | 0.002174 | n.s. |
| Speed & class interaction | 4 | 0.004275 | 0.001069 | n.s. |
| Class & diameter interaction | 4 | 0.000242 | 0.000060 | n.s. |
| Class, speed, & diameter interaction | 8 | 0.004927 | 0.000616 | n.s. |
| Error | 27 | 0.039157 | 0.001450 | |
| Total | 53 | 0.737936 | | |

n.s. Non-significant
* Significant at the 0.05 level

Table 10. Method A. Least significant difference of the cumulative ash content means from the Tyler sieves.

| Mesh size | LSD | Roll diameter 6 inch | 12 inch | 9 inch |
|---|---|---|---|---|
| -100 | 0.0218 | 0.4850[a] | 0.5017[a] | 0.4545[b] |
| - 65 +100 | 0.0172 | 0.4823[a] | 0.4949[a] | 0.4539[b] |
| - 48 + 65 | 0.0151 | 0.4884[a] | 0.4996[a] | 0.4608[b] |
| - 35 + 48 | 0.0163 | 0.5015[a] | 0.5169[a] | 0.4706[b] |
| - 28 + 35 | 0.0158 | 0.5236[a] | 0.5447[a] | 0.4913[b] |
| - 20 + 28 | 0.0170 | 0.5948[a] | 0.6102[a] | 0.5652[b] |
| - 14 + 20 | 0.0261 | 0.7834[a] | 0.7812[a] | 0.7634[a] |

[ab] Values having the same letter are not significantly different at the 0.05 level.

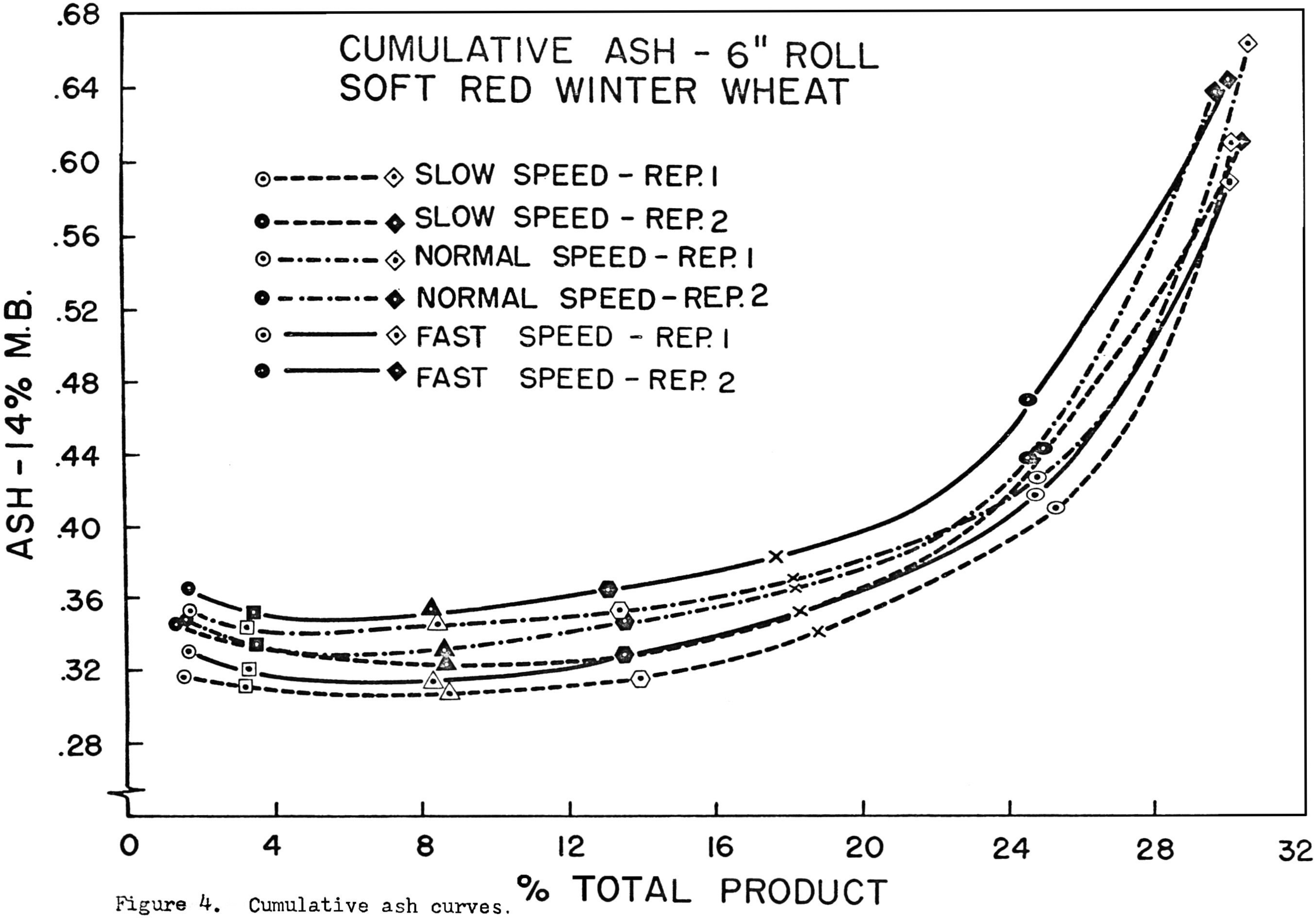



Figure 4. Cumulative ash curves.

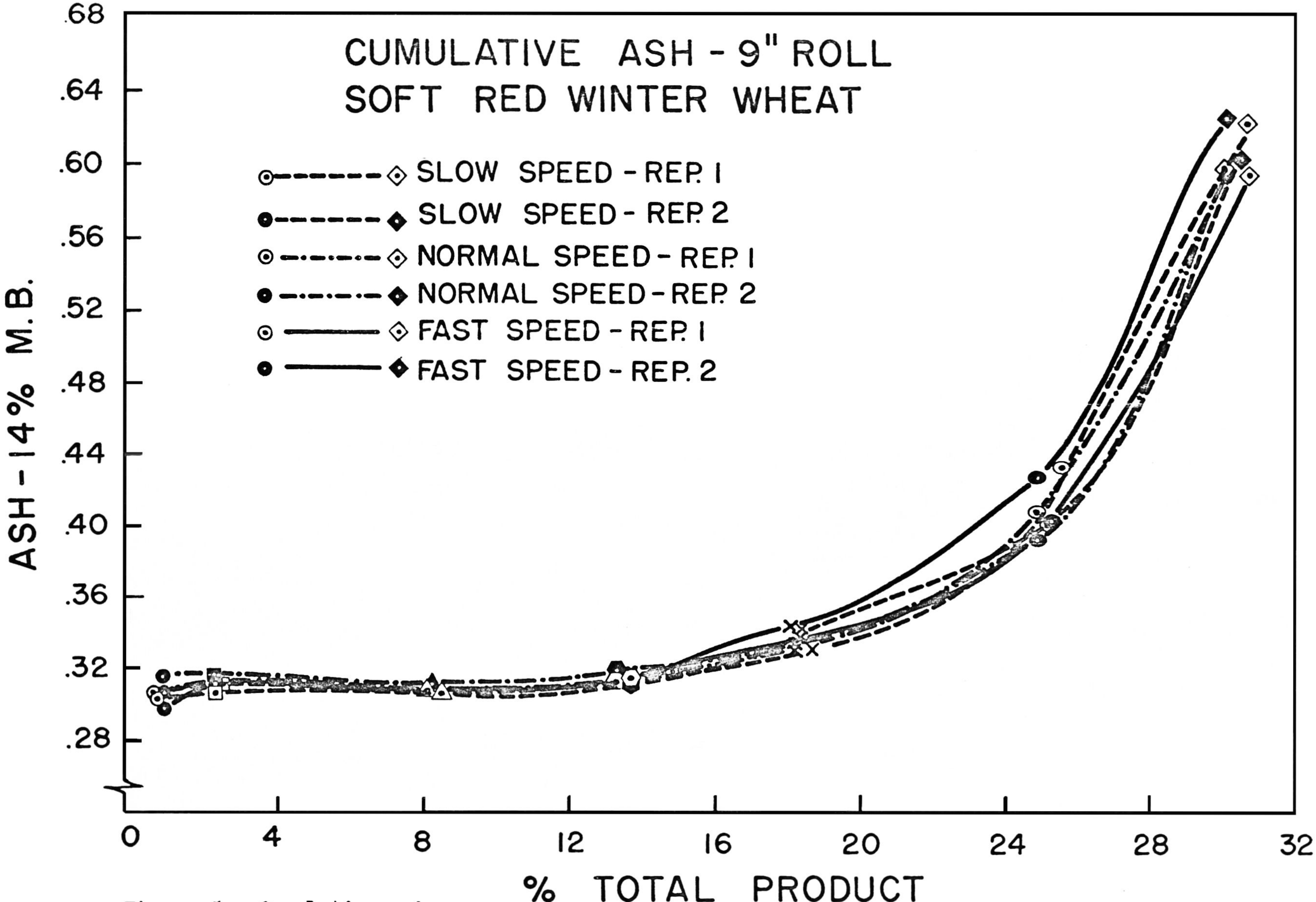



Figure 5. Cumulative ash curves.

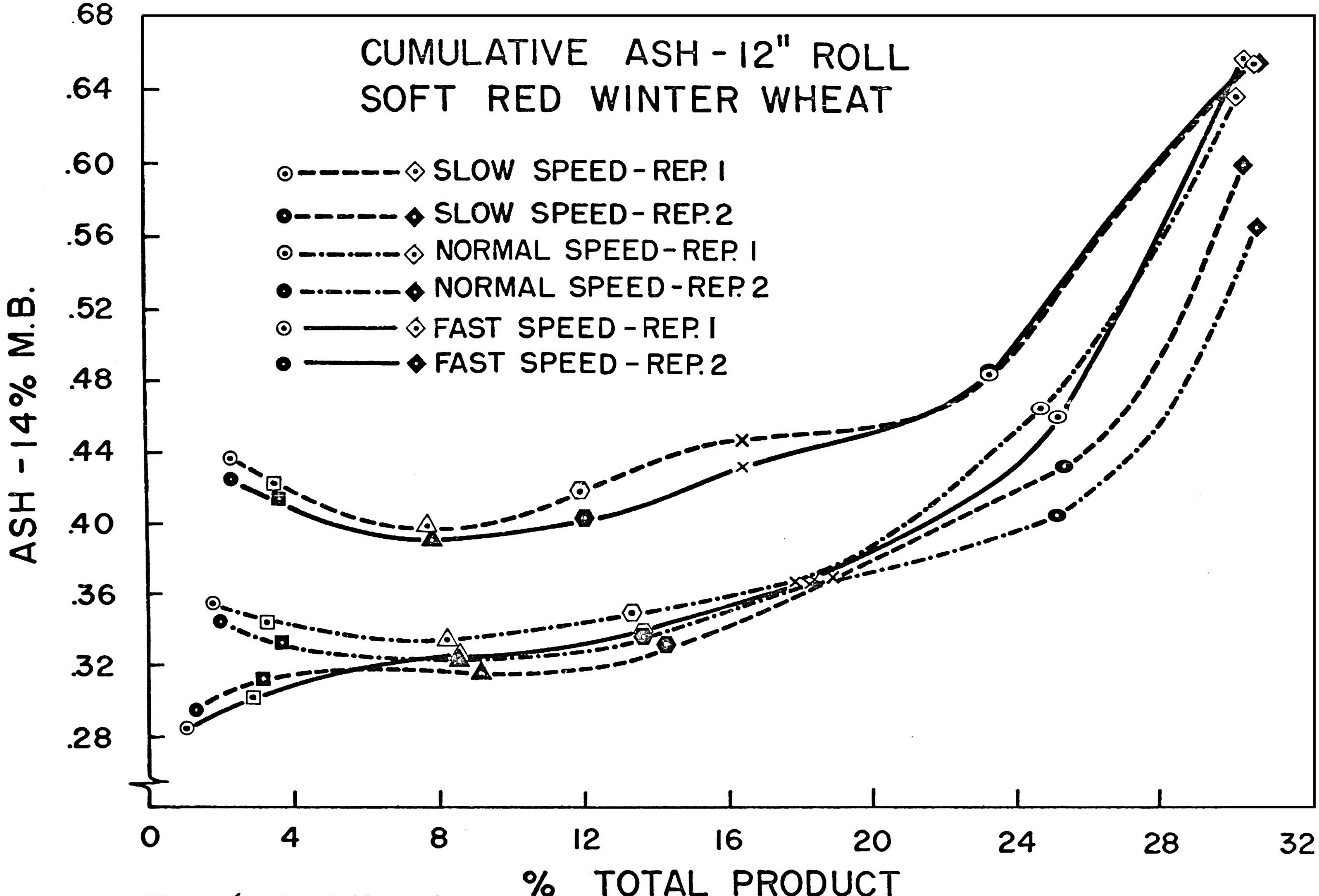



Figure 6. Cumulative ash curves.

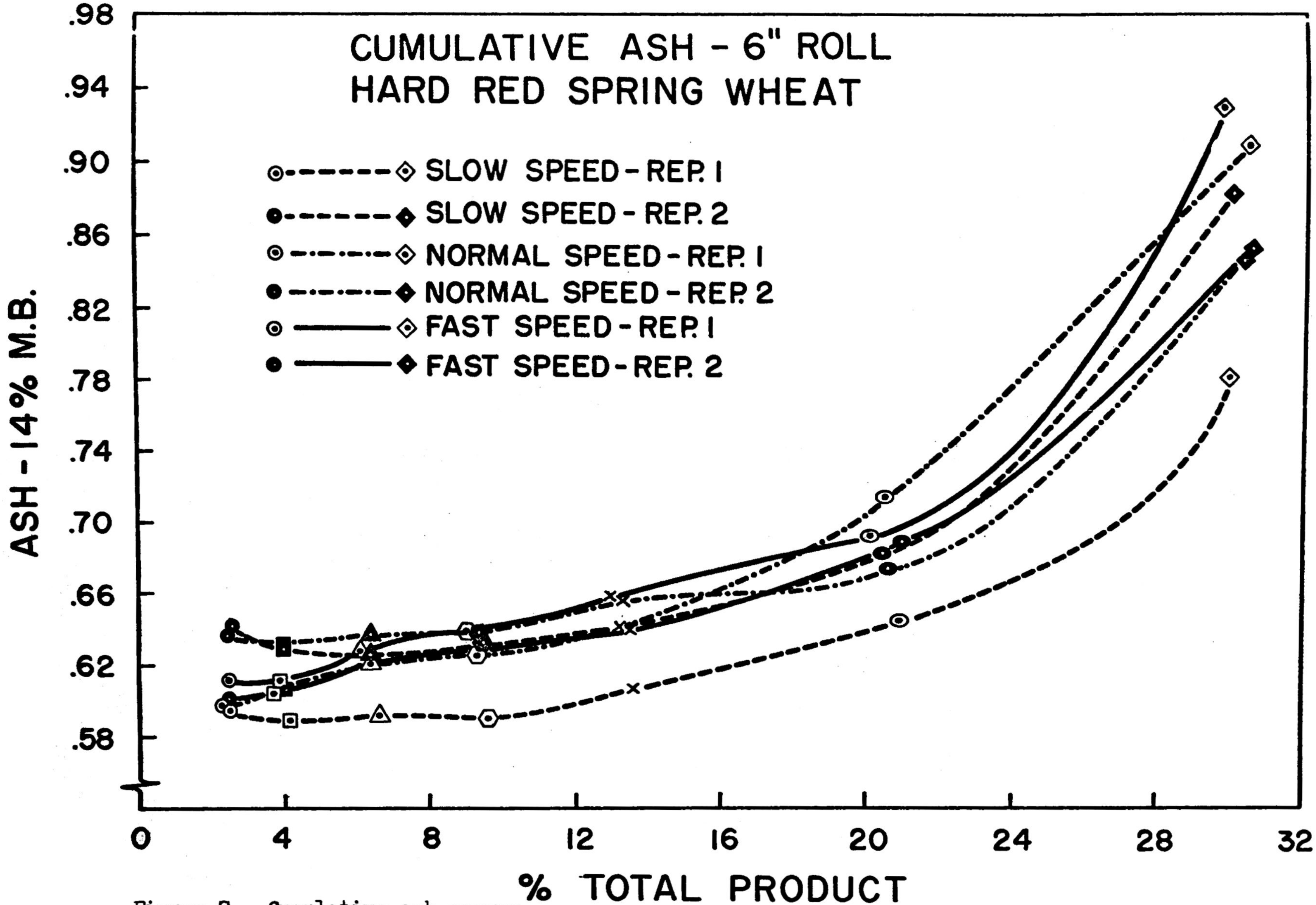



Figure 7. Cumulative ash curves.

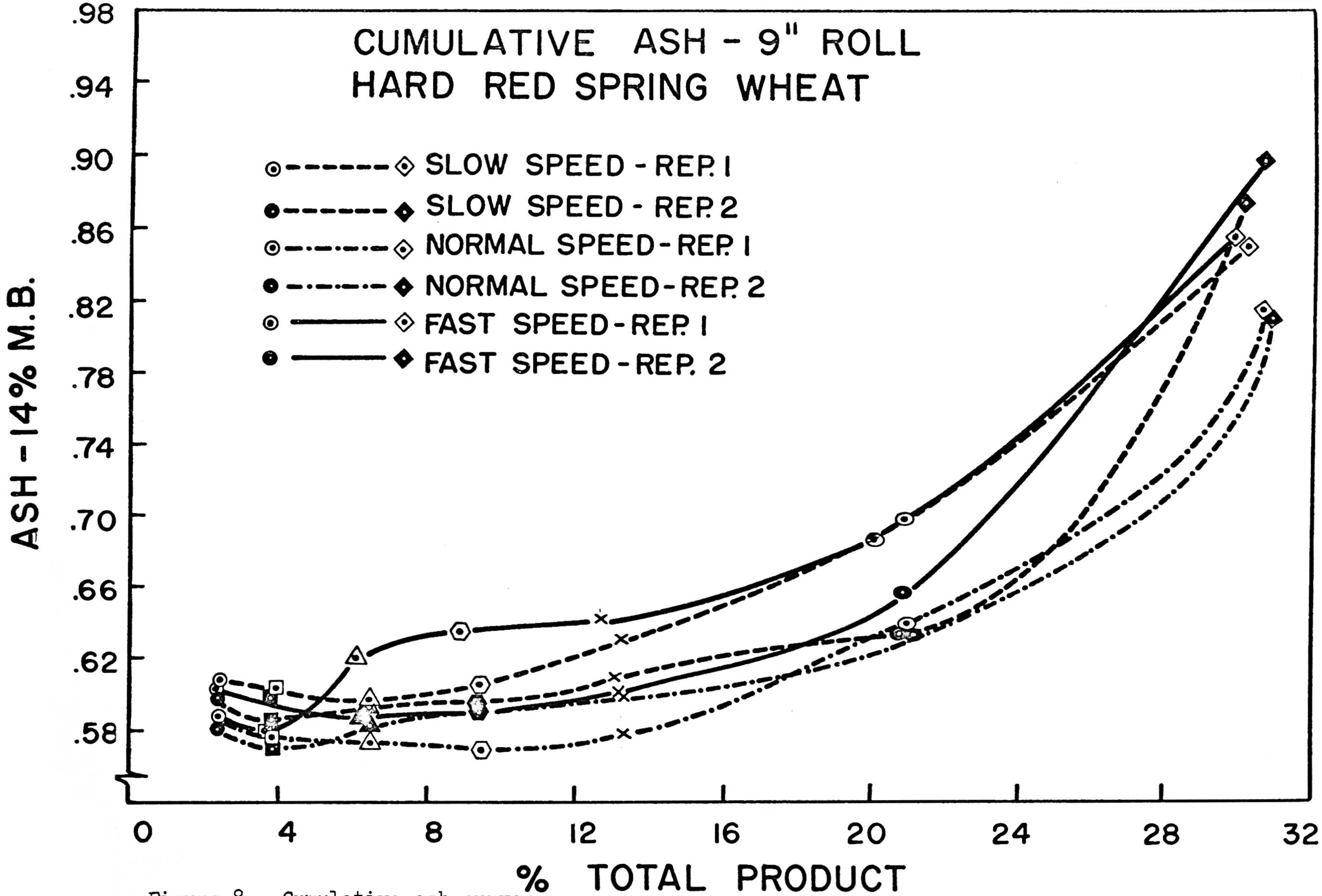



Figure 8. Cumulative ash curves.

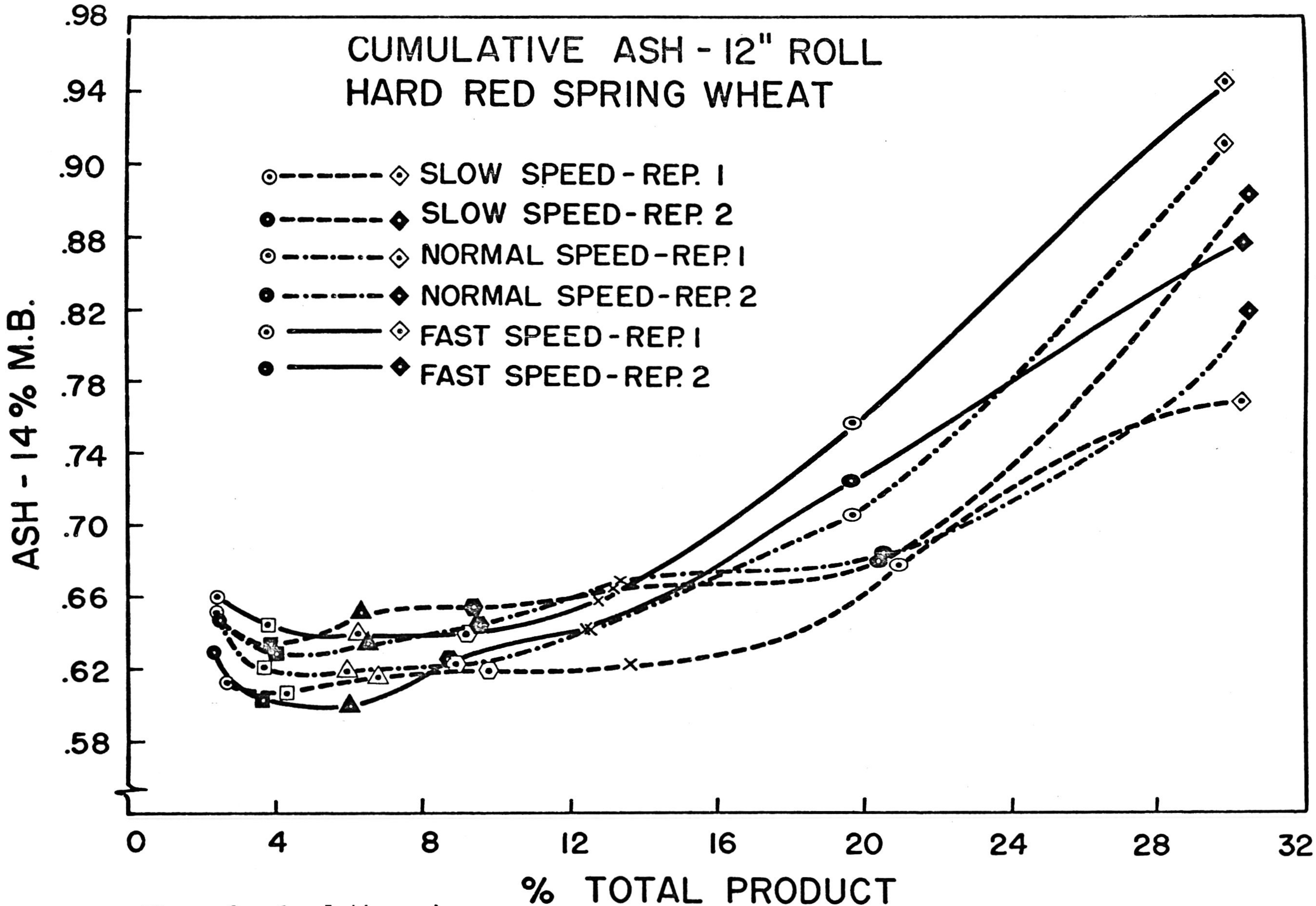



Figure 9. Cumulative ash curves.

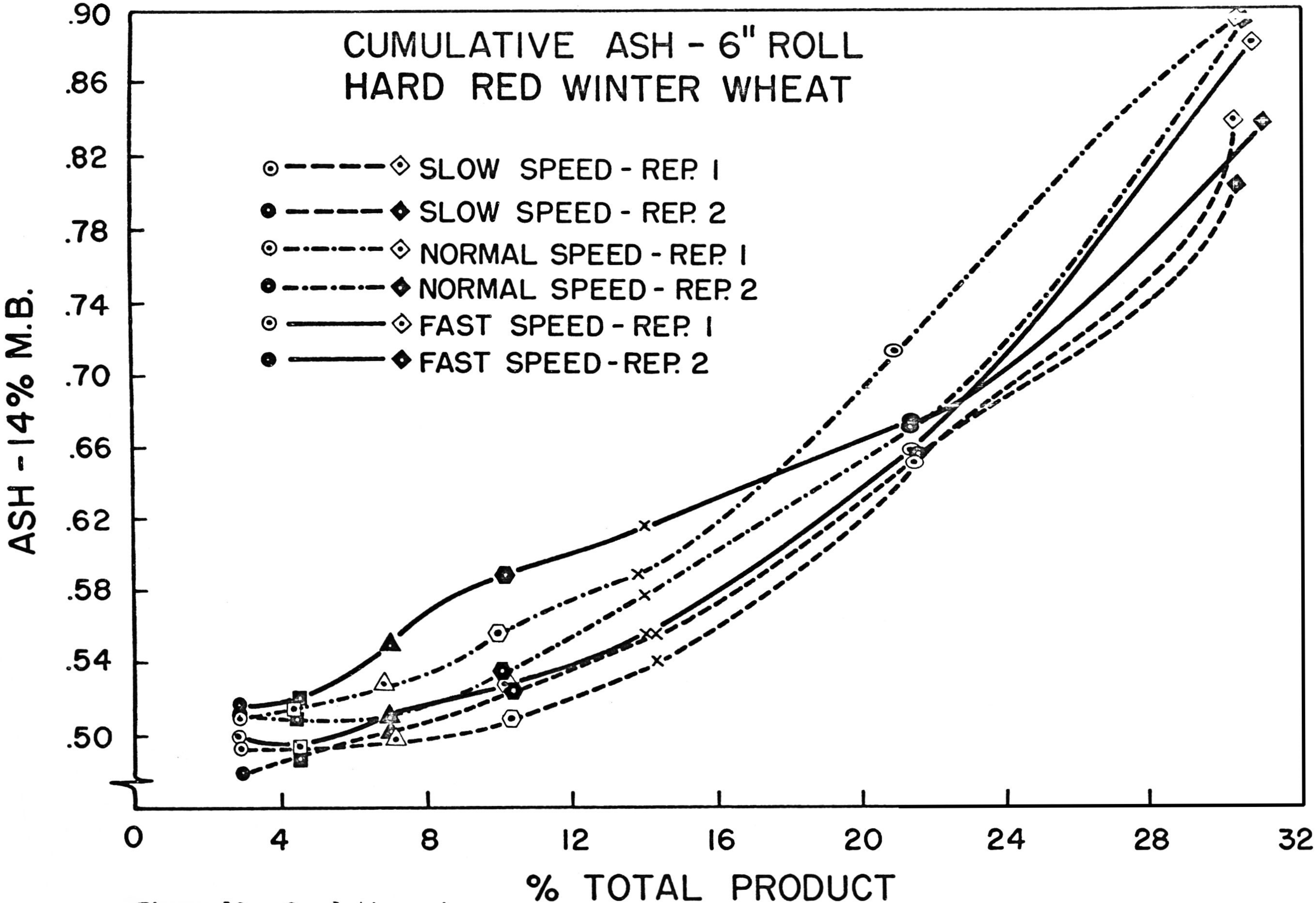



Figure 10. Cumulative ash curves.

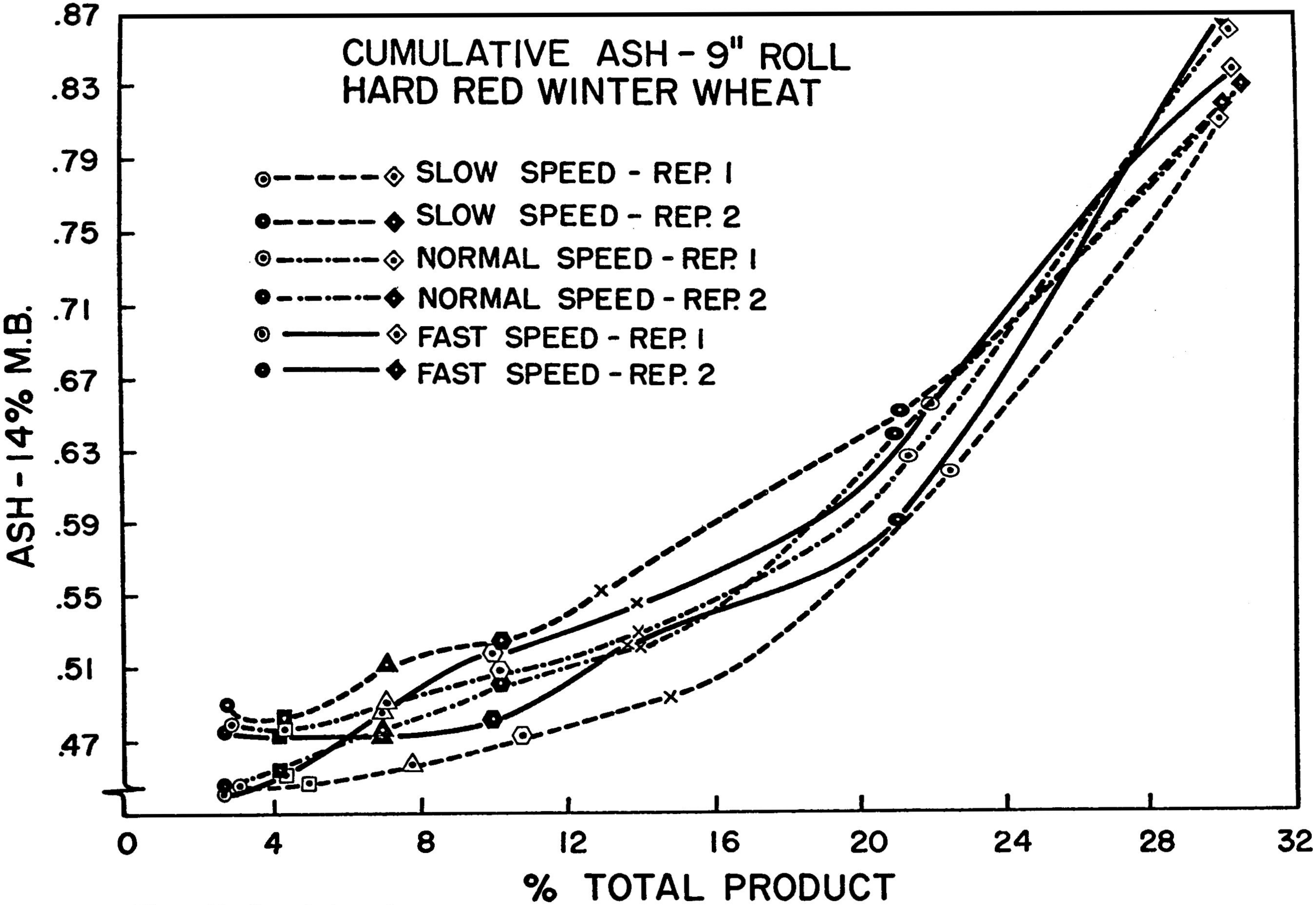



Figure 11. Cumulative ash curves.

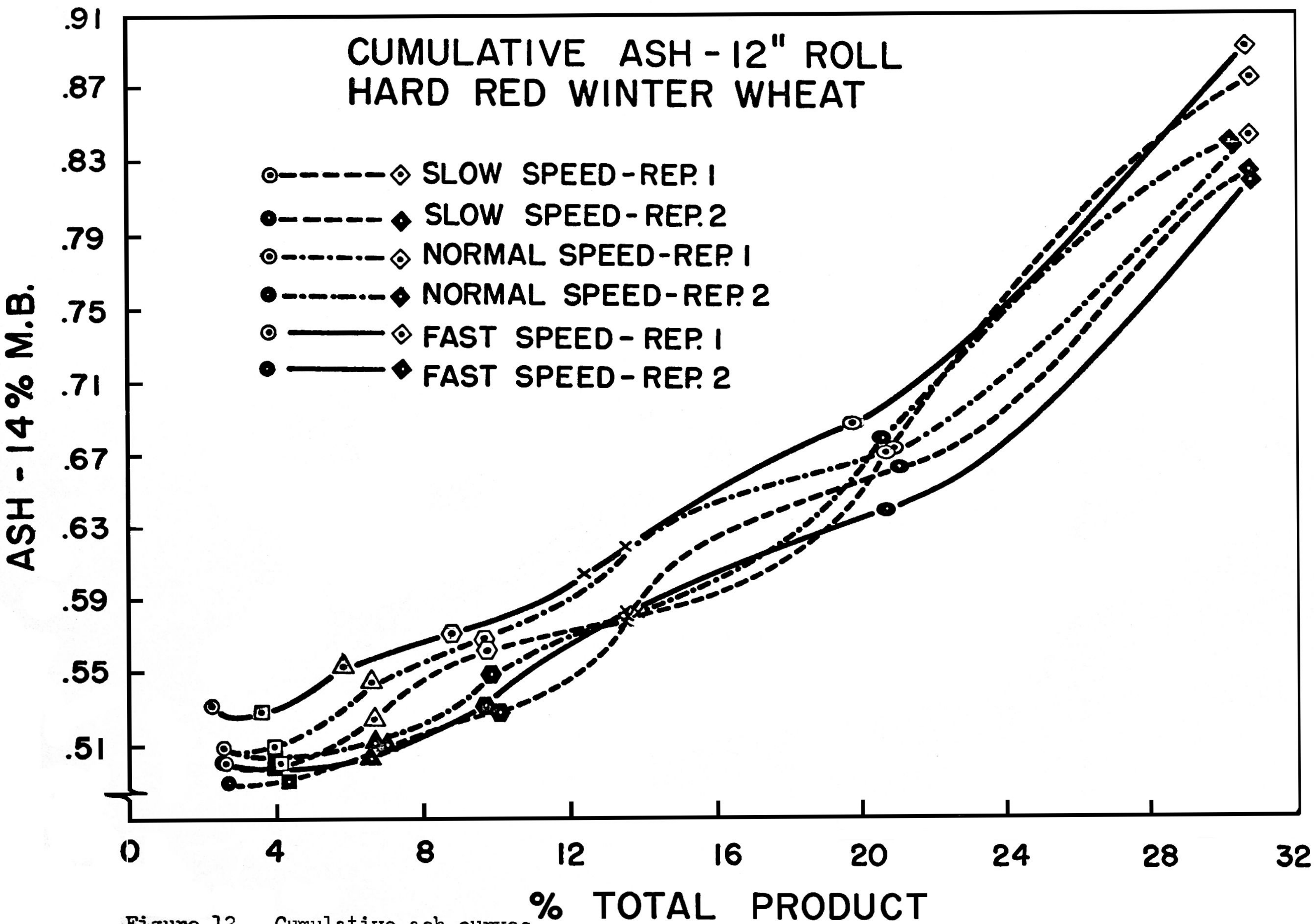



Figure 12. Cumulative ash curves.

Roll Diameter. Changes in roll diameters did cause a significant variation as shown in Tables 3 to 9. It was found that the particle size distribution and cumulative ash content of the samples from the 6, 9, and 12 inch diameter rolls had significant differences.

Further statistical testing to determine specific roll diameter conclusions was done using the least significant difference (LSD) method of mean comparisons. The results are shown in Table 10. It is apparent from the results that the product remaining on the bottom 6 Tyler mesh sieves (denoting the smallest particle sizes), showed a significant difference using ash means as the analysis method between comparisons of the 6 and 12 inch diameter rolls with the 9 inch diameter rolls. The 9 inch diameter roll samples had the smallest ash content amount and could be interpreted as the roll diameter performing best in the experiment.

The cumulative ash curves drawn in Figs. 4 through 12, visually indicate that the ash content of the product on the finer mesh sieves is lower when using 9 inch diameter rolls than for either the 6 or 12 inch diameter rolls.

Roll Speed. The experimental results of the tests on the effect of roll speed on particle size distribution and cumulative ash content were analyzed statistically in Tables 3 to 9. It is evident from the data in the Tables that there were no significant differences in the ash content of the product from the effect of the 3 different roll speeds. This discovery is in agreement with the conclusions obtained through theoretical investigations by Kozmin (25).

The cumulative ash curves shown in Figs. 4 to 12 can be interpreted similarly to indicate no real difference, because of the closeness and interchange of individual curves between speeds within roll diameters and wheat classes.

Treatment Interactions. The experiment was also designed to determine if any interaction or influence was evident between combined factor effects. There were four types of interaction possible in the 3 factorial experiment. That of: (a) roll speed with roll diameter, (b) roll speed with wheat class, (c) wheat class with roll diameter, (d) wheat class with roll speed with roll diameter effects.

There were no indications of significant interaction effects by any of 4 types possible, when analyzed statistically in Tables 3 to 9.

## Method B

The samples evaluated under the procedure of Method B were companion samples of the ones analyzed in Method A, since they were taken under identical circumstances as explained in the Materials and Method section. The purpose of Method B was to determine if a valid procedure could be developed to analyze first break roll products after further reduction in a system somewhat similar to one in the commercial milling process. This purpose corresponds to the one stated by Cleve and Will (9), who felt the best possibility of control on the results from test curves for break roll settings was through transfer of the results to large mills. In their particular case, the use of the Multomat test mill for this purpose was mentioned.

Wheat Class. The results of the wheat class tests (Appendix B) did show a statistically significant variation in Tables 11 to 15. It was found that there was a significant difference within samples of the wheat classes when tested for ash content, protein content, Agtron color, and Fisher average size particle measurement of the product through the 9 XX sieve. Product yield through the 64 GG sieve also showed a significant difference as evident in Table 15. This variation is in accord with statistical results from the Method A tests.

Roll Diameter. The statistical analyses of the experimental results from the tests performed are shown in Tables 11 to 15. It is clear from the Tables that there were no significant differences in the variations from the effects of roll diameter. This is not in agreement with statistical results from Method A tests.

Roll Speed. The statistical analyses of the experimental results from the tests performed are shown in Tables 11 to 15. It is evident from the Tables there were no significant differences in the variations from the effects of roll speed. The results coincide with the conclusions obtained from statistical analyses of data from Method A.

Treatment Interactions. The only significant variation in factor interaction found by statistical analyses, was that of wheat class and roll diameter sample results measured by product yield, as shown in Table 15.

The wheat class effect in Method A had far greater significance, as measured on a numerical scale, when compared to the wheat class effect in Method B. This could indicate either less detection power in Method B due to test procedures or first break roll effect minimization by continued milling of the break roll product. Because of the possibility of either factor occurring, only general inferences about Method B may be concluded.

It was thought that several factors which did not affect experimental design accounted for the discrepancy between results from Methods A and B.

First, the original particle size of material passed through the reduction side of the Quadrumat Senior experimental laboratory mill was larger than the normal size of material usually run on the reduction side when both sections of the mill are in operation. The larger size particles possibly did not permit proper reduction roll operation since the roll clearances on the Quadrumat Senior mill are fixed, thus causing a larger than normal variation in flour yield. Second, the sieve arrangement on the Quadrumat mill did not permit as precise a sieving operation as the Tyler sieve arrangement, which used more sieves at closer opening sizes and was a batch load and discharge operation. The combination of the two factors could have increased the experimental statistical error function to the extent that only large variations such as the one that occurs between wheat classes could be detected. However, this assumption should not be construed to imply significant variations between roll diameters were present in the sample after milling through the Quadrumat Senior. It may be possible that the milling process can negate significant effects of various factors affecting first break roll operation. A better method is required to evaluate total milling operation so that a simultaneous evaluation of milling factors can be studied. Then, it would be possible for recommended changes in first break roll design to incorporate all process aspects affected by the design changes in the recommendation.

The overall investigation suggests that Method A is a valid procedure to analyze first break roll results at the point of discharge from the rolls. Furthermore, it would suggest that Method B was not an entirely satisfactory method to evaluate results of first break roll changes through continued milling of the break roll product.

Table 11. Method B. Analysis of variance of the ash percentage of the product through the 9XX sieve.

| Source of variation | d.f. | S.S. | M.S. |
|---|---|---|---|
| Roll diameter | 2 | 0.002586 | 0.001293 n.s. |
| Roll speed | 2 | 0.000769 | 0.000384 n.s. |
| Wheat class | 2 | 0.143721 | 0.071861 * |
| Speed & diameter interaction | 4 | 0.000554 | 0.000138 n.s. |
| Speed & class interaction | 4 | 0.001330 | 0.000332 n.s. |
| Class & diameter interaction | 4 | 0.001550 | 0.000388 n.s. |
| Class, speed, & diameter interaction | 8 | 0.001808 | 0.000226 n.s. |
| Error | 27 | 0.012075 | 0.000447 |
| Total | 53 | 0.164394 | |

Table 12. Method B. Analysis of variance of the protein percentage of the product through the 9XX sieve.

| Source of variation | d.f. | S.S. | M.S. |
|---|---|---|---|
| Roll diameter | 2 | 0.1135 | 0.0568 n.s. |
| Roll speed | 2 | 0.1361 | 0.0680 n.s. |
| Wheat class | 2 | 59.1693 | 29.5846 * |
| Speed & diameter interaction | 4 | 0.0730 | 0.0176 n.s. |
| Speed & class interaction | 4 | 0.1255 | 0.0314 n.s. |
| Class & diameter interaction | 4 | 0.2396 | 0.0599 n.s. |
| Class, speed, & diameter interaction | 8 | 0.2825 | 0.0353 n.s. |
| Error | 27 | 2.6555 | 0.0984 |
| Total | 53 | 62.7923 | |

Table 13. Method B. Analysis of variance of the Agtron color reading of the product through the 9XX sieve.

| Source of variation | d.f. | S.S. | M.S. |
|---|---|---|---|
| Roll diameter | 2 | 12.11 | 6.06 n.s. |
| Roll speed | 2 | 6.99 | 3.50 n.s. |
| Wheat class | 2 | 1045.77 | 522.88 * |
| Speed & diameter interaction | 4 | 6.22 | 1.56 n.s. |
| Speed & class interaction | 4 | 2.21 | 0.55 n.s. |
| Class & diameter interaction | 4 | 2.77 | 0.69 n.s. |
| Class, speed, & diameter interaction | 8 | 11.27 | 1.41 n.s. |
| Error | 27 | 93.50 | 3.46 |
| Total | 53 | 1180.84 | |

n.s. Non-significant
* Significant at the 0.05 level

Table 14. Method B. Analysis of variance of the Fisher average particle size reading of the product through the 9XX sieve.

| Source of variation | d.f. | S.S. | M.S. |
|---|---|---|---|
| Roll diameter | 2 | 3.099 | 1.550 n.s. |
| Roll speed | 2 | 0.665 | 0.332 n.s. |
| Wheat class | 2 | 1028.065 | 514.032 * |
| Speed & diameter interaction | 4 | 3.890 | 0.972 n.s. |
| Speed & class interaction | 4 | 1.190 | 0.298 n.s. |
| Class & diameter interaction | 4 | 3.077 | 0.769 n.s. |
| Class, speed, & diameter interaction | 8 | 1.937 | 0.242 n.s. |
| Error | 27 | 17.540 | 0.650 |
| Total | 53 | 1059.463 | |

Table 15. Method B. Analysis of variance of the percentage of total product (yield) through the 64GG sieve.

| Source of variation | d.f. | S.S. | M.S. |
|---|---|---|---|
| Roll diameter | 2 | 1.54 | 0.77 n.s. |
| Roll speed | 2 | 3.49 | 1.74 n.s. |
| Wheat class | 2 | 55.46 | 27.73 * |
| Speed & diameter interaction | 4 | 2.18 | 0.54 n.s. |
| Speed & class interaction | 4 | 3.62 | 0.90 n.s. |
| Class & diameter interaction | 4 | 23.64 | 5.91 * |
| Class, speed, & diameter interaction | 8 | 7.49 | 0.94 n.s. |
| Error | 27 | 27.24 | 1.01 |
| Total | 53 | 124.66 | |

n.s. Non-significant
* Significant at the 0.05 level

# SUMMARY AND CONCLUSIONS

Class of wheat had a significant effect on the size distribution and cumulative ash content of the product obtained from wheat passed through the 3 diameters of break rolls at 3 different speeds of the break rolls, with all other known factors held constant. Class of wheat also had a significant effect on ash content, protein content, Agtron color, and Fisher average particle size measurement of the flour through a 9 XX sieve when the first break roll product was milled with a Quadrumat Senior experimental laboratory mill reduction system.

Diameter of rolls had a significant effect on the size distribution and cumulative ash content of the product from the first break rolls when grinding 3 classes of wheat at the 3 roll speeds. The least significant difference of the means of the cumulative ash content, indicated that the 9 inch diameter rolls were preferable to either the 6 or 12 inch diameter rolls.

Speed of break rolls at the fast roll speeds tested and with 2.5 to 1 differential, did not have a significant effect on the size distribution and cumulative ash content of the product resulting from grinding wheat of 3 classes through the 3 sizes of roll diameters.

It can be concluded that:

1. A difference in wheat class can affect test results when using the cumulative ash content method of product evaluation.

2. Roll diameter will have an effect on the percentage of ash content and particle size of the product from the first break rolls, with all other factors constant. Nine inch diameter break rolls were the most satisfactory of the 3 diameters tested, for first break grinding at 2.5

to 1 differential and with the corrugation style used; ash content and particle size of the product being the indices of evaluation.

3. Roll speeds, within the levels tested, at constant differential of 2.5 to 1, and at a fixed load below maximum capacity, will not significantly affect first break roll operation as measured by ash content and particle size of the resultant product.

## SUGGESTIONS FOR FUTURE WORK

The investigations performed in this experiment were of the nature outlining a framework to use in first break roll analysis. Possibilities for future work may include the continuation of this research with emphasis on the following:

1. Development of a better method of evaluating the total results of first break roll factors. The use of a fixed reduction roll system in conjunction with a Tyler sieve series for cumulative ash analysis seems most promising, based on a review of the techniques used in this experiment.

2. Design of a technique to evaluate break roll performance under normal milling conditions so as to devise a set of standards that would provide a guide to proper break roll settings in order to compensate for changes in first break roll factors.

## ACKNOWLEDGMENTS

The writer wishes to take this time to express his sincere appreciation to Professor E. P. Farrell, major instructor, for his guidance and suggestions during the research and preparation of the manuscript.

The writer is also grateful to J. A. Shellenberger, Head, Department of Flour and Feed Milling Industries, for providing the facilities and materials that were needed to carry out the work.

Special acknowledgment is due Professor A. B. Ward for his guidance and helpful suggestions throughout the research project.

Also, the writer expresses his appreciation to all the members of the department who most willingly gave assistance and advice during the course of this project.

## LITERATURE CITED


(1) American Association of Cereal Chemists.
Cereal laboratory methods. 7th., St. Paul, Minnesota: American Association of Cereal Chemists, Inc., 1962.

(2) Anderson, J. E.
Principles of humidification applied to the flour milling process. Kansas City: Association of Operative Millers Bulletin, Vol. I, pp. 374-84.

(3) Anonymous.
Bellera. General Mill's progress report on its new milling system. American Miller and Processor 88 (8):32-36; (11):33, 1960.

(4) Anonymous.
Technical details of roller mills rolls. Technische einzelheiten von walzen. Die Muhle 102 (7):108-109; (8):126; (9):145, 1965.

(5) Association of Operative Millers.
Correspondence course of flour milling. Unit No. 1, Lesson No. 11. Kansas City: Association of Operative Millers, 1950, pp. 1-5.

(6) Association of Operative Millers.
Correspondence course in flour milling. Unit No. 2, Lesson No. 11. Kansas City: Association of Operative Millers, 1950, pp. 1-5.

(7) Bradbury, Dorothy, Irene M. Cull, and Majel M. MacMasters.
Structure of the mature wheat kernel. I. Gross anatomy and relationship of parts. II. Microscopic structure of pericarp, seed coat, and other covering of the endosperm and germ of hard red winter wheat. III. Microscopic structure of the endosperm of hard red winter wheat. Cereal Chemistry 33:329-73, 1956.

(8) Bradbury, Dorothy, J. E. Hubbard, Majel M. MacMasters, and F. R. Senti.
Conditioning wheat for milling. A survey of literature. Washington, D. C.: Department of Agriculture Miscellaneous Publication, No. 824, May, 1960, 147 p.

(9) Cleve, H. and F. Will.
Research with the help of the varioroll. Cereal Science Today 11 (4):128-32, 1966.

(10) Crewe, Joan, and C. R. Jones.
The thickness of wheat bran. Cereal Chemistry 28:40-49, 1951.

(11) Dedrick, B. W.
How roll corrugations affect our grinding. National Miller 31 (3): 18-20, 1926.

(12) Essmueller, B.
Roll corrugation. Kansas City: Association of Operative Millers Bulletin, Vol. I, pp. 69-74.

(13) Eustace, W. D.
Some effects of cold, warm, and hot wheat conditioning on the milling and baking characteristics of wheat. Unpublished master's thesis, Kansas State University, Manhattan, Kansas, 1962.

(14) Farrell, E. P. and A. B. Ward.
Flow rates and analyses for ash and protein of all streams in the Kansas State University pilot mill. Association of Operative Millers Bulletin, pp. 2842-47, March, 1965.

(15) Fisher Scientific Company.
Directions for determination of average particle diameters of powders with the Fisher Sub-Sieve sizer. Pittsburgh: Fisher Scientific Company, Pamphlet No. 14-312.

(16) Gehle, H.
The Miag Vario rollstand-design and purpose. Association of Operative Millers Bulletin, pp. 2861-62, May, 1965.

(17) Gillis, J. A.
The Agtron. Cereal Science Today 8:40-45, 1963.

(18) Heide, F. M.
Roll corrugation. Association of Operative Millers Bulletin, pp. 2292-94, December, 1956.

(19) Hinton, J. J. C.
The distribution of ash in the wheat kernel. Cereal Chemistry 36:19-31, 1959.

(20) Hlynka, I. (ed.).
Wheat chemistry and technology. St. Paul, Minnesota: American Association of Cereal Chemists, 1964, 589 p.

(21) Howe, S.
Grinding and its effect. Kansas City: Association of Operative Millers Bulletin, Vol. II, pp. 267-71.

(22) Jurkow, J.
Breaking, grading, flouring. Northwestern Miller, Milling Production 241 (2):3-8, 1950.

(23) Kent-Jones, D. W.
Modern cereal chemistry. 4th ed. Liverpool: Northern Publishing Co., Ltd., 1947, 619 p.

(24) Kozmin, P. A.
Flour milling. London: George Routledge & Sons, Ltd., 1921, 582 p.

(25) Kozmin, P. A.
Roll speeds. National and American Miller 61 (3):18-19; (4): 18-19, 52, 1933.

(26) Larkin, R. A., Majel M. MacMasters, M. J. Wolf, and C. E. Rist.
Studies on the relation of bran thickness on millability of some Pacific Northwest wheats. Cereal Chemistry 28:247-58, 1951.

(27) Lockwood, Sir Joseph.
Flour milling. 4th ed. Liverpool: Northern Publishing Co., Ltd., 1960, 518 p.

(28) McCluggage, M. D.
Factors influencing the pearling test for kernel hardness in wheat. Cereal Chemistry 20:686-700, 1943.

(29) Nordstrom, K. L.
Measuring milling results. Association of Operative Millers Bulletin, pp. 2869-70, July, 1965.

(30) Paige, W. A.
Breaking with five breaking rolls. American Miller and Processor 63 (7):28, 1935.

(31) Pence, R. O.
Grinding zones and effects of varying the differential in break grinding. National Miller 33 (8):16-20,82,85-86,89-90, 1928.

(32) Pence, R. O. and R. E. McCormick.
Corrugations and differential. Kansas City: Association of Operative Millers Bulletin, Vol. I, pp. 70-77.

(33) Roethe, G. (ed.).
Milling techniques in modern mills. Braunschweig, Germany: Miag, 1960, 93 p.

(34) Schafer, W.
Principles for judging test mills. Translated from the reprint of an article in Die Muhle. Die Muhle 97 (51); (52), 1960.

(35) Scott, J. H.
Flour milling processes. 2nd ed. rev. London: Chapman & Hall, Ltd., 1951, 662 p.

(36) Senti, F. R. and W. D. Maclay.
Wheat utilization research program of the U. S. Department of Agriculture and its relation to the operative miller. Association of Operative Millers Bulletin, pp. 2264-70, August, 1956.

(37) Smith, L.
Flour milling technology. 3rd ed. rev. Liverpool: Northern Publishing Co., Ltd., 1944, 564 p.

(38) Snedecor, G.
Statistical methods. 5th ed. Ames, Iowa: Iowa State University Press, 1956, 523 p.

(39) Speight, J.
Is the roller mill capable of greater effort? Milling 145 (10): 213, 1965.

(40) Stiver, Jr., T. E.
American corn milling systems for de-germed product. Association of Operative Millers Bulletin, p. 2179, June, 1955.

(41) Swanson, C. O.
Is there any relief from ash? Kansas City: Association of Operative Millers Bulletin, Vol. I, pp. 168-73.

(42) Swanson, C. O.
Meaning of atmospheric control. Kansas City: Association of Operative Millers Bulletin, Vol. I, pp. 7363-73.

(43) Tesarek, G. J.
Flour milling flows. Association of Operative Millers Bulletin, pp. 2287-89, November, 1956.

(44) Tyler, W. S.
Testing sieves and their uses. Handbook No. 53. Cleveland: W. S. Tyler Company, 1964 edition.

(45) U. S. Department of Agriculture.
Official grain standards of the United States. Grain Division, Agricultural Marketing Service. Washington D. C.: U. S. Government Printing Office, 93 p.

(46) Vilm, H.
Grinding and its effects. Kansas City: Association of Operative Millers Bulletin, Vol. II, pp. 268-71.

(47) Wissmar, K.
Analytical methods to control mill efficiency. Association of Operative Millers Bulletin, pp. 2521-23, August, 1960.

(48) Wolff, E.
The Pratique system of grinding. American Miller and Processor 86 (3):18-19, 1958.

(49) Wolff, E.
The short high milling system. American Miller and Processor 86 (10):22-24, 1958.

(50) Youdale, L. M.
Effects of developments in milling machinery on mill design and layout. Milling 140 (14):349, 1963.

(51) Zerull, L.
Roller mills for A. O. M. panel. Association of Operative Millers Bulletin, p. 2782, March, 1964.

# APPENDIX A

## Method A Data

Table 16. First break grinding of soft red winter wheat with six inch diameter rolls.

| Roll speed | Tyler mesh | % Ash 14 M.B. | Cumulative % ash | % of total product | Cumulative % of total product |
|---|---|---|---|---|---|
| 600 rpm | -100 | 0.316 | 0.316 | 1.501 | 1.501 |
| | +100 | 0.305 | 0.310 | 1.762 | 3.263 |
| | + 65 | 0.305 | 0.307 | 5.483 | 8.746 |
| | + 48 | 0.327 | 0.314 | 5.221 | 13.986 |
| | + 35 | 0.413 | 0.340 | 4.830 | 18.798 |
| | + 28 | 0.614 | 0.410 | 6.527 | 25.326 |
| | + 20 | 1.696 | 0.611 | 4.699 | 30.026 |
| 600 rpm | -100 | 0.345 | 0.345 | 1.383 | 1.383 |
| | +100 | 0.326 | 0.333 | 2.102 | 3.486 |
| | + 65 | 0.315 | 0.323 | 5.257 | 8.743 |
| | + 48 | 0.337 | 0.328 | 4.814 | 13.558 |
| | + 35 | 0.414 | 0.350 | 4.759 | 18.317 |
| | + 28 | 0.694 | 0.442 | 6.640 | 24.958 |
| | + 20 | 1.406 | 0.611 | 5.312 | 30.271 |
| 750 rpm | -100 | 0.352 | 0.352 | 1.691 | 1.691 |
| | +100 | 0.334 | 0.343 | 1.636 | 3.327 |
| | + 65 | 0.346 | 0.345 | 5.019 | 8.346 |
| | + 48 | 0.369 | 0.354 | 5.019 | 13.366 |
| | + 35 | 0.414 | 0.370 | 4.746 | 18.112 |
| | + 28 | 0.578 | 0.426 | 6.764 | 24.877 |
| | + 20 | 1.717 | 0.664 | 5.619 | 30.496 |
| 750 rpm | -100 | 0.345 | 0.345 | 1.591 | 1.591 |
| | +100 | 0.323 | 0.333 | 1.909 | 3.500 |
| | + 65 | 0.326 | 0.329 | 5.092 | 8.593 |
| | + 48 | 0.377 | 0.346 | 4.901 | 13.494 |
| | + 35 | 0.425 | 0.366 | 4.646 | 18.141 |
| | + 28 | 0.636 | 0.437 | 6.365 | 24.506 |
| | + 20 | 1.609 | 0.638 | 5.092 | 29.598 |
| 900 rpm | -100 | 0.325 | 0.325 | 1.683 | 1.683 |
| | +100 | 0.314 | 0.320 | 1.620 | 3.304 |
| | + 65 | 0.307 | 0.312 | 4.987 | 8.291 |
| | + 48 | 0.356 | 0.329 | 5.112 | 13.403 |
| | + 35 | 0.415 | 0.351 | 4.800 | 18.204 |
| | + 28 | 0.595 | 0.416 | 6.546 | 24.750 |
| | + 20 | 1.423 | 0.590 | 5.174 | 29.925 |
| 900 rpm | -100 | 0.363 | 0.363 | 1.726 | 1.726 |
| | +100 | 0.335 | 0.350 | 1.668 | 3.394 |
| | + 65 | 0.357 | 0.354 | 4.833 | 8.227 |
| | + 48 | 0.379 | 0.363 | 4.890 | 13.118 |
| | + 35 | 0.437 | 0.382 | 4.602 | 17.721 |
| | + 28 | 0.697 | 0.469 | 6.731 | 24.453 |
| | + 20 | 1.403 | 0.644 | 5.638 | 30.092 |

Table 17. First break grinding of soft red winter wheat with nine inch diameter rolls.

| Roll speed | Tyler mesh | % Ash 14 M.B. | Cumulative % ash | % of total product | Cumulative % of total product |
|---|---|---|---|---|---|
| 400 rpm | -100 | 0.304 | 0.304 | 0.688 | 0.688 |
| | +100 | 0.306 | 0.305 | 1.652 | 2.341 |
| | + 65 | 0.305 | 0.305 | 6.198 | 8.539 |
| | + 48 | 0.326 | 0.313 | 5.165 | 13.705 |
| | + 35 | 0.389 | 0.333 | 5.027 | 18.732 |
| | + 28 | 0.698 | 0.431 | 6.818 | 25.550 |
| | + 20 | 1.616 | 0.621 | 4.889 | 30.440 |
| 400 rpm | -100 | 0.304 | 0.304 | 0.954 | 0.954 |
| | +100 | 0.314 | 0.310 | 1.295 | 2.249 |
| | + 65 | 0.304 | 0.306 | 6.339 | 8.588 |
| | + 48 | 0.323 | 0.312 | 5.112 | 13.701 |
| | + 35 | 0.429 | 0.342 | 4.703 | 18.404 |
| | + 28 | 0.561 | 0.401 | 6.816 | 25.221 |
| | + 20 | 1.601 | 0.601 | 5.044 | 30.265 |
| 500 rpm | -100 | 0.304 | 0.304 | 0.728 | 0.728 |
| | +100 | 0.314 | 0.311 | 1.324 | 2.052 |
| | + 65 | 0.304 | 0.306 | 6.092 | 8.145 |
| | + 48 | 0.318 | 0.311 | 5.165 | 13.311 |
| | + 35 | 0.391 | 0.332 | 4.900 | 18.211 |
| | + 28 | 0.609 | 0.406 | 6.622 | 24.834 |
| | + 20 | 1.515 | 0.591 | 4.966 | 29.801 |
| 500 rpm | -100 | 0.316 | 0.316 | 0.833 | 0.833 |
| | +100 | 0.317 | 0.316 | 1.528 | 2.362 |
| | + 65 | 0.306 | 0.309 | 5.837 | 8.200 |
| | + 48 | 0.328 | 0.316 | 5.142 | 13.342 |
| | + 35 | 0.399 | 0.338 | 4.864 | 18.207 |
| | + 28 | 0.536 | 0.391 | 6.671 | 24.878 |
| | + 20 | 1.613 | 0.593 | 4.933 | 29.812 |
| 600 rpm | -100 | 0.304 | 0.304 | 0.892 | 0.892 |
| | +100 | 0.314 | 0.310 | 1.402 | 2.294 |
| | + 65 | 0.304 | 0.306 | 6.054 | 8.349 |
| | + 48 | 0.327 | 0.314 | 5.162 | 13.511 |
| | + 35 | 0.407 | 0.338 | 4.780 | 18.291 |
| | + 28 | 0.561 | 0.399 | 6.883 | 25.175 |
| | + 20 | 1.507 | 0.592 | 5.289 | 30.465 |
| 600 rpm | -100 | 0.296 | 0.296 | 0.813 | 0.813 |
| | +100 | 0.317 | 0.311 | 1.829 | 2.642 |
| | + 65 | 0.306 | 0.307 | 5.826 | 8.468 |
| | + 48 | 0.337 | 0.318 | 4.878 | 13.346 |
| | + 35 | 0.408 | 0.342 | 4.742 | 18.089 |
| | + 28 | 0.646 | 0.425 | 6.775 | 24.864 |
| | + 20 | 1.611 | 0.622 | 4.945 | 29.810 |

Table 18. First break grinding of soft red winter wheat with twelve inch diameter rolls.

| Roll speed | Tyler mesh | % Ash 14 M.B. | Cumulative % ash | % of total product | Cumulative % of total product |
|---|---|---|---|---|---|
| 300 rpm | -100 | 0.436 | 0.436 | 2.312 | 2.312 |
| | +100 | 0.397 | 0.422 | 1.250 | 3.562 |
| | + 65 | 0.376 | 0.397 | 4.062 | 7.625 |
| | + 48 | 0.451 | 0.417 | 4.312 | 11.937 |
| | + 35 | 0.525 | 0.446 | 4.375 | 16.312 |
| | + 28 | 0.573 | 0.483 | 6.875 | 23.187 |
| | + 20 | 1.205 | 0.654 | 7.187 | 30.375 |
| 300 rpm | -100 | 0.295 | 0.295 | 1.328 | 1.328 |
| | +100 | 0.326 | 0.313 | 1.792 | 3.120 |
| | + 65 | 0.318 | 0.316 | 5.976 | 9.096 |
| | + 48 | 0.357 | 0.331 | 5.112 | 14.209 |
| | + 35 | 0.490 | 0.370 | 4.648 | 18.857 |
| | + 28 | 0.607 | 0.430 | 6.374 | 25.232 |
| | + 20 | 1.517 | 0.599 | 4.648 | 29.880 |
| 375 rpm | -100 | 0.356 | 0.356 | 1.828 | 1.828 |
| | +100 | 0.326 | 0.343 | 1.436 | 3.265 |
| | + 65 | 0.326 | 0.333 | 4.964 | 8.229 |
| | + 48 | 0.377 | 0.350 | 5.029 | 13.259 |
| | + 35 | 0.423 | 0.369 | 4.572 | 17.831 |
| | + 28 | 0.720 | 0.464 | 6.662 | 24.493 |
| | + 20 | 1.421 | 0.636 | 5.355 | 29.849 |
| 375 rpm | -100 | 0.344 | 0.344 | 2.002 | 2.002 |
| | +100 | 0.314 | 0.330 | 1.668 | 3.671 |
| | + 65 | 0.314 | 0.321 | 4.806 | 8.477 |
| | + 48 | 0.365 | 0.338 | 5.073 | 13.551 |
| | + 35 | 0.444 | 0.365 | 4.672 | 18.224 |
| | + 28 | 0.504 | 0.403 | 6.809 | 25.033 |
| | + 20 | 1.309 | 0.562 | 5.340 | 30.373 |
| 450 rpm | -100 | 0.285 | 0.285 | 1.061 | 1.061 |
| | +100 | 0.317 | 0.305 | 1.803 | 2.864 |
| | + 65 | 0.335 | 0.325 | 5.835 | 8.700 |
| | + 48 | 0.369 | 0.341 | 4.880 | 13.580 |
| | + 35 | 0.439 | 0.366 | 4.668 | 18.249 |
| | + 28 | 0.741 | 0.467 | 6.737 | 24.986 |
| | + 20 | 1.605 | 0.656 | 4.986 | 29.973 |
| 450 rpm | -100 | 0.425 | 0.425 | 2.268 | 2.268 |
| | +100 | 0.396 | 0.415 | 1.373 | 3.641 |
| | + 65 | 0.366 | 0.389 | 4.059 | 7.701 |
| | + 48 | 0.435 | 0.405 | 4.179 | 11.880 |
| | + 35 | 0.502 | 0.431 | 4.417 | 16.298 |
| | + 28 | 0.602 | 0.482 | 6.865 | 23.164 |
| | + 20 | 1.207 | 0.652 | 7.104 | 30.268 |

Table 19. First break grinding of hard red spring wheat with six inch diameter rolls.

| Roll speed | Tyler mesh | % Ash 14 M.B. | Cumulative % ash | % of total product | Cumulative % of total product |
|---|---|---|---|---|---|
| 600 rpm | -100 | 0.593 | 0.593 | 2.591 | 2.591 |
| | +100 | 0.580 | 0.588 | 1.528 | 4.119 |
| | + 65 | 0.596 | 0.591 | 2.458 | 6.578 |
| | + 48 | 0.588 | 0.590 | 3.056 | 9.634 |
| | + 35 | 0.643 | 0.606 | 3.986 | 13.621 |
| | + 28 | 0.711 | 0.642 | 7.308 | 20.930 |
| | + 20 | 1.100 | 0.780 | 9.036 | 29.966 |
| 600 rpm | -100 | 0.641 | 0.641 | 2.578 | 2.578 |
| | +100 | 0.606 | 0.628 | 1.473 | 4.051 |
| | + 65 | 0.617 | 0.624 | 2.332 | 6.384 |
| | + 48 | 0.646 | 0.631 | 3.007 | 9.392 |
| | + 35 | 0.666 | 0.641 | 3.806 | 13.198 |
| | + 28 | 0.753 | 0.681 | 7.243 | 20.441 |
| | + 20 | 1.312 | 0.882 | 9.576 | 30.018 |
| 750 rpm | -100 | 0.596 | 0.596 | 2.275 | 2.275 |
| | +100 | 0.613 | 0.603 | 1.437 | 3.712 |
| | + 65 | 0.649 | 0.622 | 2.574 | 6.287 |
| | + 48 | 0.636 | 0.626 | 2.994 | 9.281 |
| | + 35 | 0.675 | 0.641 | 3.892 | 13.173 |
| | + 28 | 0.843 | 0.713 | 7.365 | 20.538 |
| | + 20 | 1.310 | 0.907 | 9.880 | 30.419 |
| 750 rpm | -100 | 0.636 | 0.636 | 2.592 | 2.592 |
| | +100 | 0.622 | 0.631 | 1.434 | 4.026 |
| | + 65 | 0.649 | 0.638 | 2.371 | 6.398 |
| | + 48 | 0.635 | 0.637 | 3.033 | 9.431 |
| | + 35 | 0.698 | 0.655 | 3.861 | 13.292 |
| | + 28 | 0.708 | 0.674 | 7.335 | 20.628 |
| | + 20 | 1.209 | 0.844 | 9.652 | 30.281 |
| 900 rpm | -100 | 0.609 | 0.609 | 2.480 | 2.480 |
| | +100 | 0.612 | 0.610 | 1.417 | 3.898 |
| | + 65 | 0.656 | 0.627 | 2.244 | 6.142 |
| | + 48 | 0.661 | 0.638 | 2.953 | 9.096 |
| | + 35 | 0.708 | 0.658 | 3.780 | 12.876 |
| | + 28 | 0.754 | 0.692 | 7.088 | 19.964 |
| | + 20 | 1.409 | 0.927 | 9.746 | 29.710 |
| 900 rpm | -100 | 0.599 | 0.599 | 2.484 | 2.484 |
| | +100 | 0.620 | 0.607 | 1.490 | 3.975 |
| | + 65 | 0.649 | 0.623 | 2.422 | 6.397 |
| | + 48 | 0.649 | 0.631 | 3.105 | 9.503 |
| | + 35 | 0.665 | 0.641 | 3.975 | 13.478 |
| | + 28 | 0.771 | 0.688 | 7.453 | 20.931 |
| | + 20 | 1.207 | 0.850 | 9.503 | 30.434 |

Table 20. First break grinding of hard red spring wheat with nine inch diameter rolls.

| Roll speed | Tyler mesh | % Ash 14 M.B. | Cumulative % ash | % of total product | Cumulative % of total product |
|---|---|---|---|---|---|
| 400 rpm | -100 | 0.610 | 0.610 | 2.500 | 2.500 |
| | +100 | 0.590 | 0.603 | 1.500 | 4.000 |
| | + 65 | 0.590 | 0.598 | 2.500 | 6.500 |
| | + 48 | 0.620 | 0.605 | 3.000 | 9.500 |
| | + 35 | 0.698 | 0.632 | 3.833 | 13.333 |
| | + 28 | 0.814 | 0.698 | 7.583 | 20.916 |
| | + 20 | 1.195 | 0.850 | 9.250 | 30.166 |
| 400 rpm | -100 | 0.599 | 0.599 | 2.389 | 2.389 |
| | +100 | 0.561 | 0.585 | 1.493 | 3.883 |
| | + 65 | 0.611 | 0.595 | 2.539 | 6.422 |
| | + 48 | 0.591 | 0.594 | 2.987 | 9.410 |
| | + 35 | 0.652 | 0.610 | 3.734 | 13.144 |
| | + 28 | 0.670 | 0.632 | 7.617 | 20.761 |
| | + 20 | 1.406 | 0.872 | 9.335 | 30.097 |
| 500 rpm | -100 | 0.589 | 0.589 | 2.362 | 2.362 |
| | +100 | 0.557 | 0.576 | 1.532 | 3.895 |
| | + 65 | 0.569 | 0.574 | 2.554 | 6.449 |
| | + 48 | 0.559 | 0.569 | 3.065 | 9.514 |
| | + 35 | 0.604 | 0.579 | 3.831 | 13.346 |
| | + 28 | 0.743 | 0.639 | 7.662 | 21.008 |
| | + 20 | 1.201 | 0.815 | 9.578 | 30.587 |
| 500 rpm | -100 | 0.581 | 0.581 | 2.355 | 2.355 |
| | +100 | 0.554 | 0.570 | 1.519 | 3.875 |
| | + 65 | 0.599 | 0.582 | 2.583 | 6.458 |
| | + 48 | 0.616 | 0.593 | 3.039 | 9.498 |
| | + 35 | 0.615 | 0.599 | 3.799 | 13.297 |
| | + 28 | 0.691 | 0.633 | 7.826 | 21.124 |
| | + 20 | 1.211 | 0.814 | 9.650 | 30.775 |
| 600 rpm | -100 | 0.601 | 0.601 | 2.317 | 2.317 |
| | +100 | 0.568 | 0.589 | 1.390 | 3.707 |
| | + 65 | 0.668 | 0.602 | 2.375 | 6.083 |
| | + 48 | 0.663 | 0.634 | 2.896 | 8.980 |
| | + 35 | 0.663 | 0.642 | 3.707 | 12.688 |
| | + 28 | 0.762 | 0.687 | 7.415 | 20.104 |
| | + 20 | 1.198 | 0.854 | 9.791 | 29.895 |
| 600 rpm | -100 | 0.603 | 0.603 | 2.294 | 2.294 |
| | +100 | 0.596 | 0.600 | 1.460 | 3.755 |
| | + 65 | 0.595 | 0.598 | 2.573 | 6.328 |
| | + 48 | 0.576 | 0.591 | 3.059 | 9.388 |
| | + 35 | 0.621 | 0.600 | 3.824 | 13.212 |
| | + 28 | 0.752 | 0.655 | 7.649 | 20.862 |
| | + 20 | 1.418 | 0.898 | 9.735 | 30.598 |

Table 21. First break grinding of hard red spring wheat with twelve inch diameter rolls.

| Roll speed | Tyler mesh | % Ash 14 M.B. | Cumulative % ash | % of total product | Cumulative % of total product |
|---|---|---|---|---|---|
| 300 rpm | -100 | 0.611 | 0.611 | 2.798 | 2.798 |
| | +100 | 0.598 | 0.606 | 1.472 | 4.270 |
| | + 65 | 0.632 | 0.616 | 2.503 | 6.774 |
| | + 48 | 0.623 | 0.618 | 2.945 | 9.720 |
| | + 35 | 0.628 | 0.621 | 3.829 | 13.549 |
| | + 28 | 0.784 | 0.678 | 7.363 | 20.913 |
| | + 20 | 0.970 | 0.768 | 9.278 | 30.191 |
| 300 rpm | -100 | 0.648 | 0.648 | 2.487 | 2.487 |
| | +100 | 0.607 | 0.633 | 1.403 | 3.890 |
| | + 65 | 0.678 | 0.650 | 2.423 | 6.313 |
| | + 48 | 0.660 | 0.653 | 2.997 | 9.311 |
| | + 35 | 0.691 | 0.664 | 3.762 | 13.073 |
| | + 28 | 0.704 | 0.678 | 7.270 | 20.344 |
| | + 20 | 1.293 | 0.881 | 10.012 | 30.357 |
| 375 rpm | -100 | 0.649 | 0.649 | 2.394 | 2.394 |
| | +100 | 0.567 | 0.620 | 1.323 | 3.717 |
| | + 65 | 0.619 | 0.619 | 2.268 | 5.986 |
| | + 48 | 0.627 | 0.622 | 2.898 | 8.884 |
| | + 35 | 0.691 | 0.642 | 3.654 | 12.539 |
| | + 28 | 0.813 | 0.704 | 7.057 | 19.596 |
| | + 20 | 1.306 | 0.908 | 10.081 | 29.678 |
| 375 rpm | -100 | 0.652 | 0.652 | 2.498 | 2.498 |
| | +100 | 0.597 | 0.632 | 1.473 | 3.971 |
| | + 65 | 0.638 | 0.634 | 2.498 | 6.470 |
| | + 48 | 0.667 | 0.645 | 3.074 | 9.545 |
| | + 35 | 0.724 | 0.667 | 3.779 | 13.324 |
| | + 28 | 0.714 | 0.684 | 7.174 | 20.499 |
| | + 20 | 1.100 | 0.819 | 9.929 | 30.429 |
| 450 rpm | -100 | 0.659 | 0.659 | 2.436 | 2.436 |
| | +100 | 0.616 | 0.643 | 1.400 | 3.836 |
| | + 65 | 0.628 | 0.637 | 2.375 | 6.211 |
| | + 48 | 0.638 | 0.637 | 2.923 | 9.135 |
| | + 35 | 0.704 | 0.656 | 3.593 | 12.728 |
| | + 28 | 0.941 | 0.756 | 6.881 | 19.610 |
| | + 20 | 1.298 | 0.942 | 10.231 | 29.841 |
| 450 rpm | -100 | 0.628 | 0.628 | 2.322 | 2.322 |
| | +100 | 0.568 | 0.606 | 1.283 | 3.606 |
| | + 65 | 0.588 | 0.599 | 2.261 | 5.867 |
| | + 48 | 0.678 | 0.625 | 2.872 | 8.740 |
| | + 35 | 0.681 | 0.642 | 3.667 | 12.408 |
| | + 28 | 0.863 | 0.723 | 7.212 | 19.621 |
| | + 20 | 1.101 | 0.856 | 10.635 | 30.256 |

Table 22. First break grinding of hard red winter wheat with six inch diameter rolls.

| Roll speed | Tyler mesh | % Ash 14 M.B. | Cumulative % ash | % of total product | Cumulative % of total product |
|---|---|---|---|---|---|
| 600 rpm | -100 | 0.492 | 0.492 | 2.915 | 2.915 |
| | +100 | 0.498 | 0.494 | 1.647 | 4.562 |
| | + 65 | 0.508 | 0.499 | 2.661 | 7.224 |
| | + 48 | 0.531 | 0.509 | 3.168 | 10.392 |
| | + 35 | 0.627 | 0.541 | 3.929 | 14.321 |
| | + 28 | 0.868 | 0.649 | 7.097 | 21.419 |
| | + 20 | 1.304 | 0.839 | 8.745 | 30.164 |
| 600 rpm | -100 | 0.480 | 0.480 | 2.943 | 2.943 |
| | +100 | 0.497 | 0.486 | 1.628 | 4.571 |
| | + 65 | 0.531 | 0.502 | 2.567 | 7.138 |
| | + 48 | 0.571 | 0.524 | 3.256 | 10.394 |
| | + 35 | 0.625 | 0.551 | 3.944 | 14.339 |
| | + 28 | 0.857 | 0.653 | 7.138 | 21.477 |
| | + 20 | 1.182 | 0.806 | 8.766 | 30.244 |
| 750 rpm | -100 | 0.508 | 0.508 | 2.828 | 2.828 |
| | +100 | 0.529 | 0.515 | 1.527 | 4.355 |
| | + 65 | 0.548 | 0.527 | 2.488 | 6.843 |
| | + 48 | 0.626 | 0.558 | 3.110 | 9.954 |
| | + 35 | 0.660 | 0.586 | 3.846 | 13.800 |
| | + 28 | 0.961 | 0.713 | 7.070 | 20.871 |
| | + 20 | 1.301 | 0.895 | 9.332 | 30.203 |
| 750 rpm | -100 | 0.511 | 0.511 | 2.830 | 2.830 |
| | +100 | 0.507 | 0.510 | 1.579 | 4.410 |
| | + 65 | 0.510 | 0.510 | 2.501 | 6.912 |
| | + 48 | 0.592 | 0.536 | 3.225 | 10.138 |
| | + 35 | 0.677 | 0.576 | 3.949 | 14.088 |
| | + 28 | 0.861 | 0.672 | 7.241 | 21.329 |
| | + 20 | 1.423 | 0.894 | 8.953 | 30.283 |
| 900 rpm | -100 | 0.500 | 0.500 | 2.839 | 2.839 |
| | +100 | 0.498 | 0.499 | 1.604 | 4.444 |
| | + 65 | 0.531 | 0.511 | 2.592 | 7.037 |
| | + 48 | 0.562 | 0.527 | 3.209 | 10.246 |
| | + 35 | 0.621 | 0.553 | 3.950 | 14.197 |
| | + 28 | 0.862 | 0.658 | 7.283 | 21.481 |
| | + 20 | 1.411 | 0.882 | 9.135 | 30.617 |
| 900 rpm | -100 | 0.518 | 0.518 | 2.947 | 2.947 |
| | +100 | 0.529 | 0.522 | 1.587 | 4.535 |
| | + 65 | 0.591 | 0.547 | 2.494 | 7.029 |
| | + 48 | 0.674 | 0.586 | 3.174 | 10.204 |
| | + 35 | 0.698 | 0.617 | 3.911 | 14.115 |
| | + 28 | 0.779 | 0.672 | 7.256 | 21.371 |
| | + 20 | 1.211 | 0.838 | 9.523 | 30.895 |

Table 23. First break grinding of hard red winter wheat with nine inch diameter rolls.

| Roll speed | Tyler mesh | % Ash 14 M.B. | Cumulative % ash | % of total product | Cumulative % of total product |
|---|---|---|---|---|---|
| 400 rpm | -100 | 0.449 | 0.449 | 3.174 | 3.174 |
| | +100 | 0.447 | 0.448 | 1.763 | 4.938 |
| | + 65 | 0.472 | 0.457 | 2.821 | 7.760 |
| | + 48 | 0.509 | 0.471 | 2.998 | 10.758 |
| | + 35 | 0.549 | 0.493 | 4.056 | 14.814 |
| | + 28 | 0.856 | 0.618 | 7.760 | 22.574 |
| | + 20 | 1.404 | 0.812 | 7.407 | 29.982 |
| 400 rpm | -100 | 0.488 | 0.488 | 2.823 | 2.823 |
| | +100 | 0.478 | 0.484 | 1.515 | 4.338 |
| | + 65 | 0.551 | 0.510 | 2.754 | 7.093 |
| | + 48 | 0.552 | 0.523 | 3.168 | 10.261 |
| | + 35 | 0.629 | 0.551 | 3.719 | 13.980 |
| | + 28 | 0.842 | 0.649 | 7.024 | 21.005 |
| | + 20 | 1.218 | 0.820 | 9.022 | 30.027 |
| 500 rpm | -100 | 0.480 | 0.480 | 2.808 | 2.808 |
| | +100 | 0.469 | 0.476 | 1.560 | 4.368 |
| | + 65 | 0.511 | 0.490 | 2.730 | 7.098 |
| | + 48 | 0.550 | 0.508 | 3.120 | 10.218 |
| | + 35 | 0.581 | 0.528 | 3.744 | 13.962 |
| | + 28 | 0.817 | 0.627 | 7.332 | 21.294 |
| | + 20 | 1.411 | 0.858 | 8.892 | 30.187 |
| 500 rpm | -100 | 0.449 | 0.449 | 2.730 | 2.730 |
| | +100 | 0.459 | 0.453 | 1.625 | 4.356 |
| | + 65 | 0.511 | 0.475 | 2.730 | 7.087 |
| | + 48 | 0.554 | 0.500 | 3.185 | 10.273 |
| | + 35 | 0.572 | 0.520 | 3.901 | 14.174 |
| | + 28 | 0.854 | 0.638 | 7.802 | 21.976 |
| | + 20 | 1.315 | 0.828 | 8.582 | 30.559 |
| 600 rpm | -100 | 0.428 | 0.428 | 2.772 | 2.772 |
| | +100 | 0.489 | 0.451 | 1.625 | 4.397 |
| | + 65 | 0.542 | 0.485 | 2.676 | 7.074 |
| | + 48 | 0.594 | 0.518 | 3.059 | 10.133 |
| | + 35 | 0.614 | 0.544 | 3.824 | 13.957 |
| | + 28 | 0.853 | 0.657 | 8.030 | 21.988 |
| | + 20 | 1.312 | 0.835 | 8.221 | 30.210 |
| 600 rpm | -100 | 0.476 | 0.476 | 2.716 | 2.716 |
| | +100 | 0.468 | 0.473 | 1.541 | 4.258 |
| | + 65 | 0.469 | 0.471 | 2.716 | 6.975 |
| | + 48 | 0.499 | 0.480 | 3.083 | 10.058 |
| | + 35 | 0.630 | 0.520 | 3.671 | 13.729 |
| | + 28 | 0.714 | 0.587 | 7.268 | 20.998 |
| | + 20 | 1.500 | 0.865 | 9.177 | 30.176 |

Table 24. First break grinding of hard red winter wheat with twelve inch diameter rolls.

| Roll speed | Tyler mesh | % Ash 14 M.B. | Cumulative % ash | % of total product | Cumulative % of total product |
|---|---|---|---|---|---|
| 300 rpm | -100 | 0.499 | 0.499 | 2.758 | 2.758 |
| | +100 | 0.500 | 0.499 | 1.504 | 4.263 |
| | + 65 | 0.573 | 0.526 | 2.507 | 6.771 |
| | + 48 | 0.642 | 0.563 | 3.072 | 9.843 |
| | + 35 | 0.637 | 0.583 | 3.761 | 13.605 |
| | + 28 | 0.852 | 0.675 | 7.084 | 20.689 |
| | + 20 | 1.309 | 0.877 | 9.655 | 30.344 |
| 300 rpm | -100 | 0.491 | 0.491 | 2.853 | 2.853 |
| | +100 | 0.500 | 0.494 | 1.545 | 4.399 |
| | + 65 | 0.541 | 0.512 | 2.734 | 7.134 |
| | + 48 | 0.573 | 0.530 | 3.091 | 10.225 |
| | + 35 | 0.735 | 0.585 | 3.745 | 13.971 |
| | + 28 | 0.816 | 0.663 | 7.134 | 21.105 |
| | + 20 | 1.209 | 0.829 | 9.215 | 30.321 |
| 375 rpm | -100 | 0.510 | 0.510 | 2.633 | 2.633 |
| | +100 | 0.512 | 0.510 | 1.477 | 4.110 |
| | + 65 | 0.602 | 0.546 | 2.569 | 6.679 |
| | + 48 | 0.625 | 0.571 | 3.082 | 9.762 |
| | + 35 | 0.757 | 0.623 | 3.789 | 13.551 |
| | + 28 | 0.780 | 0.677 | 7.193 | 20.745 |
| | + 20 | 1.216 | 0.848 | 9.633 | 30.378 |
| 375 rpm | -100 | 0.511 | 0.511 | 2.691 | 2.691 |
| | +100 | 0.501 | 0.508 | 1.413 | 4.104 |
| | + 65 | 0.518 | 0.512 | 2.691 | 6.796 |
| | + 48 | 0.641 | 0.552 | 3.095 | 9.892 |
| | + 35 | 0.661 | 0.582 | 3.701 | 13.593 |
| | + 28 | 0.885 | 0.683 | 6.864 | 20.457 |
| | + 20 | 1.202 | 0.846 | 9.353 | 29.811 |
| 450 rpm | -100 | 0.531 | 0.531 | 2.300 | 2.300 |
| | +100 | 0.528 | 0.530 | 1.305 | 3.606 |
| | + 65 | 0.592 | 0.554 | 2.300 | 5.907 |
| | + 48 | 0.612 | 0.573 | 2.860 | 8.768 |
| | + 35 | 0.687 | 0.607 | 3.669 | 12.437 |
| | + 28 | 0.836 | 0.691 | 7.213 | 19.651 |
| | + 20 | 1.307 | 0.906 | 10.572 | 30.223 |
| 450 rpm | -100 | 0.501 | 0.501 | 2.595 | 2.595 |
| | +100 | 0.499 | 0.500 | 1.483 | 4.079 |
| | + 65 | 0.517 | 0.506 | 2.533 | 6.613 |
| | + 48 | 0.593 | 0.534 | 3.090 | 9.703 |
| | + 35 | 0.719 | 0.586 | 3.770 | 13.473 |
| | + 28 | 0.748 | 0.643 | 7.292 | 20.766 |
| | + 20 | 1.212 | 0.823 | 9.641 | 30.407 |

# APPENDIX B

## Method B Data

Table 25. First break product of soft red winter wheat milled on the reduction side of the Quadrumat Senior experimental mill.

| Roll size | Roll speed | Analyses of product through sieve size 9XX: Agtron color | Fisher size | % Ash content* | % Protein content* | 64 GG: % of total product |
|---|---|---|---|---|---|---|
| 6 inch | 600 rpm | 78 | 14.4 | 0.285 | 7.845 | 85.9 |
| | | 78 | 15.0 | 0.313 | 8.195 | 90.1 |
| | 750 rpm | 75 | 14.8 | 0.302 | 8.075 | 86.2 |
| | | 79 | 14.6 | 0.285 | 8.151 | 86.8 |
| | 900 rpm | 78 | 14.2 | 0.294 | 8.021 | 85.3 |
| | | 76 | 14.8 | 0.304 | 8.214 | 87.0 |
| 9 inch | 400 rpm | 77 | 14.2 | 0.295 | 8.040 | 87.1 |
| | | 79 | 13.4 | 0.303 | 7.891 | 84.5 |
| | 500 rpm | 79 | 14.2 | 0.285 | 7.947 | 81.4 |
| | | 79 | 13.6 | 0.315 | 7.947 | 84.4 |
| | 600 rpm | 78 | 14.4 | 0.304 | 8.132 | 83.8 |
| | | 79 | 14.0 | 0.304 | 8.113 | 85.4 |
| 12 inch | 300 rpm | 76 | 16.0 | 0.354 | 9.127 | 86.9 |
| | | 79 | 13.6 | 0.285 | 7.660 | 86.0 |
| | 375 rpm | 79 | 14.4 | 0.324 | 8.214 | 86.7 |
| | | 79 | 13.4 | 0.283 | 7.901 | 87.7 |
| | 450 rpm | 79 | 13.6 | 0.294 | 7.827 | 86.4 |
| | | 76 | 16.2 | 0.333 | 8.903 | 86.0 |

* 14 % moisture basis

Table 26. First break product of hard red spring wheat milled on the reduction side of the Quadrumat Senior experimental mill.

| Roll size | Roll speed | Analyses of product through sieve size 9XX: Agtron color | Fisher size | % Ash content* | % Protein content* | 64 GG: % of total product |
|---|---|---|---|---|---|---|
| 6 inch | 600 rpm | 70 | 23.8 | 0.408 | 10.724 | 88.1 |
| | | 67 | 25.0 | 0.413 | 10.686 | 88.3 |
| | 750 rpm | 67 | 25.2 | 0.403 | 10.686 | 87.8 |
| | | 70 | 24.6 | 0.413 | 10.598 | 88.5 |
| | 900 rpm | 67 | 24.8 | 0.415 | 10.636 | 88.4 |
| | | 69 | 24.0 | 0.418 | 10.711 | 88.4 |
| 9 inch | 400 rpm | 65 | 24.4 | 0.465 | 10.522 | 88.4 |
| | | 72 | 24.0 | 0.426 | 10.458 | 89.7 |
| | 500 rpm | 67 | 25.0 | 0.425 | 10.636 | 88.5 |
| | | 72 | 24.0 | 0.417 | 10.584 | 88.4 |
| | 600 rpm | 68 | 24.0 | 0.445 | 10.724 | 89.0 |
| | | 70 | 23.6 | 0.410 | 10.557 | 88.6 |
| 12 inch | 300 rpm | 71 | 23.4 | 0.396 | 10.482 | 88.5 |
| | | 69 | 24.0 | 0.434 | 10.497 | 88.8 |
| | 375 rpm | 68 | 23.8 | 0.445 | 10.724 | 88.3 |
| | | 69 | 22.6 | 0.433 | 10.473 | 88.2 |
| | 450 rpm | 68 | 24.6 | 0.425 | 10.028 | 87.9 |
| | | 69 | 24.4 | 0.425 | 10.838 | 87.4 |

* 14 % moisture basis

Table 27. First break product of hard red winter wheat milled on the reduction side of the Quadrumat Senior experimental mill.

| Roll size | Roll speed | Analyses of product through sieve size 9XX: Agtron color | Fisher size | % Ash content* | % Protein content* | 64 GG: % of total product |
|---|---|---|---|---|---|---|
| 6 inch | 600 rpm | 68 | 22.8 | 0.386 | 10.075 | 87.0 |
| | | 69 | 23.4 | 0.388 | 10.009 | 81.4 |
| | 750 rpm | 66 | 24.4 | 0.387 | 9.985 | 86.1 |
| | | 68 | 23.6 | 0.384 | 9.926 | 87.2 |
| | 900 rpm | 68 | 23.4 | 0.386 | 10.063 | 86.1 |
| | | 66 | 23.4 | 0.396 | 9.962 | 86.3 |
| 9 inch | 400 rpm | 71 | 23.0 | 0.407 | 9.970 | 87.3 |
| | | 67 | 23.2 | 0.396 | 9.860 | 87.1 |
| | 500 rpm | 71 | 22.8 | 0.398 | 9.919 | 87.8 |
| | | 70 | 21.6 | 0.407 | 9.872 | 87.9 |
| | 600 rpm | 66 | 23.4 | 0.478 | 10.189 | 87.5 |
| | | 68 | 23.0 | 0.395 | 9.735 | 85.7 |
| 12 inch | 300 rpm | 69 | 22.8 | 0.395 | 9.950 | 86.1 |
| | | 69 | 23.6 | 0.356 | 9.668 | 86.6 |
| | 375 rpm | 70 | 23.4 | 0.398 | 10.021 | 85.6 |
| | | 69 | 21.8 | 0.395 | 9.724 | 87.5 |
| | 450 rpm | 67 | 23.4 | 0.424 | 10.712 | 87.0 |
| | | 70 | 23.4 | 0.396 | 9.973 | 85.7 |

* 14 % moisture basis

# ROLL DIAMETER AND SPEED - THEIR EFFECTS ON FIRST BREAK GRINDING OF WHEAT

by

FLOYD FRANCIS NIERNBERGER

B. S., Kansas State University, 1955

---

AN ABSTRACT OF A MASTER'S THESIS

Submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Flour and Feed Milling Industries

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1966

The objective of this experiment was to find the influence of certain variables on first break grinding of wheat, measured in terms of milling quality.

The grinding action of the first break roll begins a series of mechanical operations performed in the processing of wheat into flour. The product resulting from passage of wheat through the first break rolls can generate effects felt throughout the processing system. Analysis of these first break roll effects can lead to a better understanding and possible improvement of the milling process.

The factors in first break grinding that were varied in this research were: (1) wheat class, (2) roll diameter, (3) roll speed. Three levels of each factor were tested. The types of wheat class were: hard red winter, soft red winter, and hard red spring. Roll diameters used were: 6, 9, and 12 inches. The fastest roll of each pair ran: 942, 1,178, and 1,414 feet per minute while the slow roll ran 0.4 as fast. The speed differential between the fast and slow rolls was kept at a ratio of 2.5 to 1.

First break roll factors that were held constant were: (1) break release, 30 percent through a number 18 light wire sieve, (2) wheat feed rate, 1.5 pounds per minute per inch of roll contact length, (3) wheat conditioning, 15.5 percent moisture held 18 hours at room temperature, (4) roll differential, 2.5 to 1, (5) roll corrugation, 10 per inch of Minneapolis 19 configuration, 0.375 inch spiral per linear foot, dull to dull.

A roller mill consisting of a single pair of adjustable rolls arranged in a horizontal position was used for the grinding tests. Two identical samples were taken at the point of discharge of the break rolls and analyzed by 2 different methods. Method A consisted of a sieving procedure to separate the product into eight fractions. The percentage of total product and ash content of each portion was determined. Using these data, cumulative ash curves were plotted and statistically evaluated. Method B samples were milled through the reduction side of a Quadrumat Senior experimental mill. The flour through the 9 XX sieve was statistically analyzed for percentage of total product, average particle size, color, ash, and protein content.

Findings from the results indicated: (1) class of wheat had a significant effect on the size distribution and cumulative ash content of the product obtained from wheat passed through the break rolls. Furthermore, class of wheat had a significant effect on ash content, protein content, Agtron color, and Fisher average particle size measurement of the flour. (2) diameter of rolls had a significant effect on the size distribution and cumulative ash content of the product from the first break rolls when grinding 3 classes of wheat at fast roll speeds of 942, 1,178, and 1,414 feet per minute. The least significant difference of the means of the cumulative ash content indicated that the 9 inch diameter break rolls were preferable to either the 6 or 12 inch diameter rolls. (3) speed of break rolls, at the 3 levels tested and using constant differential of 2.5 to 1, did not have a significant effect on the size distribution and cumulative ash content of the product resulting from grinding wheat of 3 classes through 3 sizes of roll diameters.