MECHANICAL DURABILITY OF FEED PELLETS

by

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B. S., Kansas State University, 1960

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Flour and Feed Milling Industries

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1962

ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation to Dr. Harry B. Pfost, whose encouragement, counsel, and guidance have had much to do with making this manuscript a reality. To Dr. J. A. Shellenberger, head of the Department of Flour and Feed Milling Industries and to the entire staff of this department, thank you for making materials and equipment available for use in this experimental work.

Acknowledgement is also given to Sprout Waldron Manufacturing Company and to the Soft Phosphate Research Institute for their cooperation and support in making this research possible.

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INTRODUCTION

Feed pelleting is defined as "agglomerating individual ingredients or mixtures by compacting and forcing through die openings by any mechanical process" (5).

Pellet mills were first developed in Europe. In the late 1920's, manufacture of pellet mills began in the United States and led to rapid acceptance of feed pelleting in this country. Today more than one-half of all formula feed produced in the United States is pelleted.

One of the major problems of pelleting is to manufacture a pellet of sufficient strength to withstand the handling from the mill to the consumer without manufacturing pellets too hard to be used by the animal or otherwise be detrimental to the product. This ability to withstand handling without breakage is defined here as pellet durability.

The durability of feed pellets and the measurement of this property have practical significance from several viewpoints. The efficiency of producing a durable pellet is an important consideration. The relative cost of pellet mill maintenance, including die wear is probably influenced by the durability of the pellets produced. Durability may be related to chemical changes during pelleting and the nutrient value and feeding acceptability of the pellets. The appraisal of these considerations depends upon a standard reliable measurement of pellet durability; such, however, the feed industry has not adopted.

The general production practice in the feed industry is to vary feed formulas, feed rates and speeds, moisture content, and other production factors until pellets, which the manufacturer considers of satisfactory durability, are consistently produced. In recent years the addition of binding agents, which are not ordinarily classified as feed ingredients, has been used in an attempt to manufacture more durable pellets.

This project was initiated to acquire information regarding the effect of colloidal material upon the binding of ingredients in pelleted feeds, to establish measures for evaluating the durability of pelleted feeds, and to provide data regarding the effect of other factors on the cost of manufacturing pelleted feeds.

The first objective of this investigation was to determine to what extent a few factors will affect pellet durability and cost of pelleting. Factors studied included: the amount of steam added, fineness of grind on grain, and the addition of binding agents.

The second objective, that of determining pellet durability and establishing a standard of durability measurement, required an evaluation of several types of equipment used in industry and research laboratories and the development and evaluation of some new devices.

REVIEW OF LITERATURE

The pelleting process contains many variables and is difficult to standardize with great accuracy.

Wornick (17) listed many variables in the pelleting process including: formulation, mash texture, mash uniformity, steaming rate, ingredient particle size, steam temperature and pressure, ambient conditions, operator experience, pelleting pressure and temperature in die, equipment used, die condition, pellet length, and fines recycled.

Binding Agents

The use of binding agents in formula feeds is limited by the nutritional value of the agent and the binding quality of the material.

The use of soft phosphate in poultry feeds is limited by the American Feed Control Officials to the amount which will add not more than 0.035 percent fluorine to the ration. Using the analysis given for soft phosphate, this sets the limit at 55 pounds per ton. No limit is defined for bentonite.

Numerous tests have shown that soft phosphate can be used to supply part of the supplemental phosphorus in poultry rations (3, 4, 9, 15).

Studies using bentonite in poultry rations showed no adverse effects on growth rate or feed intake (2, 7).

Bentonite has been used extensively to improve pellet durability but no data was available for soft phosphate.

Fineness of Grind

It is generally felt that finely ground mash is advantageous in pelleting of formula feeds (13, 14, 16). The smaller particle size provides more surface area to absorb the added steam and other binding qualities that may be present in the formula; this results in higher production and better quality pellets. Stroup (13) found that the most practical fineness of grind was one in which all the mash will pass through a 7-mesh screen. Williams (16) states that pellets containing finely ground ingredients will not fracture or break into small pieces as easily as when coarse particles are present.

Conditioning

Wake (14) states that the steam added during conditioning brings the natural oils present in most grains to the surface of the mash particles which provides lubrication of the pellet die and also results in greater pelleting capacity and better pellet quality. Pelleting feeds at higher temperatures will give more complete gelatinization of the starch which may result in better feed conversion through more rapid and complete digestion.

Stroup (13) states that "proper conditioning is one of the more important factors in realizing high capacity in pelleting. A temperature range of 160 to 180 F.°, and in some cases higher, will generally give the best results". By adding moisture with live steam to raise the final mash moisture content to somewhere between 13 and 17 percent, the best results can be obtained. Insufficient conditioning results in higher power input, low production rates, pellets which appear to be shiny, and pellets of irregular lengths. Pellets made from poorly conditioned mash seem to be quite durable as they come from the die, but are actually brittle and soft near the center. Excessive die and roll wear occurs when pelleting at low temperatures.

Smith (10) reported research on the effects of increased steam conditioning on gelatinization of starches, on levels of fines, and on pellet toughness. It was noted that a gelatinized pellet tended to be a durable pellet. It was thought that by increasing gelatinization of the ingredients used in a hard pellet, the level of fines could be reduced. Results showed that the percent of fines were not proportional to percent of gelatinization of starches but could be reduced by higher amounts of steam and longer conditioning time.

Wornick (17) listed some factors which may influence the amount of moisture which can be added during conditioning. These included: the original moisture of the mash, formulation of the mash, steam quality, steam pressure, steam temperature, particle size of ingredients, die specifications which include hole diameter, die thickness, die taper and also die wear, along with production rate, and time in the conditioning chamber.

Formulation

Different ingredients have different pelleting characteristics. Factors which cause this difference include moisture content, fat content, fiber content, density, and the abrasive character of the ingredients; also, many feed ingredients have excellent binding qualities which are highly desirable in a formula that is to be pelleted. One source of binding material is the natural starches contained in a formula. When the raw starches are gelatinized by heat and moisture in the form of steam and by pressure and shear which occur inside of the die, the pellets tend to be extremely durable (13).

Pellet Durability Testing

McCormick and Shellenberger (8) reported devices and methods of testing pellet durability. Included in these was a bending test where the pellet was loaded to fracture as a beam; this gave a value of modulus of rupture. Hardness in metals is usually interpreted to mean resistance to indentation as measured by the depth or area of the indentation formed by a standard point and load. In using this test on pellets it was found that the depth of indentation bore little relation to strength and this phase of the study was, therefore, discontinued. Compression testing, both longitudinal and transverse, was tried. In longitudinal compression, the pellets did not break at any definite point but gradually deformed with any constant load applied for a considerable amount of time. This effort was abandoned. Testing pellets in transverse compression is rather common in the feed industry by use of the Stokes hardness tester.

The tests used above give some indication of the physical properties of the pelleted material; however, none subjects the pellets to the handling conditions which occur in the mill.

In order to simulate these handling conditions, McCormick and Shellenberger (8) reported several tumbling and shaking test procedures. No shaking test that was tried was sufficiently destructive to be accurate. A tumbling can was constructed using a one-quart can with the shaft perpendicular to the cylinder. This was not sufficiently destructive until some steel balls were introduced along with the charge of pellets.

In work done by Gustafson (6), a machine was designed to test for durability of pellets of many sizes and shapes. During handling, the pellets are physically damaged by the mechanical actions of the various components. The damaged material is generally referred to as fines. An analysis of the durability problem lies in a determination of the nature of the forces causing pellet damage during handling.

Gustafson states that these forces may be divided into three general classes; impact, compression, and shear. The impact forces result in breakage on the surface of the pellet and also along any natural cleavage planes of the pellet. These forces result from gravity drops and contact with moving equipment. The compressive forces result in the crushing of pellets which produces more fines. These forces are caused by crushing between screw conveyor tube and flighting. The shearing forces result in abrasion of pellet edges and surfaces. These forces occur when pellets rub against each other or against container or conveyor walls. With these forces in mind, Gustafson developed a machine for testing the durability of various types of pellets and hay wafers.

Smith (10), in the gelatinization work mentioned above, reported tests using an ordinary paint shaker.

Stegner (12) used a tumbling jar for the testing of pellet durability.

MATERIALS AND METHODS

Three controlled variables in the pelleting process used in this project included: types of binding agents used, particle size of grain in each formula, and the amount of steam added. Three different formulas were used in the pelleting studies but were not designed as variables. The formulas were turkey starter, turkey grower, and turkey finisher (Table 1).

Table 1. Basal rations used in pelleting studies.

Ingredients	Turkey Starter	Turkey Grower	Turkey Finisher
	%	%	%
Ground Yellow Corn	20.0	30.0	30.0
Ground Sorghum Grain	20.0	30.0	40.0
Soybean Oil Meal	40.0	25.0	15.0
Dehydrated Alfalfa Meal	5.0	5.0	4.0
Meat and Bone Scraps	4.0	2.0	5.0
Fish Meal	4.0	2.0	---
Ground Limestone	2.5	2.0	2.0
Dicalcium Phosphate	2.0	2.0	2.0
Distillers Solubles	2.0	1.0	1.0
Salt	---	.5	.5
Vitamin, Drug Premix	.5	.5	.5
	100.0	100.0	100.0

Statistical Design

A randomized split-plot experimental design with grind as the whole plot and combination levels of steam and binding agents in sub-plots with two replications was used in making the tests for each formula.

The characteristics of primary interest of each test included the energy required to pellet and the amount of fines produced in the laboratory model handling system (described later). Of secondary interest was the correlation of different laboratory devices to the model handling system.

Separate analyses were run on the three different formulas (that is, the formulas were not used as variables).

One shipment of corn and sorghum grain was purchased which would provide enough grain for three different grinds. Each grind produced sufficient material for 9 tests. The 27 different treatments consisted of the different combinations of three steam levels, three grinds, and three different binding agents.

Binding Agents

The basal ration was used as a control against a ration containing bentonite and one containing soft phosphate. These materials were added at the level of 52 pounds per ton each. A partial chemical analysis of these two binding agents is shown in Table A1(a and b) in the appendix.

Fineness of Grind

The grain, consisting of corn and sorghum grain, was ground to three different finenesses. Grain ground through a hammermill using a screen with openings of 1/8 inch diameter was defined as fine grind. Grain ground through a hammermill using a screen with openings of 1/4 inch diameter was defined as medium grind. Grain crimped in a roller mill with 0.005 inch clearance between rolls was defined as coarse grind. These different grinds include the range of particle sizes commonly found in feed mills. Particle size analysis will be given later.

Conditioning

The amount of steam added was controlled by the temperature rise of the mash going through the steam conditioner of the pellet mill. The low temperature rise was 16 C^{o}., the medium temperature rise was 33 C°., and the high temperature rise was 50 C°. These temperature rises would include the amount of steam commonly added in a feed mill using the same pelleting equipment.

Pelleting Process

Other pelleting process variables listed by Wornick (17) and variables concerning durability were treated in the following manner.

All mash was mixed in the same equipment for a constant time and conveyed to the pellet mill holding bin through the same equipment insuring a constant relative uniformity in each set of tests.

Standard sieve analyses were run on all mashes to determine ingredient particle size; sieve analyses were also run on each grind of grain.

Steam temperature was constant and steam pressure was constant at 90 psig. A condensate trap was included in the steam line to improve steam quality.

Wet and dry bulb temperatures were taken at the cooler before and after cooling of the pellets. The relative humidity was tested as a covariate in the statistical analysis, but was shown to be non-significant in these studies.

No means were available for measuring internal pressures in the die. This may be affected by other variables, so there was no indication of constant pressure.

The preceding statement also holds true for internal die temperatures.

Temperatures were taken of the mash before entering the die and directly after pelleting.

The time the feed was in the die varied with feed rate and other factors and was not constant.

The die used was previously run for a period of time long enough to polish and smooth any rough spots present but not long enough to produce excessive die wear.

All mash was pelleted through a die 2 inches thick with 3/16 inch diameter openings.

Fines were not allowed to return to the pellet mill.

Factors which may be concerned with durability and which could be controlled were handled in the following manner.

Knife setting was held constant at 3/4 inch and the roll to die spacing was also held constant at 0.01 inches.

Pelleting Procedure. Before each series of tests, 100 pounds of ground corn was run through the system to clean it out and also warm up the die. Then for each test, 1000 pounds of mash was mixed and transferred to the pellet mill holding bin.

After the temperature of the mash was taken the pellet mill was started. The pellet mill used was a California Master Model Pellet Mill with a standard size conditioning chamber and was driven by a 25 horsepower motor. Pellets were dumped directly into a California Vertical Pellet Cooler, size 2-B, by gravity. The cooler was run continually to keep it empty. The cooling fan was not operated at this time. Feed rate and steam rate were adjusted until the pre-determined temperature rise and maximum production at rated motor load were reached. Then the cooler conveyor was turned off so that all remaining pellets would stay in the cooler.

At the same time the power panel was turned on. The power panel was equipped with a recording wattmeter which gave directly the amount of energy used.

During pelleting, mash temperature and conditioned mash temperature were checked to insure a constant temperature rise. The temperature of the pellets leaving the die was taken at three intervals. Samples were taken of the mash, conditioned mash, and pellets leaving the die for moisture content at two intervals. A sample of mash was taken for sieve analysis.

Pelleting was continued until the cooler was filled to the normal operating level. Then the pellet mill was turned off, the power panel read and turned off, and the cooler fan started.

Effect of Cooling Time on Pellet Durability. Preliminary studies of the effect of cooling time, that is the time that the cooler fan was in operation, on durability were made.

Mash was pelleted with a temperature rise of 50 C°. through the conditioner. The cooler was filled and the cooler fan allowed to run for a period of 5 minutes. Then the pellets were tested in the model handling system (described later) and the amount of fines produced was measured. This procedure was repeated using cooling times of 10 and 15 minutes. Moisture content of the pellets was determined on samples taken before and after cooling. Results are shown in Table 2.

Table 2. Effect of cooling time on pellet durability

Cooling Time	Moisture before Cooling	Moisture after Cooling	Percent Fines
5 minutes	14.4	11.4	10.5
10 minutes	14.3	11.8	8.5
15 minutes	14.5	10.8	8.6

From these results, it was decided that a cooling period of 10 minutes could be used. This time corresponds closely to the time for pellets to enter and leave the cooler in the automatic operation used in regular production.

The fan was then turned off and the cooler was discharged. The pellets were elevated to the scalping screen and then flowed by gravity into the sack-off bin. Fines from the scalper were sacked off and weighed. The pellets were sacked and weighed; this weight was used in the calculation of efficiency.

Sampling. All testing of relative durability of pellets encounters the universal problem of sampling. During the cooling process, the location of an individual pellet in the cooler plus other factors are all variables as far as the final durability of an individual pellet is concerned.

As a result, there is usually a considerable variation between sacks of pellets. Therefore it is necessary to establish consistent sampling procedures and to depend upon averages and composites instead of a single analysis.

To be consistent in sampling pellets for laboratory tests, the following procedure was used.

Three hundred pounds were sacked off, then four commercial paper sacks were filled with approximately 60 pounds of pellets each. Temperatures were taken in each paper sack and samples for moisture tests were taken from the first and third sack by filling a sample jar off the top of the sack. The paper sacks were marked for identification, sewed, and taken to the laboratory.

Effect of Storage Time on Pellet Durability. Preliminary studies were made to determine the effect of storage time on pellet durability.

In this series of tests, the pellets were tested in the model handling system (described later) and the amount of fines produced indicated the relative durability. Durability tests were made on pellets taken directly from the cooler, on pellets that were stored for 24 hours in the laboratory, and on pellets that were stored for 48 hours in the laboratory. The tests were replicated three times. The results are shown in Table 3.

Table 3. Effect of storage time on pellet durability.

Storage Time	Percent Fines
0 hours	15.6
24 hours	14.5
48 hours	14.5

These tests showed that any effects of storing for more than 24 hours on durability of pellets was negligible. From these studies the storage time was set at 24 hours before any testing was done in the laboratory.

Laboratory Tests

Before describing the laboratory tests, the term "fines" as used in the study must be defined. With 3/16 inch diameter pellets, any material passing through a 6-mesh screen (36 openings per square inch) was designated as fines. These openings are just smaller than the nominal pellet diameter of 3/16 inch.

<u>Model Handling System.</u> The first test run in the laboratory was in the model handling system shown in Fig. 1. This apparatus consisted of a bucket elevator 8 feet from boot to head running at a linear velocity of 254 feet per minute, a hopper with a slide valve 6 inches in diameter, and a screw conveyor 6 inches in diameter and 3.5 feet long inclined at 30 degrees with the horizontal and revolving at 130 revolutions per minute. The clearance between screw tube and flighting was 15/32 inch radially. The elevator discharge was equipped with a swivel spout

which could be turned to emptying position or to the operating position where the pellets would drop by gravity into the hopper. From there the pellets emptied through the slide valve into the screw conveyor which, in turn, completed the cycle by discharging into the bucket elevator.

The only damaging forces on a pellet in a bucket elevator occur when the pellet is picked up in the boot and discharged at the head. In a gravity drop, the amount of impact on the pellet is proportional to the height from which it drops (6). The amount of damage in a screw conveyor is proportional to the length of the conveyor.

The pellets encountered the three types of forces mentioned before; impact forces during the gravity fall and the fall against the conveyor flight and moving buckets, compressive forces when the pellets are crushed between conveyor flighting and wall, and abrasive forces when the pellets rub against each other and against the conveyor wall and hopper wall.

Each sample sack was screened on a 4-mesh screen to remove all fines. Fifty pounds were weighed and dumped into the hopper. The elevator and conveyor were started and allowed to run 10 minutes, recycling the pellets. After this period of time, the elevator and conveyor were turned off and the elevator discharge spout turned to emptying position. The equipment was started again and the pellets and fines emptied into a container. Drop out bottoms on the elevator and conveyor facilitated cleaning out after each test.

The material was then hand screened on a 4-mesh screen. The feeling here was that any fines present would readily pass through this screen and the good pellets would remain. This procedure was used to eliminate the need for screening of all material on the Ro-Tap shaker which was used next. The material passing through the 4-mesh screen was then screened on a 6-mesh screen by use of the Ro-Tap for one-half minute.

Instead of measuring the amount of fines produced directly, the amount of material, which includes the good pellets and material remaining on the 6-mesh screen, was weighed and subtracted from the original 50 pounds to determine the amount of fines produced. This was to account for possible dust losses and other losses due to cleaning out. It was felt that no pellets would be lost because of poor clean-out of the system. This test was run on three sacks of each individual pelleting test to obtain an average value.

It should be noted here that screening pellets or pieces of pellets on the 6-mesh screen in the Ro-Tap for a period of one-half minute produced no further reduction of pellets to fines.

Tumbling Can. Another of the laboratory tests was the tumbling can shown in Fig. 2. Five hundred grams of pellets, from which the fines had been removed, were placed in the can along with twenty 3/8 inch hexagonal nuts. The can was then revolved for a period of 10 minutes at a speed of 100 revolutions per minute. The contents were removed, the nuts taken out, and the material screened on the Ro-Tap for one-half minute. The fines produced were measured and recorded.

Tumbling Jar. A third test was the tumbling jar device, also shown in Fig. 2. In preliminary studies, it was observed that 1200 grams of 3/16 inch diameter pellets was the optimum amount to place in the jar at the speed of rotation used (142 revolutions per minute). With more than 1200 grams, the pellets would not tumble but rather moved to the periphery of the jar and rotated with the jar. With less than 1200 grams the pellets would lie on the bottom and slide on the jar; again no tumbling occurred. The jar was rotated for 30 minutes, the material removed, screened on the Ro-Tap on the 6-mesh screen for one-half minute and the amount of fines produced weighed and recorded.

Farmhand Machine. The Farmhand testing apparatus, shown in Fig. 3, was used by the procedure of Gustafson (6) with the exception that a period of 4 minutes was employed instead of the one minute period used in the original work. The unit of durability was percent fines produced.

Stokes Hardness Tester. For transverse compression testing, the Stokes Hardness Tester was used. This consisted of a calibrated spring pressing on the frustrum of a cone whose tip diameter was 0.23 inches. This tip bore on the cylindrical surface of the pellet which, in turn, was supported on the opposite side by a plate 0.46 inches wide. The pressure was regulated by means of a screw turned by hand to compress the spring.

From each pelleting test, 10 pellets were tested and the average value was used in correlation. The unit of durability was stress in pounds per square inch.

Pneumatic Hardness Tester. It has been suggested that there is a non-uniform loading when using the Stokes tester as a result of turning the screw at a varying rate and also because of making one turn, then regripping the handle and making another turn. To compensate for this non-uniformity of applying the load, a pneumatic hardness tester was developed, Fig. 4, where air pressure loaded the piston at a uniform rate. A tip whose diameter was 0.25 inches was pressed against the pellet which lay on a flat surface 2 inches square. A pressure gauge reading was taken at the time of fracture of the pellet. Here again the unit of durability is stress in pounds per square inch.

Shear Tester. Using the pneumatic system, a shear test was devised and is shown in Fig. 5. Holes were drilled in the three plates, large enough to insert the pellets with ease but small enough to allow only a tolerable amount of bending. The outer two plates were fixed and the center plate connected to a movable piston. Sixteen pellets were inserted and by applying pressure to the center plate at a uniform rate until the pellets sheared, the shear stress could be calculated in pounds per square inch.

EXPLANATION OF PLATE I

Fig. 1. Photograph of model handling system.

Fig. 2. Photograph of tumbling can (left) and tumbling jar (right).

Fig. 3. Photograph of Farmhand machine.

Fig. 4. Photograph of pneumatic hardness tester.

Fig. 5. Photograph of shear tester.

PLATE I

FIG. 1

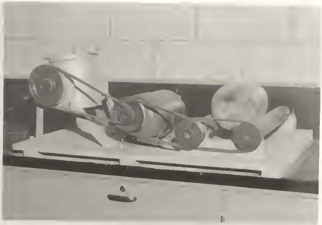

FIG. 2

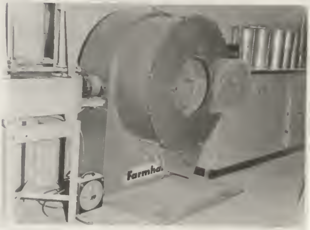

FIG. 3

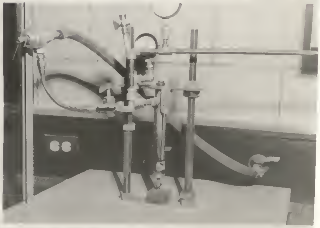

FIG. 4

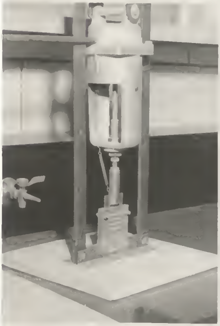

FIG. 5

Beam Test. A device for testing pellets as beams was built, but use of the 3/16 inch diameter pellet produced such small gauge readings that the degree of accuracy was too small to use this test.

Longitudinal Compression. Testing in longitudinal compression was tried by crushing pellets between two plates. The pellets were sanded until the ends were plane and parallel. The same problem that McCormick and Shellenberger (8) experienced was encountered in these tests. Therefore this test was abandoned.

The preceding tests were run on one shipment of each formula, so that 81 points were obtained for correlation.

After observing the correlations of the different types of apparatus and the ease of operating, it seemed desirable to try the tumbling can on pellets taken directly from the die and still hot. Samples were taken from the pellet mill and the same tumbling can procedure used.

EXPERIMENTAL RESULTS

Binding Agents

The shape of the bentonite particles as photographed by the electron microscope is shown in Fig. 6 and that of the soft phosphate particles is shown in Fig. 7. The bentonite is composed of montmorillinite particles (arrow) which are plate or disc shaped. The soft phosphate is composed of halloysite, kaolinite, and montmorillinite. The halloysite (arrow 1 in upper left-hand corner) was cylindrically shaped. The kaolinite (arrow 2 in upper left-hand corner) was hexagonal and disc shaped. The montmorillinite particles (arrow in upper right-hand corner) were also disc shaped.

Density, as determined in an air displacement apparatus, was 2.33 grams/cubic centimeter for bentonite and 2.55 grams/cubic centimeter for soft phosphate.

Fineness of Grind

From particle size analysis by sieving on a Ro-Tap shaker, the Fineness Modulus and Modulus of Uniformity (1) of each grind of grain was calculated; results are shown in Table 4.

Table 4. Fineness Modulus and Modulus of Uniformity of the three grinds of corn and milo.

Grind	Grain	Fineness Modulus	Standard Deviation	Modulus of Uniformity
Fine	Corn	2.14	.050	0-3-7
	Milo	2.01	.104	0-4-6
Medium	Corn	2.69	.164	0-6-4
	Milo	2.38	.162	0-5-5
Coarse	Corn	3.95	.212	4-5-1
	Milo	3.53	.210	1-8-1

Mash Particle Size

Within one grind in a formula, the addition of bentonite or soft phosphate did not change the values of Fineness Modulus or

EXPLANATION OF PLATE II

Fig. 6. Electron microscope photograph of bentonite particles magnified 29,600 times.

PLATE II

EXPLANATION OF PLATE III

Fig. 7. Electron microscope photograph of soft phosphate particles magnified 20,600 times.

PLATE III

Modulus of Uniformity significantly from that of the basal ration. Table 5 shows the average values for Fineness Modulus and Modulus of Uniformity for each grind of grain in each of the three formulas.

Table 5. Fineness Modulus and Modulus of Uniformity of mash.

Formula	Grind	Fineness Modulus	Standard Deviation	Modulus of Uniformity
Turkey Starter	Fine	2.14	.083	0-4-6
	Medium	2.32	.154	0-5-5
	Coarse	2.76	.183	1-5-4
Turkey Grower	Fine	2.07	.073	0-4-6
	Medium	2.29	.088	0-5-5
	Coarse	2.95	.066	1-6-3
Turkey Finisher	Fine	1.99	.046	0-3-7
	Medium	2.22	.093	0-4-6
	Coarse	3.05	.111	1-6-3

Conditioning

From the moisture tests it was found that the percent of moisture added was proportional to the temperature rise of the mash going through the conditioner. This relationship is shown in Fig. 8.

Temperature Rise Through Die

The temperature rises of the material going through the die were averaged for each formula for each different temperature rise due to conditioning. Results are shown in Table 6.

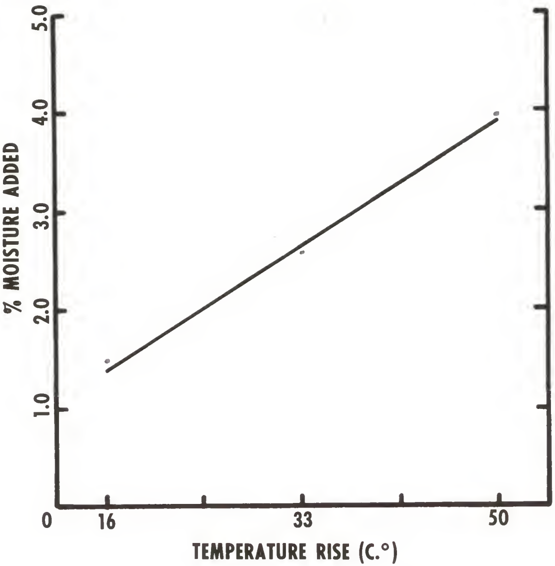

FIG. 8. PLOT OF PERCENT MOISTURE ADDED AGAINST TEMPERATURE RISE OF MASH THROUGH CONDITIONER.

Table 6. Temperature rise through die.

Formula	Temperature Rise through Conditioner	Temperature Rise through Die
Turkey Starter	16 C°.	18 C°.
	33 C°.	10 C°.
	50 C°.	4 C°.
Turkey Grower	16 C°.	19 C°.
	33 C°.	11 C°.
	50 C°.	5 C°.
Turkey Finisher	16 C°.	24 C°.
	33 C°.	14 C°.
	50 C°.	7 C°.

These were correlated with the average energy consumed within one formula at the three different steam levels over all combinations of grinds and binding agents, and the linear coefficient of correlation was 0.984. By determining the specific heat of the mash going into the die, it may be possible to determine from the temperature rise going through the die, the energy actually required to compress and to extrude the material through the die.

Pelleting Process

Shown in Table 7 are the average energy requirements of the three individual tests for each treatment within each formula. In Table 8 are the average percentages of fines produced in the model handling system for the same tests.

The statistical treatment for the turkey starter data is shown in Table 9, that for turkey grower in Table 10, and that for turkey finisher in Table 11. A rejection level of 5 percent was used in all treatments.

To determine significant differences at the 5 percent level between grinds of grain, levels of steam added, and the binding agent used, a table of means and the Least Significant Differences for these tables are shown in Table 12.

Graphs of all interactions are shown in Figures 9 through 15.

Turkey Starter. From the statistical treatment of the data for turkey starter, effects on pellet durability and energy required to pellet due to grind of grain could not be detected because of the variability within the grinds. Pellet durability increased significantly with increased steam levels, while the energy requirements decreased significantly with an increase in level of steam. It was observed that pellet durability increased significantly from the control ration to the ration containing soft phosphate to the ration containing bentonite. There was no significant difference in energy consumption between the ration with bentonite and the control ration, but the ration with soft phosphate used significantly more energy to pellet than either the control or bentonite rations.

The grind by steam interaction showed that at the low steam level the mash containing finely ground grain required the least energy to pellet. At the medium steam level there was no difference, while at the high steam level, the pellets containing

Table 7. Energy requirements for pelleting (KWH per ton).

Formula	Grind	Temperature Rise	Binding Agent		
			Control	Bentonite	Soft Phosphate
Turkey Starter	Fine	16 C°.	13.4	13.0	15.2
		33 C°.	9.3	9.6	10.3
		50 C°.	7.6	7.9	8.0
	Medium	16 C°.	16.2	15.1	16.2
		33 C°.	9.8	9.8	10.6
		50 C°.	8.1	9.4	8.1
	Coarse	16 C°.	15.2	15.5	16.0
		33 C°.	9.6	10.3	10.5
		50 C°.	7.5	7.5	7.6
Turkey Grower	Fine	16 C°.	16.2	14.6	16.7
		33 C°.	9.4	10.4	10.6
		50 C°.	7.1	7.4	7.6
	Medium	16 C°.	15.2	15.8	14.8
		33 C°.	10.3	9.8	10.1
		50 C°.	7.8	8.0	7.7
	Coarse	16 C°.	15.5	15.1	14.7
		33 C°.	9.5	10.8	10.7
		50 C°.	7.4	9.1	7.2
Turkey Finisher	Fine	16 C°.	18.1	17.4	18.0
		33 C°.	11.0	12.1	11.9
		50 C°.	8.5	11.1	9.0
	Medium	16 C°.	16.8	17.8	17.3
		33 C°.	10.9	11.5	11.4
		50 C°.	8.3	10.0	9.9
	Coarse	16 C°.	16.6	16.3	17.4
		33 C°.	10.9	11.1	11.2
		50 C°.	9.1	10.2	8.9

Table 8. Percent fines produced in model handling system.

Formula	Grind	Temperature Rise	Binding Agent		
			Control	Bentonite	Soft Phosphate
Turkey Starter	Fine	16 C°.	28.1	19.9	23.7
		33 C°.	16.6	10.1	13.3
		50 C°.	11.1	6.7	10.7
	Medium	16 C°.	29.3	21.6	24.8
		33 C°.	18.1	12.0	15.7
		50 C°.	14.0	7.3	12.8
	Coarse	16 C°.	22.3	18.1	18.7
		33 C°.	17.4	10.7	13.7
		50 C°.	10.4	7.9	10.4
Turkey Grower	Fine	16 C°.	28.6	19.3	21.4
		33 C°.	14.1	11.2	15.3
		50 C°.	11.4	7.8	9.1
	Medium	16 C°.	28.8	20.5	25.1
		33 C°.	18.4	13.3	14.9
		50 C°.	11.0	7.1	10.3
	Coarse	16 C°.	24.5	20.8	21.8
		33 C°.	18.3	14.8	15.8
		50 C°.	11.9	9.8	11.3
Turkey Finisher	Fine	16 C°.	29.4	21.4	23.7
		33 C°.	18.9	12.2	17.7
		50 C°.	12.5	8.8	10.7
	Medium	16 C°.	29.4	28.1	25.3
		33 C°.	22.1	13.8	15.5
		50 C°.	14.2	9.2	11.8
	Coarse	16 C°.	29.4	23.0	24.7
		33 C°.	21.7	14.4	20.3
		50 C°.	13.0	10.1	12.8

Table 9. Statistical treatment for turkey starter data.

Source of Variation	d.f.	Mean Square: % Fines		KWH/Ton	
Whole Plot					
Shipments (S)	2	33.60	ns	9.53	ns
Grind (A)	2	56.65	ns	6.98	ns
S x A (Error a)	4	43.48		2.19	
Sub-Plot					
Steam (B)	2	1151.30	***	365.99	***
Binding Agent (C)	2	236.44	***	2.99	*
A x B	4	18.09	*	3.23	**
B x C	4	8.49	ns	1.66	*
A x C	4	4.17	ns	.54	ns
A x B x C	8	1.82	ns	.55	ns
Error b	48	4.93		.59	
Total	80				

ns - non-significant

* - P<.05
** - P<.01
*** - P<.001

Table 10. Statistical treatment for turkey grower data.

Source of Variation	d.f.	Mean Square: % Fines		KWH/Ton	
Whole Plot					
Shipments (S)	2	91.66	**	1.29	ns
Grind (A)	2	10.62	ns	.03	ns
S x A (Error a)	4	4.23		.34	
Sub-Plot					
Steam (B)	2	1260.56	***	418.12	***
Binding Agent (C)	2	150.05	***	0.59	ns
A x B	4	14.56	*	1.08	ns
B x C	4	11.02	ns	1.37	ns
A x C	4	4.99	ns	1.69	*
A x B x C	8	4.69	ns	1.05	ns
Error b	48	4.30		.54	
Total	80				

ns - non-significant

* P<- .05
** P<- .01
*** - P<.001

Table 11. Statistical treatment for turkey finisher data.

Source of Variation	d.f.	Mean Square % Fines		KWH/Ton	
Whole Plot					
Shipments (S)	2	29.62	ns	10.32	ns
Grind (A)	2	22.56	ns	2.62	ns
S x A (Error a)	4	19.97		2.62	
Sub-Plot					
Steam (B)	2	1450.99	***	453.18	***
Binding Agent (C)	2	205.53	***	4.54	***
A x B	4	7.69	ns	.54	ns
B x C	4	15.07	*	2.32	**
A x C	4	6.72	ns	.53	ns
A x B x C	8	6.21	ns	.82	ns
Error b	48	5.32		.53	
Total	80				

ns - non-significant

* - P < .05
** - P < .01
*** - P < .001

Table 12. Statistical treatment of averages.

Formula	Variable	KWH/Ton	LSD	Percent Fines	LSD
Turkey Starter	Steam				
	16 C°.	15.09	.423	22.92	1.22
	33 C°.	9.97		14.18	
	50 C°.	7.95		10.14	
	Grind				
	Fine	10.47	1.120	15.58	4.98
	Medium	11.48		17.28	
	Coarse	11.06		14.39	
	Binding Agent				
	Control	10.74	.423	18.60	1.22
	Bentonite	10.89		12.69	
	Soft Phosphate	11.38		15.96	
Turkey Grower	Steam				
	16 C°.	15.41	.403	23.50	1.20
	33 C°.	10.18		15.13	
	50 C°.	7.70		9.96	
	Grind				
	Fine	11.12	.440	15.48	1.54
	Medium	11.06		16.59	
	Coarse	11.12		16.53	
	Binding Agent				
	Control	10.94	.403	18.55	1.20
	Bentonite	11.23		13.84	
	Soft Phosphate	11.12		16.20	
Turkey Finisher	Steam				
	16 C°.	17.29	.395	26.04	1.26
	33 C°.	11.33		17.39	
	50 C°.	9.44		11.46	
	Grind				
	Fine	13.01	1.220	17.21	3.38
	Medium	12.67		18.80	
	Coarse	12.38		18.80	
	Binding Agent				
	Control	12.24	.395	21.16	1.26
	Bentonite	13.05		15.66	
	Soft Phosphate	12.77		18.07	

LSD - Least Significant Difference

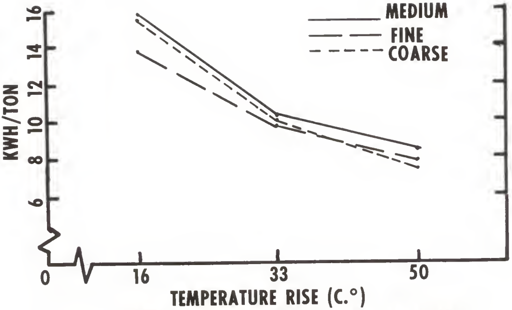

FIG. 9. GRIND BY STEAM INTERACTION FOR TURKEY STARTER.

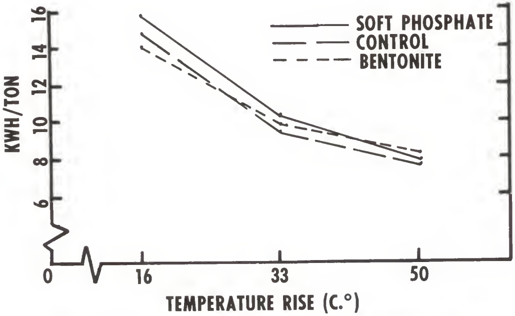

FIG. 10. STEAM BY BINDING AGENT INTERACTION FOR TURKEY STARTER.

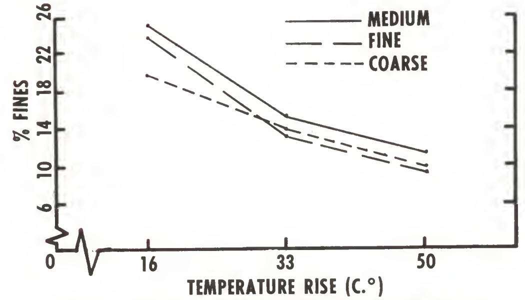

FIG. 11. GRIND BY STEAM INTERACTION FOR TURKEY STARTER.

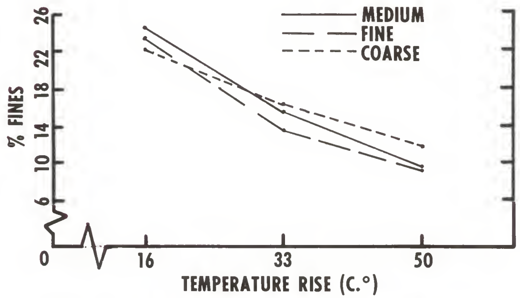

FIG. 12. GRIND BY STEAM INTERACTION FOR TURKEY GROWER.

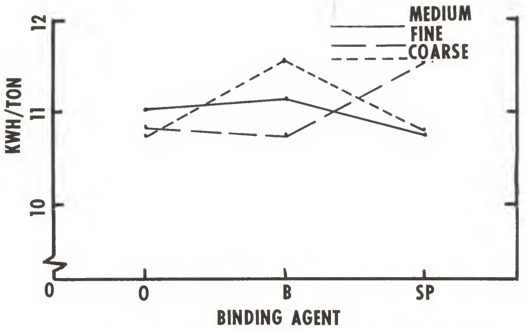

FIG. 13. GRIND BY BINDING AGENT INTERACTION FOR TURKEY GROWER.

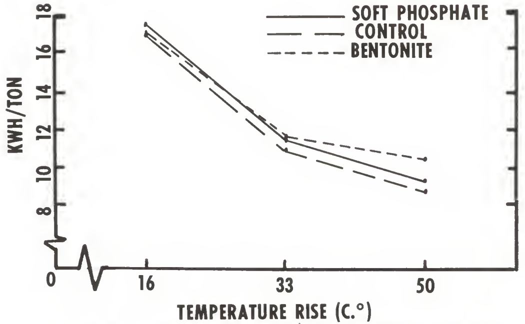

FIG. 14. STEAM BY BINDING AGENT INTERACTION FOR TURKEY FINISHER.

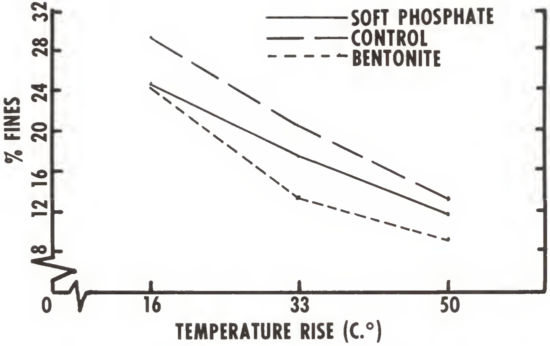

FIG. 15. STEAM BY BINDING AGENT INTERACTION FOR TURKEY FINISHER.

coarsely ground grain consumed the least energy. At the high and medium steam levels, there was no difference in durability of pellets containing the three different grinds of grain, but at the low steam level, the coarsely ground grain produced the most durable pellet.

At the low and medium steam levels, the soft phosphate ration consumed the most energy, while there was no difference in energy requirements among the control ration and rations containing bentonite and soft phosphate at the high steam level.

Turkey Grower. In the statistical treatment of turkey grower, once again the effects on pellet durability or energy requirements due to grind of grain could not be detected. The durability increased significantly as steam level increased while the energy requirements decreased significantly. Durability of pellets increased from the control ration to the soft phosphate ration to the bentonite ration, while energy requirements were non-significantly different. Pelleting of mash containing finely ground grain consumed the most energy when soft phosphate was used. With medium ground grain there was no significant difference in energy requirements for the control, bentonite, or soft phosphate rations. When coarsely ground grain was used, the most energy to pellet was required when bentonite was added.

In pelleting of mash at the high steam level, there was no difference in durability among pellets containing fine, medium, or coarse ground grain. Pellets containing finely ground grain were the most durable when made at the medium steam level, while at the low steam level, pellets containing coarsely ground grain were the most durable.

Turkey Finisher. In the statistical treatment of turkey finisher, the effect of grind of grain on energy requirements or pellet durability could not be detected. As in the starter and grower rations, the more steam added, the greater the durability and the lower the energy requirements. The addition of bentonite or soft phosphate to the ration increased energy requirements over that of the control ration. The addition of bentonite increased durability significantly more than the addition of soft phosphate, but both agents gave greater durability than the control.

At the low and medium steam levels, there was no significant difference in energy requirements among the control, bentonite, and soft phosphate rations. At the high steam level, the ration containing bentonite required the most energy for pelleting.

At the low steam level, pellets with bentonite and pellets with soft phosphate were the most durable, while at the medium and high steam levels, the pellets with bentonite were the most durable.

Pellet Durability Testing

The results obtained by use of the various apparatus to test pellet durability are shown in Table A2 in the appendix.

As stated before, each test was correlated with the model handling system. The linear correlation coefficient was computed for each test (Table 13). A correlation coefficient of 1.00 would be perfect correlation.

Table 13. Correlation coefficients of laboratory devices with model handling system.

Laboratory Device	Correlation Coefficients
Tumbling Can	.949
Farmhand Machine	.944
Pneumatic Hardness Tester	.839
Tumbling Jar	.798
Stokes Hardness Tester	.784
Shear Test	.726

The relationship between the tumbling can and the model handling system is shown in Fig. 16 as an example.

Hot pellets taken directly from the die and tested in the tumbling can, gave the results shown in Table A3 in the appendix. The linear correlation coefficient with the model handling system, was calculated as .967; this relationship is shown in Fig. 17. These values were compared with values of stored pellets tested in the tumbling can and the correlation coefficient was .970.

The two devices with the highest correlation coefficients, the tumbling can and the Farmhand machine, were devices that tested a larger number of pellets than the pneumatic hardness test, shear test and the Stokes tester. The tumbling jar also tested a relatively large number of pellets, but the amount of

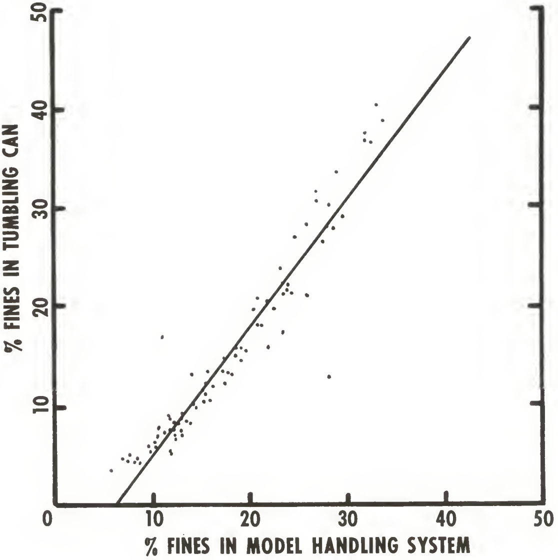

FIG. 16. PLOT OF PERCENT FINES PODUCED IN TUMBLER CAN ON PELLETS STORED FOR 24 HOURS AGAINST PERCENT FINES PRODUCED IN MODEL HANDLING SYSTEM.

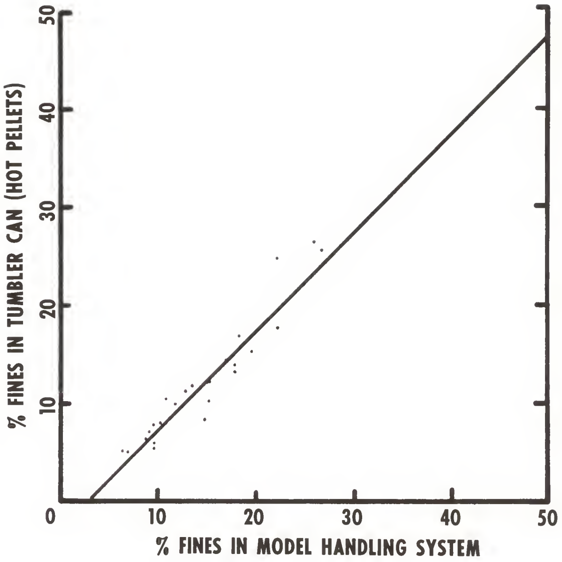

FIG. 17. PLOT OF PERCENT FINES FROM TESTING OF HOT PELLETS IN TUMBLING CAN AGAINST PERCENT FINES PRODUCED IN MODEL HANDLING SYSTEM.

fines obtained was too small to remove and measure accurately. Also, the pellets tested in the Farmhand machine and tumbling can were of different sizes and shapes and included a range from any material just remaining on a 6-mesh screen to the cylindrical pellets approximately 3/4 inch long. The pellets tested in the pneumatic hardness tester, the shear tester, and the Stokes tester had to be good pellets at least 1/2 inch long before they could be tested.

DISCUSSION

No comparison was made between the three different formulas with respect to durability or energy requirements. Tests were made to determine if any die wear might have occurred. The first test run in this project was made on turkey starter with no binding agent, at the high steam level. The second test was the pelleting of the control ration of turkey starter at the low steam level. After all tests were completed, when a total of 400 tons or more had gone through the die, the first and second tests were repeated. The results are shown in Table 14.

Table 14. Effect of die wear on pelleting performance.

Test	Percent Fines*	KWH/Ton
1 (original)	14.0	6.09
(repetition)	9.0	9.00
2 (original)	29.3	16.19
(repetition)	16.0	15.88

* - Percent fines produced in the model handling system.

These results indicated that die wear might have been present, as all other conditions were replicated to a substantial degree of accuracy. There can be no true comparison of the energy requirements or pellet durability among the three formulas.

Results of the investigation showed that, due to the great variability within grinds of grain, effects on the energy required to pellet or on pellet durability could not be detected. Previous investigators had expressed the opinion that the finer the grind, the better the pellet durability.

The general procedure in industry is to add as much steam as possible to improve durability and to reduce energy consumption. Results from this study confirm the value of this procedure.

No attempt is made here to evaluate the economic justification for the addition of binding agents, as the improvement of durability cannot be expressed as yet in monetary values.

In this study, bentonite was added at the 2 1/2 percent level. Higher levels might further improve durability, but more work is needed to determine this. Lower levels might improve durability sufficiently to be justifiable.

In testing pellet durability, it was shown that use of a device which tests relatively large numbers of pellets will give the best correlation with the model handling system. However, this factor must be combined with the ease of testing.

If a device is to be used for making a quality control test, it must be of laboratory scale and should require a small amount of time and work to operate.

The tumbling can used to test pellets taken directly from the die will give a quick and accurate indication of pellet durability. This will give the pellet mill operator an indication of what variables to change in order to improve durability at the time of pelleting. This test may be correlated with tests run on pellets which are leaving the warehouse. From this comparison, the final durability of the pellets may be closely estimated from testing of hot pellets.

The tumbling can gave better correlation to the model handling system than the Stokes tester which is used extensively in the feed industry. Several of these hardness testers have been developed to allow a quick check of pellet durability. Here again, the pellets tested must be long enough to test, and testing of a large number of pellets would take a considerable amount of time.

It should be noted that the results obtained in pelleting the turkey rations are not necessarily typical of all formulas.

The investigation of all the variables in the pelleting process will require extensive work. The three variables investigated here should give a good basis for the future study of the other variables.

SUMMARY

In evaluating durability testing devices, it was shown that in testing for pellet durability, devices which tested relatively large numbers of pellets gave the best indication of pellet durability. Due to the considerable variation among pellets, the devices which tested individual pellets did not give as accurate an indication of pellet durability as those which tested many pellets. The test with the tumbling can gave a correlation coefficient of .949 with the model handling system, that with the Farmhand machine, .944, and that with the tumbling jar, .798. The individual pellet testers and the correlation coefficients obtained by their use were: the Stokes tester, .784; pneumatic hardness tester, .839; and the shear tester, .726.

The tumbling can, testing pellets taken directly from the die, gave the best correlation with the model handling system, with a coefficient of .967.

In the pelleting studies, it was found that the high steam level required approximately 6 KWH/Ton less to pellet and reduced the amount of fines produced in the model handling system in comparison with that obtained at the medium steam level. The amount of fines produced from the pellets made at the medium steam level amounted to 16 percent while pellets made at the high steam level produced only 10 percent fines. The medium steam level used 2 KWH/Ton less to pellet than the low steam level and produced 16 percent fines as compared to 24 percent for the low steam level.

Fineness of grind of grain had no effect, which could be detected, on either pellet durability or energy required for pelleting. This was due to the large variability within grinds.

The addition of soft phosphate decreased the amount of fines to 17 percent compared with 19 percent for the control ration while the addition of bentonite further decreased the amount of fines to 14 percent (average of all tests). Energy requirements were not significantly different.

Due to possible die wear, the variables cannot be compared among formulas and the formulas cannot be compared accurately.

CONCLUSIONS

Results of this study indicate that:

1. The grind of grain had no significant effect, which could be detected, on energy required to pellet or on pellet durability.
2. The high steam level, which corresponded to a temperature rise of 50 C°., reduced energy consumption from the energy required to pellet at the medium steam level, which corresponded to a temperature rise of 33 C°. The medium steam level showed the same trend with respect to the low steam level, which corresponded to a temperature rise of 16 C°. The medium steam level increased the durability of the pellets over that of

of the low steam level. Durability was further increased at the high steam level. Therefore, the more steam that was added, the less energy consumed during pelleting and the greater the durability.

3. Soft phosphate improved durability over the control ration and bentonite further improved durability over soft phosphate. Energy requirements were not significantly different.
4. Evaluation of durability testing devices showed that the devices which gave the highest correlation with the model handling system were ones which tested a relatively large number of pellets.
5. The tumbling can test, testing both pellets taken directly from the die and pellets that were stored for 24 hours, gave the highest correlation with the model handling system.

SUGGESTIONS FOR FURTHER RESEARCH

Some of the pelleting process variables which possibly may have an important effect upon pellet durability and also upon energy requirements include:

1. Roll to die spacing.
2. Different levels of binding agents.
3. Internal die temperatures and pressures.
4. Different types of formulas.
5. Die thickness.
6. Die hole geometry.
7. Additional conditioning.

The future study of these factors may help to make the pelleting process more of a science than it has been in the past.

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APPENDIX

Table A1(a). Partial chemical analysis of bentonite.*

	%
Silica (SiO_2)	64.32
Alumina (Al_2O_3)	20.74
Ferric Oxide (Fe_2O_3)	3.03
Ferrous Oxide (FeO)	.46
Phosphoric Acid (P_2O_5)	.01
Lime (CaO)	.52
Magnesia (MgO)	2.30
Soda (Na_2O)	2.59
Potash (K_2O)	.39
Sulfur (SO_3)	.35

* - Manufacturer's data

Table A1(b). Partial chemical analysis of soft phosphate.*

	%
Minimum Calcium (Ca)	15.00
Maximum Calcium (Ca)	18.00
Minimum Phosphorus (P)	9.00
Maximum Fluorine (F)	1.50

* - Guaranteed Tag Analysis

Table A2. Results of laboratory tests.

Test No.	Model Handling System % Fines	Pneumatic Hardness Test Tensile Stress (psi)	Stokes Hardness Test Tensile Stress (psi)
1	10.6	265	251
2	20.6	169	188
3	27.0	190	153
4	14.2	231	198
5	9.6	236	251
6	5.8	292	316
7	19.8	195	192
8	12.8	234	218
9	28.2	192	169
10	15.8	231	198
11	24.8	204	169
12	10.6	278	267
13	19.6	186	198
14	12.0	242	228
15	13.2	209	224
16	7.6	275	280
17	21.0	221	204
18	28.2	169	185
19	15.6	242	214
20	7.5	308	283
21	19.2	198	195
22	11.8	250	228
23	18.6	202	201
24	13.2	237	231
25	14.5	260	208
26	17.5	233	214
27	22.6	165	176
28	15.6	230	181
29	28.6	139	148
30	21.4	148	166
31	23.6	190	179
32	10.4	250	228
33	23.5	146	158
34	11.4	232	269
35	18.2	187	187
36	16.4	196	175
37	33.6	123	149
38	19.4	180	161
39	11.8	229	192
40	23.2	118	155
41	29.0	150	163

Table A2 (continued).

Test No.	Model Handling System % Fines	Pneumatic Hardness Test Tensile Stress (psi)	Stokes Hardness Test Tensile Stress (psi)
42	14.8	166	184
43	7.0	250	231
44	17.4	190	166
45	12.4	234	218
46	12.2	234	203
47	11.1	157	160
48	8.2	274	242
49	24.4	154	160
50	27.0	152	160
51	15.2	180	182
52	13.5	222	192
53	32.0	107	156
54	10.1	233	235
55	21.0	134	145
56	17.5	156	184
57	8.5	209	266
58	22.0	166	176
59	26.0	103	136
60	12.5	174	200
61	13.0	172	231
62	23.8	115	168
63	12.0	202	228
64	33.0	108	138
65	26.0	113	151
66	14.0	160	185
67	32.0	112	173
68	16.0	147	171
69	8.5	231	253
70	32.5	127	162
71	18.0	143	169
72	13.0	212	182
73	12.5	192	188
74	22.0	153	143
75	23.5	141	138
76	27.5	140	166
77	24.0	151	135
78	13.0	---	---
79	29.5	108	114
80	9.8	---	---
81	15.5	196	179

Table A2 (continued).

Test No.	Shear Test Shear Stress (psi)	Tumbling Jar % Fines	Tumbling Can % Fines	Farmhand Machine % Fines
1	316	1.33	7.8	23.8
2	260	1.25	20.0	36.9
3	279	2.00	31.8	44.7
4	382	1.58	13.2	32.6
5	373	.83	6.0	24.0
6	466	.50	3.6	17.9
7	307	1.75	15.8	35.6
8	373	1.25	8.4	25.1
9	316	2.58	13.0	48.4
10	344	1.75	13.6	33.8
11	316	2.25	27.0	44.9
12	373	1.58	7.0	25.8
13	298	2.17	16.0	34.1
14	335	1.08	8.6	28.4
15	354	1.67	8.8	26.8
16	410	1.00	5.2	21.4
17	307	1.75	21.0	38.4
18	279	2.58	30.2	46.0
19	344	1.50	11.4	33.1
20	457	.67	4.4	19.8
21	326	1.67	14.6	34.3
22	391	1.83	7.6	25.9
23	373	2.00	15.4	37.0
24	316	1.58	9.4	27.1
25	316	1.92	10.4	30.7
26	335	1.17	14.0	45.5
27	288	2.00	20.0	51.8
28	279	1.25	12.4	31.9
29	251	2.17	28.0	48.5
30	298	2.00	18.4	37.7
31	316	1.83	21.4	39.9
32	382	.83	6.0	21.2
33	279	1.42	22.4	38.9
34	326	1.25	7.4	24.1
35	326	1.92	13.6	33.2
36	344	2.17	12.2	29.1
37	251	3.17	38.8	48.9
38	307	2.50	16.0	33.4
39	382	1.67	9.0	23.7
40	269	1.83	24.0	41.0
41	326	2.00	33.8	45.0

Table A2 (concluded).

Test No.	Shear Test Shear Stress (psi)	Tumbling Jar % Fines	Tumbling Can % Fines	Farmhand Machine % Fines
42	288	1.08	10.0	27.5
43	354	.75	4.8	21.2
44	316	1.67	12.2	30.1
45	307	1.58	8.4	25.4
46	307	1.25	7.6	23.4
47	298	1.75	17.0	33.3
48	391	.58	4.4	18.3
49	279	1.50	21.4	37.8
50	279	1.67	30.8	44.5
51	335	1.08	11.8	29.9
52	307	.75	8.6	24.7
53	232	2.17	37.8	46.8
54	344	1.08	6.4	22.6
55	279	1.33	18.2	36.1
56	251	1.00	13.8	32.1
57	401	.42	4.8	19.8
58	326	.92	20.8	37.8
59	307	1.00	28.4	43.1
60	382	.83	6.8	22.5
61	288	.58	7.6	25.2
62	279	.75	22.2	39.3
63	382	.58	5.4	22.7
64	270	1.42	40.2	50.6
65	260	1.83	21.4	44.3
66	288	.67	8.2	26.1
67	204	1.17	37.0	52.8
68	232	.50	10.8	31.6
69	419	.25	4.4	17.6
70	307	1.83	36.8	51.7
71	279	1.50	12.8	33.7
72	373	1.58	7.4	24.6
73	307	.83	7.0	25.3
74	279	1.17	16.0	38.2
75	269	2.67	17.6	30.4
76	326	2.50	26.8	36.2
77	269	1.75	22.0	33.9
78	---	1.67	7.6	24.9
79	223	2.33	29.2	41.4
80	---	.42	5.6	20.9
81	307	.83	10.6	34.4

Table A3. Results of tumbling can tests on pellets taken directly from the die and stored pellets.

Model Handling System % Fines	Tumbling Can (Stored Pellets) % Fines	Tumbling Can (Hot Pellets) % Fines
15.0	8.6	8.6
10.5	5.6	8.2
18.0	10.4	13.4
22.4	15.4	17.8
9.8	4.2	5.8
19.6	14.0	15.4
11.0	8.0	10.8
17.4	12.8	14.8
15.5	10.4	12.4
22.5	19.2	25.0
9.4	5.2	7.2
13.0	8.0	11.4
13.8	9.0	12.0
12.5	7.4	9.8
6.6	3.6	5.2
27.0	28.4	25.8
9.0	3.8	6.6
18.5	19.6	17.0
15.2	10.4	12.2
26.2	20.8	26.6
9.3	6.8	8.0
18.0	12.4	14.0
8.3	4.8	5.2
15.5	12.0	10.4
12.0	7.4	10.0
9.8	5.6	6.0
7.2	4.0	5.2

Fig. A1. Sample data sheet for pelleting studies.

Test No. ____ Grind ____ Degrees Temperature Rise ____ (C°.)

Formula ________ Pellet Diameter ____" Binding Agent ________

Wet Bulb Temperature ___ ___ (F°.) Dry Bulb Temperature ___ ___ (F°.)

Power Panel Reading ____	Amount Pelleted: Pellets ____ Fines ____
Moisture Before Conditioning (%) ____ ____	Temperature Before Conditioning (C°.) ____ ____ ____
Moisture After Conditioning (%) ____ ____	Temperature After Conditioning (C°.) ____ ____ ____
Moisture After Pelleting (%) ____ ____	Temperature After Pelleting (C°.) ____ ____ ____
Moisture After Cooling (%) ____ ____	Temperature After Cooling (C°.) ____ ____ ____

Tyler Sieve Analysis 500 grams - 5 minutes

4	8	14	28	48	100	200	Pan

Fig. A2. Sample data sheet for durability testing.

Test Number	Tumbling Jar Fines		Tumbling Can Fines	
	Grams	Percent	Grams	Percent
———	——	——	——	——
———	——	——	——	——
———	——	——	——	——
———	——	——	——	——
———	——	——	——	——
———	——	——	——	——

Fig. A3. Sample data sheet for durability testing.

Test Number	Model Handling System Fines		Farmhand Machine Fines	
	Pounds	Percent	Pounds	Percent
———	——	——	——	——
———	——	——	——	——
———	——	——	——	——
———	——	——	——	——
———	——	——	——	——
———	——	——	——	——

Fig. A4. Sample data sheet for durability testing.

Test Number	Stokes Hardness Test — Kilograms	Shear Test — Gauge reading	Pneumatic Hardness Test — Gauge reading
—	—	—	—
	—		—
	—		—
	—		—
	—		—
	—		—
	—		—
	—		—
	—		—
	—		—
Average			

MECHANICAL DURABILITY OF FEED PELLETS

by

LEE ROY YOUNG

B. S., Kansas State University, 1960

ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Flour and Feed Milling Industries

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1962

One of the major problems of feed manufacturing today is to manufacture feed pellets of sufficient strength to withstand handling from the feed mill to the consumer without making pellets too hard for the intended use. This ability to withstand handling without breakage is defined as "pellet durability".

The first objective of this investigation was to determine what effect three variables; fineness of grind of grain, amount of steam added in conditioning, and the addition of binding agents, would have on the pellet durability and also the energy required to pellet.

The second objective was the evaluation of devices and methods of testing pellet durability which are used in industry and research.

The formulas pelleted were turkey starter, turkey grower, and turkey finisher. Three different finenesses of grind on corn and milo were used and these were defined as: coarse grind which was grain cracked in a roller mill, medium grind which was grain ground through a 1/4 inch screen in a hammermill, and fine grind which was grain ground through a 1/8 inch screen in a hammermill.

Bentonite and soft phosphate were added as binding agents and checked against the basal ration. The binding agents were added at the level of 52 pounds per ton of mash each.

Three levels of steam were used and were controlled by the temperature rise of the mash going through the conditioner. The high temperature rise was 50 C°. and added 3.9 percent moisture to the mash, the medium temperature rise was 33 C°. and added 2.7 percent moisture to the mash, while the low temperature rise was 16 C°. and added 1.4 percent moisture to the mash.

Pelleting was done with a California Master Model Pellet Mill using a die 2 inches in thickness with 3/16 inch diameter holes.

Damaged pellet material is usually referred to as "fines". In this study the term "fines" was defined as any material which would pass through a 6-mesh screen. The openings on a 6-mesh screen are just smaller than the nominal pellet diameter of 3/16 inch.

Samples of pellets, which were 24 hours old, were tested in the laboratory. The first device used for testing was the model handling system which consisted of a bucket elevator dumping into a hopper which emptied into a screw conveyor which then discharged into the bucket elevator. The pellets were recycled in this system and damage was produced.

Other devices which were evaluated included a tumbling can, tumbling jar, Farmhand machine, Stokes hardness tester, pneumatic hardness tester, and a shear tester. The results obtained from the use of these devices were correlated with the results of the model handling system. The correlation coefficients were: tumbling can, .949, Farmhand machine, .944, pneumatic hardness tester, .839, tumbling jar, .798, Stokes hardness tester, .784, and the shear tester, .726.

The tumbling can test was made with hot pellets taken directly from the die. The results obtained correlated with the results of the model handling system at .967. Another sample of the same pellets, 24 hours old, was tested in the tumbling can and the results obtained correlated with the hot pellet results at .970.

Fineness of grind had no effect, which could be detected, on energy requirements or pellet durability.

Approximate values of the effects of binding agents and steam levels are given in the following statements.

Pelleting at the low steam level required 16 KWH/Ton and 24 percent fines were produced in the model handling system. Pelleting at the medium steam level required 10 KWH/Ton and 16 percent fines were produced. Pelleting at the high steam level required 8 KWH/Ton and 10 percent fines were produced.

With the control ration, 19 percent fines were produced in the model handling system, while the addition of soft phosphate to the ration lowered the fines produced to 17 percent. Only 14 percent fines were produced from the pellets containing bentonite. There was no significant difference in the amount of energy required to pellet among the three rations.

Evaluation of durability testing devices showed that devices which tested relatively large numbers of pellets gave the best indication of durability.