THE EFFECTS OF CONDENSED FERMENTED CORN EXTRACTIVES ON THE PELLETING PROCESS

by

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INTRODUCTION

One of the most important processes in a feed mill is the production of hard pellets. Two of the most important problems in the pelleting process are: the production of pellets durable enough to withstand the abrasion and impact of handling, and producing these pellets with a minimum of power consumption.

At the present time one of the main methods used to alleviate the first of these problems is to add a binding agent to the mash before it is pelleted. Most of the binding agents used at the present time, however, have little or no food value. This situation is undesirable since it leads to the purchase and handling of large amounts of inert material. Adding inert materials to the formula means that more tons of feed must be produced, handled and shipped because the nutritive value of the feed, on a per pound basis, has been lowered. It was for these reasons, among others, that it was considered desirable to look into the binding qualities of a product of known nutritional value such as corn steep water (Condensed Fermented Corn Extractives).

Steep water is a product resulting from the steeping of corn to prepare it for wet milling. In the steeping process, whole corn is placed in large tanks where it is soaked for about 36 hours in circulating warm water containing a small amount of sulfur dioxide, to retard fermentation and to disintegrate the protein which surrounds the starch granules. At the end of this steeping process, the steep water contains much of the soluble protein and minerals of the corn kernel and is, in effect, the first byproduct yielded by the wet milling process (1).

Originally the steep water, which has a rather offensive odor, was not evaporated at all, and was discharged into streams and lakes near the corn mills. This practice, however, caused it to be a public nuisance, as a result the wet miller began evaporating the steep water to higher solids levels, mixing it with other solids such as hulls, and selling it as an ingredient for live stock feeds (15). More recently, steep water has been sold in a liquid form.

Little work has been done on how the mixing of steep water with a mash to be pelleted affects pellet durability and pellet mill power consumption. The present study was undertaken primarily to see what effects the addition of given levels of steep water, to the rest of the formula, would have on pellet durability, and pellet mill power consumption. Secondary objectives of this study were to see how the ratio of the thickness of the pellet mill ring die to the die hole diameter, as well as the roughness of these holes, affect pellet durability and pellet mill power consumption.

REVIEW OF LITERATURE

According to the 1962 Feed Production School Proceedings, the main factors that affect pellet durability are: (A) conditioning; (B) granulation; (C) binding agents; (D) die selection; (E) adequate and proper cooling; and (F) operator ability(10). The formulation, obviously, affects the durability.

Simmons (11) reports, that the most suitable feedstuffs for use in pelleting are those containing a high percentage of oils, such as oil cakes, because oil lubricates the mash in its passage through the die; the most unsuitable are those containing much fiber, for example grass meal.

With the exception of proper cooling, all of the previously mentioned factors have been shown to affect pellet mill power consumption (16, 9, 8, 11).

During this work the effects of die selection, the addition of various levels of binder, the addition of fats, and to a limited extent conditioning, on pellet durability and pellet mill power consumption were studied. An attempt was made to hold the rest of the factors previously mentioned constant, and thus they will not be discussed in the rest of this literature review.

Binding Agents

A. G. Heideman (5) reported in the 1962 Feed Production School Proceedings that a good binding agent should have the following characteristics:

A. It should have definite adhesive properties that will bind feed particles together when traveling through the pellet mill.

B. It should materially improve the durability of the pellets in which it is used.

C. It should reduce the amount of fines produced, and thus improve the efficiency of the pellet mill.

D. It sometimes may improve the capacity of the pellet mill.

E. It can add nutritional value equivalent to the grain it replaces, and should have no destructive or absorptive action on vitamins and other feed additives.

F. It should be economical to use when all other factors are considered.

Some of the major nutritional qualities of steep water are reported by D. D. Christianson, J. F. Cavins, and J. S. Wall, (3). They determined the identities and quantities of the nonprotein nitrogeneous substances, including amino acids, and quaternary nitrogen compounds, in corn steep water because of their nutritional importance in animal feeds and in supplements for fermentation media. Of the total nitrogen in steep water, they found 90 percent was extractable as nonprotein nitrogen, and one half in free amino acids and ammonia. The four major amino acids, according to their work, are alanine, leucine, proline, and alpha-aminobutyric acid. Choline and trigonelline are the primary quaternary nitrogen compounds. Major purine and pyrimidine deratives are adenine, xanthine, cytidine and guanosine. Steep water contains a much higher level of free nitrogenous constituents than the corn from which it is derived. They also found that the amino acid content varied among the three batches of steep water they obtained from a single manufacture.

Die Selection

The die hole diameter is usually chosen by the need for a certain size pellet for a certain type of animal or feeding practice (7).

Pfost (9) found that increasing die thickness increased pellet durability on standard non-fat rations, and increased the power required for pelleting. He also found that increasing the die thickness when pelleting rations containing four percent animal fat did not significantly increase pellet durability.

Patterson, Bates, and Foster (8) found in their work that, as the resistance to feed flow increased, pellet hardness also increased.

Conditioning

It usually has been found that, the higher the conditioning temperature, the higher the pellet durability. At least one reason why increased steam temperature helps in producing a durable pellet is because the starch in the formula is partially gelatinized causing it to become adhesive.

Oak B. Smith (12) of Wenger Mixer Mfg. reported in the 1959 Feed Production School Proceedings that he was able to reduce fines from 8.43% at 20% gelatizination to 6.51% at 47.5%

gelatizination. His work was done with a special pre-conditioner designed to attain and maintain for a period of time temperatures of around 180°F.

Young and Pfost (16) reported that pelleting efficiency and durability were directly related to the amount of steam added. They reported that, with low level steam, 24% fines were produced in pellets, at a medium steam level fines were 16%, and at a high steam level only 10% fines were produced.

Robert Bartikoski (2) reported that a tight adjustment of rolls to die allowed pelleting at higher temperatures and moistures. Pellets run at low volume and high temperatures with this roll setting ran as high as 14.5 on a Stokes hardness tester. He also reported that very little if any gelatinization of starch was obtained at 160°F while at 190°F considerable gelatizination occurred. He reported that this took place while using conventional pelleting equipment. A summary of his results are: pellet durability, as produced and measured by conventional manufacturing and handling processes, can be substantially improved by proper conditioning of the mash. Pellet durability bears a definite relationship to the amount of gelatinization accomplished in the process.

The two graphs on page 33 are from work done by Hastings (4). Fig. 1 shows the relationship of power consumption to the rate of steam added to the mash. Fig. 2 shows that the percent of fines decreases as the rate of steam addition increases.

MATERIALS AND METHODS

The two pelleting process variables that were definitely controlled in this project were the level of binding agent (corn steep water) and die size. Some control was also exerted over conditioning temperature when pelleting one of the formulas, and the effect of die hole roughness was observed.

Two poultry layer formulas were used in the pelleting studies, but were not designated as variables. The major difference between these formulas was that one of them contained 4% animal fat (a formula is considered a high fat formula when it contains this much animal fat) while the other one contained no animal fat (Table 1).

Table 1. Basal rations used in pelleting studies.

Ingredients	Non-fat Layer	High-fat Layer
	Percent	Percent
Soybean Oil Meal	9.20	7.60
Alfalfa Meal	2.00	2.60
Ground Sorghum Grain	45.40	30.20
Ground Corn	25.00	25.00
Wheat Mill Feed	1.80	14.00
Animal Fat	.00	4.00
Meat and Bone Meal	10.00	10.00
Ground Limestone	5.40	5.40
Salt	.30	.30
Trace Minerals	.05	.05
Vitamin & Drug Premix	1.00	1.00
	100.15	100.15

Although the two formulas were not considered as variables in the statistical analysis of the work done, some comparisons were made between the results obtained using each of the two formulas to check on the reproducability of some data. As far as pellet durability and power consumption were concerned, it was assumed that both of these factors would have lower values for the high fat ration than for the non-fat ration. This was obvious in the work reported here.

Experimental Design

The variables studied included: (A) steep water at levels of 0, 2, and 4%; (B) three hole diameters; (C) three thicknesses of die for each of two hole diameters.

Each of the seven dies was tested with every level of steep water using every test on each of the two formulas. These tests were each replicated three times.

The characteristics of primary interest in each of the tests were the power required to manufacture the given quantity of pellets and the durability of these pellets. Of secondary interest were the temperatures of the mash before it entered the conditioning chamber and after it left the chamber.

Factors Not Studied

As stated in the literature review an attempt was made to hold the following factors constant: (A) granulation; (B) adequate and proper cooling; (C) operator ability.

Granulation was held constant by using the same peripheral speeds and screen sizes when the raw ingredients were ground.

Cooling was held constant by maintaining a minimum cooling time of fifteen minutes. Young (16) found that there was little effect on durability after ten minutes cooling time, so it is doubtful, if the durability of pellets increases after fifteen minutes cooling time.

An attempt was made to hold operator ability constant by having the same person operate the pellet mill at all times. This same person also set the rolls after all die changes.

The procedure used to set the rolls was: (A) they were moved toward the die until they ran continuously when the die was rotating at full speed and turned intermittently as the die began to slow down, after the pellet mill was shut off; (B) after the first condition had been achieved, a sheet of feed tags, having a thickness of one tag (.01"), was placed between each of the rolls and the die. The mill was then started for an instant, and shut off as soon as the tags had passed between the roll and the die. The operator could then judge the impressions on the card to see if they appeared to be consistent.

Binding Agent

The steep water was added to each of the two formulas at the rates of two and four percent of the original weight of the dry ingredients. For example when twenty pounds of steep water were added to one thousand pounds of either formula as listed in Table 1 this was called a two percent addition.

The analysis of the steep water used is given in Table 2.

Table 2. Corn Steep Liquor Composition

		As in (50% solids)	Air dry
Protein	min.	23.0%	40.0%
Fat	min.	0.0	0.0
Fiber	min.	0.0	0.0
Arginine		1.0	1.7
Cystine		.3	.5
Glutamic Acid		3.1	5.2
Glycine		.9	1.6
Histidine		.9	1.5
Isoleucine		1.0	1.5
Leucine		2.3	4.0
Lysine		1.0	1.7
Methionine		.5	.9
Phenylalanine		1.0	1.7
Theonine		1.0	1.7
Tryptophan		.1	.2
Tyrosine		.4	.8
Valine		1.5	2.6
Vitamin A		-	-
B-Carotene		-	-
Choline		320.0	560.0
Niacin		40.0	70.0
Pantothenic Acid		6.8	11.7
Pyridoxine		4.0	6.9
Riboflavin		2.7	4.7
Thiamine		1.3	2.2
Total Ash %		10.0	17.0
Calcium & Copper %		0.0	0.0
Iron %		.01	.02
Magnesium %		1.0	1.7
Phosphorus %		1.8	3.1
Potassium %		2.4	4.1
Metabolizable Energy (Poultry		707 Cals/16	1219 Cal.
NFE %		16	28
Other		Unidentified growth factor	

Die Size

The die sizes and length to diameter ratios are given in Table 3.

Table 3. Die Selection

Die Thickness (in.)	Die Hole Dia. (in.)	Length to Diameter Ratio, (40)
1-3/4	3/16	9.31
2	3/16	10.64
2-1/4	3/16	11.96
2-1/4	1/4	9.00
2-3/4	1/4	11.00
3	1/4	12.00
3	3/8	8.00

It will be noted that for each 3/16" diameter die of a given length to diameter ratio, there was a corresponding 1/4" diameter die of as close a length to diameter ratio as standard die sizes would permit.

All of these dies were obtained from the manufacturer just prior to starting this work and showed no signs of wear.

The dies were sized in this manner so the effects of the length to diameter ratio versus diameter on pellet durability could be observed.

Die Hole Roughness

An effort was made to determine the surface roughness of the interior of the die holes by the use of a Micrometrical Mfg. "Proflometer" (6) equipped with type QC amplimeter and 2V moto tracer. This machine was equipped with a probe which was placed into the outer end of the die hole, and protruded into the die hole approximately 3/8". The probe was attached to the moto trace which moved it back and forth in the hole a short distance, always over the same path. The speed at which the probe was moved, or the so called tracing speed, was .3 inches per second.

A minimum number of holes selected at random and tested with this machine were 42 for the dies with 3/16" diameter holes, 35 for the dies with 1/4" diameter holes, and 24 holes for the die having 3/8" diameter holes.

Conditioning

In the case of the non-fat ration, the mash temperature was maintained at what is generally considered to be the optimum temperature for pelleting. This temperature varied with the die that was used, ingredient conditions, etc. The way in which this temperature is attained will be covered as part of the starting up procedure given under the section of this paper entitled "The Pelleting Process".

In the case of the high fat formula, an attempt was made to vary the conditioning temperature by means of the way in which the pellet mill feed and steam rates were set.

The Pelleting Process

The pellet mill used was a California Master Model Pellet Mill with a standard size conditioning chamber, ratchet type feeder screw, and driven by a 25 horsepower motor. The cooler was a California Vertical Pellet Cooler size 2B.

The procedure used was as follows:

First - the ingredients making up the mash were weighed and mixed up for a period of five minutes.

Second - the pellet mill holding bin was charged with 1000 pounds of this mash.

Third - the belt, under the pellet cooler which emptied the cooler, was started.

Fourth - the pellet mill was started. In the case of the ration containing no fat, the feeder control was set so that the feed rate was such that the ammeter connected to the pellet mill motor gave a reading of 30 amps. Steam at 90 psig was then injected into the conditioning chamber until the ammeter dropped. The feed rate was again increased until the ammeter read 30 amps; this procedure was continued until increasing the steam level no longer caused the ammeter to drop below 30 amps.

The results of Hastings (4) work indicate why it was felt that this method of starting the pellet mill gave optimum conditions of feed rate and temperature. It is obvious that power consumption decreases as the rate of steam addition increases. Fig. 2 would indicate that pellet durability increases as the rate of steam addition increases.

From these two graphs, as well as the rest of the literature on conditioning, it was assumed that higher conditioning temperature would increase pellet durability, lower power consumption and increase the production rate.

When starting up using the high fat formula, two systems were used. The first system was the same as the one used for the non-fat formula; this method was used for the first of the three replications of the work done using this formula. Many times, however, when this system was used, the feeder control on the pellet mill was wide open when the addition of more steam decreased the ammeter reading. When this situation occurred, steam was added to the conditioning chamber until the cone on the pellet mill showed evidence of plugging, or until the ammeter stopped falling. If the ammeter stopped falling and more steam was added, it would then start to rise, and usually would continue to rise until the mill plugged.

The second procedure, which was used to start and set the pellet mill when making the second and third replications of the work on high fat formula, was as follows. The feeder control on the pellet mill was arbitrarily set on 30 (the feeder control notches number from 0 to 55), and then steam was added to the conditioning chamber until the die showed evidence of plugging.

When the plugging temperature was determined, the steam level was decreased to the level such that the mash temperature was 3 to 5°C below plugging temperature. The feed rate was increased slowly, while the temperature was held constant by slowly adding steam to compensate for the addition of more mash, until the mill showed evidence of plugging. When this system was used to start up the pellet mill, the final ammeter reading was always around 20 amps. If the ammeter reading exceeded 20 amps, either because of the addition of too much steam or too much mash, the mill usually plugged.

It was believed that this second starting up procedure would allow higher mash temperatures to be reached thus producing more durable pellets, but would also tend to increase power consumption and operating time.

Fifth - after the power and temperature conditions were established then the power panel, which consisted of a kilowatt hour meter equipped with a counter which counted the revolutions of the kilowatt hour meter disc and a switch, was turned on. At the same time the power panel was started, the belt under the cooler was stopped. Since the belt was running during the starting up period, the cooler was empty when the power panel was started, thus the cooler contained only pellets made when the power panel was running.

Sixth - the mash that was left in the pellet mill holding bin was pelleted out, the mill shut off, and the power panel reading taken.

Seventh - the cooler fan was started, and the pellets were cooled for 15 minutes.

Eighth - the cooler was emptied, the pellets bagged, weighed and the weight recorded.

Ninth - the pellets were sampled.

Tenth - the kilowatt hours of electricity that were used were divided by the weight of the pellets produced while the power panel was running; this gave the power consumption value in kilowatt hours per ton.

Laboratory Tests

The laboratory work done in connection with this project consisted primarily of pellet durability testing. The procedure used was that given by Stroup (14) in the 1962 Feed Production School Proceedings.

The sieve sizes were Tyler No. 5 for 3/16" pellets, Tyler No. 3 1/2 for 1/4" pellets and Tyler No. 2 1/2 for the 3/8" pellets. These sieve sizes as well as the rest of the equipment were the same as that recommended in the 1962 Feed Production School Proceedings.

The sieving was done by hand. One sample was taken from each of the pelleting tests made in the pilot feed mill. Each of these samples was divided into three sub-samples and durability tests were made on these sub-samples. The durability values recorded were an average of the three values obtained from these sub-samples.

The durability tests were always made within eight hours after the pellets were removed from the cooler, and usually within two hours.

Statistical Methods

The first analysis performed on the data collected in this project was to determine whether there was a significant difference between the durability of the high fat pellets obtained using the first starting up procedure described under the "Pelleting Process", and those obtained while using the second starting up procedure described under that heading.

The data were considered to be arranged in the form of a Randomized Complete Block Design with the three replications considered to be the blocks, and each die and steep water combination considered to be a treatment. An analysis of variance was carried out on the data in this form.

An F test was made to see if there were any significant differences between blocks. Where the F tests showed evidence of significance, the differences between each block mean and each one of the other block means were tested by means of the Student-Newman-Keul's test (13). Two separate analysis of variances had to be made, one for power consumption, and the other for pellet durability.

After the preceeding tests were made, the two sets of data (the set from the work done on the non-fat formula as well as the one from the work done on the high fat formula) were considered to be in the form of a 3x7 factorial experiment. The factors were considered to be the length to diameter ratio of each of the seven dies and the level of the steep water added to each of the two formulas. The levels of these two factors were considered to the size of the length to diameter ratios, and the percentages of the steep water added to the formula.

An analysis of variance table was constructed and the mean squares calculated for the effects of steep water level, die length to diameter ratio, as well as the interaction between these two variables. These mean squares were used to carry out F tests to see if the differences between the levels of the two variables, or their interaction had any significant effect on either pellet durability, or power consumption.

Two separate analysis of variances for the work done on each formula had to be carried out, one for power consumption data, and the other for pellet durability data. Wherever the F tests showed evidence of significant differences, the individual differences between the mean values were tested by means of the Student-Newman-Keul's test (13).

Plots, of both length to diameter ratio versus total mash temperature after conditioning, were made in an effort to see if there was any meaningful relationship between these two variables. Separate plots were made on each of the two formulas for every level of steep water.

Correlation coefficients were calculated for pellet durability versus total mash temperature after conditioning. Sums of squares, and cross products for these correlation coefficients were summed across the complete die selection.

Correlation coefficients for mean die hole roughness versus mean power consumption values were calculated. The values used to calculate these coefficients were the mean roughness values and the mean power consumption values for each die. The mean roughness values were calculated by adding all the Proflometer values for each of the dies together and dividing by the number of holes tested per die. The mean power consumption values were calculated by summing across the three levels of steep water used on each formula and the three replications of each die steep water level combination, and then dividing this sum by nine, the number of observations that went into each sum.

RESULTS OF EXPERIMENTAL WORK

Tables 4 and 5 give the values of the pellet durability indices obtained in this work.

Tables 6 and 7 give the power consumption values.

Table 8 gives the mash temperatures that were attained during each of the pelleting tests.

Table 9 shows the statistical treatment used to determine whether significant differences existed between the replications of the high fat formula.

Table 10 gives the mean values of the pellet durability indices obtained for each of the three replications of the work done using the high fat formula. Any two values not underscored by the same solid line in this graph were found to be significantly different at the 5% level by means of the Student-Newman-Keul's test.

Tables 11 and 12 show the statistical analysis of data performed to see whether the level of steep water added to the mash, the die length to diameter ratio or the interaction of these factors had any significant effect on pellet durability or power consumption.

Tables 13 and 14 show which steep water levels caused significant differences in pellet durability and power consumption.

Tables 15 through 18 show which dies caused significant differences in pellet durability and power consumption.

In all of the tables from 13 through 18 any two mean values not underscored by the same solid line were found to be significantly different at the 5% level by the Student-Newman-Keul's Test (12). Any two means underscored by the same dotted line were found to be non-significantly different at the 1% level by the Student-Newman-Keuls Test (12).

Table 19 gives the mean roughness values of each of the dies used in this work as well as the standard deviations of these means.

Table 20 contains the correlation coefficients for conditioning temperature versus pellet durability index.

Table 21 contains the correlation coefficients for die hole roughness versus power consumption.

Figures 3 through 8 are plots of conditioning temperature versus length to diameter ratio.

Table 4. Pellet Durability Indices Obtained

Using the Non-Fat Formula

Die Size	Replicate	Steep Water Level		
		0%	2%	4%
3"x3/8"	1.	7.52	9.16	9.35
	2.	8.54	8.70	8.95
	3.	9.00	9.05	8.95
2 1/4"x1/4"	1.	8.39	8.20	8.30
	2.	8.36	8.65	8.57
	3.	8.33	8.70	8.75
1 3/4"x3/16"	1.	8.70	8.94	8.67
	2.	8.85	9.10	9.28
	3.	9.15	8.77	9.05
2"x3/16"	1.	9.17	8.98	9.24
	2.	9.18	9.34	9.06
	3.	9.07	9.15	9.05
2 3/4"x1/4"	1.	8.57	8.60	8.84
	2.	9.00	9.05	9.06
	3.	8.20	8.65	9.06
2 1/4"x3/16"	1.	8.76	9.00	9.25
	2.	9.31	8.76	9.04
	3.	8.95	9.05	9.03
3"x1/4"	1.	8.49	8.65	8.73
	2.	9.04	9.10	9.25
	3.	8.75	8.84	8.75

Table 5. Pellet Durability Indices Obtained Using the High Fat Formula

Die Size	Replicate	Steep Water Level		
		0%	2%	4%
3"x3/8"	1.	7.85	7.91	7.75
	2.	7.85	7.30	7.95
	3.	8.00	8.06	7.58
2 1/4"x1/4"	1.	7.24	6.51	7.18
	2.	7.54	8.06	8.45
	3.	6.88	6.95	7.08
1 3/4"x3/16"	1.	8.13	8.14	8.27
	2.	8.26	8.73	8.27
	3.	8.68	8.19	8.71
2"x3/16"	1.	8.35	8.35	8.69
	2.	8.57	8.55	8.24
	3.	8.75	8.80	8.66
2 3/4"x1/4"	1.	7.95	8.32	7.62
	2.	8.50	8.75	8.74
	3.	7.35	8.15	8.06
2 1/4"x3/16"	1.	8.60	8.39	8.68
	2.	8.66	8.64	8.90
	3.	8.20	8.10	8.34
3"x1/4"	1.	7.35	7.30	7.52
	2.	8.75	8.75	8.54
	3.	7.65	8.45	8.24

Table 6. Power Consumption Data, Kilowatt Hours Per Ton, Obtained While Pelleting the Non-Fat Formula

Die Size	Replicate	Steep Water Level		
		0%	2%	4%
3"x3/8"	1.	13.20	9.02	12.30
	2.	7.46	9.80	10.98
	3.	8.00	10.60	10.50
2 1/4"x1/4"	1.	4.82	5.40	5.82
	2.	5.18	5.66	6.72
	3.	5.02	5.34	8.30
1 3/4"x3/16"	1.	5.52	4.88	5.24
	2.	3.92	4.18	7.44
	3.	3.02	5.14	5.76
2"x3/16"	1.	5.90	6.52	6.28
	2.	4.58	6.28	7.38
	3.	4.58	5.78	7.30
2 3/4"x1/4"	1.	7.00	7.52	9.60
	2.	6.92	8.20	8.26
	3.	6.72	8.18	10.40
2 1/4"x3/16"	1.	5.70	6.24	6.24
	2.	4.82	6.38	8.28
	3.	5.06	6.40	8.16
3"x1/4"	1.	7.34	6.12	7.00
	2.	6.82	6.62	9.40
	3.	5.50	6.60	6.96

Table 7. Power Consumption Data, Kilowatt Hours Per Ton, Obtained While Pelleting the High Fat Formula

Die Size	Replicate	Steep Water Level		
		0%	2%	4%
3"x3/8"	1.	7.60	4.78	5.56
	2.	4.42	3.66	6.06
	3.	5.20	4.88	5.40
2 1/4"x1/4"	1.	2.96	3.46	3.90
	2.	3.68	3.52	5.98
	3.	4.20	4.44	4.56
1 3/4"x3/16"	1.	3.78	2.52	2.82
	2.	2.30	3.32	4.22
	3.	4.38	2.46	4.16
2"x3/16"	1.	3.60	4.48	3.48
	2.	4.66	6.72	6.30
	3.	3.64	5.74	4.92
2 3/4"x1/4"	1.	3.86	4.88	4.36
	2.	3.56	4.08	4.90
	3.	4.38	4.64	5.02
2 1/4"x3/16"	1.	2.94	3.42	3.72
	2.	3.50	2.74	4.28
	3.	3.84	3.16	5.54
3"x1/4"	1.	5.00	3.04	2.70
	2.	5.02	4.44	3.32
	3.	3.14	4.48	4.78

Table 8. Total Conditioning Temperatures (in °C) Attained During the Pellet Tests

Die Size	Rep.	Steep Water Level					
		High Fat Ration			Non-Fat Ration		
		0%	2%	4%	0%	2%	4%
1 3/4x3/16	1.	80	80	72	80	80	73
	2.	83	80	74	94	85	80
	3.	92	80	80	96	90	84
2 x3/16	1.	83	71	71	80	77	70
	2.	83	80	73	95	88	80
	3.	86	84	74	94	91	84
2 1/4x3/16	1.	80	74	67	84	77	72
	2.	85	76	71	90	93	80
	3.	90	85	80	96	94	86
2 1/4x1/4	1.	81	80	75	81	71	70
	2.	85	80	85	94	88	85
	3.	90	88	77	92	87	80
2 3/4x1/4	1.	81	68	67	83	88	67
	2.	87	80	79	95	95	87
	3.	83	80	80	93	95	89
3 x1/4	1.	81	75	67	81	70	73
	2.	83	80	75	95	87	81
	3.	87	84	77	97	93	88
3 x3/8	1.	76	77	70	80	82	67
	2.	84	78	71	91	86	78
	3.	87	80	71	94	89	78

Table 9. Statistical Analysis Used to Determine the Effects of the Starting Up Procedures Used With the High Fat Formula.

Source of Variation	df	Mean Square Durability Index	F	Mean Square KWH/Ton	F
(Treatments) Die & Steep Water Level Combinations	20	.638		.513	
(Blocks) Replications	2	1.25	8.38**	.33	1.94n.s.
Error	40	.149		.17	

**PL.01
n.s.-non significant

Table 10. Mean Values of the Pellet Durability Indices Obtained for the Three Replications of the Work Done Using the High Fat Formula.

	Replications	
1	3	2
	Durability Indices	
7.90	8.04	8.38

Table 11. Statistical Analysis of Pellet Durability and Power Consumption Data for the Non-Fat Formula.

Source of Variation	df	Mean Square Durability Index	F Durability Index	Mean Square KWH/Ton	F KWH/Ton
Effect of Steep Water Level (A)	2	.820	15.5**	21.54	16.31**
Effect of Die (40) (B)	6	.59	11.32**	26.32	19.94**
Effect of (A)(B) Interaction	12	.055	1.04n.s.	.271	.2053n.s.
Error	42	.053		1.32	

**-PL.01

n.s. non-significant

Table 12. Statistical Analysis of Pellet Durability and Power Consumption Data for the High Fat Formula

Source of Variation	df	Mean Square	F	Mean Square	F
		Durability Index		KWH/Ton	
Effect of Steep Water Level (A)	2	.07	.564n.s.	1.35	1.89n.s.
Effect of Die L/B (B)	6	1.73	13.95**	4.18	5.88**
Effect of (A)(B) Interaction	12	.064	.516n.s.	1.10	1.54n.s.
Error	42	.124		.711	

**-PL.01
n.s.-non-significant

Table 13. Mean Pellet Durability Index Values Obtained For the Various Steep Water Levels While Pelleting the Non-Fat Ration

	Steep Water Level		
Mean Pellet	0%	2%	4%
Durability Indices	8.73	8.88	8.96

Table 14. Power Consumption Values (KWH/Ton) Obtained for the Various Steep Water Levels While Pelleting the Non-Fat Formula.

	Steep Water Level		
Mean Power	0%	2%	4%
Consumption Values	6.05	6.60	8.01

Table 15. Pellet Durability Indices Obtained While Pelleting the Non-Fat Formula.

Die Size & L/D						
2x3/16	2 1/4x3/16	1 3/4x3/16	3x1/4	2 3/4x1/4	3x3/8	2 1/4x1/4
10.64	11.96	9.31	11.00	12.00	8.00	9.00
Mean Pellet Durability Indices						
9.14	9.02	8.95	8.84	8.80	8.78	8.47

Table 16. Power Consumption Values Obtained While Pelleting the Non-Fat Formula.

Die Size & L/D						
3x3/8	2 3/4x1/4	3x1/4	2 1/4x3/16	2x3/16	2 1/4x1/4	1 3/4x3/16
8.00	11.00	12.00	11.96	10.64	9.00	9.31
Mean Values of KWH/Ton						
10.09	8.09	6.93	6.25	6.07	5.78	5.01

Table 17. Pellet Durability Indices Obtained While Pelleting the High Fat Formula

Die Size & (L/D)						
2x3/16	2 1/4x3/16	1 3/4x3/16	2 3/4x1/4	3x1/4	3x3/8	2 1/4x1/4
10.64	11.96	9.31	11.00	12.00	8.00	9.00
Mean Pellet Durability Indices						
8.56	8.50	8.38	8.16	8.05	7.81	7.32

Table 18. Power Consumption Values KWH/Ton Obtained While Pelleting the High Fat Ration

Die Size & (L/D)						
3x3/8	2x3/16	2 3/4x1/4	3x1/4	2 1/4x1/4	2 1/4x3/16	1 3/4x3/16
8.00	10.64	11.00	12.00	9.00	11.96	9.31
Mean Values of KWH/Ton						
5.28	4.84	4.41	3.99	3.94	3.68	3.33

Table 19. Die Hole Roughness (Measured in RMS microinches) and Corresponding Standard Deviations

Die Size						
1 3/4x3/16	2x3/16	2 1/4x3/16	2 1/4x1/4	2 3/4x1/4	3x1/4	3x3/8
Mean Roughness Before Work						
39	52	11	32	46	55	
Standard Deviations of Roughness Means						
1.45	5.31	1.37	5.21	6.28	4.77	
Mean Roughness After Work						
36	37	16	38	60.07	39	66
Standard Deviations of Roughness Means						
1.89	2.86	1.28	6.81	9.35	3.33	4.62

Table 20. Correlation Coefficients for Conditioning Temperatures v.s. Pellet Durability Indices.

Formula	Steep Water Level 0%	 2%	 4%
Non-fat	.018	.0913	.0122
High Fat	.220	.158	.36

Table 21. Correlation Coefficients for Die Hole Roughness v.s. Power Consumption.

Formula	Before Tests	After Tests
Non-fat	.25	.79*
High Fat	.65	.69

*P <.05

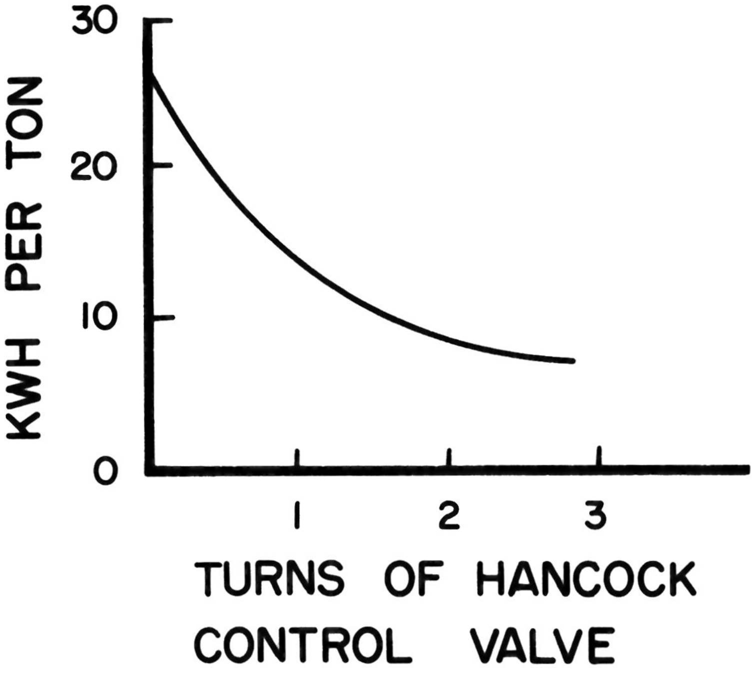

FIG. 1. THE EFFECT OF STEAM ON ELECTRICAL ENERGY REQ'TS.

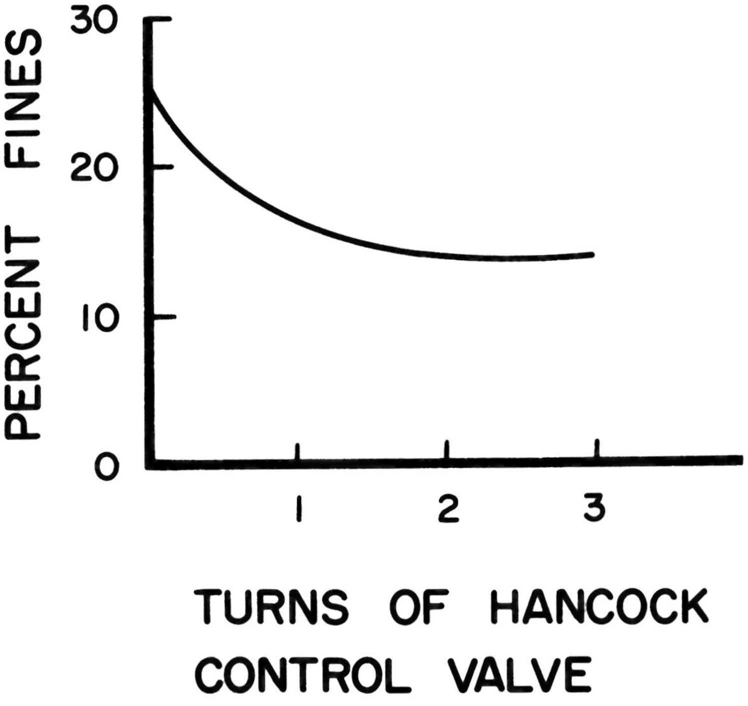

FIG. 2. THE EFFECT OF STEAM ON AMOUNT OF FINES PRODUCED.

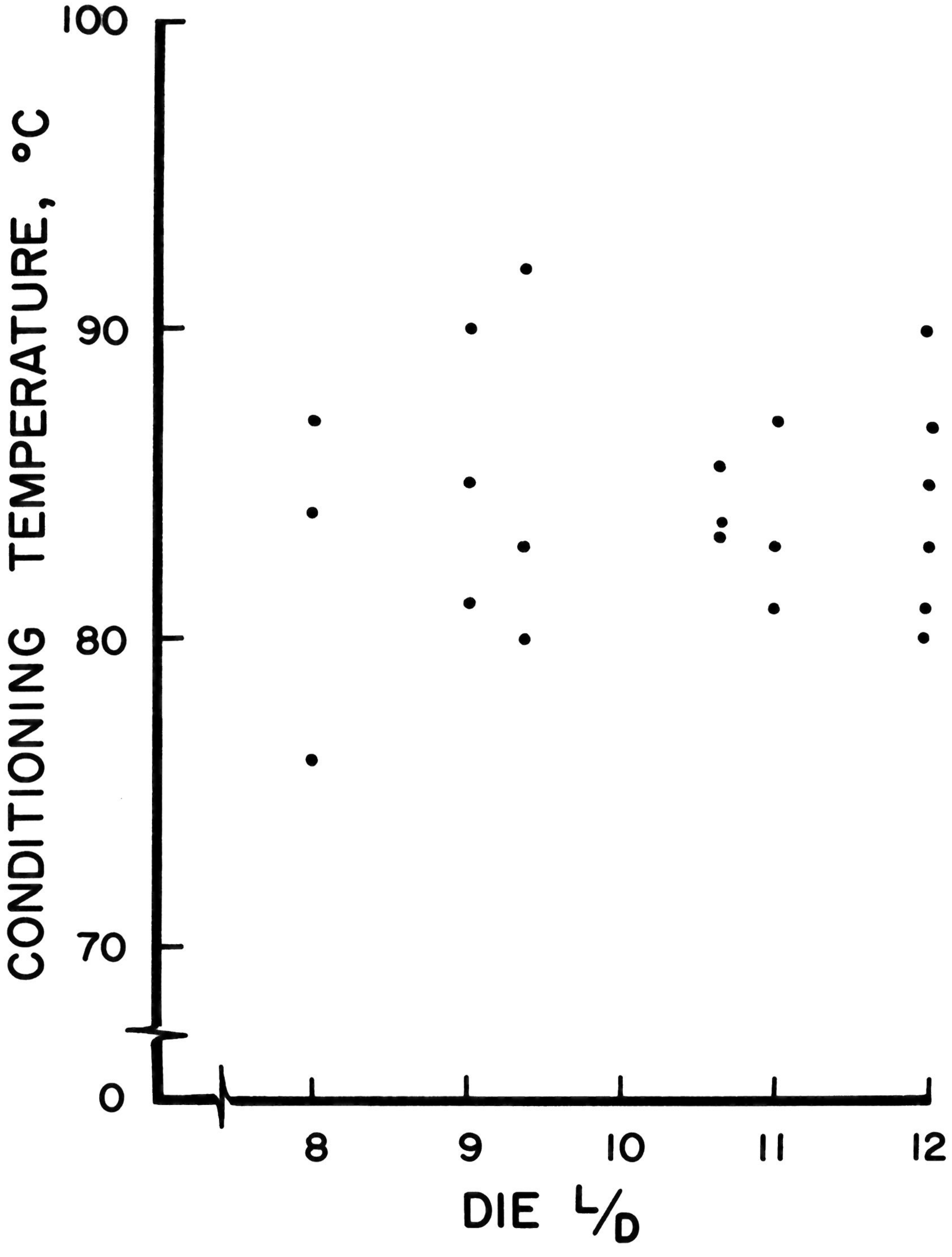

FIG. 3. THE EFFECT OF L/D ON CONDITIONING TEMPERATURE (NON-FAT FORMULA WITH 0% ADDED STEEP WATER).

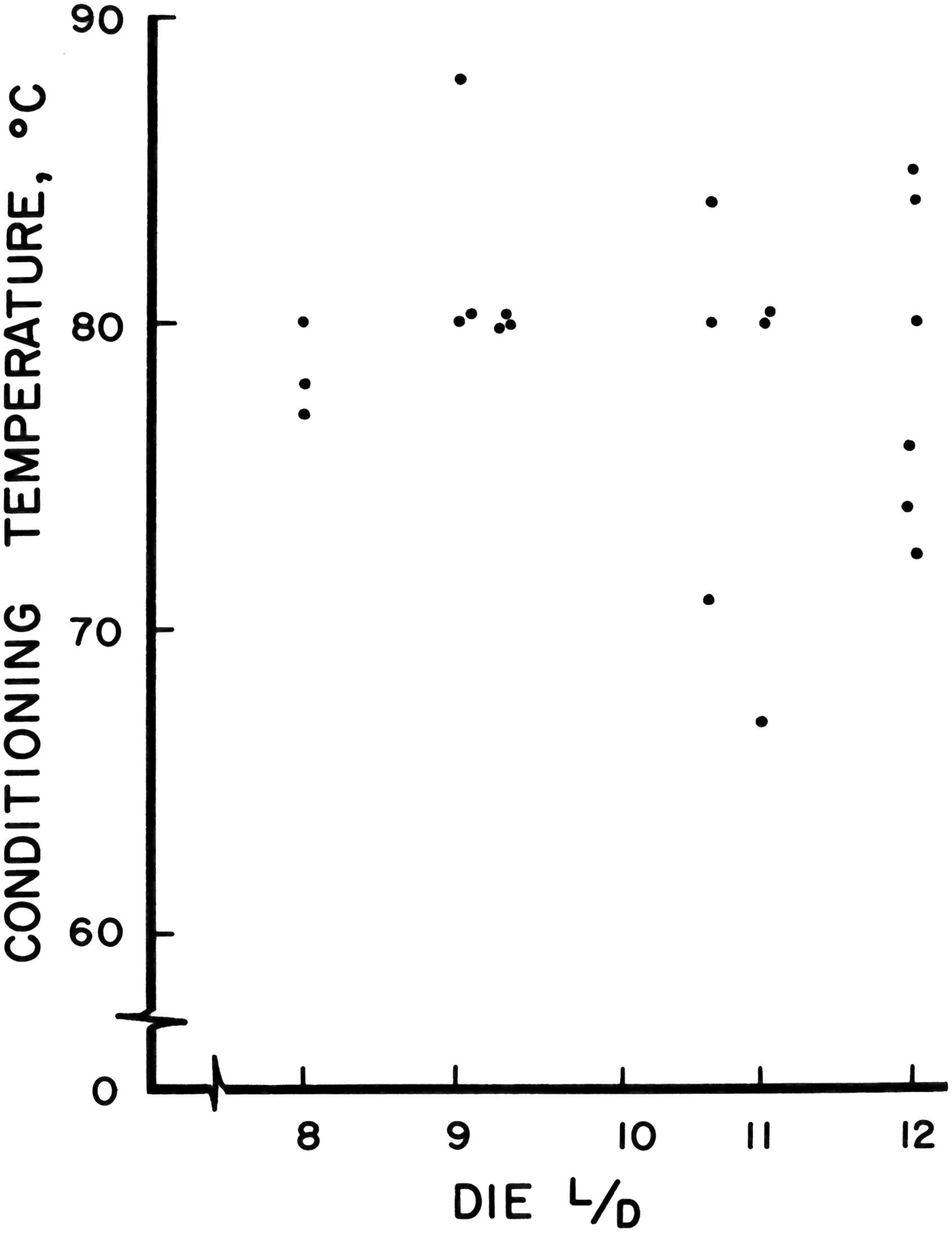

FIG. 4. THE EFFECT OF L/D ON CONDITIONING TEMPERATURE (NON-FAT FORMULA WITH 2% ADDED STEEP WATER).

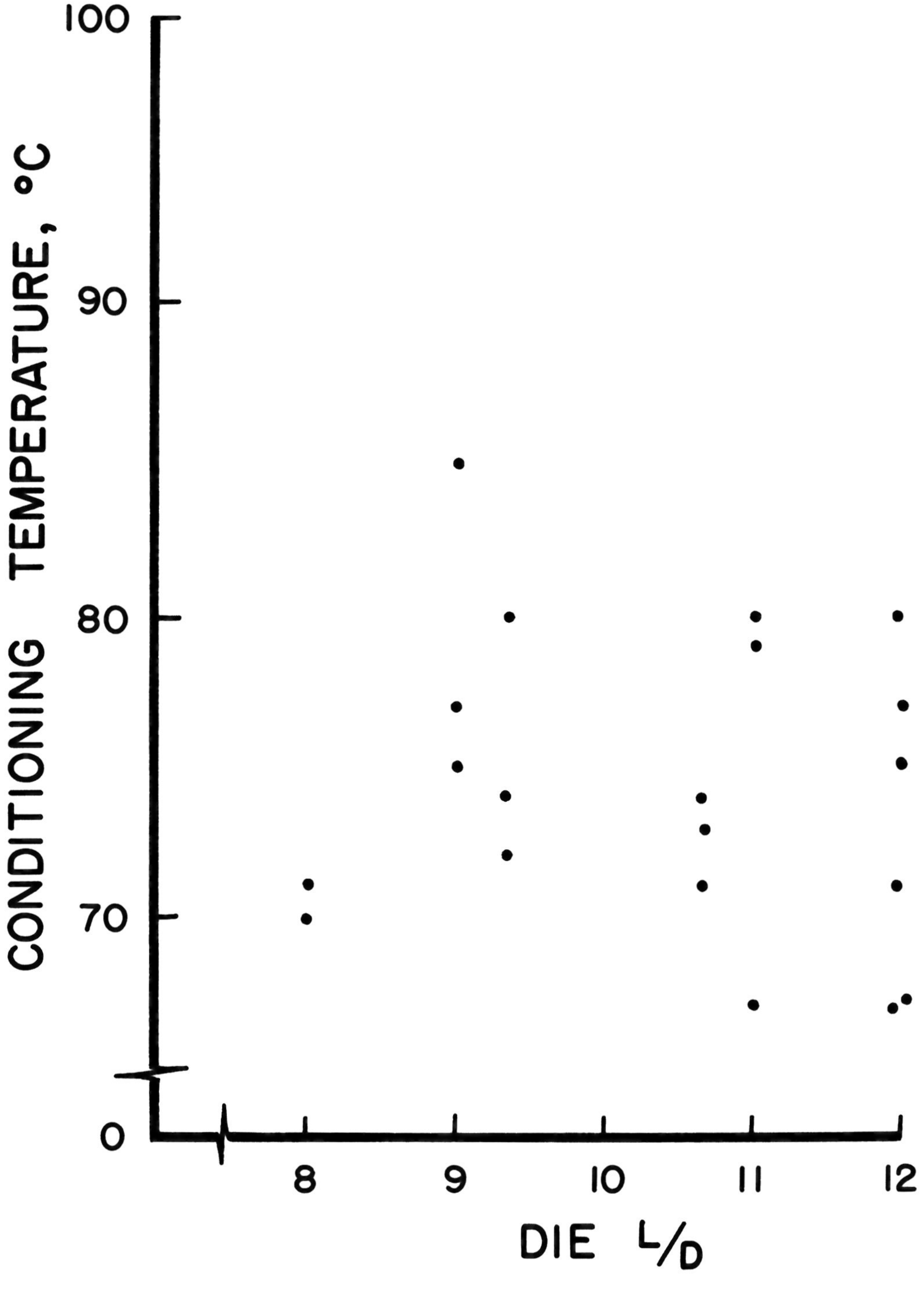

FIG. 5. THE EFFECT OF L/D ON CONDITIONING TEMPERATURE (NON-FAT FORMULA WITH 4% ADDED STEEP WATER).

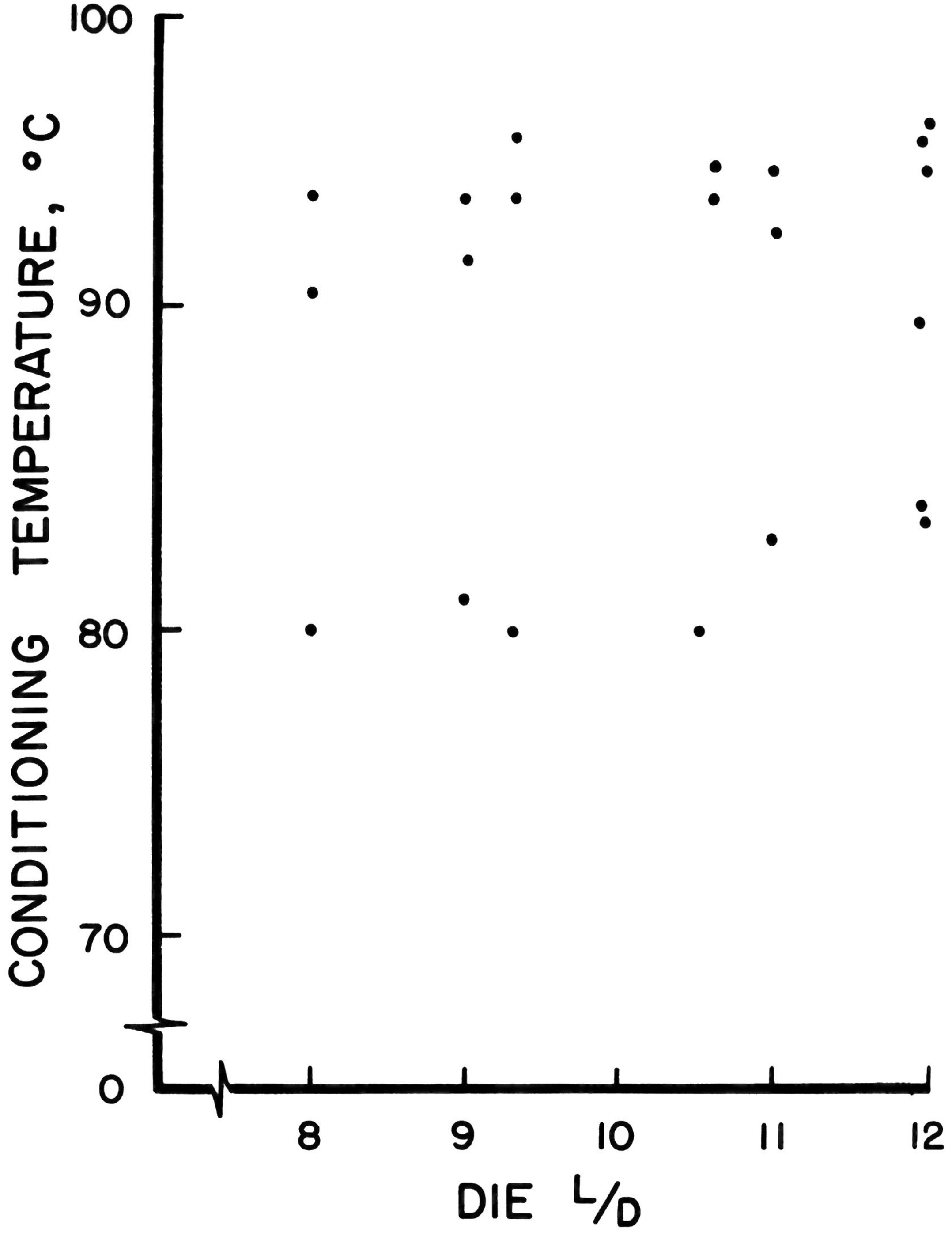

FIG. 6. THE EFFECT OF L/D ON CONDITIONING TEMPERATURE (HIGH FAT FORMULA WITH 0% ADDED STEEP WATER).

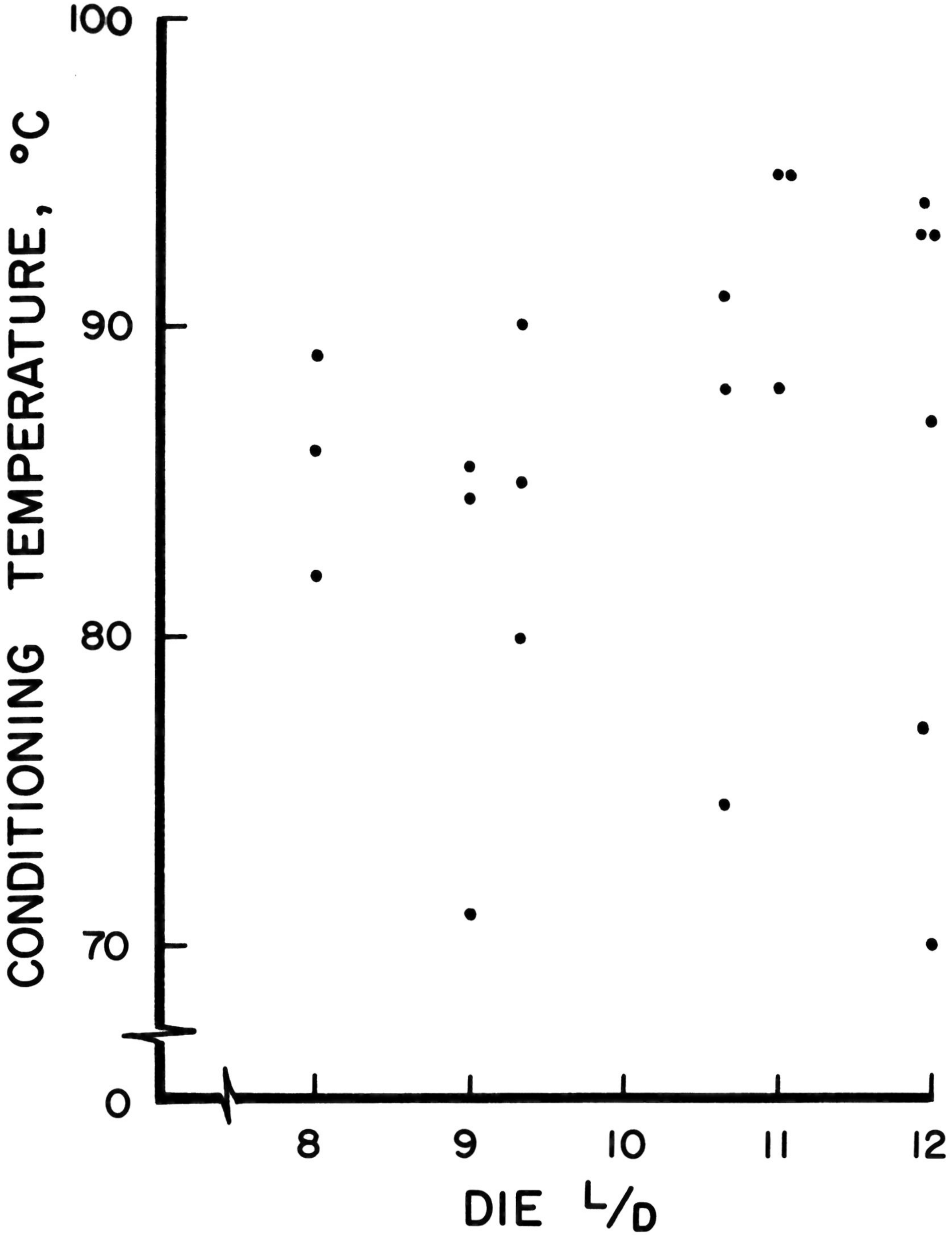

FIG. 7. THE EFFECT OF L/D ON CONDITIONING TEMPERATURE (HIGH FAT FORMULA WITH 2% ADDED STEEP WATER).

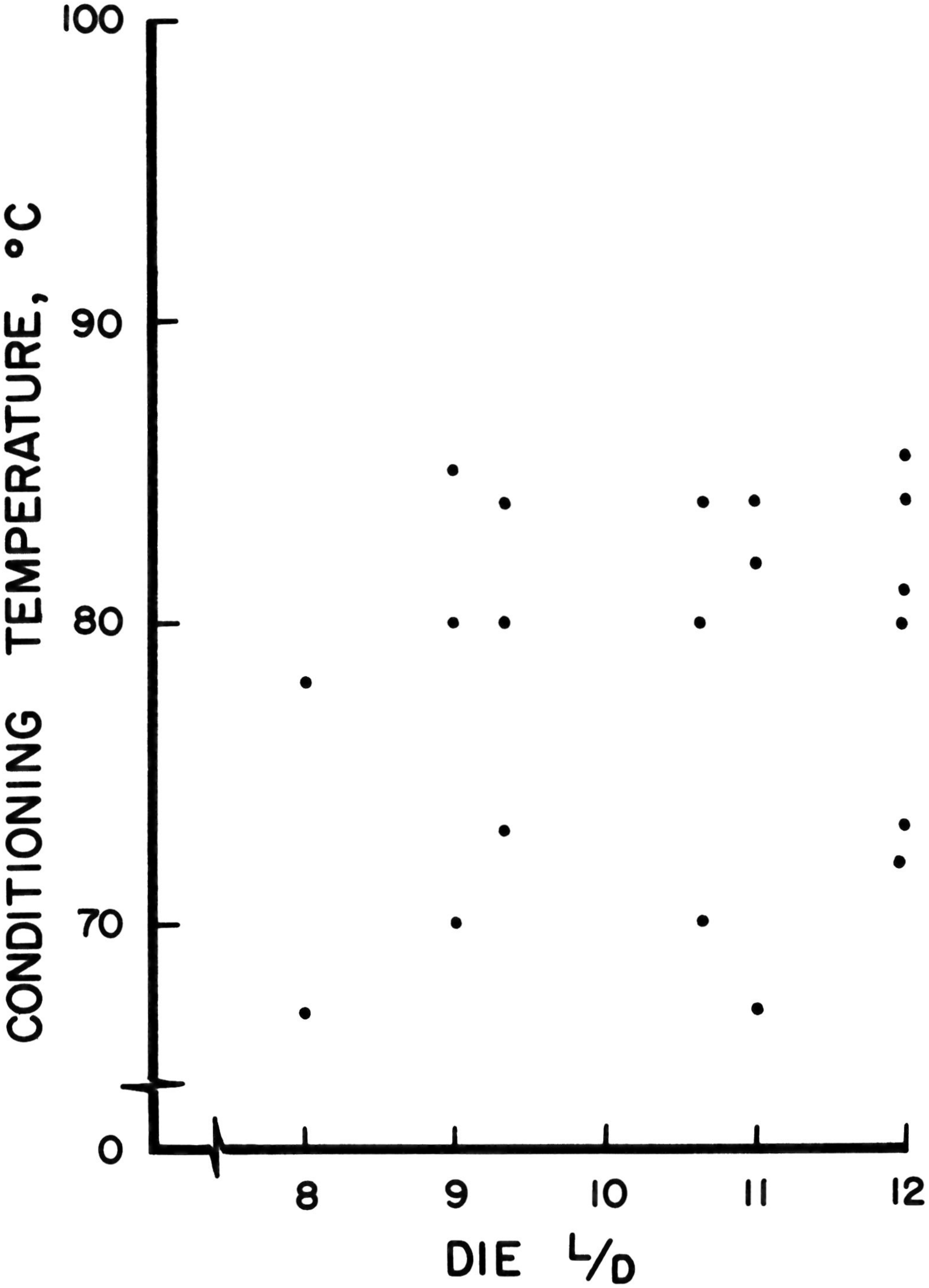

FIG. 8. THE EFFECT OF L/D ON CONDITIONING TEMPERATURE (HIGH FAT FORMULA WITH 4% ADDED STEEP WATER).

DISCUSSION

While no statistical tests were made to determine the effects of adding animal fat to the formula, it was obvious that the high fat produced less durable pellets and required less power to pellet. These facts are in agreement with past works on pelleting feeds containing a high fat content.

The statistical analyses of the data on the starting up procedures used with the high fat formula showed that there were no significant differences in the amount of power consumed using either of these procedures. There were, however, significant differences between the three replications of the work done with the high fat formula with regard to pellet durability. It will be noted that the Student-Newman-Keul's test showed that significant differences existed between the first and second replications as well as between the second and third replications of this work. The significant differences between the first and second replications might have at first been attributed to the difference in starting up procedure. The difference between the second and third replications could definitely not be attributed to a difference in starting up procedure as both the second and third replications were made using the same procedure. This latter significant difference would tend to cast doubt on an assumption that the first significant difference was due to the starting up procedure. The fact that there was a significant difference between the first and third replications definitely cast doubt on an assumption that the difference in the starting up procedure used had an effect on pellet durability. The second starting up procedure did, however, allow for a definite increase in conditioning temperature. No attempt was made to replicate the first replication, so that there would be three identical replications of the work done using the high fat formula. Even if there had been a significant difference between the first replication and the second two, all of the values calculated in the rest of the statistical analyses of the data could have been assumed to have been affected by equivalent amounts.

Steep water significantly increased pellet durability when added to the non-fat formula at both the 2 and 4 percent levels. Steep water did not, however, significantly increase the durability of the high fat formula.

The mean values of the pellet durability indices did not follow the expected order with regard to the L/D ratio. It had been expected that as the L/D ratio got larger, the durability of the pellets would improve.

From tables 15 and 17 it might appear that durability was more a function of die hole diameter than the L/D ratio, since the 3/16 inch dies produced more durable pellets as a group than the 1/4 inch dies. It will be noted, however, that the 3/8 inch die which had the lowest L/D ratio and the largest diameter holes did not produce the poorest pellets; thus the conclusion could not be drawn, that in this work the pellet durability increased as the hole diameter decreased. This conclusion would also be contrary to the theory that larger pellets are stronger because they are less affected by large particles of feedstuffs in the mash. It will be noted that there were some tendencies within the particular groups of dies having the same hole sizes for the dies having the larger L/D ratios to produce more durable pellets. While the differences were not statistically significant, the 2"x3/16" and 2 1/4"x3/16" dies produced more durable pellets than the 1 3/4"x 3/16" die when both the high fat and non-fat formulas were pelleted. The 3"x1/4" and 2 1/4"x1/4" dies both produced more durable pellets than the 2 1/4"x1/4" die and the differences in the durability indices obtained between the thicker dies and the 2 1/4"x1/4" dies were significant in the cases of both formulas.

The effect of L/D ratio on power consumption appeared to be even more erratic than it did on pellet durability. It should be noticed, however, that when pelleting tests were made on both the non-fat and high fat formulas that the 3"x3/8" die had the highest power consumption rate, while the 1 3/4"x3/16" die had the lowest power consumption rate. According to what had previously been thought about L/D ratios, the 3"x3/8" die should have had the lowest power consumption rate. This die, however, was the roughest of the seven dies used according to the proflometer tests and actually had the least amount of breaking in the seven dies. The 1 3/4"x3/16" die had one of the lower L/D ratios so was expected to rank low among the rest of the dies on the basis of power consumption.

In the case of the non-fat formula, if the arrangement of the dies with respect to power consumption is looked at without taking the 3"x3/8" die into consideration, it will be noticed that the three dies with the highest L/D ratios rank above the three dies with the lowest L/D ratios. The results obtained with the high fat formula were considerably more erratic than the ones obtained using the non-fat formula, and no trends except for the highest and lowest values could be detected.

It was in an effort to find some explanation for the preceding results that the correlation coefficients for the mash temperature versus pellet durability were calculated and the plots of L/D ratio versus mash temperature were made. It was felt that as the L/D ratio got larger, less steam could be added to the mash, and thus pellet durability would decrease. This phenomenon would have helped explain why the L/D ratio did not have the effect on pellet durability that previously had been thought possible.

This explanation would have only been valid, of course, if a sizable positive correlation between pellet durability and conditioning temperature had been established. It would not have helped explain, however, why the power consumption data was not more greatly affected by the L/D ratio, as would be expected since, as the mash temperature decreased, the power consumption would increase. If this phenomenon had been true, there would have been a stronger relationship between L/D ratio and power consumption.

If there had been a sizable correlation between pellet durability and conditioning temperature, this correlation would also have suggested one reason why steep water did not aid in producing a more durable high fat pellet because increasing the steep water level caused a definite decrease in conditioning temperature in almost all cases.

From the results of the correlation coefficients and the graphs it can be seen that there was little or no relationship between the L/D ratio and the conditioning temperature, as between pellet durability and conditioning temperature.

One reason why there may not have been a relationship between conditioning temperature and pellet durability, as other experimenters have found, was that the range of temperatures over which the correlation coefficients were calculated were not as great as those found in work where the temperature was definitely set.

No consistant change could be detected in die hole roughness between the start of this work and its completion. A positively significant correlation between die hole roughness, determined after the pelleting tests were made, and power consumption was established.

SUMMARY

Pelleting a poultry layer formula containing 4 percent fat at maximum pellet mill feed rates produced as durable a pellet with as high a power consumption rate as pelleting the same formula at lower feed rates and higher temperatures.

The addition of corn steep water to a non-fat poultry layer formula prior to its being pelleted was shown to increase the durability of the pellets. It was also shown to increase the power consumption rate of the pellet mill, if the level of the added steep water was as high as 4 percent.

The addition of steep water to a high fat poultry layer formula had no significant effect on either pellet durability or pellet mill power consumption.

The effects of the die L/D ratios on pellet durability and power consumption appeared to be rather erratic when either the high fat or non-fat formulas were pelleted. Attempts were made to explain these erratic results by calculating correlation coefficients for pellet durability versus conditioning temperature. It was thought that as the L/D ratios got larger the conditioning temperature values might be forced downward thus causing the durability of the pellets to decrease. None of the correlation coefficients even approached a statistically significant value and the plots of L/D ratio versus conditioning temperature failed to detect any trends.

A positive correlation for die hole roughness versus power consumption was established for the work done with the non-fat formula. This correlation was statistically significant at the 5 percent level. A correlation coefficient calculated for the high fat ration was not quite significant at the 5 percent level. These coefficients were for the roughness measurements made on the dies after the rest of the work had been completed. The correlations for power consumption versus die hole roughness using the roughness values determined before the pelleting tests were made were quite low.

CONCLUSIONS

(1) Steep water significantly increased the pellet durability of the non-fat formula.

(2) Steep water significantly increased power consumption at the 4 percent level when the non-fat formula was pelleted.

(3) Steep water had no effect on pellet durability or power consumption when the high fat formula was pelleted.

(4) The effect of die L/D ratio on both power consumption and pellet durability was very erratic.

SUGGESTIONS FOR FURTHER RESEARCH

Some suggestions for further research on the factors varied in this work are to study:

(1) The effects of various steep water levels on pellet durability and power consumption when added to formulas other than the poultry layer formulas used here.

(2) The effects of steep water levels greater than 4 percent on pellet durability and power consumption when added to the formulas pelleted in this work particularly the non-fat layer formula.

(3) The effect of steep water on high urea pellets.

(4) The effects of L/D ratio on pellet durability and power consumption using dies showing more wear.

(5) More completely the effects of die hole roughness on power consumption and pellet durability.

LITERATURE CITED

(1) Anonymous
Corn in Industry. Corn Industries Research Foundation, Inc., 1001 Connecticut Ave., N. W., Washington, D.C., Fifth Edition 1960, pages 15-16.

(2) Bartikoski, Robert
The effect of steam on pellet durability, 1962 Feed Production School Proceedings, pages 41-50.

(3) Christianson, D.D., Cavins, J.F., and Wall, J.S.
Identification and determination of nonprotein nitrogenous substances in corn steep liquor. Agricultural and Food Chemistry, Vol. 13, No. 3, page 277, May/June 1965.

(4) Hastings, W. H.
How operating adjustments affect pelleting. Feed Age, April, 1960, pages 45-47.

(5) Heideman, A. G.
Effect of Binding Agents on Pellet Durability, 1962 Feed Production School Proceedings, page 51.

(6) Micrometrical Mfg. Co., Ann Arbor, Michigan.

(7) Nesseth, K. A.
The importance of die selection in increasing pellet durability. 1962 Feed Production School Proceedings, page 53.

(8) Patterson, R. L., Bates, R.A., Foster, D., and Kathman, A.J.
Extending die life. 1959 Feed Production School Proceedings, page 92.

(9) Pfost, Dr. Harry
The effect of lignin binders, die thickness and temperature on the pelleting process. Feedstuffs, May 30, 1964, Vol. 36, No. 22, page 20.

(10) Robinson, Roy
Methods available for improving pellet durability. 1962 Feed Production School Proceedings, pages 41-42.

(11) Simmons, N. O.
Practical cubing and pelleting, Part I. Milling, Sept. 6, 1963, page 236.

(12) Smith, Oak B.
Factors in conditioning pellet mash. 1959 Feed Production School Proceedings, pages 40-50.

(13) Steel, Robert G. D. and Torrie, James H.
Principals and Procedures of Statistics. McGraw-Hill Book Company, Inc., New York, 1960.

(14) Stroup, Robert L.
Proposed standard method of testing pellet durability. 1962 Feed Production School Proceedings, pages 37-38.

(15) Walker, William Wells
Inactive inositol and other products from starch factory steep water. Dissertation submitted in partial fulfillment of the requirements for a PhD, Department of Chemistry, Iowa State, June 1935, page 6.

(16) Young, L. R. and Pfost, H. B.
Colloidal binders. Feedstuffs. Vol. 34, No. 32, August 11, 1962, pages 36-38.