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Factors affecting pellet quality

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Pelleting has been, and continues to be, a popular processing technique in feed manufacturing. In basic terms, pelleting converts a finely-ground blend of ingredients into dense, free-flowing agglomerates (pellets). There are many reasons used to justify the process, but it may be appropriate to list just a few:

- Improved animal performance;
- Decreased feed wastage;
- Reduced selective feeding;
- Improved bulk density;
- Better material handling characteristics;
- Destruction of deleterious organisms; and
- Customer expectations.

Pelleting operations are not without cost. It is a fairly expensive process in terms of both capital and variable costs, but the expense is usually justified in improved plant profit as well as animal performance. The purpose of this chapter is to discuss the pelleting process in terms of operations, and to describe how the success or failure of the operation can impact on profit as well as animal performance.

The process

The formation of the pellet actually occurs at the "nip" between the rolls and the die. All other activities associated with the operation such as conditioning, cooling, etc., really support and augment the action at that point in the system. In order to understand the process and be in a position to make intelligent decisions to improve throughput, quality or appearance, one must have a thorough understanding of what happens at the nip point. Chapter 3 shows representations of the die-roll assembly, and reviewing those figures will help the reader further understand the following discussions.

Depending upon the physical characteristics of the feed, a lesser or greater proportion of the work done by the pellet mill is used for compression. For example, if the feed mix contains a high level of fibrous ingredients such as bagasse, bran or ground alfalfa, the mill will expend a large amount of energy simply compressing the mash to the density of the subsequent pellet. Conversely, for a relatively dense feed such as high grain and soy meal, the mill will expend a lesser amount of energy for compression and a greater amount for throughput.

The "extrusion area" is the point at which the mash has reached pellet density and begins to flow through the die holes. There are many physical forces that must be dealt with in the pelleting process. The primary purpose of the roll is to provide a force on the mash to densify the feed and cause it to flow toward the die. The gap between the roll and the die, the roll surface characteristics and the physical properties of the mash determine how great this potential force might be.

The die provides not only the final diameter of the pellet, but the resistance force on the feed and has a direct influence on throughput rate and pellet quality. These two forces (roll and die) are opposite each other, but must work together to provide quality pellets at an acceptable production rate. The force generated by the roll must be greater than the resistive force provided by the die—if not, throughput is zero.

With a general understanding of the process inside the pellet chamber, it is appropriate to move to a discussion of various factors that affect both throughput and pellet quality.

Pellet quality

For purposes of this chapter, pellet quality will be equated to the ability of pellets to withstand repeated handling without excessive breakage or fines generation. There are many factors that affect pellet quality, but the following will be discussed in some detail:

- Formulation;
- Ingredient particle size;
- Mash conditioning;
- Feed rate;
- Die speed;
- Die specifications (design); and
- Other factors.

Formulation

There are feedstuff materials that pellet well and produce a durable pellet, and there are others that will not. MacBain (1966) developed a pelletability chart in which he ranked feed ingredients on their pelletability and degree of abrasiveness. Bartikoski (1962) experimented with applying a numerical value to each major (feed) ingredient to indicate its "stickiness," or its ability to help form a tough, durable pellet. He called that value a "stick factor" and fed that factor into the computer, along with the various nutritive values of each ingredient, to provide formulas that meet all nutritional specifications as well as supply a formula that will produce a quality pellet at least-cost.

Those early workers led others to experiment with the effects of various ingredients—grains, milled grain byproducts, fats, pellet binders, minerals, etc.—on pellet quality or durability. They also led the development of a standard method for testing pellet durability perfected in the 1960s by Dr. Harry B. Pfost at Kansas State University and accepted as a standard by the American Association of Agricultural Engineers—ASAE S-269.5 (ASAE, 2012).

That method is generally known as the K-State, or Tumbling Can durability test, and it provided a means of quantifying the toughness of pellets, or their ability to withstand the downstream handling that is typical in feed plants and feed delivery systems. That was a major breakthrough in the technology of pelleting and has served the industry for all these years.

Table 19-1. Swine diets used for pelleting experiment with hard red winter wheat (HRW) as pelleting aid.

		HRW, %			
Ingredient	Ref #	0	5	10	20
Corn or sorghum	4-26-023 4-20-893	76.1	71.1	66.1	56.1
Soybean meal, 44%	5-20-367	20.3	20.3	20.3	20.3
Dicalcium phosphate	6-28-335	1.2	1.2	1.2	1.2
Limestone	6-02-632	1.3	1.3	1.3	1.3
Salt	6-04-152	0.5	0.5	0.5	0.5
Trace mineral premix	-	0.1	0.1	0.1	0.1
Vitamin premix	-	0.5	0.5	0.5	0.5

[1] Provided per kg of diet

[2] Provide per kg of diet 4405 USP Units vitamin A; 330 USP Units vitamin D_3; 22 International Units vitamin E; 5 mg riboflavin; 1.7 mg menadione; 13.2 d-pantothenic acid; 27.5 mg niacin; 508 mg choline chloride and 0.2 mg vitamin B_{12}.

Time and space do not begin to allow for a presentation of all, or even a significant part, of the research that has been conducted on the effects of ingredients, mixes of ingredients or binders on pelletability. However, a good example of the impact of formulation on pellet quality can be found in a comparison of cereal grains used in feeds. Behnke (1990) describes his research at Kansas State University on the effect of hard winter wheat, die thickness, and cereal type on pellet durability index in a swine diet (**Table 19-1**), in which the corn or sorghum grain portion of the ration was replaced with 5%, 10% and 20% ground hard red winter wheat (HRW). Results are shown in **Tables 19-2** and **19-3**.

Table 19-2. Effect of hard red winter wheat (HRW), die thickness, and cereal type on pellet durability index[1].

Die thickness:	38.1 mm		50.8 mm	
Cereal:	Corn	Sorghum	Corn	Sorghum
HRW, %				
0	74.5^{a}	76.5^{a}	94.3^{a}	93.4^{a}
5	77.0^{b}	76.8^{b}	95.2^{b}	94.3^{a}
10	79.6^{b}	80.4^{c}	95.3^{c}	95.2^{b}
20	83.0^{c}	86.2^{d}	96.5^{d}	96.7^{c}

[1] Values are means of three replications with four observations averaged per replication.

[abc] Values within the same column without a common superscript differ $P < 0.05$.

Table 19-3. Effect of hard red winter wheat (HRW), die thickness, and cereal type on pellet production rate, kg/hr[1].

Die thickness:	38.1 mm		50.8 mm	
Cereal:	Corn	Sorghum	Corn	Sorghum
HRW, %				
0	994	908	647	630
5	985	928	696	625
10	986	937	683	620
20	987	930	700	628

[1] Values are means of three replications with four observations averaged per replication.

Stevens (1987) conducted experiments using corn and wheat as the grain portion of the swine ration shown in **Table 19-4** as he attempted to determine the effect of low (20 psig) and high (80 psig) steam processes at the conditioning chamber of the pellet mill.

He found no significant (p<.05) effects due to steam pressure on the production rate, electrical efficiency or pellet durability; however, the pellets from the corn formula were of a distinctly lower quality (PDI) than those from the wheat formula (**Table 19-5**).

Table 19-4. Swine diets used for pelleting experiment with steam pressure changes.

Ingredient, %	
Corn or wheat	72.4
Soybean meal, 44%	20.0
Dicalcium phosphate	3.2
Limestone	2.4
Salt	1.0
Trace mineral premix	0.5
Vitamin premix	0.2
Diluent in premixes	0.3

[1] Provided per kg of diet

[2] Provide per kg of diet 4405 USP Units vitamin A; 330 USP Units vitamin D_3; 22 International Units vitamin E; 5 mg riboflavin; 1.7 mg menadione; 13.2 d-pantothenic acid; 27.5 mg niacin; 508 mg choline chloride and 0.2 mg vitamin B_{12}.

Table 19-5. Effect of steam pressure on pellet production rate, pellet mill electrical efficiency, and pellet durability index (PDI)[1].

	Production rate, kg/hr	Efficiency, kWh/ton	PDI
Corn			
Low (20)	1,399	6.8	57.5
High (80)	1,273	7.4	57.6
Wheat			
Low (20)	1,224	7.8	91.0
High (80)	1,265	8.1	90.3

[1] The modified method of the tumbling box method was used, which included six 12.7 mm national coarse hexhead nuts in each compartment to more severely challenge pellet durability.

Now, if we are looking for a quick fix, the cited research results would indicate that we should substitute wheat for corn or sorghum grain in our rations. But what are the economics? Wheat farmers would be pleased with such a decision; but formula costs would increase in most cases, hammermill and pellet mill capacities would decrease and manufacturing costs would rise by some factor. There may, however, be room for compromise by replacing some portion of the corn or milo with wheat or incorporating wheat middlings or red dog in the ration at something like 65% of the cost of whole wheat. Of course, other adjustments in the feed formula would be necessary to provide the nutrient balance required for the target animal.

While cereal grains make up the majority of many feed formulas, fats and oils, present in much smaller amounts, can have as much or even greater impact on pellet quality. In pelleted feeds, the amount of added, or total, fat in the ration and how and where that fat is added are critical to pellet quality. Fat may act as a barrier to moisture addition in the conditioner, and lubricates the mash passing through the pellet die, reducing friction. Both of these will negatively impact pellet quality. Research has shown the impact of fats and oils to vary based on source, type, and other processing conditions. However, regardless of other variables, fat will nearly always reduce pellet quality significantly if added in large amounts prior to pelleting.

Minerals

Pellet mill performance can be significantly affected by the physical and chemical forms of the calcium and phosphorus sources used in the formula. Sutton (1979) investigated the effect of defluorinated phosphate (two particle sizes) and dicalcium phosphate (18.5%) on pellet mill performance with a broiler grower formula. He found the production rate for the diet containing regular grind defluorinated phosphate to be 68.9% greater than for the diet containing an equal amount of dicalcium phosphate. The finely-ground defluorinated phosphate had a 52.5% advantage over dicalcium phosphate.

A similar study (Behnke, 1981) examined the effect of mineral sources on pellet mill performance and pellet quality. Two defluorinated phosphate sources, a fine grind (DPF) and a regular grind (DPR), as well as an 18.5% dicalcium phosphate (DCP) were used. A practical layer diet was used in which each test mineral source was evaluated at both high (2.5%) and low (1.5%) levels in the diet (**Table 19-6**).

Table 19-6. Effects of mineral sources on pellet production rate, electrical efficiency and pellet durability.

Table 19-6. Effects of mineral source on pellet production rate, pellet mill electrical efficiency, and pellet durability index (PDI)[1].

	Production rate, kg/hr	Efficiency, kWh/ton	PDI
High mineral level (2.5%)			
Dicalcium phosphate	1,360	11.46	92.8
Defluorinated phosphate, regular grind	1,491	10.46	89.9
Defluorinated phosphate, fine grind	1,560	10.27	91.3
Low mineral level (1.5%)			
Dicalcium phosphate	1,531	10.78	91.2
Defluorinated phosphate, regular grind	1,557	10.49	89.9
Defluorinated phosphate, fine grind	1,650	9.96	90.0

At both levels tested, the production rate for the defluorinated phosphate sources significantly outperformed dicalcium phosphate; while the DCP had a slightly, but not significantly, higher pellet durability index. That would indicate that a physical change - thicker die or reduced feed rate - could be made to improve pellet quality without a substantial loss of system throughput.

Behnke, Verner (1988), and McEllhiney and Zarr (1983) reported similar results comparing phosphorus sources in a variety of pelleted feeds produced under many conditions. Anne and Richardson (1979) evaluated pelleting efficiency and pellet quality of diets containing dicalcium phosphate or a liquid ammonium phosphate source. They found that diets containing ammonium polyphosphate required significantly more electrical energy than corresponding diets containing dicalcium phosphate, while pellet durability was significantly enhanced by the addition of ammonium polyphosphate over diets containing dicalcium phosphate and dicalcium phosphate plus fat.

Those cases are cited, not to encourage or discourage the use of any mineral source or any other ingredient—that's the nutritionist's decision—but to indicate that those sources and ingredients can affect pellet quality and production rate and should be considered in the quest for improved pellet quality.

Binders

Pellet binders are used on occasion by many feed manufacturers to produce more durable pellets. The most commonly-used binders are colloidal clays and lignin sulfonates, but there are many others available—some effective under given conditions, some not so effective. Most offer little nutritional value and they take up valuable space in a formulation, adding significantly to the cost of the diet. There are instances where the use of pellet binders is justified; however, it is usually preferable to enhance pellet quality with formula modifications and/or changes in die configurations and operation of the pellet mill (Behnke, 1990).

Mill operators shouldn't be discouraged from trying any one of the available binders while seeking to improve pellet quality; but they should be sure to measure the results and that their use is cost-effective in a particular operation.

Particle size

Optimum particle size for best pelleting results has been a matter of controversy for almost as long as feeds have been pelleted. Young (1960) found no significant differences in pellet durability when he experimented with feed rations containing 40%, 60% and 70% ground corn or milo when the grain portions were ground coarse, medium and fine.

Smith (1962) experimented with high (65-80%) corn-based rations and found a slight increase in the "hardness" of pellets using a Stokes hardness tester and a very slight improvement of percent "toughness" measured as a percentage of fines through a 10 U.S. screen when the corn was ground through a 1.6 mm hammermill screen as opposed to a 3.2 mm screen (**Table 19-7**).

This study concluded that:
- Pellet durability improves as (the) particle size of the major ingredient of a given formula becomes finer (based on grinding tests using 1.6 mm and 3.2 mm screens).
- The greatest value of grinding can be realized in formulae that are high in starch or fiber.
- The additional production costs attributed to fine grinding can make the practice too expensive to be economical.

Table 19-7. Effect of fine grinding grain on pellet mill performance and pellet durability index[1].

Mash temp, °C	71		82		93	
Hammermill screen, mm	3.2	1.6	3.2	1.6	3.2	1.6
Motor load, amps	18-20	17-19	16-17	15-16	16-17	15-16
Pellet hardness[2]	9.8	10.2	10.5	10.9	12.2	13.2
Percent fines	1.9	1.7	1.4	1.4	1.0	0.8

[1] Feed rate was held constant at 1,137 kg/hr.

[2] Average of 20 pellets assessed by a Stokes hardness tester.

It is interesting to note in **Table 19-7** that the improvements in "hardness" and "toughness" may have been as much a function of the temperature of the conditioned mash as a result of the particle size of the grain or, possibly, a combination of the two factors.

Martin (1984) compared pelleting efficiencies and durabilities using a hammermill and a roller mill to grind the corn portion (59.5%) of a pelleted feed. He did not find any differences ($P<.05$) among the various treatments. The average particle size of the hammermilled corn (3.2 mm and 6.4 mm screens) ranged from 595 to 876 microns, and the roller milled corn (fine and coarse) ranged from 916 to 1,460 microns.

Stevens (1987) conducted similar experiments in which No. 2 yellow corn was used as the grain portion of the typical swine formula shown in **Table 19-4**. The corn was ground with a hammermill through three screen sizes: 1.6 mm (fine); 3.2 mm (medium); and 6.4 mm (coarse). The average geometric mean particle sizes of the grain portion produced and the final mash feed are shown in **Table 19-8**.

Table 19-8. Average geometric mean particle size of hammermilled or roller milled grains and mash.

	Corn		Wheat	
	Grain	Diet	Grain	Diet
Screen size, mm				
6.4	1,023	944	1,710	967
3.2	794	761	802	797
1.6	551	578	365	539

He then measured the effect of the ground grain particle size on the pelleting production rate, electrical efficiency and pellet durability (**Table 19-9**).

Table 19-9. Effect of particle size on pellet mill performance and pellet durability index (PDI).

	Prod. rate, kg/hr	Grind eff., kWh/ton	Pellet eff., kWh/ton	PDI
Corn µm				
1,023	1,964	3.3	8.0	89.8
764	2,018	4.3	7.0	88.8
551	2,035	8.3	6.9	90.3
Wheat, µm				
1,710	1,695	2.1	10.0	92.4
802	1,833	6.5	8.8	97.4
365	1,833	6.5	8.8	97.4

There were no significant ($p<.05$) differences in the pelleting production rate or PDI values from different particle sizes of corn mixed into the swine ration—although, the total electricity required to grind the corn and pellet the mash was significantly greater for the fine ground corn. When ground wheat was used as the grain portion of the swine ration, pellet production rates and PDIs improved as the grain was ground finer, but the finer ground wheat also required substantially more electrical energy.

McEllhiney (1987) conducted research on the effect of re-grinding mixed mash prior to pelleting on manufacturing costs, pellet mill performance and pellet quality. The results of that research were that grinding a 16% dairy ration and a dairy concentrate between the mixer and the pellet mill increased total manufacturing costs by more than US$2.00 per tonne, reduced the pellet mill's production rate, and adversely affected the durability of the pellets (**Table 19-10**).

Table 19-10. Effect of regrinding on pellet mill performance and pellet durability index (PDI).

	Particle size, µm	Std. dev.	PDI	Fines, %	Prod. rate, kg/h
Dairy feed					
Unground	412	2.01	98.9	3.4	910
Reground	366	1.82	93.2	2.9	890
Concentrate					
Unground	591	2.19	96.3	3.3	1,105
Reground	467	1.88	95.1	3.8	752

In that test, grinding the mash to a smaller average particle size caused a deterioration of pellet quality; but that was not a grain-based ration. Incidentally, the loss of vitamin A potency in the concentrate feed due to post-grinding alone was 29.3%, and when the re-ground mash was pelleted another 12.9% was lost. Pelleting alone, without re-grinding the mash, caused a 17.9% vitamin A loss; but when this mash was re-ground and pelleted, the total loss was 38.4%.

While the research cited may seem to provide conflicting results, there is overwhelming evidence that the average particle size of the ground grain portion of a ration, or of the total ration (mash), affects the pelleting process throughput and/or pellet quality. The effects are not the same under all conditions or for all rations. That is where operators must conduct their own research under their own operating conditions and on the feeds that they produce.

We are well aware that some portion of a plant's product mix is often in mash or meal form and that grinding the grains more finely in a pre-grind system, or the whole mix in a post-grind system, causes handling problems in those mash feeds. There are two solutions to that dilemma—either provide two ground grain bins over the mixing system or find a grind (particle size) in the middle somewhere that will produce the better quality pellet and still provide the flowability or angle of repose that is needed for mash feeds. The first option is, of course, the better one but may not be possible, or too expensive, in a given grinding/mixing system situation.

Remember that the capacity of a given hammermill is partially a function of the total area of the screen perforations or holes, not the diameter of the holes themselves. So, rather than reducing throughput by 50% from a 6.35 mm to a 3.2 mm screen, it is more nearly reduced by 25% in capacity. In addition, very fine grinding will result in greater shrink through moisture and dust losses, and if the hammermill does not have an air-assist system on it now, it will need one even more for finer grinding.

In summary, grind as fine as is necessary for the best possible pellet quality in an operation with given feed rations, but don't over-grind. That is wasteful of energy, reduces production rates, adds to manufacturing costs and may do more harm than good to the consuming animal.

Mash conditioning

Mash conditioning is a subject unto itself and as it has been addressed earlier, will not be addressed in much detail in this chapter. Many researchers and practitioners have proven that pellet durability and pelleting efficiency can be substantially improved by the proper steam conditioning of mash. Steam brings to the surface of pellet mash particles the natural oils, which are common to most grains and provide lubrication of the pellet die, reducing wear on the die and roller assembly and increasing production rates (Behnke, 1990).

In some instances, thorough conditioning may be counterproductive from the standpoint of pellet durability. If the material slips through the die too easily, dwell time in the die hole is reduced, causing the pellet to be less durable and the starch gelatinization caused by the heat and friction in the die may be reduced.

Stevens (1987) conducted extensive research into the phenomenon of starch gelatinization during the feed pelleting process by pelleting corn that was hammermill ground through a 3.2 mm screen. He used a Perkin-Elmer DSC-2[3] (differential scanning calorimeter) with an intra-cooler II system for gelatinization analysis. Ground corn before pelleting was used as the control. The ground corn from the hammermill was re-ground in a UDY cyclone sample mill for the DSC analysis. Samples of the pellets were prepared for analysis in the DSC by grinding them in a Braun coffee grinder, then re-grinding in the UDY mill. A 2-mm thick outer portion of pellets was scraped with a razor blade from selected samples and ground in the UDY mill.

The results of the gelatinization measured in the samples taken immediately after the die are shown in **Table 19-11**.

Table 19-11. Effect of conditioning and pellet temperatures on starch gelatinization (gelat).

	Conditioner, °C	Pelleting, °C	Gelat., %
Whole pellet	23	69	41.9
Whole pellet	43	76	37.1
Whole pellet	63	82	33.5
Whole pellet	80	84	28.0
Outer pellet	23	69	58.3
Outer pellet	80	84	25.9

There was a negative relationship between the conditioned meal temperature and degree of gelatinization. As the temperature of the conditioned mash was increased, the degree of gelatinization decreased.

The high degree of gelatinization that occurred in the outer portion of the pellet at 23°C conditioning temperature indicated that heat and mechanical shear next to the surface of the die hole caused a substantial portion of the gelatinization at all temperatures. However, it was especially seen when there were greater temperature differentials between the conditioned meal and the pellet. There is a relationship between that temperature difference and the degree of gelatinization observed. As the temperature differential decreased, the degree of gelatinization decreased.

Stevens suggested that the conditioning temperature of 80°C was adequate to gelatinize corn starch; however, the length of time in the pellet mill conditioner at that temperature was probably not adequate for a substantial amount of gelatinization. It would appear, from that research, that most starch gelatinization occurred as the feed material passed through the die.

The temperature of conditioning mash has long been a pelleting criterion and an indication of thorough conditioning that may, or may not, be a totally viable indicator. Time at a given mash temperature will affect the conditioning, may affect the degree of gelatinization, and will certainly affect the pelletability of the mash.

Feed rates

Reducing feed rates in order to improve pellet quality is unpopular, but is one method available to all pellet mill operators. By reducing feed rate, the dwell (residence) time of a given particle of mash is proportionately increased. This has the same effect as increasing the die bore length (thickness), but does not require a die change. Pellet efficiency will be reduced, but pellet quality usually improves.

Die speed

There is very little published information concerning the effect of die speed on pellet mill performance and pellet quality. Leaver (1982) stated that a peripheral speed of 610 meters/minute is the optimum speed for pellets in the 3.2 mm through 6.35 mm diameter range and that die speeds of 366-396 meters/minute produce the best quality cubes – 16 mm, 19 mm and larger diameter. Dual-speed pellet mills have been available for many years, but they have two set speeds—one or the other of which may or may not be the optimum speed for a given pelleted product.

Stevens (1987) experimented with die speeds using a California (CPM) 30 HP (Master Model HD) pellet mill equipped with a 38 mm thick die with a 4.8 mm hole diameter. The pellet mill drive was equipped with a manually-adjustable belt varidrive that can deliver die speeds ranging from 126 to 280 RPM. Using the swine formula shown in **Table 19-4**, he achieved the production rates, electrical efficiencies and PDI results shown in **Tables 19-12 and 19-13**.

Table 19-12. Effect of die speed on pellet mill performance and pellet durability index (PDI) in a swine diet with 72.4% ground wheat.

Die speed		**Production**	**Efficiency,**	
RPM	**m/min.**	**rate, kg/hr**	**kWhr/ton**	**PDI**
126	120	1,667	11.9	97.5
150	143	1,740	11.3	97.7
174	166	1,582	12.6	97.8
198	189	1,525	13.1	97.6
222	212	1,462	13.4	97.8
246	235	1,491	13.5	97.7
268	256	1,342	14.9	97.7

Table 19-13. Effect of die speed on pellet mill performance and pellet durability index (PDI) in a swine diet with 72.4% ground corn.

Die speed		**Production**	**Efficiency,**	
RPM	**m/min.**	**rate, kg/hr**	**kWhr/ton**	**PDI**
126	120	-	-	-
150	143	1,264	15.8	91.0
174	166	1,660	12.2	90.0
198	189	1,460	13.8	89.6
222	212	1,582	12.9	89.4
246	235	1,670	11.6	89.7
268	256	1,465	13.7	89.8

For the corn-based ration, the most desirable die speeds for both production rates and electrical efficiency were 174 and 246 RPM; the poorest performance was at the slowest die speed (150 RPM). Incidentally, at 126 RPM, the die kept plugging and there were no usable test results.

For the wheat-based ration, production rates and electrical efficiency were best at 150 RPM and poorest at 268 RPM. Those results indicate quite clearly that die speeds affect production rates and electrical efficiency and that different rations react differently to the speed of the die. Interestingly, however, there was no practical difference in the durability of the pellets at the various speeds, but the wheat-based ration clearly out-performed the corn-based ration in durability.

Die specifications

The die is the heart of the pellet forming operation. Many characteristics of the die can be varied to get the desired results on a particular formulation to be pelleted. In order to discuss dies and die performance, it is important to understand die terminology. Definitions as provided by Leaver (1982) are as follows:

- **d** = pellet diameter
- **L** = effective length, or thickness
- **T** = total thickness
- **X** = counterflow depth—the difference between total and effective length, or thickness, of the die
- **D** = inlet diameter
- **Compression ratio** = D^2/d^2 (a relationship of inlet area to pellet cross-sectional area)
- = inlet angle (normally 30° for small hole dies)
- **L/d** = performance ratio (relates the effective thickness of a die to the diameter of the pellet).

Behnke (1990) studied the effect of effective die thickness, or length (L), on pellet durability in the experiments reported earlier in this chapter (**Tables 19-2** and **19-3**). The results indicate that durabilities were significantly enhanced with the use of the thicker die; however, production rates were as significantly reduced (**Table 19-14**).

Summary

Almost anything that is done to improve pellet quality (durability) will either increase the cost of the ration or reduce the capacity of the pelleting system, or both. Adding to the effective thickness of the die is a perfect example of the sort of tradeoff that can be expected, and must be recognized, in the search for improved pellet quality.

One of the primary objectives of all commercial feed manufacturers is to economically produce the best pellet quality possible. This is not only important from a customer satisfaction standpoint, but it is apparent that animal performance can be affected by poor quality pellets. Dairy cattle used to consuming pellets readily reject fines. Even the US broiler integrators are recognizing that poor pellet quality can reduce bird performance.

Table 19-14. Effect of die thickness on pellet mill performance and pellet durability index (PDI)

	Production rate		Pellet durability	
Die, mm:	38	51	38	51
Hard red winter wheat, %				
0	647	99	94.3	74.5
5	695	985	95.2	77.0
10	683	986	95.3	79.6
20	700	988	96.5	83.0

There are numerous factors that affect pellet quality and many are inter-related. It takes a great deal of effort to determine what changes to make and how other aspects of the system or operation might be affected. Factors not addressed in this chapter include: Double pelleting, optimum cooling, automation of the pelleting system, gentler handling of pellets, and new binders. This chapter has not dealt with issues of water stability of pellet aquatic diets, but that topic is gaining great importance around the world. As can be seen, pelleting is a very complex issue and one that deserves a good deal of thought and investigation.

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