FACTORS INFLUENCING PELLET QUALITY
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SUMMARY
The use of the pelleting process to improve feed nutrient utilization and meet customer expectations has continued to increase. Today in the U.S. more than 80% of feed for non-ruminant animals is pelleted and that number is increasing.

The factors that influence pellet quality can be divided into several categories. It is generally agreed that the formulation is, by far, the most important factor affecting pellet quality. The cereal grain used (corn vs. wheat) and its percentage can have great influence. The inclusion of fats or oils (above 1%), regardless of the source, can dramatically reduce pellet quality.

Fineness of grind can have a great deal of influence on pellet quality. As a rule, the finer the grind, either pre- or post-grind, the better the pellet quality. Particle size affects both the extent of conditioning and the way in which particle bonding occurs in the pellet itself.

In terms of pellet mill operations, the conditioning process has greater influence on pellet quality than does die specification. A great deal of attention must be paid to steam quantity and control, moisture content, retention time and mixing action within the conditioner. In general, most feed manufacturers have not optimized the conditioning process but try to solve pellet quality issues using a thicker die. While this often results in improved quality, we often see an unacceptable drop in production rate.

Developing a full understanding of pellet quality and the factors that influence it is still fertile ground for research and idea development. As new ingredients become available and equipment and technological advances occur, a thorough understanding of factors affecting pellet quality will be mandatory.

BACKGROUND
Pelleting was introduced into Europe about 1920 and into the U.S. feed industry in the late 1930s (Schoeff, 1994). Its popularity has grown steadily until about 80% of all feed in the U.S. are currently pelleted. Today, the process is widely used because of both the physical and the nutritional benefits it provides. The physical benefits include improved ease of handling, reduced ingredient segregation, less feed wastage, and increased bulk density. Nutritional benefits have been measured through animal feeding trials (Wondra, et al,1995).

EFFECT OF FEED FORM (MEAL VS. PELLETS) ON ANIMAL PERFORMANCE
As a rule, feeding pelleted feed improves animal performance and feed conversion compared with feeding a meal form of a diet. The improvements in performance have been attributed to (Behnke, 1994):

1. Decreased feed wastage
2. Reduced selective feeding
3. Decreased ingredient segregation
4. Less time and energy expended for prehension
5. Destruction of pathogenic organisms
6. Thermal modification of starch and protein
7. Improved palatability

Research has concentrated primarily on the benefits of feeding pellets versus meal. Pellet quality has become more important in the swine and poultry industries as integrators continue to expand and recognize the value of feeding quality pellets.

PELLET QUALITY TESTING

If one assumes that pellet quality has some influence on animal performance, then an accurate, precise, and objective assay is necessary to document that influence.

Pellet quality can be measured using several methods. Indirect methods such as the Stokes® Tablet Hardness Tester (Bristol, PA) (developed for the tableting industry) was one of the first tests used in the feed industry (McCormick and Shellenberger, 1960). Indirect testing methods allow feed manufacturers to make predictions of pellet quality immediately after the pellet mill and therefore make adjustments accordingly.

Young (1970) developed the tumbling box test, which has become an industry standard for measuring pellet quality. The pellet durability index (PDI) (ASAE S269.3) was developed as a predictor of pellet fines produced during mechanical handling. Young (abid) reported a correlation of $R = 0.967$ and $0.949$ for hot pellets and pellets cooled for 24 hr. respectively, using the tumbling can as a predictor of pellet fines.

The Holmen Pellet Tester (TEKPRO Ltd, Norfolk, UK) is a pneumatic, rather than mechanical, method of measuring the durability of pellets. Pellets are transferred through tubes with high velocity air to model the handling process (MacMahon and Payne, 1981). McEllhiney (1988) reported the Holman Pellet Tester gave consistent results, however, pellet durability results were lower than the values obtained from the tumbling can method (ASAE, 1987). More recently, the TeKPro group (Norfolk, UK) has developed a simpler and less expensive device for testing pellet quality (Holmen Model HKP100).

The use of indirect methods for predicting pellet quality may be useful at the feed plant for adjusting equipment. However, livestock producers are concerned with the direct measurement of fines at the feeders. Fines in feeders can result in feed wastage, animal refusals, and increased feeder management.

EFFECT OF FORMULATION ON PELLET QUALITY

Least-cost formulation is designed to meet the nutritional parameters required by the target animal. However, the effect of formulation on processing, specifically pelleting, is seldom considered by most nutritionists.
The addition of fat to the mash pre-pellet usually results in decreased pellet quality (Richardson and Day, 1976; Headly and Kershner, 1968). However, the addition of protein and fibrous materials increase pellet quality. Fahrenholz (1989) reported an increase in the pellet durability of swine diet pellets and the level of wheat middlings increased from 0 to 45%. McKee (1988) increased pellet quality and water stability of catfish diets by increasing the level of wheat gluten from 0% to 10%. Lopez (1993) also reported the addition of vital wheat gluten resulted in a positive effect on pellet quality and water stability, but the addition of cassava meal had a negative effect. Lawton (1989) reported a linear increase in tensile strength as the amount of protein in a tablet increased at the expense of starch.

EFFECT OF PARTICLE SIZE ON PELLET QUALITY

Stevens (1987) reported no difference in pellet quality when the mean particle size of corn and wheat was reduced from 1023 to 551 microns (µ) and from 802 to 365 µ, respectively. Martin (1983) reported similar results using corn and grain sorghum. However, Wondra et al. (1995) reported an increase in pellet durability as particle size was reduced from 1000 to 400 µ. The aquaculture feed industry will typically grind ingredients to less than 250 µ for greater pellet water stability. The combination of small particle size and long term, high temperature conditioning produces pellets that have the greatest water stability.

EFFECT OF CONDITIONING ON PELLET QUALITY

The importance of steam conditioning was quantified by Skoch et al. (1981) in an experiment comparing dry pelleting with pelleting using steam conditioning. The results of this study indicated that steam conditioning improved pellet durability and production rates and decreased the amount of fines generated and energy consumption. From this, it was concluded that steam acted as a lubricant to reduce friction during pelleting.

Mash entering the conditioner is typically comprised of a wide variety of ingredients that make up the diet formulation. The nutritional, as well as physical, properties of this mash have an effect on conditioning and eventual pellet quality. According to Reimer (1992), pellet quality is proportionally dependent on the following factors: 40% diet formulation, 20% particle size, 20% conditioning, 15% die specifications, and 5% cooling and drying. If this is correct, 60% of pellet quality is determined before the mash enters the conditioner. This increases to 80% after conditioning, but before mash has even entered the die chamber of a pellet mill.

There has been some research conducted looking at the effects of the first two of these variables, diet formulation and particle size, on pellet quality. Studies by Stevens (1987) and Winowiski (1998) have compared the pellet durability of diets containing corn with those where some or all of the corn was replaced with wheat. In both instances, pellet durability was higher for the diets containing wheat. It can be reasoned that this is due to the higher crude protein content of wheat (~13%) as compared to corn (~8%). This finding is in agreement with a study conducted by Briggs et al. (199) which found that increasing the protein content in a poultry diet from 16.3% to 21% increased the average pellet durability from 75.8 to 88.8%.

Particle size is the second factor that Reimer (1992) proposed would dictate about 20% of pellet quality. Decreasing particle size from a coarse to a fine grind exposes more surface area per unit volume for absorption of condensing steam and increases the surface area available for
bonding. MacBain (1968) indicated that a variation in particle size produces a better pellet than a homogeneous particle size. Work by Stevens (1987) when pelleting corn or wheat based diets, however, found that particle size had no effect on pellet durability index (PDI) as determined by the tumbling can method.

**MASH MOISTURE**

Some familiar with feed technology may argue that the moisture of mash entering the conditioner should fall into the category of diet formulation. Water may be physically removed or added to ingredients or formulations in a diet in order to alter moisture content. There are, however, two types of moisture: bound moisture and added moisture (MacBain, 1966 and Leaver, 1988). Bound moisture is that which is chemically or physically bound to ingredient components and is not easily removed. Added moisture is that which is added at the conditioner or mixer and serves to soften feed particles and lubricate the mash as it moves through the die.

The initial moisture of mash entering the conditioner is thought to dictate the amount of steam that can be added to the mash. Leaver (1988) indicates that, typically, no more than 6% moisture can be added at the conditioner. Thus, large variations in initial mash moisture will be reflected in the moisture of hot mash. This may cause varying pellet mill performance if the characteristics of steam added to the mash are not adjusted as the moisture changes. Experiments recently conducted at Kansas State University have compared the effects of mash moisture contents between 12% and 15% on pellet quality. The results of these experiments show that there is a high correlation between cold mash moisture and PDI (Greer and Fairchild, 1999). Adjustment of mash moisture to 14% produced the highest quality pellet with the most efficient pellet mill operating conditions (Muirhead, 1999).

**RETENTION TIME AND CONDITIONER DESIGN**

Retention time refers to the amount of time that mash feed spends in the conditioner. Thus, it is a measurement of the duration of exposure mash has to steam for heat and moisture absorption. A conditioner operates as a continuous system in which mash is constantly entering and exiting. Flow through a conditioner, however, cannot be characterized as simple plug-flow since the mash experiences some axial and longitudinal mixing as well. Therefore, retention time may better be characterized as a residence time distribution (RTD) function (van Zuilichem et al., 1997). This is a mathematical relationship describing the dwell time of components within the conditioner with respect to time (van Zuilichem et al., abid).

Retention time is affected by conditioner design including physical dimensions and operating parameters. The design and dimensions of conditioners vary in diameter, length, type of picks, number and placement of picks, pick angles, steam inlet location, presence or absence of baffles, and baffle placement. Changing any of these physical parameters will affect conditioner retention time.

Within an existing conditioner, the most common ways to manipulate retention time are by adjusting pick angles or changing shaft speed. Adjusting pick angles changes the forward motion and tossing of product as it is conveyed through the conditioner. This angle adjustment, however, can be time consuming as the conditioner must be powered down and locked out before the operator can access the picks inside of the conditioner. In addition, the pick angle is
not easily measured, and the location in relation to the shaft is, at best, an estimate. Increasing or decreasing shaft speed as a means of manipulating retention time requires that there be a variable speed drive on the conditioner. In addition to slowing down the conditioner RPM, this adjustment will affect the amount of tossing motion that a product undergoes as it passes through the conditioner.

Briggs et al. (1999) used the first of these methods, pick angle adjustment, to examine the effect of retention time on pellet quality. One conditioner was used in the experiment and the angles of the picks were changed to give two different retention times. A standard setting was used in which all mixing picks were set at about a 45° forward angle. The second setting was a parallel pitch where all picks were set parallel to the conditioner shaft, except for the first and last. Average retention time was estimated at five seconds for the standard pitch and fifteen seconds for the parallel pitch design.

The results of this study indicated that degree of pitch, or conditioner design, affected pellet quality. Pellet durability of mash conditioned using the parallel pitch averaged 5 points higher than pellets produced with the standard pitch. This improved durability can be explained by the longer retention time achieved with the parallel pitch. Conditioner design and retention time remains an area where additional research is needed so that benefits of different designs, dimensions, and operating parameters can be understood and used to the feed manufacturer’s benefit.

STEAM PROPERTIES

High levels of heat and moisture are needed to achieve proper pelleting of grain-based diets that are high in starch (MacBain, 1966). Because of its unique thermodynamic properties that allow for the transfer of heat and moisture simultaneously, steam conditioning has presented itself as one of the most important factors in pelleting.

According to Reimer and Beggs (1993), the purpose of heat in conditioning is to gelatinize the starch portion of the feed. Other benefits of heat are to destroy pathogens and other microorganisms, and to promote drying of pellets in the cooler. Smallman (1996) explains that the moisture contribution from steam forms a cohesive bridge between particles and has a profound effect on pelleting. This moisture soaks into feed particles to soften them, and has been found to act as a lubricant to reduce friction between the mash and the walls of the die (Skoch et al., 1981). To optimize the conditioning process, the proper balance of heat and moisture must be obtained. Steam has the ability to provide this combination, however, it exhibits a wide variety of properties that must be understood and correctly utilized to produce high quality pellets.

There has been a lot of discussion concerning the use of high pressure versus low pressure steam for conditioning. The thermodynamic properties of low (138 kPa or 20 psig) and high (552 kPa or 80 psig) pressure steam are compared in the following table:
### Table 1. Properties of Saturated Steam

<table>
<thead>
<tr>
<th>Pressure</th>
<th>138 kPa (20 psig)</th>
<th>552 kPa (80 psig)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>126°C (259°F)</td>
<td>162°C (324°F)</td>
</tr>
<tr>
<td>Specific Volume</td>
<td>.75 m³/kg (11.9 ft³/lb)</td>
<td>.29 m³/kg (4.67 ft³/lb)</td>
</tr>
<tr>
<td>Sensible Heat, ( h_f )</td>
<td>529.3 kJ/kg (227 BTU/lb)</td>
<td>684.3 kJ/kg (881 BTU/lb)</td>
</tr>
<tr>
<td>Latent Heat, ( h_{fg} )</td>
<td>2185.4 kJ/kg (939 BTU/lb)</td>
<td>2075.96 kJ/kg (881 BUT/lb)</td>
</tr>
<tr>
<td>Total Heat, ( h_g )</td>
<td>2714.7 kJ/kg (1166 BTU/lb)</td>
<td>2760.3 kJ/kg (1185 BTU/lb)</td>
</tr>
</tbody>
</table>

The temperature of 552 kPa steam is 36°C (65°F) higher than the temperature of 138 kPa steam. Regardless of the steam pressure in the line, in an atmospheric conditioner, condensation and heat transfer only occurs at atmospheric pressure. This means that the temperature of steam in the conditioner must first be reduced to around 100°C before any condensation including moisture and heat transfer occurs.

Enthalpy refers to the heat or energy that steam has available in kJ/kg. This energy is broken down in the steam table as sensible heat, latent heat, and total hat. Sensible heat is the energy required to heat one kilogram of water from 0°C to the boiling point at the corresponding temperature and pressure. Latent heat, or heat of vaporization, is the energy needed to convert this kilogram of boiling water into one kilogram of steam. The table shows that there is less than a 2% difference in the total energy of the high and low pressure steam.

Though the thermodynamic properties of saturated steam at a given temperature and pressure are known, the debate still continues as to what pressure gives the best pellet quality and mill performance. MacBain (1966) presents data to show that low pressure steam produces a higher quality pellet with greater capacity on high-starch formulations. This is in contrast to Leaver (1988) who states that the use of high pressure steam is more advantageous than the use of low pressure steam. Yet others, such as Thomson (1968), believe that the total energy of high and low pressure steam are similar enough that it does not make much difference as to which is used.

Stevens (1987) completed a study comparing the use of steam at 138 and 552 kPa (20 and 80 psig) to condition mash to 65°C (149°F). A swine diet consisting of primarily 72.4% corn or wheat was used in the study. Results indicated no significant differences in production rate, mill efficiency, pellet quality, percent fines, or moisture addition at the conditioner for the two diets at these pressures. Research by Briggs et al. (1999) agreed with these results in a study also comparing the effects of 138 and 552 kPa (20 and 80 psig) steam on poultry diets.
EFFECT OF DIE SELECTION ON PELLET QUALITY:
If the summary of Reimer (1992), relating the effect of various operational parameters (grind, conditioning, formulation, etc.) to pellet quality is to be believed, die selection is a relatively minor component (15%) of factors considered. However, it is important and must be considered when dealing with a pellet quality issue. In general, a die with a greater thickness within a specific die diameter (greater L/d ratio) will result in improved pellet quality. This is because of the greater flow resistance generated by a thicker die as well as longer retention time under elevated pressure as the pellet passes through the die. As a general rule, the operator should choose the thinnest die possible in order to gain the greatest production rate at an acceptable pellet quality.

An important parameter in describing a pellet die is its’ L/d ratio. Simply put, L/d ratio is the effective length of the die hole over the minimum die opening diameter. For example, a 6 mm die with an effective hole length of 60 mm would have an L/d ratio of 10:1. For most common livestock diets, L/d ratios should be between 8:1 and 12:1. Greater L/d ratios will result in improved pellet quality but will sacrifice production rate. Lower L/d ratios can result in increased production but pellet quality will likely suffer.

Many uninformed livestock producers perceive pellet diameter as an important factor to consider for different species at various stages of growth. In their minds, small animals require small pellets and larger animals require larger diameter pellets. Studies at our University (Wondra, et al, 1995) have constantly shown that, within reason, pellet diameter can be ignored. Optimal growth and feed efficiency can be obtained using the same sized pellet (~4 mm) for all phases of growth for pigs and larger ruminants. For broiler production, a 4 to 4.5 mm pellet works well at all phases except that starter diets should be crumbled to provide a suitable sized particle for very young animals.

SUMMARY
After reviewing the body of published scientific literature as well as reports from field studies and skilled practitioners of pelleting, it is easy to conclude that there is still a great deal of art in the science of pelleting. There is a great deal that we don’t understand or, perhaps, that we misunderstand about pelleting. Reimer (1992) indicated that the factors that affect pellet quality can be identified as formulation, particle size, conditioning, die specification, cooling, and drying. If his hypothesis is true, these allocations provide a useful road map to solving many of the quality problems associated with pelleting.

If we assume that the formulation and particle size are relatively constant, the next significant factor is conditioning. While a good deal has been done in the way of research there is still a great deal of misunderstanding concerning the design, configuration, and operation of these devices.

Managing steam quality and control in a pelleting operation is critical to success. In many instances, items as simple as proper sizing of pipes and valves and adequate insulation have been overlooked and have caused quality problems. While die selection was only briefly discussed, it should be noted that this factor has significant impact on both pellet quality and
system productivity. A thicker than needed die can result in good quality pellets but less than acceptable production rates. An overly thin die will often result in poor quality pellets but excellent throughput. It is often necessary to have several dies of the same bore diameter but different effective thickness in order to optimize both pellet quality and production.

It should be recognized that pelleting is still fertile ground for research and new developments. As new technology and new ingredients become available, changes will have to be made to optimize pelleting operations.
LITERATURE CITED


