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Principles of mash conditioning

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As the term "conditioning" implies, it is common to modify the physical properties of mash before it is delivered to the pellet die chamber. Most commonly, conditioning involves the addition of steam to the mash; however, conditioning may also involve the addition of liquids such as water, molasses, pellet binders or, in some cases, indirect heat (jacket heat). All of these things are done for the primary purpose of improving pellet quality and/or pellet mill throughput.

For purposes of this chapter, the conditioning process will include any addition to the mash after it leaves the mixer, but before it reaches the pellet die chamber. Traditionally, processes like expanding and compacting have been treated separately from conditioning; however, the purpose of these processes is, like conditioning, to improve pellet quality and pellet mill throughput.

Pellet quality and conditioning

Pellet quality is an abstract term that means different things to the various segments of our industry. In general terms, pellet quality refers to the ability of feed pellets to withstand mechanical handling without excessive breakage and fines generation. The confusion comes in determining what level of fines or breakages is acceptable. For example, the commercial feed industry often assigns a much higher value to pellet quality (low fines) than do integrators who manufacture feeds for their own use.

If we operate on the assumption that pellet quality is important, the next issue is to develop an understanding of the factors in the process that influence pellet quality and the relative importance of each factor. Reimer (1992) proposed that the primary factors controlling pellet quality are: Formulation (40%), fineness of grind (20%), steam conditioning (20%), die selection (15%) and cooling/drying (5%). The percentage figures following each item represent the relative contribution of that factor to overall pellet quality. It is important to note that by combining the influences of formulation and grind, 60% of the potential pellet quality is determined before the mash even reaches the pellet mill. If true, it is obvious that quality problems can't always be solved by modifying the conditioning process or using a thicker die.

When dealing only with the pelleting system, it is apparent that conditioning is the most important factor that influences pellet quality. If done correctly, proper conditioning allows the use of the thinnest possible die and, therefore, the greatest potential throughput. Though conditioning is far more important than die or roll selection, it is a process that is often overlooked, and certainly not well understood by many feed manufacturers.

Conditioning defined

The conditioning process, at least for our purposes, includes any processing or additions made to the mash after it leaves the mixer, but before it reaches the pellet die chamber. Therefore, "conditioning" may include steam and/or water addition, expanding, compacting, pre-pelleting, "ripening" and so on. While only steam conditioning will be addressed in some detail, it should be understood that anything done during the conditioning process is done to prepare the mash for final processing (pelleting). Whatever the type of conditioning employed, it should be optimized to give the best pellet quality at a reasonable rate, without significant destruction of available nutrients or feed additives.

Steam: Introduction

Steam is a commonly-used input in many feed manufacturing operations, yet is poorly understood and often mismanaged. In large facilities, steam generation and its use represent a very significant cost, but is often a cost to which little attention is paid until a problem arises. Even in small facilities, steam generation can represent a significant part of manufacturing costs and, if left uncontrolled, can have serious implications for the bottom line. Much of the following discussion will be a review for many people; however, it is necessary to have a solid understanding of the basics before one can really deal with the practical issues involved in steam conditioning.

Steam defined

Like many other substances, water can exist in the form of a solid (ice), liquid (water) or vapor (steam). For purposes of this discussion, we will focus on only the liquid and vapor phases and the transition of one phase to the other. As heat energy is added to water, its temperature rises until the water can no longer exist as a liquid. From this "saturation" point, any additional heat added to the water will cause some water to boil off as steam.

This evaporation requires a huge amount of energy per unit weight of water vaporized. It is on this principle that so-called "swamp coolers" are based (i.e., heat in the air is used to evaporate water in the pad, thus cooling the air). By the same token, if we surround a relatively cool object (e.g., a particle of corn) with steam, steam will release energy to the object and condense onto the surface of the object.

If the reader fully understands the concepts of moving heat energy into and out of water vapor and of using steam to transport huge quantities of heat to a needed location, the remaining concepts are easily mastered.

Steam formation

To understand steam formation, we can use an imaginary experiment in which we place 0.5 kg of ice water (0°C) into a perfectly insulated container. On top of the water, we place a weightless, frictionless piston. The ice water, for our purposes, is assumed to have zero heat content or "enthalpy."

As heat is applied to the water, its temperature begins to rise. We can continue to heat the water until its temperature is 100°C with no change in the state of the water (i.e., it is still a liquid). If any additional heat is added to the water, it can no longer exist only as a liquid and some of the water will be converted to vapor (steam).

The total heat (enthalpy) held by the liquid water at the boiling temperature is known as "sensible" heat and is denoted by the symbol h_f. The additional heat added that results in evaporation into steam is called "latent" heat and is denoted by the symbol h_{fg}. The total heat (h_g) in each 0.5 kg of steam is the sum of latent heat plus the sensible heat and is shown by the equation:

$$h_g = h_{fg} + h_f$$

If enough heat is added, the 0.5 kg of water will be converted to 0.5 kg of steam at atmospheric pressure. The volume that the steam will occupy is tremendous compared to that of water; in fact, the steam volume will be 1,650 times that of the water. It is obvious that water molecules are held together more closely in the liquid phase than in the vapor phase. If the pressure on the piston in our imaginary cylinder was to increase, the water molecules in the liquid would find it more difficult to move to the vapor phase. Therefore, more energy (heat) input would be required to force the evaporation, and the temperature of the water would have to increase beyond 100°C. This is exactly what happens in a boiler operated at an elevated pressure.

Steam pressure

As heat is applied to the water in a closed system (i.e., a boiler) the water temperature rises. As the temperature rises above 100°C, the "vapor pressure" of the water is increased beyond atmospheric pressure. This pressure is uniformly distributed over all of the surfaces of our closed vessel. If the water level is maintained at say 80% of the vessel capacity, the "head" space will be filled with steam at the same temperature as the water. By referring to **Table 6-1**, the relationship of pressure and temperature can be determined.

Table 6-1. Properties of saturated steam.

Pressure, psi	0	20	80
Pressure, kPa	0	138	552
Temperature, °C	100	126	162
Specific volume, m^3/kg	1.67	0.75	0.29
Sensible heat, h_f	418.9	529.3	684.3
Latent heat, h_{fg}	2,257.5	2,185.4	2,076.0
Total heat, h_g	2,676.5	2,714.7	2,760.3

The above properties were sourced from ASME, 1967.

In processing, pressure is typically measured in gauge rather than absolute pressure. Gauge pressure is zero at standard atmospheric conditions (sea level), and is typically the value seen on process gauges (hence the name.) It is important when using steam tables to use those denoting gauge pressure, or to do the necessary conversions to get accurate results. For the purposes of discussions here, gauge pressures are used throughout.

It is obvious that as heat is added to the system, the pressure rises directly with the temperature It is also interesting to look at the relationship between pressure and specific volume. At 0 kPa (0 psi) gauge pressure, 0.5 kg of steam occupies 0.84 m^3, but at 552 kPag (80 psi), that same 0.5 kg of steam occupies only 0.15 m^3. It is this relationship that is useful in determining pipe and valve sizes, as well as insulation costs for a given installation. Though the thermodynamic properties of saturated steam at a given temperature and pressure are well documented, the debate still continues as to what pressure results in the best pellet quality and mill performance for a given feed type. MacBain (1966) presented data to show that low-pressure steam produced a higher quality pellet with greater throughput on high-starch formulas compared with high-pressure steam. This is in contrast to results published by Leaver (1988), who stated that high-pressure steam was more advantageous with these diets than was low-pressure steam.

Yet others, such as Thomson (1968), believe that the total energy in either high- or low-pressure steam is similar enough that it should make little difference as to which is used. To verify this point, Stevens (1987) completed a study comparing the use of steam at 138 kPa (20 psi) and 552 kPa (80 psi) to condition mash to 65°C. 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 kPa (20 psi) and 552 kPa (80 psi) steam on poultry diets. If the control valve, piping size and system design are sufficient to give good control, actual steam pressure is of little consequence.

Steam quality

Steam quality is simply defined as the percentage of the steam-water mixture in a steam system that is in the vapor phase. In other words, if in 0.5 kg of steam-water mixture, 0.45 kg is vapor and 0.05 kg is liquid, steam quality is described as 90%. The importance of steam quality is that it is an indication that enough heat has been lost from the system to condense 10% of the steam vapor back to a liquid phase. This heat loss represents not only a significant loss in energy costs, but can result in pelleting problems if the balance between mash moisture and the conditioning temperature is wrong.

Energy conservation is the topic of another chapter, so the impact of energy loss will not be discussed further. However, because steam quality can have a significant impact on pelleting, particularly if it varies, it is worth considering in any discussion of conditioning. As an example, 0.5 kg of steam at 100°C has 1.2 X 10^6 J of total heat, while 0.5 kg of water at 100°C has only 1.9 X 10^5 J of total heat—or 84% less heat than the steam. If one attempts to condition to a particular temperature, say 82°C, the mash can become far too wet to pellet if poor-quality steam is used.

A review of the literature indicates a general agreement that high-quality steam is recommended for efficiently producing a durable pellet (MacBain, 1966; Skoch, *et al.*, 1981; Stark, 1990; Maier and Gardecki, 1993). Despite this, there is little published data examining the effects of steam quality on pellet durability or pellet production. Wet steam, or that which has a quality less than 100%, is known to contain less energy than saturated steam; therefore, using wet steam requires that a larger quantity be added to reach a target conditioning temperature. Taking this a step further, it can be reasoned that moisture addition to the mash should increase as steam quality decreases. Steam quality directly affects the maximum obtainable feed temperature because of moisture limits (Reimer and Beggs, 1993). If the pellet mill reaches a choke point before the conditioning temperature is obtained, adjustments must be made. This is an area where additional research is needed.

It should be the objective of every pelleting operator to use the driest steam possible. If additional moisture is needed, as is often the case, it can be added much more economically as water either in the mixer or in the conditioner. **Table 6-1** is included to help the reader understand the thermodynamic relationship of heat, pressure and volume. To appreciate the value and usefulness of steam in the conditioning process, a reasonable understanding of these relationships is necessary.

Conditioning options

Atmospheric conditioners

The typical conditioner commonly associated with a pelleting system is referred to as an "atmospheric conditioner." As the name implies, these conditioners operate under atmospheric pressure and are typically exposed to ambient conditions. As a rule, the atmospheric conditioner is basically a single cylinder with an agitator shaft. The function of the conditioner is to provide for the intimate contact and mixing of steam with the pellet mash. An understanding of how steam and pellet mash interact is critical to the understanding and management of a pelleting system. See Chapter 9 for more information on atmospheric conditioning.

Water addition during conditioning

It is well recognized that water is a critical component in the bonding that takes place during pellet formation. In typical pelleting, the only water added is in the form of steam. It is the authors' opinion that the pelleting process is done with less than optimum moisture at least six to eight months of each year in most regions of the US. In areas where local corn is the predominant grain, excess moisture may be experienced as new crop grain begins to arrive. However, as the crop year proceeds, drier grain is received as stored grain enters the market.

Depending upon formulation, optimum conditioned mash moisture is in the range of 16.0 to 17.5%, with 4 to 5% coming from conditioning. As a rule, we can expect to add 1% moisture to the pellet mash for each 12.5°C increase in mash temperature from steam. If the mash is cool, say 10°C, and we target 85°C as our mash temperature, we will be adding about 6% moisture. If the mash is already at 11-12%, the final mash moisture will be at or above the upper level of the range of optimum moisture. Conversely, if the mash temperature is at 35°C and we target 85°C, we'll only be adding about 4% moisture. If the initial mash moisture is 11-12%, the final mash moisture will be at or below the lower level of the optimum for pellet quality and throughput. Both of these situations (or even more extreme) can arise depending on the season of the year and ingredient moisture content.

There are times when we simply can't reach target temperatures before the upper moisture level is met. Other times, when the grain is dry and warm, we simply can't get enough steam into the mash without exceeding target temperatures. Late in the crop year it is often advantageous to add 1 to 2% water during conditioning to improve pellet quality and production rate. Studies at Kansas State University have shown that moisture addition at the mixer can be highly accurate and can result in substantial improvement in pellet quality (Greer and Fairchild, 1999). The equipment for precise moisture addition was perfected in applications to the steam flaking operation and can be easily adapted to feed milling operations. The best option will have to be determined locally through experimentation.

Double- or triple-pass conditioner

In an effort to extend and control dwell time, double- or triple-pass conditioners are sometimes used. Basically, this can be accomplished by stacking two or three "standard" conditioners above the pellet mill. Variable speed drives, multiple steam injecting points and steam jacketing are options in various designs.

A distinct advantage of a double- or triple-pass conditioner over a single, large-volume conditioner is that some semblance of "first-in-first-out" order can be maintained. It is also a relatively economical choice compared with more exotic conditioning; however, a good deal of head room above the pellet mill is required, making installation something of a problem. As an alternative to "stacked" conditioners, either "twin-shell" or horizontal double-pass designs can be used. In either case, retention time is extended. However, the head room needed above the pellet mill is no greater than that needed for a single-pass conditioner.

Jacketed conditioners

Many attempts have been made to use jacketed conditioners, conveyors or holding vessels (ripeners) with varying success. The basis for this concept is that, with jacket steam, heat can be introduced without adding excessive moisture. This is certainly a good idea, but is difficult to implement practically. The typical reason for failure is that the heat is transferred to the mash only at the surface of the barrel. Most often, the surface-to-volume ratio is so low that little heat is actually transferred into the mash—particularly in large-volume conditioners.

Pressure conditioning

This concept involves the use of conditioning chambers operating at elevated pressures. By increasing the pressure in the vessel, conditioning temperatures well in excess of 100°C can be attained. The reasoning behind the concept follows the law of thermodynamics and, simply put, forces the moisture and heat into mash particles more quickly and thoroughly than is possible at atmospheric pressure.

The challenge of getting the mash into and out of a pressurized vessel is obvious. The exit problem is solved by making the die chamber and rollers part of the pressurized area. The inlet uses a spring-loaded pressure plate, forced open by the feed, to contain the pressure.

Success is conditional

The conditioning process is, without doubt, the most important component of any feed pelleting system, at least as far as pellet quality is concerned. It is also, perhaps, the least understood component by pellet mill operators, many plant managers and even equipment suppliers. It was the purpose of this chapter to provide insight into some of the less-understood aspects of conditioning and to point out some of the strong points and weak points of each option available.

There is no single conditioning option that is best for all applications and situations. In most cases, replacement is not an option; therefore, steps taken to optimize a given installation will result in the best pellet quality at the best production rate possible. It must be remembered, however, that all factors involved in pellet quality are inter-related and must ultimately be addressed if the process is to be successful.

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