Critical Steps in Mash Conditioning

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Even today, with new advances in processing technology such as extrusion, the pelleting process continues to be the most popular and economical method of compounding animal feeds. The most critical step in this process is preconditioning. The quality of the preconditioning process will depend on particle size of the mix; the steam quality; initial moisture content of the mix; meal initial temperature as it enters the preconditioner; and the residence time in the preconditioner. Longer residence time in the conditioner permits more penetration of the moisture and better distribution of heat, which results in better binding of the feed particles—hence, increasing the pellet hardness that can result in a reduction of fines produced.

Starch gelatinization

The term gelatinization has been widely used in connection with the pelleting process, and more so in relation to the production of high-quality pellets. Starch gelatinization is defined as the loss of bi-refringence, or as the irreversible rupture of the native secondary bonds in the crystalline region of the starch granule. According to Hoseney (1986), the loss of bi-refringence occurs under continuous heating and excess moisture, which can lead to increased viscosity and increased swelling (water uptake) of the starch granules.

It is clear that moisture and temperature are required to cause the starch granule to gelatinize. Therefore, the preconditioner works as a continuous mixer or chamber in which the meal is moistened and heated via saturated steam. This process is time-dependent, thus the residence time, or the time the meal spends passing through the preconditioner, is a major factor for attaining the target moisture and temperature.

Starch damage

Starch can be broken by mechanical forces during grinding and pelleting. The broken or sheared starch granules can be read by the starch gelatinization method as cooked starch. In reality, this is not true starch gelatinization but starch damage. During pelleting, damage is mainly caused by friction as the mash is compressed and extruded through the working area of the die, as has been well documented by several authors (Skoch, 1979; Stevens, 1987).

If one wants to measure the actual degree of cook caused by steam conditioning, one must first consider the starch damage caused by grinding and the damage caused during pelleting. The latter can be done first by establishing a baseline with the mash meal before it is preconditioned and the same meal after it is preconditioned. The difference between the two will be the degree of cook caused by exposing the meal to the steam in the preconditioner. One advantage of the starch damage caused during the grinding process is the exposure of greater surface area, which in turn can increase the water absorption of the mix.

Steam conditioning

The process of adding steam to the mixed meal is known as preconditioning, or steam conditioning. During this process, the mixed meal is exposed to saturated steam to increase its moisture and temperature, which will eventually result in some starch gelatinization and the activation of other binding agents found in the mix. The conditioning is achieved in a continuous mixer or chamber known as the preconditioner, or conditioning chamber (see **Figure 7-1**).
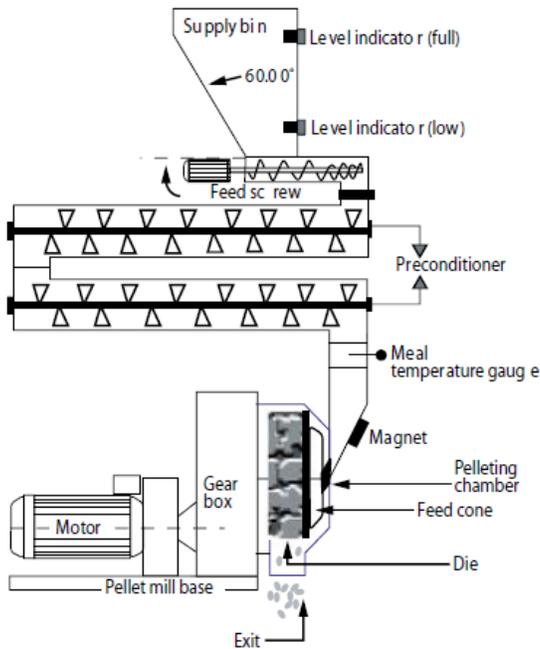
Figure 7-1. Preconditioner.

Preconditioning equipment

The preconditioner (see **Figure 7-2**) is made up of a screw feeder that takes the meal from the holding bin to the conditioner; the paddles, which convey and expose the meal to the steam being injected; and the exit port, which drops the meal into the chute or feeding port of the pellet mill.

Figure 7-2. Pelleting overview.

The residence time and the degree of fill in the preconditioner can be increased by reducing the speed of the shaft (see **Figures 7-3 & 7-4**) for the same feed rate, or changing the pitch angle of the paddles. To change the angle of the paddles it is recommended to use a template (see **Figure 7-5**) that shows the number of paddles and the location with respect to the shaft. Once the layout has been established, the operator then can proceed to change the paddle configuration (see **Figures 7-6 and 7-7**).

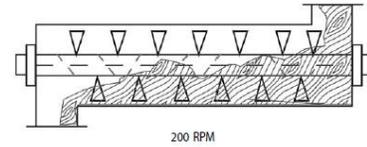**Figure 7-3. Shaft speed influences residence time.**

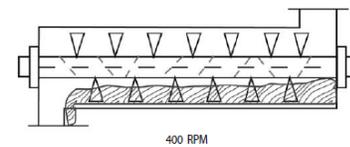**Figure 7-4. Increased shaft speed at same feed rate.**

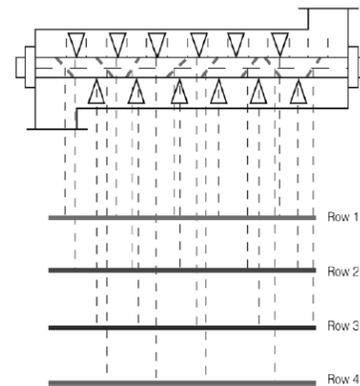**Figure 7-5. Paddle template.**

Figure 7-6. Determining configuration of paddles.
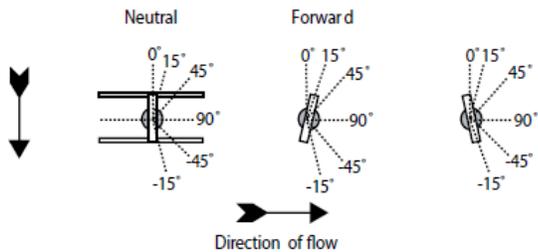

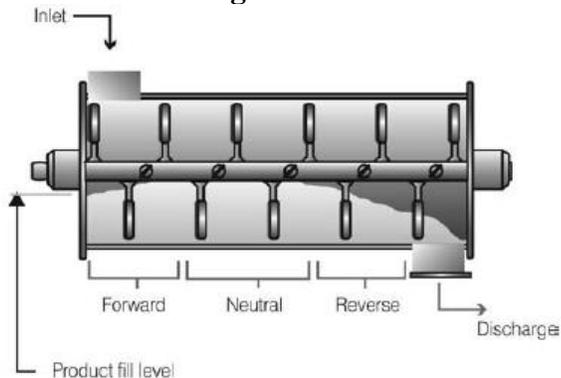**Figure 7-7. Arranging paddle layout.**

The paddles can be arranged: in a forward orientation (0 to 90 degrees), which moves the feed towards the discharge; in a neutral orientation (0 degrees); in a reverse orientation (0 to -90 degrees), which moves feed away from the discharge and increases the degree of fill and residence time; or may be set perpendicular to the rotation (90 degrees) to maximize the mixing effect (see **Figure 7-8**).

Figure 7-8. Paddle angle maximizes mixing effect.

The best configuration should be one that allows the mash to fill the center section of the preconditioner. This can be accomplished by putting some of the paddles in the reverse, some in the neutral and some in the forward pitch orientation (see **Figure 7-9**). Immediately after the reverse, and closer to the exit port, the paddles should again have a forward pitch to allow the mash to flow out of the conditioner. Beware that too many paddles in the reverse position can cause the preconditioner to overfill and overload the drive motor. The configuration of the paddles should be one that permits the maximum degree of fill, maximum residence time, and a high degree of mixing. This encourages constant contact between the feed particles and the steam being injected into the chamber.

Figure 7-9. Pitch angles.

Steam

An essential part of the preconditioning process is the addition of steam to moisten and heat the meal. Steam can be classified as saturated, superheated or "wet" steam. Saturated steam is 100% vapor held at the temperature and pressure representing its vaporization point. Superheated steam is also 100% vapor, but has a temperature greater than that of its vaporization temperature at current pressure. "Wet" steam contains both vapor and free water. In the pelleting process, saturated steam is used to increase the temperature and moisture of the mash via the process of condensation. The condensation occurs as a result of the drop in pressure and temperature as steam enters the conditioning chamber, which is at atmospheric conditions. As wet steam enters the conditioning chamber it contacts the colder meal particles and condenses. During the condensation process, heat is transferred to the meal, elevating its temperature.

Steam quality

Steam used in the process of conditioning must be as dry (saturated) as possible. The dryness of steam describes its quality and is defined as the proportion of water droplets in suspension present in the steam. Reimer and Beggs (1993) reported that when steam of 80% quality (dryness fraction) was used, mash feed entering the conditioning chamber at 12% moisture and 18°C, exited the conditioner chamber at 16% moisture and 84°C. However, at 100% steam quality, the conditioned mash was 91°C.

The latter can be explained by looking at steam tables, which show that wet (unsaturated) steam has substantially lower energy content than dry, saturated steam at the same pressure. Therefore, it is very important to ensure the quality of steam being delivered to the pelleting system. This can be accomplished by proper insulation of the steam lines and having adequate steam traps and separators.

Steam condensation and molecule binding

When steam condenses, it adds moisture to mash feed, and at the same time it transfers its energy.

During this time-dependent process, the starch granules swell up until they gelatinize. Similarly, proteins will start changing their molecular structure, in some cases becoming more fluid. It is during this process that the binding of molecules starts, which is responsible for producing high quality pellets. Because it is a time-dependent process, steam conditioners should have enough residence time to allow the particles to hydrate and heat.

In the pelleting process, the maximum moisture that can be attained without causing the pellet mill to plug is about 17%. In contrast, during the extrusion process moistures can be 20% or higher. The extrusion process is more flexible in the amount of water it can handle, and this makes it easier to raise the meal moisture and degree of cook to the desired levels. Therefore, preconditioners are designed differently depending on the process.

Steam conditioning: Residence time, mixing and particle size

To understand preconditioning it is important to understand the heat and mass transfer between the components. The medium in the preconditioner is a three-phase system of gas (steam), liquid (water) and solids (meal mixture). Steam transfers energy to the particles via condensation. The particles of meal are relatively cool and steam condenses onto them, forming a thin film of water on the particle surface. This water is absorbed into the particle, increasing the moisture content. How fast the heat transfer and moisture uptake occurs will depend on the film resistance on the surface of the particle and the speed by which the heat and moisture travel to the core of the particles. The more solid-to-fluid contact, the lower the film resistance.

Having good mixing in the preconditioner encourages more contact between the feed particles and the steam, thus reducing the film resistance and speeding up the process. The speed at which heat and moisture travel to the interior of the particle is governed by Fourier's and Fick's second laws. The meal is composed of particles that have different internal resistance for heat and moisture. Therefore, by knowing the coefficients of diffusivity, one can apply the physical laws to estimate the necessary amount of time (residence time) to heat and humidify the particles homogeneously. In general, the higher the heat and water diffusivity, the faster the heat and moisture will flow into the particles.

Most feeds have high amounts of ingredients such as corn, sorghum, wheat and their byproducts. One of the major components of these ingredients is starch. At ambient temperature, starch has a thermal diffusivity coefficient 100 times greater than the water diffusivity. In simple words, heat transfer is faster than moisture uptake by the starch granules. In most preconditioning situations it is possible to heat up the mash to the target temperature, but it is more difficult to hydrate it to the target moisture level because it requires more time. The latter is one of the reasons why it is important to have the adequate residence time in the preconditioner: to allow moisture to penetrate the particles. Keep in mind that moisture and temperature are key elements, working together, responsible for attaining good pellet durability.

Film resistance around the particle can be measured using the dimensionless Biot number (Bi). When the resistance is in the film around the particle, as is the case with preconditioners with poor mixing, the Biot number is very small (< 0.1). In conditioners with good mixing action, the main resistance is the diffusion of water to the particle, and the Biot number is large (> 10). Based on this number, we can classify most of the preconditioners available today for pelleting and they would fall into an intermediate category in mixing efficiency where the Biot number is approximately 1. The film and internal resistance have a direct impact on the rate of hydration into the particle.

Particle size also has a direct effect on how well the mash is preconditioned. This can be explained by understanding the relationship between particle size and the rates of hydration and heat transfer. It has been demonstrated (Bouvier, 1996) that larger particles (> 400 microns) require twice as much hydration time than smaller particles (< 200 microns). This is logical since the moisture added via the steam in the preconditioner will require more time to be internalized in a larger particle than a small one. In addition, smaller the particle size

results in greater the surface area. The hydration rate can be explained in mathematical terms by applying the laws of thermodynamics.

The following formula allows one to calculate the required time necessary to adequately hydrate particles based on the particle radius:

$$Fo = Dt \, / \, [(R/3)^2]$$

Where *Fo* is Fourier number, *D* is the water diffusivity, *t* the diffusion time and *R* the radius of the particle.

Solving for *t* shows that as the particle radius increases a longer time is required to hydrate it. This clearly demonstrates that particle size not only needs to be small enough to improve feed digestibility, but also to improve hydration rate that can lead to better pellet quality. If particles are of more uniform dimensions, hydration rate will be similar for most particles, and there will therefore be a more uniform distribution of moisture among particles in the meal. This is a good reason for considering post-batch grinding systems to achieve a more uniform particle size. Keeping the particle size distribution within a narrow range can improve the overall pellet quality both in terms of degree of cook and pellet durability.

Residence time distribution

Residence time distribution (RTD) should not be confused with residence time (RT). Using a marker, one can determine the RT, which is the time it takes the marker to exit the preconditioner. This assumes a first-in, first-out flow principle. Consider this vs. the RTD, which is the average residence time a single particle may stay in the preconditioner, and is more representative of the typical material flow. The RTD has a characteristic bell-shaped curve. The shorter the distribution, the more uniform, more efficient the preconditioner is in hydrating and heating particles uniformly.

There are many kinds of preconditioners with different configurations for paddle design, shaft speed, paddle angle and volumetric capacity. Understanding RTD can help understand how hydration time can be improved in the preconditioner. In the preconditioner there can be two types of mixing. One is axial mixing, which contributes to increasing the particle-to-steam/fluid contact in the preconditioning chamber. The second is radial mixing, which also affects the contact of particles with the steam and liquid, but depends more on the shaft RPM and paddle configuration/geometry. Depending on the design, preconditioners can exhibit a plug flow (very little mixing) and mixed flow (highly axial mixing). These flows depend, again, on the paddle geometry, shaft speed and degree of fill.

A common problem in the pelleting process of animal feeds is the appearance of uneven-colored pellets. In most cases, this is caused by inadequate moisture distribution in the preconditioner. This can be more easily explained by understanding the RTD. In this particular case, the RTD is broad, meaning that some particles spend a short time in the preconditioner, thus receiving insufficient moisture, while others spend a longer time and are adequately hydrated. This problem is not only associated with inadequate paddle configuration, shaft speed or degree of fill, but also with uneven particle size. Even if the preconditioner is properly optimized, but the particle distribution is too broad, the moisture distribution among particles can be uneven. The large ones will have less moisture, while the small ones will have a higher moisture content. Therefore, particle size of the meal needs to be as uniform as possible and the RTD needs to be as narrow as possible.

Fill ratio represents the volume occupied by the meal in relation to the total volume of the preconditioner. The meal volume is measured when the preconditioner is stopped. Many preconditioners used in the pelleting industry today can have a relatively low fill ratio (~ 30%). Having a small fill ratio means that the preconditioner has more empty spaces. Knowing that steam is a gas, one can clearly visualize that it will tend to fill the voids in the preconditioner. When this happens it can be expected that less steam will be in contact with the material, and heating and hydration will suffer. Therefore, increasing the fill ratio improves not only the residence time but also the temperature and hydration uniformity of the mix.
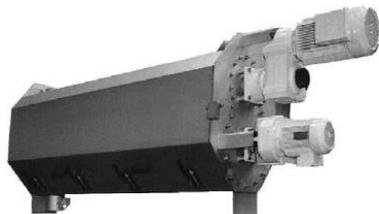
As mentioned previously, the degree of fill can be improved by properly adjusting the paddle configuration (orientations). Angled paddles can increase axial mixing. In contrast, paddles placed at 0 or 90 degrees can increase the filling ratio. Most preconditioners are fitted with paddles that can be adjusted by the operator. Again, a good paddle configuration will include paddles in the reverse, some forward and some flat (mixing action). Some preconditioners (see **Figure 7-10**) also incorporate retention plates that have the purpose of providing an obstacle at the end of the unit and thus increase the degree of fill and the residence time.

Figure 7-10. Retention plates.

In recent years, new preconditioners have been introduced to the market, and old versions have been improved. Some of the new preconditioners have been developed based on the principles of axial and radial mixing in combination with extended residence times. A good example of this type of preconditioner is shown in **Figure 7-11.**

Figure 7-11. New type preconditioner.

This incorporates a high-speed mixing zone in a small chamber and then has a larger section where the meal is allowed to hydrate and heat (see **Figure 7-12**). Others, as is the case of Stolz in France, have developed a preconditioner that is inclined (see **Figure 7-13**) to increase the residence time and degree of fill. Work done by Stolz (personal communication) has shown that residence time can be as high as six minutes. It is clear that such an extended residence time can improve the meal moisture absorption and degree of cook, since both are time- and temperature-dependent processes.
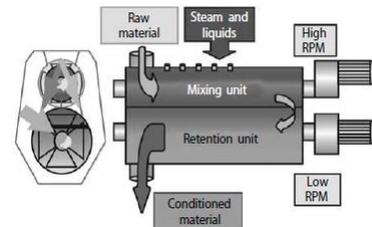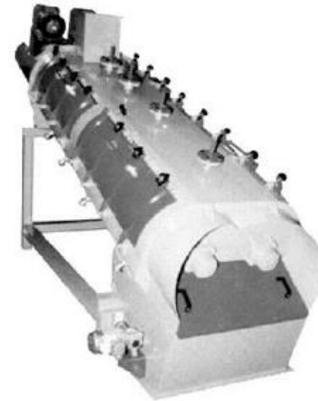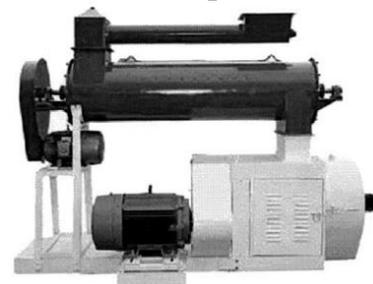
Figure 7-12. Concept of new preconditioner.

Figure 7-13. Inclined preconditioner.

Other preconditioners have been designed to work as pressure vessels, taking advantage of the fact that at higher pressures the amount of energy transfer is greater and requires less time. These conditioners have been on the market for some time, specifically the Sprout-Waldron pressurized conditioner, which has been used in the past in extrusion processing. The pressurized conditioner by Pelleting Concepts International, Inc (see **Figure 7-14**), has been used in pellet mills with some degree of success.

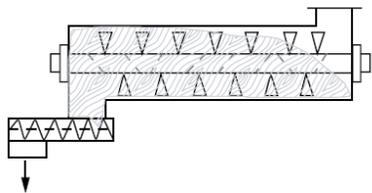**Figure 7-14. Pressurized preconditioner.**

It is clear that one advantage of pressurized conditioners, based on steam thermodynamics, is that at higher pressures steam has more energy to transfer to the mash.

Steam tables (Spirax Sarco) show that at sea level, or 1.01 bar of absolute pressure, the energy content of steam is 638.3 kcal/kg. On the other hand, at 1.15 bar the energy content is 640.7 kcal/kg. This difference of 2.4 kcal/kg represents an increase in temperature of approximately 3.6°C, which can be an advantage when trying to achieve a high degree of cook in order to improve pellet quality. Also, at higher pressures the moisture and heat can penetrate more rapidly into the core of the starch granule to gelatinize it, which may reduce the residence time in the conditioner.

Other preconditioners have been designed to become feeders by including at the exit port a metering screw that feeds the pellet mill and regulates the discharge rate of the preconditioner (see **Figure 7-15**).

Figure 7-15. Metering screw at exit port.

This type of preconditioner can also achieve high degree of fill and increased residence time. Preconditioner manufacturers continue to strive for solutions to improve the residence time that can lead to better degree of cook and better pellet quality.

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