Role of proper steam conditioning – starch gelatinisation

by Steven GOH

To create high physical quality pellets, a better understanding of factors affecting pellet quality is necessary. Pellet quality depends proportionally on the following factors: 40% feed formulation, 20% feed particle size, 20% steam-conditioning, 15% pellet die specification, and 5% cooling and drying. A number of strategies can be employed, alone or in combination, to manufacture high physical quality pellets. Even though it is generally accepted that feed formulation contributes the biggest impact to pellet quality, steam conditioning plays an equally important role in feed pelleting.

The conditioner is in reality, the most important part of the feed pelleting process. Typical diets contain high percentages of corn/soy or wheat/soy and, therefore, high proportions of starch. Under processing conditions using heat and moisture, starches gelatinise and help bind feed particles together. Raw starch needs to be appropriately cooked to achieve a high level of starch gelatinisation for intra-particle bonding to achieve good pellet formation and machine efficiency. As there is no readily available water sorption in a feed pelleting process, steam conditioning is therefore the only means to get moisture and heat sufficiently infused into the raw starch granule. This can only be done with the relevant steam quality, plus working with a well-engineered conditioner, which aptly provides sufficient dwell time for steam/mash interaction.

The industry needs to understand the effects of bad processing on micro and macro nutrient wastage and the detrimental consequence to livestock production. Working with a much higher meal temperature in Asia coupled with the incorrect engineering norm and set-up on steam conditioning has greatly affected the proper and effective cooking of raw starch.

Common conditioning problems are:

• Very low moisture uptake after steam conditioning (1.5 – 2% moisture)

• Poorly conditioned meal – this affects machine throughput capacity depending on the degree of acceptable fines

• Poor pellet quality with fines

• High production shrink – up to minus 1.5% after cooling, over the initial meal moisture before steam conditioning

As a consequence, feed pelleting became an art form, when operators learn the art of working around the problems caused by poor steam conditioning and ineffective cooking of raw starch. The current engineering norm of working with high pressure steam, generating the wrong steam to work with, from steam set-up to the conditioner

conceptual design, is the biggest issue that caused problems with steam conditioning, poor moisture uptake after conditioning, and hence pelleting efficiency and pellet quality. Working with the wrong steam has resulted in the need to use much higher conditioning temperature (90°C - 93°C on poultry feed), technically creating more temperature space allowing for more steam entering the conditioner; and using a higher die compression ratio to achieve pellet durability (PDI), are two things commonly done to work around the problem. However, doing this has a negative effect on the processed pellet feed quality and feeding value.

Pelleting may result in poor broiler performance if the appropriate temperature is not used during conditioning. It has been shown that high conditioning temperatures are associated with poor broiler performance, in terms of weight gain, feed per gain and mortality.

Weight gain of birds fed diets steam-pelleted twice was significantly lower compared to those fed diets steam-pelleted once. Feed intake of birds fed twice steam-pelleted diets was similar to those fed the mash diet, while feed intake was higher in birds fed once steam-pelleted diets. Getting the job done first time without the need to re-run fines a second time is important.

Feed Quality and feeding value

• Without an effective steam conditioning and effective cooking of starch, amylose can potentially retrograde and becomes less digestible than it was before heating.

• Maillard reaction from extensive shearing – having a thicker than necessary die thickness contributes to better PDI, but negatively impacts feeding value. The danger from Maillard reaction from extensive shearing results in a loss of lysine and arginine due to complexing with sugars.

• Improper cooking of raw starch results in the formation of resistant starch and in the loss of carbohydrates and energy value.

• Improper steam conditioning can greatly affect digestible protein value.

• Loss of heat labile vitamins and other essential micronutrients.

• In viscous cereal (wheat/barley) diets, working with super-heated steam can potentially increase feed viscosity. Greater solubilisation of fibre impedes nutrient absorption in the small intestine.

These problems can be avoided with the correct approach to effectively cook raw starch. Get it right, and everything will fall in place nicely, producing hard well-formed pellet/crumble feeds – the key to feed quality and livestock productivity. The industry should evaluate the possibility of producing 3mm pellet size (for feeding broilers) productively, which is only possible if steam conditioning is done correctly and effectively.

The main objective of feed pelleting is to effectively cook the raw starch fractions for good pellet formation, avoid destroying valuable micronutrients, and to maintain the feeding value of a well-formulated feed, whereas the industry seems have focused on the economics of production shrink (moisture loss after feed pelleting) instead. Feed pelleting needs to be approached with sound fundamentals to achieve the objectives - a lack of understanding the fundamental of raw starch cooking and not addressing the

prime objective of feed pelleting has resulted in poor moisture uptake after steam conditioning, poor pelleting efficiencies, poor pellet quality, and the ensuing problems on animal health and growth performance from poorly processed feeds.

What you need to know about surfactants

When working with poor engineering set-ups, the surfactant water-adding concept of replenishing back lost moisture over the feed pelleting process, further compounds pellet quality problems.

• Surfactant added prior to gelatinisation, adsorbs to the surface of the starch granule and forms complexes with starch (decreases water-binding capacity), typically the amylose. The surface is rendered lipophilic, which retards the migration of water to the starch granule. There is no effective softening and swelling of the starch granule which results in uncooked resistant starch. Simply put, surfactant added before steam conditioning affects the cooking of raw starch.

• Most moisture that attaches to the lipophilic surface after conditioning flashes off in the press and after cooling. Whatever added water is left behind (usually about 25%) would migrate in the form of free water and water activity (Aw) increase, due to heat and humidity in the challenging hot environment contributes to two problems;

– moving free water molecules act as a solvent and contribute to bio-chemical degradation of micronutrients. This could possibly affect the immune, health, and growth performance of livestock;

– in hot and humid environments, the moving water molecules inside a bag of feed could reach an unsafe Aw level of 0.7 and result in live mould growth.

Basically, many surfactant programs are nothing more than “obsession with the economics of recovering moisture to counter production shrink in feed pelleting”, which is totally disconnected from the real objective of cooking raw starch to improve feed pelleting. The idea in moisture recovery may sound good, but the execution is incorrect.

Pellet quality

The industry has always used PDI (pellet durability index) as a benchmark to gauge pellet quality, which in my view is not the most accurate in determining pelleting performance, simply because this do not reflect the effectiveness of raw starch cooking. The use of thicker dies and smaller pellet size can greatly improve shearing effect when conditioned meal passes through the die passage to improve PDI reading. Pellet feed with good PDI reading still have issues with fines because the shearing effect has only managed to give the pellet a good form on the outside surface, which is only temporary, and fines will flake off from handling of the finished feeds until it reaches the animal at the farm. Poor cooking of starch, and a low level of available gelling necessary for good intra-particles bonding is the cause of fines in finished pellet feed. Analyzing for degree of starch gelatinisation (Differential Scanning Calorimetry) and pellet hardness index (Kahl hardness tester) would be much better indicators on raw starch cooking.

Starch

Starch occurs naturally as water-insoluble granules in the endosperm in alternating semi-crystalline and amorphous layers with various amylose and amylopectin content.

Starch is a glucan composed of two main polysaccharides, amylose and amylopectin. Both polysaccharides are based on chains of 1→4 linked α-D-glucose, but whereas amylase is essentially linear, amylopectin is highly branched containing on average one branch point which is 1→4→6 linked for every 20-25 straight chain residues (Figure 1).

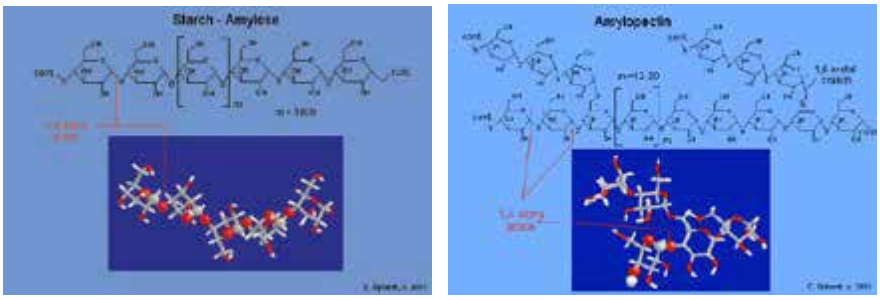

Figure 1: A starch molecule contains hundreds of glucose molecules in either occassionally branched chains (amylopectin) or unbranched chains (amylose). (*Source: Starch Science Journal*)

While amylopectin represents up to 70- 80% of normal starches, amylase comprises the balance 20 to 30%.

Amylose molecules, because of their linearity, line up more readily and have more extensive hydrogen bonding, which gives it good gel strength. Good gelling is required for intra particle bonding to form good quality pellets. Consequently, it requires more energy to break these bonds to effectively gelatinise the amylose fraction. This is the reason we need to work with saturated steam, which will be discussed in a later article – Role of proper steam conditioning – feed pellet efficiency and feeding value.

The branched amylopectin molecules cannot align as easily and, thus, give weaker hydrogen bonding and is poor in gel strength.

Gelatinisation

Gelatinisation (defined as the irreversible destruction of the crystalline order in a starch granule so that the surface of every molecule is made accessible to digestive solvents and enzymes) is a swelling driven process (Figure 2). Swelling occurs along the amorphous regions, and since the crystalline regions do not expand during swelling, stress increases at the interface between the crystalline and amorphous regions, where bonds exist between amylopectin in the crystalline regions and amylose in the amorphous regions. Thus, at a certain point in the swelling process the crystalline regions are rapidly and irreversibly broken and gelatinisation is initiated. Swelling causes nearly all amylose in the starch granule to leach out. Viscosity increases during gelatinisation and is caused by swollen granules and gels consisting of solubilized amylose.

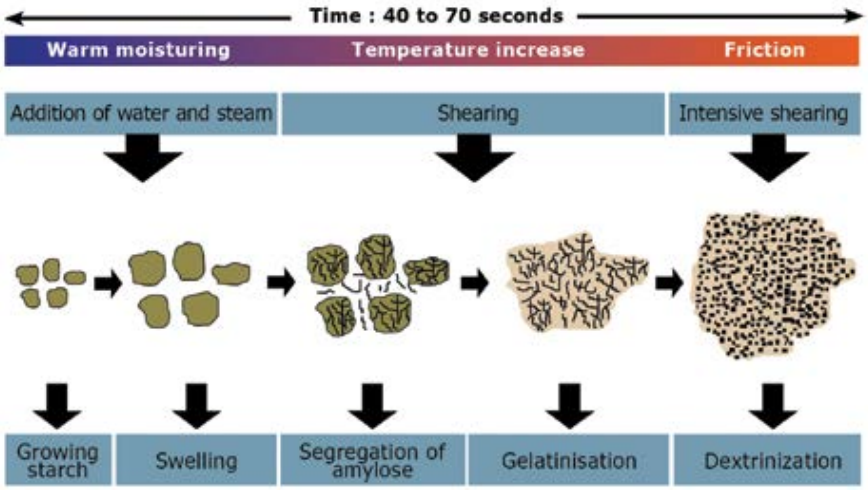

Figure 2: Starch gelatinisation

Gelatinisation of starch has two results important to digestion

• Gelatinisation enhances the ability of starches to absorb large quantities of water, and this leads to improved digestibility in almost all cases, and to improved feed conversion in many cases.

• Gelatinisation increases the speed at which amylases can break down the linkages of starch to convert it into simpler and more soluble carbohydrates, including blood sugars (glucose).

Most starches will gelatinise upon heating to above 80°C in excess water. As there is no excessive water in the conditioner, we need to capture sufficient amount of microscopic moisture from the condensing steam to be utilised for effective cooking of raw starch. Gelatinisation in the feed pelleting process, typically results from a combination of moisture, heat, mechanical energy, and pressure. Gelatinisation temperature varies with starch type. Amylose is a more crystalline type of starch that requires more heat for gelatinisation than amylopectin, a more branched type of starch. Starch gelatinisation is an order-disorder phase transition that includes the diffusion of water into a granule, hydration and swelling, uptake of heat, loss of crystalinity, and amylose leaching. Leached amylose immediately forms double helices that may aggregate (hydrogen bond) to each other and create semi-crystalline regions. As the gelatinised starch cools, the dispersed matrix forms a gel or pastel like mass that may function as an adhesive or binding agent.

The majority of gelatinisation occurs as the feed passes through the pelleting chamber, and not during conditioning. The conditioning phase is to get microscopic moisture and latent heat from the condensing steam to work on the starch granule and embedded into the starch matrixes sufficiently. The mechanical shearing going through the press and die with a further increase in friction heat will substantially gelatinise the starch.

Conclusion

It is important to cook the amylase well. This core objective underlines the need to effectively cook raw starch and to adopt the correct and effective steam conditioning approach for improved pellet feed quality and feeding value.

The importance of feeding high physical quality pellets with minimal fines is well recognised. The poultry industry talks about the relevance of coarse grinding to gizzard development, and growth and performance. It is now possible to make small hard pellets and crumbles without fines. This could be a new area to explore.

We will need to readdress a feed pelleting process if it causes feed nutrient wastage. Making the changeover to work with saturated steam is certainly not an option, if we are to get the best compromises on feed pelleting. This very fundamental approach to improving steam conditioning and feed pellet quality is certainly a new direction for the industry to look into. Improving the feed pelleting process can make a huge impact to feed formulation (working on a fine line without the need to over-formulate) and the use of feed additives (certain additives used to address problems to feed nutrition and livestock health/ performance can be dropped). Much money can be saved.

*Steven Goh (steven@delstasia.com) is Executive Director for Delst. A list of references is available from the author.