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History of pelleting

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In the past 50 years, considerable changes have occurred in the structure of animal agriculture. No longer are agricultural animals produced to any scale in “back yard” type production settings. Rather, animal production has evolved into a highly integrated volume-based business. This is particularly true for the swine and poultry industries where essentially every phase of production is owned and/or controlled by a single entity.

With the wholesale consolidation of the meat, milk, and egg production industries, feed manufacturing has become more industrialized. Though today, there are fewer feed mills in operation, feed production has increased and continues to grow. This general shift from on-farm or small-cooperative type feed processing operations to larger industrial-type feed manufacturing facilities has made processing technologies, such as pelleting, more economically feasible.

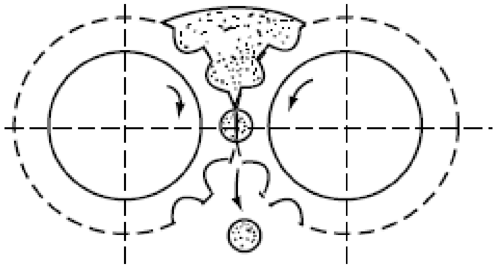
As such, the pelleting process has become a standard feed processing technique. Since the introduction of pelleting in the early 1900’s, the pelleting process has evolved in size and capacity enabling pellet mills to be operated with less labor and greater precision than ever before. The following chapter reviews how the pellet process has evolved to become a standard feed processing

Pellet evolution

Between 1900 and the 1930s, equipment designers proposed several feed processing machines, according to pelleting expert Larry Pitsch (1990). Around 1910, feed manufacturers began extruding feed to increase its value. The extruders conditioned the mash with heat and moisture prior to forcing it through a die plate and knife assembly. While the extrusion process greatly enhanced feed digestibility and improved handling, extruders were expensive and complicated to operate with early 20th century technology.

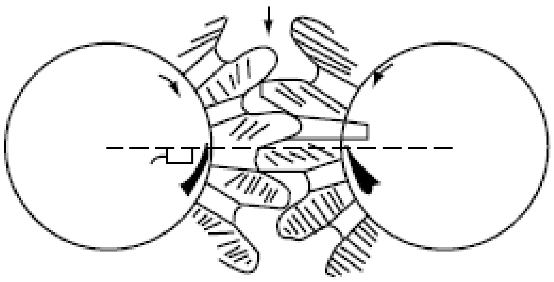
According to Pitsch, one of the first successful pellet mills was a molding machine in which two counter-rotating rollers with pockets, formed and pressed mash into wafers (see Figure 1-1). The wafers had a much lower density than modern feed pellets, which provided no advantage to feed transportation. Also, the mash was not conditioned with heat and moisture; therefore, the “wafering” process did not greatly enhance nutrient utilization.

Figure 1-1. Diagram of a mold type pellet mill.



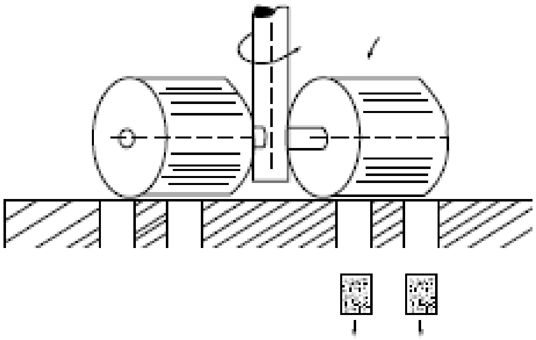
In the 1920s, feed manufacturing equipment designers introduced the Schueler pellet press (Pitsch 1990). This design used a spur gear integrated with two rolls (see Figure 1-2). The machine moved mash through indentions in the gear teeth, resulting in a dense pellet. Although this was an improvement over the earlier designs, the Schueler pellet press was relatively expensive to operate and the gear and roll assembly was subject to wear.

Figure 1-2. Diagram of Schueler type pellet system.



A short time later, the flat-die mill—a machine that was an immediate precursor to the modern roll-and-die pellet mill—was introduced to the commercial feed industry. The flat-die mill consisted of rollers traveling around a vertical axis on a stationary horizontal die (see Figure 1-3). The movement of the rollers forced the mash through holes in the die, compressing the mash forming pellets. Flat-die mills are still used in the production of some specialty feeds today.

Figure 1-3. Diagram of flat die pellet mill.



In 1928, the first commercial pellet mills were imported from England to the United States (Schoeff, 1976). The S. Howes Co. sold one of the first U.S. built pellet mills in 1930 (Schoeff, 1994). The next year, California Pellet Mill Company designed a 22 kW pellet mill that utilized a stainless steel horizontal-plate die. Shortly thereafter, feed manufacturers and livestock producers began to recognize the numerous benefits of feeding pelletized feed and the design which employed a roller inside a vertically-positioned cylindrical die—the modern ring-die pellet mill—was developed into a commercial machine. In the ring-die pellet mill, the roller forces the mash outward through the die holes. Compared to the flat-die pellet mills, the ring-die design had the advantage of quick die change, allowing feed manufacturers to produce a variety of different pellet sizes from a single pelleting system.

Pitsch (1990) pointed out that in the first modern ring-die pellet mills, the rollers rotated along the inside surface of the die. However, in later designs, the die rotated while the rolls remained in a fixed position. Other major improvements in ring-die pelleting systems have included the addition of a second and third roller, greater mash conditioning, the incorporation of binding aids to feed formations, larger dies, more efficient coolers and greater power motors (see Table 1-1). Generally, these modifications have increased pelleting throughput and pellet quality, while reducing the relative cost of the process.

Table 1-1. Changes in the power of pellet mills.

Year	Maximum motor kW
1930s	22
1940s	37
1950s	93
1960s	187
Mid 1970s	261
Late 1970s	448
1990s	522
2000s	597
2010s	750

During the remainder of the 1930s and 1940s, equipment designers and feed manufacturers focused on using pelleting technology to the greatest advantage. For example, in 1936, Beacon Milling produced pelleted duck feed. This achievement was important because ducks are particularly sensitive to fines. Other feed companies began producing pelleted dog food. In 1946, Wenger Mixer Manufacturing Company developed a method of producing high-molasses pellets, an important feed for beef cattle and dairy cows. The next year, coarsely ground pellet crumbles were fed to young chickens for the first time. Crumbles enabled broiler producers to obtain the advantages of pelleting over the entire growth curve of the bird.

After World War II, US pellet mill manufacturers began a period of expansion. California Pellet Mill Company built three manufacturing plants in the United States and began exporting machines to Europe. During the following years, several pelleting technology experts made recommendations on the most efficient operation of pelleting systems (Behnke, 2001).

Century of the conditioner

Few pellet mills in the early 1930s had the capability of conditioning the mash with heat and moisture prior to pelleting. Though it was recognized that steam conditioning enhanced pellet quality, concerns over nutrient degradation, such as the destruction of the water-soluble vitamins, overrode the desire to strive to produce a perfect pellet.

By the end of the 1930s, pellet mill designers began installing conditioners—originally referred to as "ripeners"—which added steam to the mash prior to pelleting (Pitsch, 1990). The early mash conditioners were barrel-shaped devices. A rotating shaft with various pitched paddles moved the mash forward towards the pellet mill die. Manifolds, connected to the feed mill's boilers, injected steam and water into the mash. The design of the conditioner remained largely unchanged until the 1960s.

One noticeable change in conditioner design over the years has been a steady increase in the conditioning temperatures (see Table 1-2). Between 1990 and 2000, the average mash conditioning temperature increased more than it did in the previous 10 years. This difference was likely due to the introduction of high-temperature conditioners such as short-time/high-temperature (ST/HT) systems and annular gap expanders, and the ability to add heat and moisture independently to the mash.

Modern mash conditioning systems focus on greater gelatinization of the starch in the grain. Higher levels of starch gelatinization enhance pellet durability (quality), improve carbohydrate and protein digestibility and utilization by the animal and increase pellet production. In addition, higher pelleting temperatures kill bacterial pathogens, including Salmonella and E. coli, and deactivate anti-nutritional factors. In the 1970s, feed companies were building completely automated feed mills. Improvements in the control of heat and moisture addition to the mash enabled equipment engineers to develop steam jacketed conditioners by the mid-1970s. Jacketed conditioners were used mainly to manufacture high-quality fish feeds (Pitsch, 1990).

Table 1-2. Changes in mash conditioning temperature (°C) over time. Source: BASF, 2001.

	General	Broiler	Pig
1970	65	68	65
1975	66	71	68
1980	68	74	71
1985	70	76	74
1990	71	79	76
1995	74	82	79
2000	77	86	83

By the 1980s, pellet mill operators and designers were focusing their attention on steam quality. Their aim was to maximize the amount of heat added to the mash—to optimize starch gelatinization, but minimize moisture addition. Excess moisture in conditioned mash must be removed post-pelleting and tends to plug rolls and dies. The pelleting experts at the time moved from using low-quality wet steam, which contained a combination of water vapor and free water in the form of high-velocity suspended droplets or low-velocity drops of water, to high-quality superheated steam, which contained water vapor at temperatures or pressures higher than saturated steam.

A steam harness, which consisted of a separator, regulator and trap, was eventually developed to improve steam quality (Reimer and Beggs, 1993). During the late 1980s, pellet mill system designers developed short-time/high-temperature conditioners. The aim of the ST/HT conditioners was to maximize starch gelatinization, while at the same time minimizing the retention time of the mash in the conditioner in order to maximize pellet output. Also during the 1980s, pellet mill engineers focused on steam delivery into the conditioner. One innovation towards this end was the direct-fired steam generator, which replaced traditional tube boilers (McEllhiney, 1987; 1988).

Direct-fired steam generators use combustion fuel—propane or natural gas—and air to produce steam. These units require less start-up time than traditional boilers because the direct-fired steam generators do not need to heat hundreds of liters of water before they begin producing steam. The short start-up time and other efficiency factors reduce energy consumption by 30-50%. They also generate less carbon dioxide—a major "greenhouse" gas. Proponents of direct-fired steam generators tout their safety because they do not generate high-pressure steam. Anaerobic pasteurizing conditioners combined direct-fired steam generation with counterflow heat exchange to improve mash conditioning (Redus, 1988). In the APC conditioner, the steam and combustion gases from the direct-fired steam generator travel counter to the flow of mass. The mash exiting the conditioner absorbs the heat and moisture from the in-coming steam. The mash temperature usually reached approximately 80°C with 17% moisture. The system also killed aerobic pathogens, reduced conditioner retention time to 2-4 minutes and created a weak acid that further softened the mash particles, enhancing pellet durability.

In the late 1980s, feed manufacturers began experimenting with double pelleting (Pitsch, 1990). Double pelleting is a two-step process aimed at increasing starch gelatinization and pellet durability. The first step involves standard conditioning and pelleting of mash. In the second step, the pellets are ground and pelleted a second time. In some systems, the first stage requires extrusion rather than pelleting of the mash. By the mid-1990s, pellet conditioner technology experienced a major leap forward with the introduction of the annular gap expander (Gill, 1992; Peisker, 1993; Castaldo, 1997). Expanders are similar to extruders in that they use heat, pressure, mechanical energy and shear forces to gelatinize starch.

In 1995, Ron Turner, an applications specialist at California Pellet Mill Company, reviewed numerous pelleting studies to determine the effects of various factors on pellet durability (see Figure 1-5). He discovered that 60% of the quality of pellets is due to formulation and particle size—activities upstream from the mash conditioner. Conditioning contributed approximately 20% to pellet durability. Die selection and cooling had small but noticeable impacts on pellet quality. Later, Dozier (2001) refined Turner's work. Dozier reported that a 5.5°C increase in the conditioning temperature would increase pellet durability by 10%, and replacing the standard conditioner with an annual gap expander would increase durability by 15%. He also reported that the addition of pellet binders, reducing particle size from 650 microns to 500 microns or increasing the moisture content of the mash from 12% to 14.5% would increase durability by 12.6%, 14.5% and 10%, respectively.

The development of conditioners, which added moisture and heat to mash prior to pelleting, created the need for a system to remove the heat and moisture from the pellets. The function of pellet dryers and coolers is to reduce the temperature and moisture content of the pellets so that the pellets can be stored without spoiling or facilitating mold growth. However, commercial feed mills must balance moisture loss in the cooler to prevent too much moisture removal or feed will be "given away as shrink" and pellet quality will deteriorate. Conversely, integrated feed mill operations want to minimize the amount of water hauled to the farm on each delivery.

The first pellet cooler/dryers consisted of a flat belt upon which the hot, wet pellets were spread directly from the pellet mill. Cool, dry air was drawn horizontally across the bed of pellets, extracting heat and moisture. As the capacity of the pellet mill increased, larger cooler/dryers were needed. Double-pass systems, in which pellets were loaded from the pellet mill onto an upper belt and then dropped to a second belt running under, and in an opposite direction to, the upper belt to complete the cooling and drying process, were later installed in feed mills.

In the mid-1980s, vertical counterflow cooler/dryers were developed (Heinemans, 1986; 1991). In counterflow pellet cooler/dryers, pellets are transferred from the pellet mill to a cooler with a vented bottom. The system pulls cool, dry air vertically through the pellet bed. The heat- and moisture-laden air is exhausted through the top of the cooler, while dry, cooled pellets exit the cooler through oscillating slits or a rotating grid mounted on the floor of the cooler. Generally, counterflow coolers have smaller cooling/drying capacities compared to traditional horizontal belt coolers. However, counterflow coolers feature smaller space requirements and lower maintenance requirements.

Early in the history of pelleting technology, equipment engineers and feed mill operators discovered strong relationships between the physical properties of the mash—particularly particle size, heat, and moisture addition—and pellet quality. However, they later observed that feed formulations containing certain ingredients, such as wheat and corn, formed better pellets than formulations with other ingredients, such as alfalfa and food processing byproducts. Several pelleting experts created elegant pelletability tables which scored the ability or inability of long lists of ingredients to form durable pellets (MacMahon and Payne, 1981; Kniep, et al., 1982).

Table 1-3. Commonly-used natural and synthetic pellet binders.
Agar
Anionic heteropolysaccharide
Bentonites
Carboxymethylcellulose (CMC)
Carrageenin
Corn starch
GFS (mixture of xanthan gum, locust bean gum, guar gum mixture)
Guar gum
Hemicelluloses
High-gluten wheat flour
Hydrolyzed polyvinyl alcohol
Lignosulfonates
Locust bean gum
Polymethlolcarbamide
Potato starch
Seaweed binder
Sodium alginate + sodium hexametaphosphate
Tapioca starch
Wheat gluten

Pellet mill researchers also observed that some compounds increased pellet output by “scrubbing”the die hole as feed passed through the hole opening, and enhanced pellet durability by making the mash particles adhere to each other more strongly. Over the years, researchers have discovered a multitude of ingredients—most that are effective at relatively low inclusion rates—that enhance pellet durability and quality by increasing particle adhesion (see Table 1-3).

The first pellet binders were clay based, i.e., bentonites (1956). However, clays contributed little to the nutrient content of the diet. By the late 1970s, pellet mill operators began searching for low-inclusion binders, such as lignosulfonates, to conserve space in feed formations for high-performance animals. Lignosulfonates improved pellet durability by 30 to 50%. In addition, lignosulfonates lubricate mash as it moves through the pellet die, decreasing die and roller wear by as much as 25% and increasing pellet mill output by 25 to 20%. Another pelleting aid is phosphate. However, researchers have discovered that not all phosphate sources are equal. Sutton (1979) and Behnke (1981) found that defluorinated phosphate increased pellet output by 30 to 60% compared to dicalcium phosphate.

In the early days of pelleting, feed manufacturers and livestock producers were concerned about the impact of the heat and pressure used in the pelleting process on the nutritional value of nutrients. Many feed manufacturers and livestock producers were concerned that the pelleting would destroy vitamins. Methods such as encapsulation were devised to protect vitamins from the harsh conditions inside the pelleting system (Coelho, 1994). However, as new bioactive non-nutrient ingredients, such as antibiotics, microbials, flavors and enzymes, were included in more feed formations, the effect of pelleting on ingredient viability became a growing concern in the feed industry (Peppler and Stone, 1976; Sorensen, 1996; Waldroup, et al., 2002). Risley (1992) conducted extensive studies on the effects of pelleting on bacteria and yeast cultures. He determined that bacteria cultures of Streptococcus faecium and Lactobacillus acidophilus could not survive pelleting temperatures above 52°C. However, he observed that S. faecium had a higher survivability than L. acidophilus. Yeast withstood the heat of pelleting better than bacteria.

To avoid problems with ingredient destruction in the conditioner and pellet die, many feed mill operators opted to apply heat-sensitive ingredients after pelleting. Post-pelleting application was also an effective strategy for increasing the fat content of the feed without compromising pellet integrity (Payne, 1986). The early post-pelleting ingredient application systems consisted of slowly turning mixers with proportioning systems that dusted dry ingredients onto the surface of the hot pellets. Later systems added pumps that sprayed a mist of liquid ingredients through nozzles onto a sheet of falling pellets. Challenges to the liquid application system included clogged nozzles and over-spraying, which wasted ingredients. An alterative to spray nozzle liquid application systems was developed in the early 1990s. This system consisted of a curved disk that rotated around a vertical axis. Droplets of liquid were applied to the spinning disk and were atomized and dispersed onto a curtain of falling pellets. This system substantially reduced ingredient wastage and the potential for clogged nozzles and applied the ingredients to the pellets more evenly. Later, vacuumized post-pelleting ingredient application systems were developed (Gill, 2000).

Troubleshooting

For many years, equipment designers and feed manufacturers searched for a rapid and meaningful method of testing the durability of pellets. In 1962, Dr. H.B. Pfost at Kansas State University designed one of the first pellet durability testers and testing procedures (Fairfield, 1994). This system involved screening a sample of fresh pellets and placing the sample in a dust-tight square container mounted on a steel shaft. The container was rotated for 10 minutes at 50 revolutions per minute. The sample was removed from the container, screened on a wire sieve to remove the fines and re-weighed. The pellet durability index (PDI) was calculated as the weight of the pellets after sieving divided by the weight of the pellets before tumbling, multiplied by 100. Later modifications of Pfost's system included the addition of steel nuts to the sample chamber. Proponents of this modification argued that it more closely emulated harsh handling conditions.

Almost 20 years later, a new pellet durability testing system—the Holman pellet tester—was developed in the United Kingdom (MacMahon and Payne, 1981). The Holman pellet testing system is a pneumatic, rather than mechanical, method of measuring pellet durability (Behnke, 2001). The Holmen tester used high-velocity air to move the pellets in a perforated chamber to model commercial pellet handling and distribution. The Holman pellet tester yielded consistent pellet durability results. However, these results were lower than the values obtained from the Pfost testing method (Winowiski, 1998). The use of indirect methods for predicting pellet quality has been useful in adjusting pelleting equipment. However, livestock producers were concerned with the direct measurement of fines in their feeders, Behnke emphasized. In 1996, independent pelleting system consultant Joe Gardecki surveyed 39 US feed mill managers who operated a total of 67 pellet mills about problems they had experienced with their pelleting systems (see Table 1-4).

Table 1-4. Common problems with pelleting systems. Data were obtained from a survey of 39 feed mill managers operating 67 pellet mills.

Problem	**%**
Defective steam regulator	23.1
Blocked conditioner steam jets	19.2
Worn conditioner paddles	18.2
Faulty insulation	13.5
Excessive boiler blow-down	5.8
Variations in piping size	4.8
Step-down/undersized steam regulators	3.8
Low total dissolved solids (boiler)	2.9
Pellet cooler malfunction	2.9
Low boiler pressure	2.9
Steam trap and line leaks	2.9

By far, the most problems occurred in the conditioner—steam regulator, blocked jets and worn paddles—and the fewest problems occurred in the boiler/steam supply. An explanation for this difference could have been due to the fact that laws in most states require boiler operators to be licensed and require annual boiler inspections that could detect potential problems. Gardecki also discovered the moisture content of conditioned mash was too low. He said that while optimum mash moisture should be 17.5-18%, he found the actual moisture content averaged 14.5%. During the 1990s, several experts discussed problems frequently encountered in modern pelleting systems. Boerner (1992) emphasized that the durability of high-energy pellets depended on proper starch gelatinization. He also recommended the use of pelleting aids for these difficult-to-pellet formations.

Maier and Gardecki (1993) segregated typical feeds into five categories. Each category has optimum conditioning variables. Dr. Larry Vest at the University of Georgia conducted an extensive survey of pellet mill operators making broiler feeds (Vest, 1993). He determined that factors such as mash particle size, steam pressure and retention time in the conditioner imparted minor—but consistent—effects on pellet output. Fat addition in the mixer had a greater impact on output.

Pelleting expert Bill Enterline of Sprout-Matador presented recommendations for substantially increasing a feed mill's pelleting capacity (Enterline, 1998). He promoted replacing smaller pellet mills with larger (100 tonnes per hour) systems. During the past 100 years, equipment designers, feed manufacturers and livestock producers have learned much about pelleting feed. Pellet mills are larger and more efficient and have higher outputs. The quality of the pellets—and hence animal performance—had been greatly improved due in large part to advancements in technology. However, much work needs to be done in this next century to make pelleting an even greater value to modern animal production.

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