Extrusion and other terminal agglomeration technologies

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Pellet mills and many other feed processing technologies result in an agglomerated or pelleted feed. Recognized advantages of pelleted feed are as follows:

- Increased bulk density;
- Less bridging in bins;
- Less dust;
- Reduced ingredient segregation;
- Less feed waste;
- Increased nutrient density;
- Improved palatability;
- Increased nutrient availability; and
- Decreased microbiological activity.

An alternative to conventional pelleting is the extrusion process. Extrusion may be used either to improve upon an existing process, or to manufacture feeds that a conventional pelleting system cannot. As formulated feeds become more sophisticated to meet the specific physiological needs of the animal and the expectations of the public, extrusion-based processing technologies will continue to be a factor in this industry. Several items key to extrusion such as steam preconditioning, the extrusion process and equipment, process parameters, and final products are discussed in this chapter. Novel technologies, such as the Universal Pellet Cooker (UPC), and the Sphere-izer Agglomeration System (SAS) are also discussed.

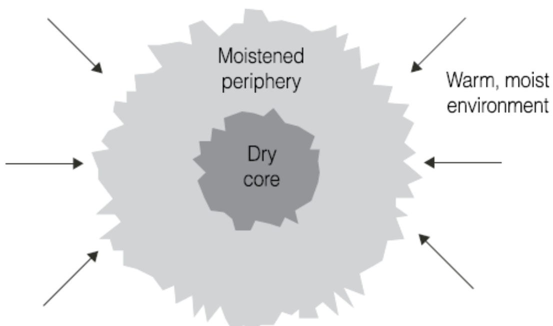
Preconditioning

Preconditioning is an integral part of any pelleting or extrusion system. As one begins to examine alternatives to the conventional pelleting process, they quickly realize the added importance of the preconditioning step. The initial portion of this chapter will not revisit the entire subject of preconditioning; however, it examines the importance of preconditioners for an extrusion-based pelleting system. While the text may only mention one of these pelleting technologies, such as extrusion, the reader should understand that the principles apply to all systems. Preconditioning with steam and water has been associated with extrusion cooking of feed products since the inception of the extrusion cooking process. Extrusion-cooked feed products whose production processes successfully employ preconditioning include petfoods, swine starter diets, full-fat soy, aquatic feeds and other specialty animal feeds.

The preconditioning step initiates the heating process by the addition of steam and water into the dry mash. Uniform and complete moisture penetration of the raw ingredients significantly improves the stability of the extruder and enhances the final product quality. In addition, plasticizing the raw material particles prior to extrusion reduces the wear on equipment caused by the abrasive raw material particles. There are generally two situations where preconditioning should be considered when producing extrusion-cooked and pelleted products. First, it should be used in conjunction with moist extrusion where material is extrusion cooked at in-barrel moisture contents greater than 18%. Second, one should consider using preconditioning in situations where the raw material particles are difficult to hydrate, such as large particles, or non-uniform particle size distributions. In general, any extrusion process that would benefit from higher moisture and longer retention time will be enhanced by preconditioning.

Because preconditioning is recognized as being important to producing premium products and operating an efficient extrusion cooking process, it is important that the basic principles of the preconditioning process are well understood. The three objectives accomplished during the preconditioning process are: hydration of raw material particles; heating of raw material particles; and mixing of materials added to the preconditioner in separate streams. This is accomplished in a preconditioner by holding the materials in a moist, warm environment for sufficient time and with sufficient mixing. This process results in the raw material particles being plasticized by the steam and water in the environment. In practice, the objective is to completely plasticize the raw material particles in order to eliminate any dry core as illustrated in **Figure 2-1**.

Figure 2-1. The objective of preconditioning is to eliminate the unplasticized core in the raw material particles.



Preconditioning hardware and operation

The preconditioners utilized for the extrusion industry are almost exclusively atmospheric preconditioners (i.e., they operate at prevailing atmospheric pressure). Their maximum operating temperature is the boiling point of water at atmospheric pressure (100°C), as further energy input beyond this point will only result in the loss of moisture as steam. Atmospheric preconditioners are relatively simple to construct and have lower manufacturing and maintenance costs associated with them compared to other preconditioner types. The three basic types of atmospheric preconditioners being used in the extrusion cooking industry today are double (DC) preconditioners, differential diameter/differential speed (DDC) preconditioners, and high intensity (HIP) preconditioners (see **Figure 2-2**). The single-shafted preconditioner, as found in most traditional pelleting systems was also utilized to a large extent in the past in extrustion, but the double-shafted conditioners represent today's technology.

Figure 2-2. Types of atmospheric preconditioners.

Double Conditioner

Differential Diameter Conditioner

High Intensity Preconditioner

When compared to the single preconditioners, double preconditioners have improved mixing and have a longer average retention time of up to 1.5 minutes for a similar throughput. As with single preconditioners, they have beaters that are either permanently fixed to the shaft or that can be changed in terms of pitch and direction of conveying. The two shafts of a double preconditioner usually counter-rotate such that material is continuously interchanged between the two intermeshing chambers.

The most recent technology in the industry are the DDC and HIP preconditioners, which have the best mixing characteristics combined with the longest average retention times. Retention times of up to 2-4 minutes for throughputs comparable to those used in double and single preconditioners can be expected. As with a double preconditioner, the two shafts of a differential diameter/differential speed preconditioner usually counter-rotate such that material is continuously interchanged between the two intermeshing chambers. The HIP gives an added layer of control as each shaft has an independent drive. This allows the direction of shaft rotation and speed of the shaft to be varied allowing direct operator control of the residence time and mixing intensity (see **Table 2-1**).

Table 2-1. Effect of Speed on Residence Time

Side A	Side B	Retention Time (minutes)
Speed (rpm)	Speed (rpm)	
100	500	1.00
250	125	1.47
800	50	2.40

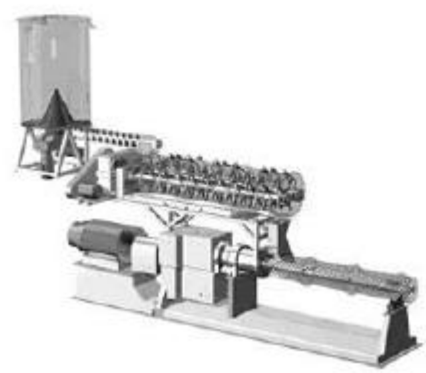
When analyzing the various preconditioner designs, one of the most efficient ways is to compare their coefficient of variation. The increased mixing intensity of twin shafted and variable speed preconditioners compared to other designs yields improved moisture distribution in the material discharging the preconditioner. Table 2-2 lists the average coefficient of variation (CV) of moisture content in four different preconditioner designs. To determine CV after stable conditions were achieved, samples were collected off the preconditioner at 15 second intervals for a 2.5 minute time period and analyzed for moisture content.

Table 2-2. Coefficient of Variation for Moisture Content in Different Preconditioner Designs

Preconditioner Design	CV (%)
HIP	2.65
DDC	4.96
DC (Double Cylinder)	6.66
SC (Single Cylinder)	9.36

The more uniform moisture distribution not only improves extrusion stability for recipes that become sticky when hydrated, but contributes to more consistent destruction of biological contaminates (salmonella) using thermal critical control points. As in traditional pelleting, preconditioners are usually installed above the extruder barrel so that the preconditioned material falls directly into the inlet of the extruder as depicted in **Figure 2-3**. In addition, there are other important installation recommendations for proper functioning of the preconditioning hardware and process.

Figure 2-3. Preconditioner installed above an extruder.



Water and water-based slurry addition

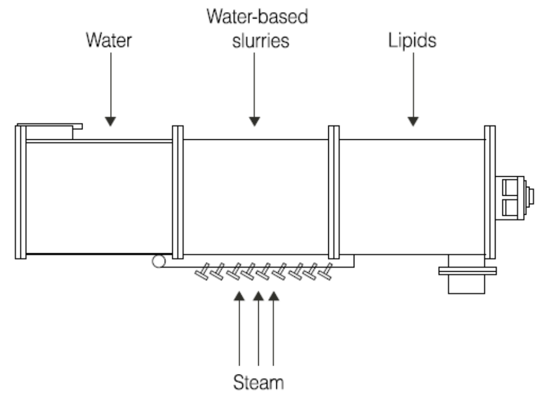
Perhaps the single largest difference between a conventional pellet mill and an extrusion-based system is the internal addition at the preconditioner of water and water-based slurries including colors, fresh meats and molasses. Extrusion processes operate at much higher moisture levels, and thus are capable of handling these additional process streams with ease. Water is added to the preconditioner from the top of the preconditioning chamber close to the raw material inlet. For best distribution of water throughout the raw materials, spray nozzles are used. Other water-based additives such as molasses, digests and fresh meats can be added in conjunction with the water or at any point in the preconditioning process. It is recommended to add these slurries as close to the inlet of the preconditioner as possible to allow for optimal hydration of the dry materials and uniform incorporation of all the added streams. Adding these streams near the discharge of the preconditioner often causes clumping of the material and does not allow enough time for the complete incorporation into the dry mash.

When adding water-based slurries, it is especially critical that the preconditioner be a dynamic mixing device, such as a twin-shafted preconditioner. Low agitation devices, such as preconditioners which utilize tempering screws will not satisfactorily incorporate the slurry into the dry material. The exiting material will often contain clumps of wet product, which causes instability in the extruder's operation. Other preconditioners, such as single-shaft preconditioners, do not have enough retention time to allow the moisture from the slurry to completely incorporate into the dry mash. The relatively short mixing time results in clumps of high-moisture material mixed with relatively dry mash being delivered to the extruder.

Steam addition

Steam should be added to the preconditioning chamber from the bottom of the chamber to ensure contact between the steam and the raw material particles as shown in **Figure 2-4**. Steam pressures should not be higher than 200 kPa (30 psig) to prevent materials from being blown out of the preconditioner. Good engineering practice should be followed in the design and installation of the steam plumbing system to ensure that only steam free of condensate is introduced into the preconditioning chamber. Adequate water separation methods and steam traps should be employed to remove condensate.

Figure 2-4. Introducing materials to the preconditioner.



Lipid addition

Fats are often used to assist with process control. They are typically added in a liquid form as a separate stream. The point of addition is critical to achieve cook, while maximizing the inclusion level of fat. Fat is usually added near the discharge of the preconditioner to allow optimum preconditioning. Fat tends to coat individual feed particles, hindering moisture absorption and the transfer of thermal energy to accomplish gelatinization. If substantial amounts of fat are to be added (15-20%) during extrusion, a portion of the total fat may be injected in the extruder barrel. Extending retention times in the preconditioner is a useful tool to enhance gelatinization in high-fat formulas.

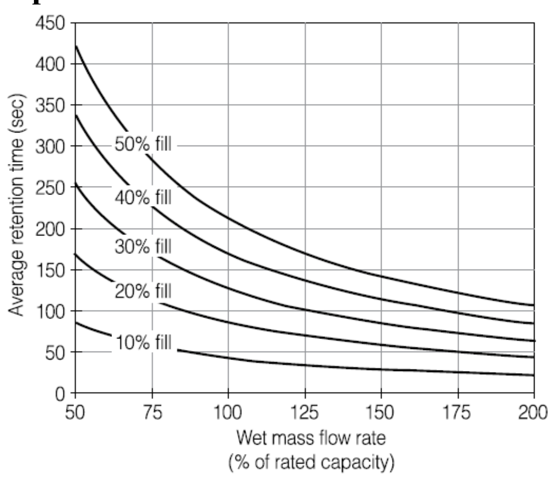
Processing variables

Preconditioning processing variables include dry recipe flow rate; water injection flow rate; steam injection flow rate; additive(s) injection flow rate; preconditioner configuration; preconditioner speed; average retention time; and degree of mixing. This list of variables may be limited by some preconditioner installations and enhanced by others due to the particular options included. Two of the most important processing parameters are average retention time and degree of mixing. These variables are those which really determine how effective the preconditioning process is at meeting the objectives of hydration, heating and mixing.

Retention time

Retention time is required for particles to completely hydrate and to become uniform in temperature and moisture. The average retention time is best measured by first operating the preconditioner at steady state with all mass flows being added. Second, determine the total throughput of the materials through the preconditioner by measurement or calculation. Third, stop all flows and the preconditioner simultaneously. Fourth, empty and weigh the material retained in the preconditioner, and finally, calculate the average retention time using the equation: Retention Time = Mass in Conditioner/Throughput. The average retention time is affected by the dry mash flow rate and the actual paddle configuration. Their effect can best be explained by looking at an example of a preconditioner average retention time "map." This map shows the average retention times obtained from combinations of flow rate and fill factor as shown in **Figure 2-5**. The fill factor is the percentage of the volume inside the preconditioning chamber which is actually filled with product.

Figure 2-5. Example average retention time map for preconditioners.



The fill factor will vary from 5% to 50% depending on the beater configuration, shaft speed and throughput. It is intuitive that configuring additional beaters to convey in a reverse direction will cause additional fill in the preconditioner. Conversely, configuring so that they convey in a forward direction will result in the opposite effect. From **Figure 2-5**, we can see that increasing the throughput for a given fill factor will cause a decrease in average retention time and vice versa. In addition, increasing the fill factor by adjusting the beater configuration at a given capacity will result in increased average retention time. Longer retention times during conditioning can also be achieved by reducing agitator speed, increasing the volume of the conditioning cylinder or decreasing the production rate. These have their disadvantages due to reduced mixing abilities and large, bulky equipment.

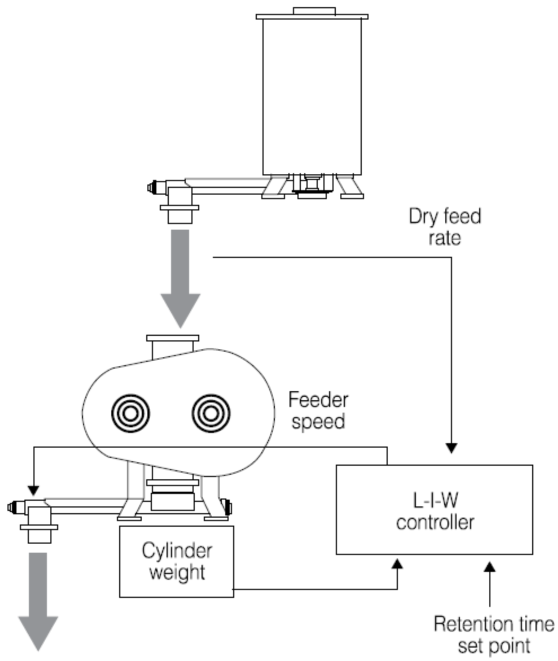
<u>Retention time controlled preconditioners</u>

Another method for controlling the retention time is the retention time controlled (RTC) preconditioner. This system allows the operator to control and adjust the preconditioner retention time on-line. This system gives the operator the following benefits:

- Continuous control of conditioning cylinder retention time.
- Simplified start-up sequence and reduced off-spec product during start-up.
- Constant discharge rate of feed during shutdown or product changeover.
- Increased retention time on current conditioning cylinders.
- Time and temperature documentation for process verification records.

This system requires two key components to be added to a conventional preconditioner. First, a metering device must be mounted at the discharge of the conditioning cylinder. It acts as a "choke" point enabling the conditioning cylinder to be filled to a much higher level. This allows the operator to make use of a greater percentage of the conditioner's free volume. **Figure 2-6** shows an illustration depicting the control schematic for this system. The operator enters the retention time and the desired production rate. Raw materials are metered into the conditioning cylinder by a feeding device. To maintain proper control, this feeding device must operate in a gravimetric mode. The other critical component is that the preconditioner must be mounted on load cells which measure the weight of feed held in the cylinder.

Figure 2-6. RTC preconditioner.



Based on the retention time and feed rate set points, the loss-in-weight (L-I-W) controller sets the discharge feeder speed to deliver the appropriate rate to the extrusion system. This feature allows the process retention time to be adjusted depending on the product characteristics. Some formulations, such as high-fat diets, may require additional retention time to allow for complete hydration of the mash. The retention time is adjusted during the process without the operator needing to shut down and make any hardware adjustments to the beater or paddle configuration. In addition, this feature simplifies the start-up, shutdown and product changeover sequence. It allows better utilization of raw materials and reduces cross-contamination between recipes and products. During start-up, the raw material is metered into the conditioning cylinder and is mixed with steam and/or water to begin the hydration and cooking process. The discharge feeder remains off until the mash within the conditioning cylinder has been held for the desired retention time. Then the discharge feeder begins delivering the conditioned mash to the extruder. This dramatically reduces the material wasted during start-up procedures for standard conditioning cylinders by reducing the amount of mash that must be discarded while waiting for the conditioning cylinder to reach the desired operating temperature and moisture content. During shutdowns or product changeovers, the discharge feeding device continues to deliver the conditioned mash at the specified rate. Thus, the extruder continues operating at its optimum capacity until the conditioning cylinder is virtually empty. In traditional systems, the extrusion rate slowly decreases once the raw mash is no longer metered into the conditioning cylinder. This feature reduces the amount of waste material and the amount of off-spec product produced.

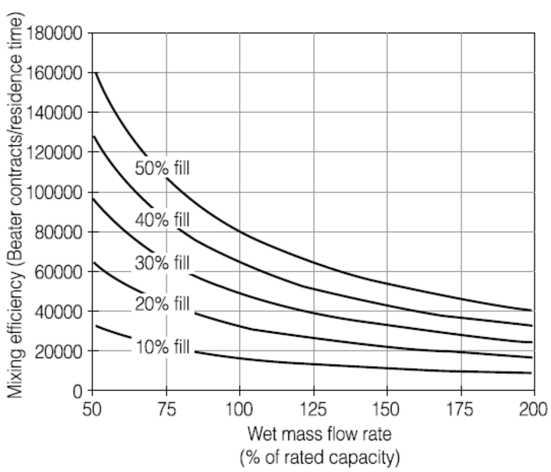
Retrofitting a current conditioning cylinder with the loss-in-weight controls can increase the retention time, and possibly allow an increase in production capacity. Since the discharge device acts as a restriction and allows the cylinder to be filled to a higher level, a current conditioning cylinder that operates with a fill level of 40% may be able to reach a fill level of 60% or even 70%. This would greatly increase the amount of retention time. Also, by more fully utilizing the conditioning cylinder's volume, an increase in production capacity may be realized if there are not downstream process restrictions. Finally, this system allows process documentation of the times and temperatures the mash was subjected to during processing. This is especially useful for those concerned with pathogen destruction and food safety. Since the retention time is one of the user inputs for the control system, the operator can document with certainty that the mash was held at a given temperature for a specified period of time.

Although a loss-in-weight conditioning cylinder offers many benefits, it is not required for all situations. In situations where long production runs on a single product occur, the additional cost for this system may not yield sufficient economic benefits to offset the additional capital costs. However, for those systems in which frequent product changeovers occur, or wide variation in raw materials exists, the additional capital investment could quickly be recouped from the reduction in product waste, increased product quality and increased product capacity.

Mixing

Adequate mixing is essential to the preconditioning process. This is especially true for those processes in which slurries such as fresh meat are added. If effective mixing is not present, individual particles may tend to agglomerate, and thus increase the effective particle size. This increases the resistance to energy and moisture transfer into the raw material particles. The particles end up with a wetted surface and a dry center which leading to an inferior product and an increase in extruder wear. In cases where slurries are added and poorly mixed in the preconditioner, clumps of wet product will be evident at the discharge and can plug the inlet of the extruder.

Figure 2-7. Mixing efficiency for a preconditioner.



The mixing mechanism in the preconditioner is complex and not well understood (Levine, 1995). It is also difficult to obtain a physical measurement of mixing efficiency in a continuous mixing device such as a preconditioner. However, a quantitative measure of mixing can be calculated to help understand the process, as well as to give a comparison between preconditioners of differing design. The degree of mixing can be expressed as the number of times the beaters in the preconditioner contact the material while it is in the preconditioning chamber. The beater contact frequency is essentially controlled by shaft speed and the number of mixing elements on those shafts. This measure of beater contacts per residence time is affected then by both shaft speed and average retention time. A map can be drawn that indicates the effect of degree fill and throughput have on the mixing efficiency of the preconditioner, as shown in **Figure 2-7**. In certain instances, operators often reduce the preconditioner shaft speed in an effort to increase the degree of fill, and therefore gain retention time for their process. However in doing this, one should also be aware that decreasing the preconditioner shaft speed can significantly decrease the mixing efficiency.

Results of proper preconditioning

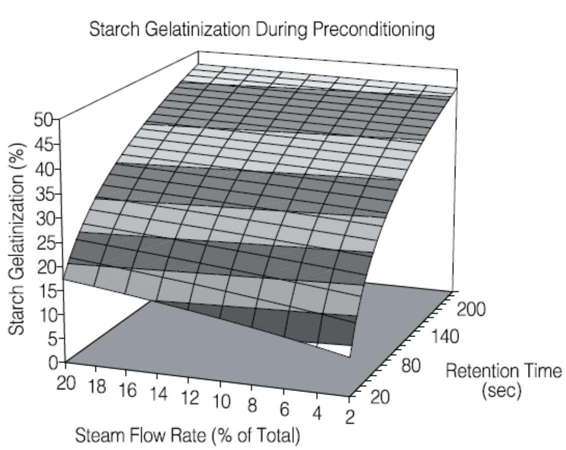
When the three essential objectives (hydration, heating and mixing) of preconditioning prior to extrusion are adequately satisfied, several results should be expected. First, in the area of machine life, preconditioning will increase the life of wear components in the extruder barrel by several times. Second, in the area of extruder capacity, preconditioning has proven to increase the throughput of the extrusion system. Third, in the area of product quality, preconditioning assists in altering product textures and functionality. Finally, adding preconditioning to the extrusion process enhances product flavor.

Un-preconditioned raw materials are generally crystalline or glassy, amorphous materials. These materials are very abrasive until they are plasticized by heat and moisture within the extruder barrel. Preconditioning prior to extrusion will plasticize these materials with heat and moisture by the addition of water and steam prior to their entry into the extruder barrel. This reduces their abrasiveness and results in a longer useful life for the extruder barrel and screw components. Extruder capacity can be limited by many things, including energy input capabilities, retention time and volumetric conveying capacity. While preconditioning cannot overcome the extruder's limitations in volumetric conveying capacity, it contributes to energy input and retention time. Retention time in the extruder barrel can vary from as little as 5 seconds to as much as two minutes, depending on the extruder configuration. Average retention time in the preconditioner can be as long as 5 minutes. For some processes, the energy added by steam in the preconditioner can be as much as 60% of the total energy required by the process.

The raw material particles should be thoroughly hydrated and heated to eliminate the dry core present in the center of raw material particles prior to entering the extruder barrel. This leads to more efficient cooking of starch and protein. This results in more complete starch gelatinization and protein denaturation. Theoretical principles of heat and mass transfer indicate that hydration usually takes 2-8 times longer than does heat penetration.

A measure of the effectiveness of a preconditioning process is to examine its effect on key constituents of the recipe being preconditioned. One key constituent is the level of starch gelatinization as measured by the susceptibility of the starch to enzymatic conversion to glucose (Mason and Rokey, 1992). It has been well documented that starch gelatinization requires three basic elements: Elevated temperature, moisture content and time. Because the amount of gelatinized starch has a proportional relationship with the amount of heat exposure, it can be used as an indicator of the final pellet quality.

Figure 2-8. Effect of steam addition and total retention time on cook.



A well-designed and properly-operated preconditioner is capable of routinely cooking from 30-40% of the starch present in a given formulation, and under certain situations the cook level can approach 70%. A study was conducted in which the retention time and steam addition level were varied and percent starch gelatinization was measured as a response. The results of the study (**Figure 2-8**) indicate that increased retention time results in increased starch gelatinization, and that the first 120 seconds of retention time are the most important. Increasing the amount of total steam injection also increased starch gelatinization, but at sufficient retention time, additional steam injection above 10% had little additional effect on starch gelatinization.

Pathogen and toxin destruction

An additional area in which preconditioning is becoming important, is in producing pathogen-free feed. Research has proven that proper conditioning of the feed prior to final processing can eliminate pathogens such as *E. coli*, *Salmonella* and *Listeria*. If the discharge temperature of the mash exiting the conditioning cylinder reaches 72ºC, *Salmonella* can be destroyed (Fung and Hoffman, 1993). This work is further supported by the data in **Figure 2-9**. These curves, if extrapolated, indicate that all three pathogens would be destroyed if a temperature of at least 80ºC is reached.

Figure 2-9. Thermal death curves for *E. Coli*, *Salmonella* and *Listeria*.

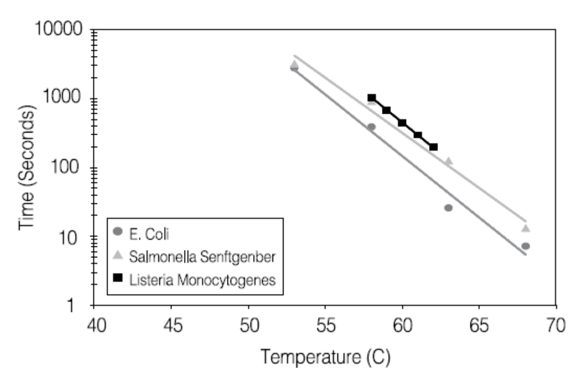


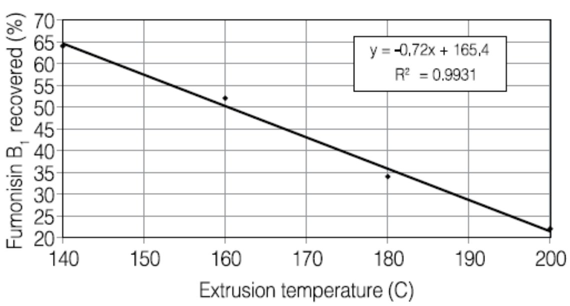
Table 2-3 also illustrates the ability of the DDC preconditioner to destroy the pathogenic organisms. However, notice that the feed was not sterilized as the total plate count (TPC) was not completely eliminated. While many processing technologies result in an agglomerated feed, only a few have sufficient energy inputs to ensure food safety. Food safety is a major factor in choosing extrusion-based methods over traditional pelleting methods.

Table 2-3. Effect of preconditioning on microbial populations (Rokey, 2001).

Microbe	Raw Recipe	After DDC
TPC, CFU/g	240,000	9,300
Coliform	22,600	< 10
Mold count	54,540	< 10
Clostridium	16,000	< 10
Listeria	Positive	Negative

Extrusion is a hydrothermal process where the critical process parameters of retention time, moisture and thermal and mechanical energy inputs can be varied over a wide range. Although extrusion does not completely eliminate toxins and other anti-nutritional or anti-growth factors, in many cases these substances or their activity are reduced to permit some level of incorporation into the recipe. Research at the University of Nebraska indicates that certain temperatures of extrusion are sufficient to reduce fumonisin levels (see Figure 2-10; Katta, *et al.*, 1999). Studies have also indicated that viruses, molds and other pathogenic organisms can be destroyed by the operating parameters employed during extrusion. However, very little published data are available on this subject, and there is a need for carefully-designed studies to investigate the effects of the extrusion process.

Figure 2-10. Effect of extrusion temperature on fumonisin levels.



Extrusion

The extrusion process can generally be divided into two basic categories: Cooking extrusion and forming extrusion. Both processes affect the feed as the name indicates. Cooking extrusion elevates feed temperature to a level that often results in an expanded product (final feed bulk density less than the bulk density of the starting raw materials).

Forming extrusion is usually a low temperature (often called cold-forming) process that increases product bulk density and cools the feed, resulting in a feed bulk density that is equal to or greater than the bulk density of the starting raw materials.

Ingredients

Raw material preparation for extrusion and related processes is very similar to that required for pellet mill installations. Individual whole grains are pre-ground to reduce particle size and then mixed with the balance of the recipe. Different from many pelleting systems, in extrusion processes the mix is then passed through a final post-grind step to achieve the desired particle size and distribution. The effect of a smaller, raw material particle size on product appearance is clearly evident in the extruded samples in **Figure 2-11**.

The correct particle size is important for many reasons:

- Improved product appearance;
- Reduced incidences of die orifices plugging;
- Greater ease of cooking; and
- Improved retention of liquid coatings due to smaller cell size in the final product matrix.

Figure 2-11. Photograph of extruded products. Sample on the left was ground through a 0.8 mm hammermill screen opening prior to extrusion. The sample on the right was ground through a 1.2 mm hammermill screen opening prior to extrusion.

A guideline to follow in grinding recipes prior to extrusion is to select a hammermill screen with holes being one-third the size of the extruder's final die orifice. Adhering to this guideline will ensure that all recipe particles will easily pass through the extruder die orifice without danger of plugging or partially plugging the orifice. A sifting device is often inserted into the process flow between the grinder and the extruder to remove all foreign material and particles that are larger than the die orifice. It is critical in the extrusion process to avoid plugging of die orifices, as product is actively flowing through all orifices simultaneously. In a pellet mill, active product flow occurs only where the rolls are forcing or "pressing" the recipe through the die ring. Several openings can plug in a pellet mill die and little capacity is lost. The total die open area in an extrusion application is typically much less than the pellet mill process and any reduction in die open area directly impacts throughput and product quality.

The grinding step for an extruder follows the guidelines discussed above, and usually precedes a sifting operation to remove foreign material and large particles. A magnet is usually installed prior to the grinding step in all feed mill process flows to remove tramp metal. It is recommended to also include a magnet just prior to the extrusion or pelleting process to prevent accidental metal from the grinding operation from damaging the equipment components.

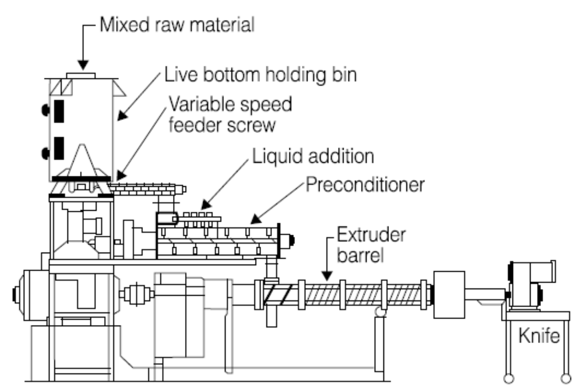
A major difference in process flows occurs after the extrusion or pelleting steps. Extruded products usually contain more moisture than pelleted products. This moisture must be removed in a drying step if moisture is greater than 12-15% by weight of the extruded product. The higher moisture levels required for most extrusion processes can lend versatility to the process and expand the feed manufacturers' product possibilities. Ingredient flexibility is an important tool for feed millers in that it allows the opportunity to take advantage of a wide variety of ingredient sources. The more positive conveyance features of an extrusion system permit the use of wet, sticky ingredients. The high-temperature/short-time extrusion cooking process is able to accommodate a wide range of raw materials that might otherwise be discarded as unqualified material. Pellet mills are limited to 15-18% process moisture to avoid plugging of the roll and die components. Wet byproducts and other high-moisture ingredients can be utilized in the extrusion process at levels up to 60%. The functionality of pellet mills is usually drastically reduced if the fat levels in the recipe exceed 5%, while extruded products have been processed with internal fat levels as high as 25%.

The pelleting process depends largely on starch and other binding agents to give durability to the final product. Mild operating parameters in the pelleting process yield low levels of starch gelatinization. Gelatinization increases the binding properties of the recipe starch. The extrusion process gelatinizes more of the starch present and thus binding is increased. This often reduces the level of starch required in an extruded feed compared to the levels required in pelleted feeds for product binding and structural strength. Extrusion provides flexibility in formulating for product characteristics such as pellet quality. An increasing number of requests come from various industries to process material currently classified as waste streams. The intent in many scenarios is to utilize these materials as a feed or feed ingredient.

Hardware components

An extrusion system includes a live bin/feeder, preconditioner, extrusion cooker and die/knife assembly as shown in **Figure 2-12**.

Figure 2-12. Extrusion system.



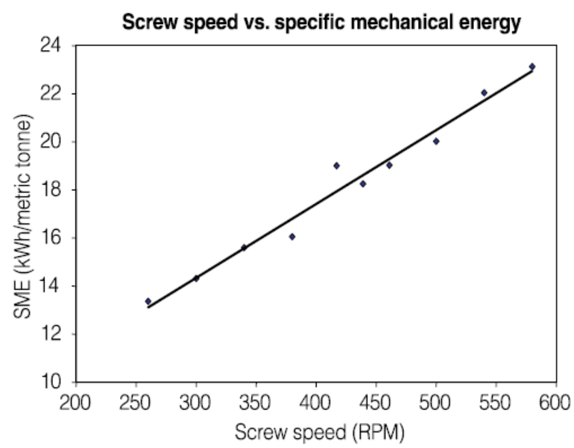
Each component is designed to accomplish a specific function in the process of cooking and forming feed products. The operating conditions can be adjusted to vary the characteristics of the finished product.

The live bin/feeder provides a means of uniformly metering the raw materials into the preconditioner and subsequently into the extruder. This flow of raw material must be uninterrupted and the rate controlled. The live bin/feeder controls the product rate or throughput of the entire system. Variable-speed augers or screw conveyors can be used to volumetrically meter ingredients into the system. These same devices can be designed and manufactured to act as loss-in-weight (gravimetric) feed systems by mounting the bin/feeder assembly on load cells and continuously monitoring its weight. Preconditioning hardware, an important and necessary step in extrusion of feeds, is discussed in depth earlier in this chapter.

As the material leaves the preconditioner, it enters the extruder barrel. Here the major transformation of the preconditioned material occurs which ultimately determines the final product characteristics. The initial section of the extruder barrel is designed to act as a feeding or metering zone to convey the preconditioned material away from the inlet zone of the barrel and into the extruder. The material then enters a processing zone where the amorphous, free-flowing material is worked into dough. The compression ratio of the screw profile is increased in this stage to assist in blending water or steam with the raw material. The temperature of the moist dough is rapidly elevated in the final few seconds of dwell time within the extruder barrel. Most of the temperature rise in the extruder barrel is from mechanical energy dissipated through the rotating screw. It may be assisted by the direct injection of steam or from external thermal energy sources. The screw profile may be altered by choosing screw elements of different pitch or with interrupted flights, or by adding mixing lobes configured to convey either in a reverse or forward direction. All of these factors affect the conveying of plasticized material down the screw channel and therefore the amount of mechanical energy added via the screw.

As shown in **Figure 2-13**, the extruder screw speed is also an influential variable for controlling mechanical energy input. This influence of extruder speed indicates the advantage of installing a variable-speed drive on an extruder. Steam injection into the extruder is also a contributing factor to cooking extruded feeds. This additional energy input results in capacity increases, more tolerance for high-fat levels in the formulations and reduced requirements for large drive motors. Moisture addition in the form of water or steam and a properly-configured extruder barrel could result in a final pressure of the extrudate prior to the extruder die of 34-37 atmospheres, a temperature of 125-150°C and a moisture content of 23-28%.The three types of extruders most common in the feed industry are the single-screw, co-rotating twin-screw and conical co-rotating twin-screw extruders.

Figure 2-13. Effect of screw speed on specific mechanical energy.



<u>Single screw extruder</u>

The single-screw cooking extruder (see **Figure 2-14**) has been the “heartbeat” of dry-expanded petfood and other feed industries for over 40 years. The screw and barrel configurations represent many years of analytical design, research and comprehensive testing.

Figure 2-14. Single-screw extruder.

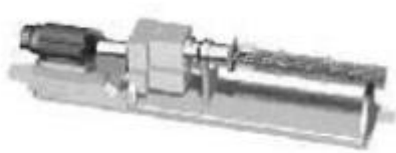
A better understanding of the interaction between the machine and materials has led to the development of screw and barrel geometries for single-screw extruders that are more efficient in converting mechanical energy to heat through friction.

These screws have increased volumetric capacity, permitting higher levels of steam injection into the heads. For both single-screw and twin-screw extruders, screw elements of single or multiple-flight geometries may be used. Single-flight elements generally yield products of higher bulk densities compared to double-flight screws when operating with the same extrusion parameters. The barrel segments may also be ribbed to alter the function of each specific extruder segment.

Twin-screw extruder

Twin-screw cooking extruders (see **Figure 2-15**) have typically found limited utility in the production of feeds. The major drawback of these extruders is their high capital investment and their higher relative costs of maintenance and operation. The capital equipment cost of a co-rotating twin-screw extruder is 1.5 to 2 times the cost of a state-of-the-art single-screw extruder with comparable hourly production capacity. Because of the increased costs, only those feed products with strong value-added potential are processed via the twin-screw extruder.

Figure 2-15. Twin-screw extruder.



Specific product characteristics or processing requirements where twin-screw extrusion systems have found applications are as follows:

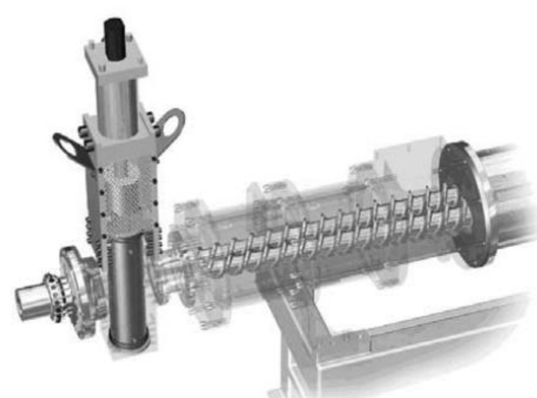
- Ultra-high fat feeds (above 17% internal fat).
- Products which have high levels of fresh meat or other high moisture slurries (above 35%).
- Uniform shape/size product (portioned foods).
- Ultra-small products (0.6 to 2.0 mm diameter products).
- Co-extruded products (complex petfood treats).

As fat levels in a formulation are increased above 15%, it becomes increasingly difficult in a single barrel extruder to transmit mechanical energy from the screws into the product. Fat actually provides lubricity and reduces friction within the extruder barrel. However, through more positive transport provided by the two intermeshing screws, the co-rotating twin-screw permits internal fat levels approaching 25% while maintaining a cooked product. While it is true that single-screw extruders process formulations containing up to 20% fat, product consistency is more easily maintained in the twin-screw system. The positive conveyance factor maintains die pressure, product expansion and textural development (Rokey, 2004).

C^2TX extruder

The C^2TX (conical co-rotating twin-screw extruder) is the most recent extrusion system introduced to the feed industry (see **Figure 2-16**).

Figure 2-16. Conical co-rotating twin-screw extruder.



The C^2TX's conical design allows for positive compression in the barrel and reduces possibility of back feeding. Positive compression yields an efficient manner of imparting mechanical energy into the extrudate. The conical design of the C^2TX causes the material to be kneaded and sheared along the screw profile. In traditional twin-screw extruders, the melt is kneaded and sheared by shear locks, mixing lobes or cut-flight screw elements. The "profile kneading" present in the C^2TX design eliminates the need for such special screws and locks to provide the appropriate cooking. Therefore, the extruder shafts and screws can be machined from a single piece of steel. The result is a lower manufacturing cost of the screws and reduced maintenance and downtime, since a screw profile change is not needed for each different product. The C^2TX design provides the possibility for a feed manufacturer to more economically process those feeds requiring twin-screw extrusion attributes.

Die/knife design

The extrusion chamber is capped with a final die which serves two major functions. The die provides restriction to product flow, causing the extruder to develop the required pressure and shear. The final die also shapes the extrudate as the product exits the extruder. Die design and its effect on expansion, uniformity and appearance of the final product are often overlooked. The amount of expansion desired in the final product can be controlled by formula manipulation and open area in the die. Unexpanded, but fully-cooked feeds generally require 550 to 600 square millimeters of open area per metric tonne of throughput. Highly-expanded feeds require 200 to 250 square millimeters of open area per metric tonne throughput.

Final dies may be as simple as single plates with a pre-determined number of sized round openings, or they may consist of two or more plate elements. The first plate element of a two-piece die serves to increase the resistance to flow and to aid in imparting shear to the extrudate. The second die plate in a two-piece die is used to size and shape the extrudate by forcing it to flow through a number of orifices. Very high shear rates are experienced by the extrudate as it flows in a radial direction between the two die plates. Typical products made on two-piece dies are light-density snacks or treats for pets and are not applicable to most feed products. Spacers may be added between the extruder barrel and the final die plate to even out the flow from the extruder screw to the final die plate and give additional retention time for cooking.

Other design advancements in die configurations have resulted in "rapid change multiple dies," where dies can be changed without stopping the extrusion system. This design reduces set-up time by up to 50%, resulting in smaller lot sizes, easier scheduling, reduced inventory, increased plant efficiency and increased profitability (Rokey and Aberle, 2001). A face cutter is used in conjunction with the die, which involves cutting knives revolving in a plane parallel to the face of the die. The relative speed of the knives and the linear speed of the extrudate result in the desired product length. The blades of the knife run in very close proximity to the die face, and in the case of spring-loaded blades, may actually ride on the surface of the die. Knife blade metallurgy, design, positioning relative to die face, speed and extrudate abrasiveness determine their life.

Many feed extrusion applications require changing or re-sharpening blades every six to eight hours. This is especially critical with intricate shapes. Dull blades distort the product shape and increase the number of "tails" or appendages on the product which later are broken off in drying and handling, resulting in fines. Final product characteristics can be controlled by the extruder or die configuration selected for processing feeds. However, feed millers prefer not to lose production time by having to change the extruder configuration to modify specific product characteristics such as final product bulk density. There are other hardware tools that can be used to control product bulk density. Four tools that are available to the industry include the following:

- Vented extruder barrel with or without vacuum assist;
- Separate cooking and forming extruders where the product is vented between the two units;
- Restriction device at the discharge end of the extruder; and
- Pressure chamber at the extruder die.

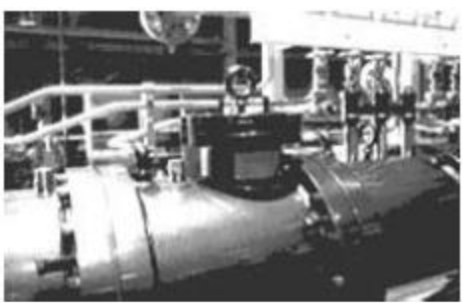
Vented extruder barrel

The extruder barrel is normally closed to the atmosphere and the extrudate is subjected to an environment of increasing pressures until it exits the die orifice. The high process pressures (0 to 40 bar) result in significant expansion ratios and product densities low enough to produce feeds such as floating aquafeeds. Expansion can be further enhanced by injection of steam into the extruder barrel, which increases thermal energy inputs. Feeds with high bulk densities are preferred for several reasons such as:

- Reduced transportation costs;
- Aquatic feeds that are sinking in fresh and sea water; and
- Increased product bin capacity within a feed mill.

Where higher product densities are required for certain feeds, the extruder barrel can be configured to include a vent which releases process pressure and reduces product temperature through evaporative cooling (see **Figure 2-17**).

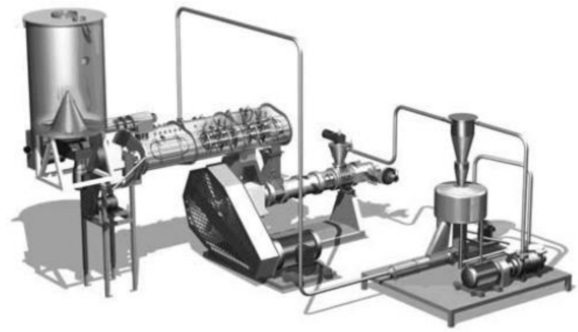
Figure 2-17. Extruder with vented barrel.



A vacuum assist can be added to the vented barrel (see **Figure 2-18**) to increase the product density even further by more evaporative cooling and de-aeration of the extrudate. Vacuum assist (up to 0.7 bar) will improve pellet durability, increase piece density and reduce extrudate moisture. Disadvantages of a vacuum-assisted, vented extruder barrel include the following:

- Increased investment for hardware;
- Potential capacity of extruder reduced 25-50%;
- Disposal of product fines from vent and water from vacuum pump (waste streams can recycle back into the system as shown in **Figure 2-18**);
- Control of SME (specific mechanical energy) inputs are reduced.

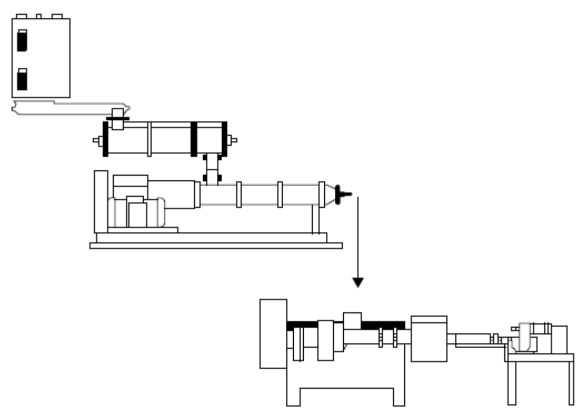
Figure 2-18. Vented extruder barrel with vacuum assist.



Separate cooking and forming extruders

Another hardware tool utilized by the feed manufacturers to control product bulk density is a dual extrusion process (see **Figure 2-19**). In this process, the first extruder is used in solo for the production of expanded feeds, or it can be used as a cooking extruder for the two-stage cooking/forming process. The second, forming extruder (product densification unit, or PDU) is used only when processing very dense feeds, such as fast-sinking aquafeeds.

Figure 2-19. Dual extrusion process for cooking and densification.

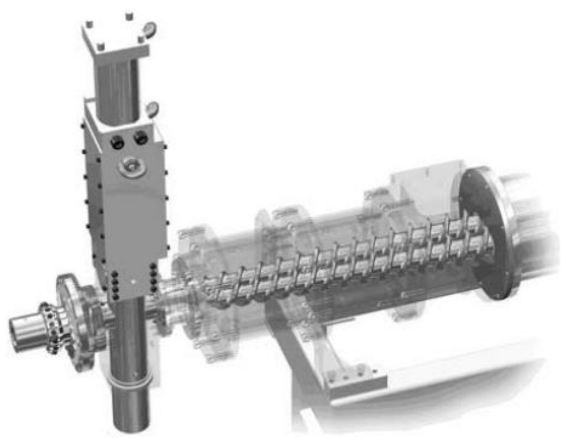


This processing system has the advantage of being able to operate both extruders at their maximum rate potential. When only one extruder is used to produce a very dense pellet, the extruder may have to be operated at lower throughputs to prevent expansion. Adding the second forming extruder (PDU) can allow a feed manufacturer to produce a wide range of feed densities from highly-expanded feeds with one extruder, or very dense feeds with the cooking extruder and PDU.

Back pressure valve

Final product characteristics such as density can be controlled by extruder die restriction. One device commonly used by feed manufacturers is termed a "back pressure valve" (BPV) which is used to adjust die restriction while the extrusion system is in operation. By changing the restriction at the discharge of the extruder during operation, the product density can be varied by up to 25% without changing the screw configuration or the final die. The BPV mounts on the end of the extruder prior to the final die assembly (see **Figure 2-20**).

Figure 2-20. Back Pressure Valve



Specific mechanical energy (SME) and extrusion pressure are process parameters controlled by the valve positioning. The BPV provides internal control of shear stress and SME for regulation of important product properties:
• Bulk density (see **Table 2-4**);
• Size and uniformity of cell structure;
• Starch gelatinization;
• Shape definition; and
• Water and fat absorption (see **Table 2-4**).

Table 2-4. Controlling feed density with the BPV.

Back Pressure Valve, % Closed	Extruder Speed Index	Uncoated Product Density, g/L	Final Product Oil After Vacuum Infusion, %
45	1.0	654	16.2
55	1.0	628	19.5
65	1.0	530	23.8
65	1.3	504	28.4
70	1.2	420	37.8
70	1.3	392	40.5

The extrusion process for feeds is reported to be more stable with a BPV, and preconditioning/extrusion process temperature requirements are lower, resulting in improved nutrient retention. The BPV eliminates the need for altering extruder configurations between different product families. An integral part of the BPV is a bypass feature to divert product from the die/knife assembly and product conveyor for service and start-up/shutdown procedures, which improves sanitation in this area.

Post-extrusion pressure chamber

Another device available in the industry is an enclosed chamber which surrounds the die/knife assembly and permits control of pressure external to the extruder and die (often referred to as an external density management system, or EDMS). Desired pressures are maintained in the die and knife enclosure by a special airlock through which the product discharges. Compressed air or steam can be used to generate the required pressure in the chamber. As pressure increases, the water vapor point increases and reduces product "flash-off expansion," and thus increases density (see **Table 2-5**).

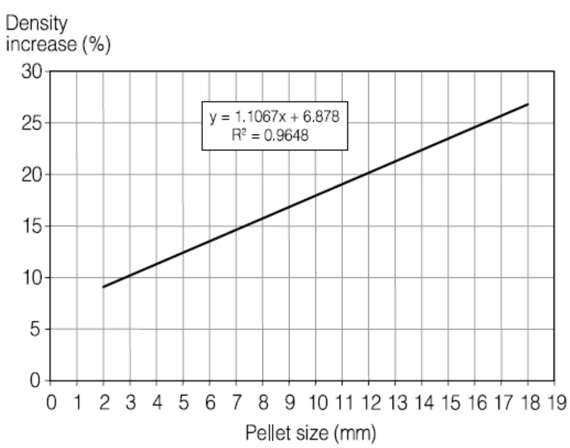
Expanded or partially-expanded products which normally exit the extruder die at a bulk density that is lower than desired, can be "densified" with this post-extrusion pressure chamber (EDMS) around the die/knife assembly. One particular challenge in the aquatic feed industry is to produce a fully-cooked feed of sufficient bulk density to sink rapidly and still absorb the required oil during the coating step.

Table 2-5. Effect of increasing pressure in die/knife chamber.

Over-Pressure in Chamber, Bar	Boiling Point of Water, °C	Expected Increase in Product Density, %
0	100	0
0.5	112	10.0
1.0	121	18.3
1.5	128	25.0
2.0	134	28.3

The level of product density increase expected from over-pressure in the EDMS depends on several factors. For example, as the feed pellet size (diameter and mass) decreases, a given pressure in the chamber results in a lower density increase, as illustrated in **Figure 2-21**.

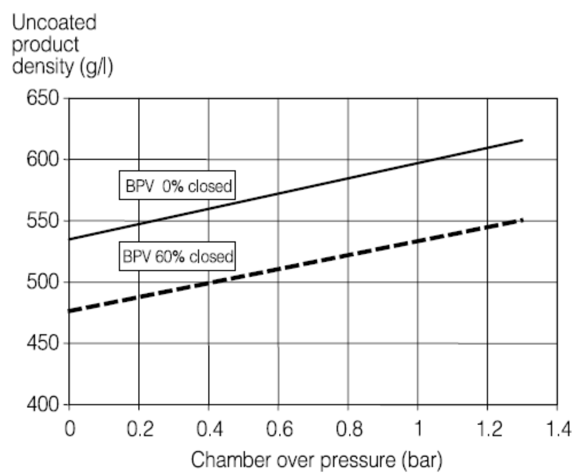
Figure 2-21. Density increase for various pellet sizes at constant chamber pressure.



The pressure chamber can be coupled with a BPV to provide additional process control such as the ability to adjust SME on-line for control of critical product properties, divert off-spec product during start-up from the pressure chamber, accurately control of product density external to the extruder and die and no extruder configuration changes required to make expanded or dense feeds, or increase extruder capacity over vented configurations by 25-50%.

The combined impact of a pressure chamber and a BPV is illustrated in **Figure 2-22**. The BPV can be used as an independent tool to alter product density and other critical properties, or can be used in conjunction with a pressure chamber to further alter product density over a wide range. The hardware tool of choice to manage product bulk density depends on the process application. Each tool has advantages and disadvantages, and these must be evaluated in light of the process requirements. For example, for very small diameter pellets (<3mm) that contain high levels of starch, such as a high-carbohydrate shrimp feed, the processing system of choice may be the combination of a cooking extruder followed by a forming extruder (PDU).

Figure 2-22. Effect of chamber pressure and BPV closure on bulk density of 8 mm feed pellets.



Because the pellet diameter is small the EDMS system may increase the density only 8-10%, and because the starch level is high the vented head approach and EDMS may have more difficulties with the sticky nature of the recipe. Another advantage of the PDU system in this scenario is the higher capacity potential. Disadvantages of the PDU system are the total, initial capital costs for this system, which are partially off-set by the greater capacity potential. A further disadvantage is the reduced stability of the pellet in water, which may or may not be a critical requirement for other applications.

Process parameters

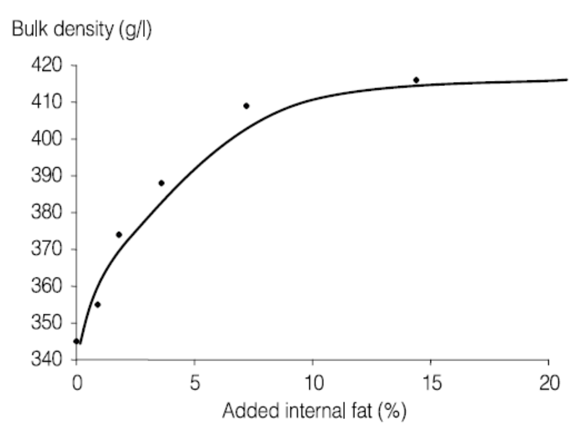
Extrusion and similar agglomeration techniques have been utilized to process various feedstuffs for many years. Extrusion cooking is universally recognized as a high-temperature/short-time process. The higher temperatures employed during the extrusion process present an interesting challenge in the assessment of nutrient retention. During extrusion, the recipe and its constituents are subjected to a succession of almost instantaneous treatments or unit operations.

These variables include moisture and temperature profiles, extruder configuration, extruder speed and preconditioning of the material prior to extrusion. The critical process parameters could be summarized into four areas—specific mechanical energy, specific thermal energy, retention time and product moisture.

The following process parameters are utilized to control product characteristics such as bulk density:

- Internal and/or external fat levels;
- Specific mechanical and thermal energy inputs; and
- Extrusion moisture.

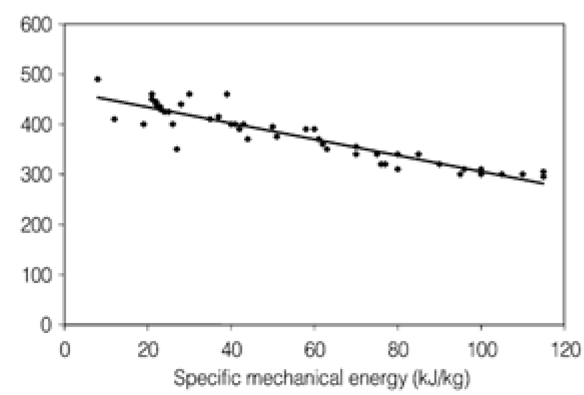
Figure 2-23. Effect of internal fat on product density.



Nutritional requirements dictate the levels of total fat required in most feeds. The total fat levels can vary from 3% to greater than 40% in some aquatic feed diets. As the fat level increases, there is an expected increase in the bulk density of the feed. In one study conducted at the Wenger Technical Center, an aquatic diet containing 60% fishmeal, 24% soybean meal and 16% wheat was extruded at six internal fat levels. The internal fat level was adjusted by continuously injecting fish oil into the preconditioning phase of a single-screw extrusion system at 0%, 0.9%, 1.8%, 3.6%, 7.2% and 14.4%. As the added internal fat level during extrusion increased, the bulk density of the final product increased significantly (see **Figure 2-23**).

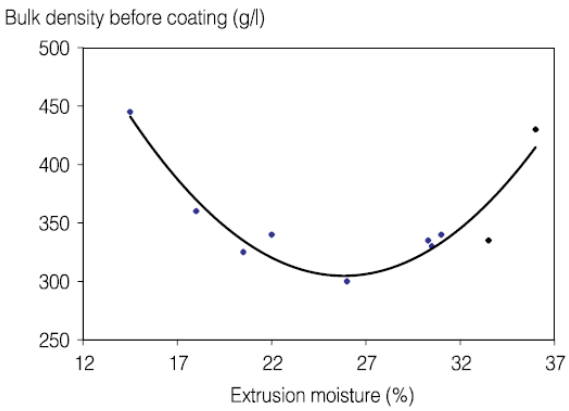
As internal fat levels increase, durability decreases. There is a remarkable decrease in durability when the total fat level of the extrudate exceeds 12%. Fat added in the extruder has a lubricating effect and reduces mechanical heat dissipation and starch gelatinization. Fat also weakens the product matrix and thus reduces the pellet strength. However, extrusion processes have been used to produce feeds of up to 22% internal fat, while pelleting processes are limited to 4-5% fat. Energy management is essential in controlling bulk density of feeds. As energy inputs increase during extrusion, the bulk density decreases. **Figure 2-24** indicates the correlation between specific mechanical energy inputs and the final bulk density of the extruded product.

Figure 2-24. Effect of specific mechanical energy on extrudate bulk density.



Extrusion moisture is also an important process variable for controlling final product density. Low extrusion moistures yield products with high densities. As extrusion moisture increases, the product density trends lower. The higher moisture levels facilitate starch gelatinization, resulting in product expansion. As the extrusion moisture continues to increase past a critical level, the product will begin to increase in density. Ultra-high moisture levels decrease the viscosity of the material in the extruder barrel and make it more difficult to expand the product. The moisture/density curve (see **Figure 2-25**) is specific for each product.

Figure 2-25. Effect of extrusion moisture on product bulk density.



The adjustment of process parameters, as described previously, can be used to control bulk density, but may unfavorably impact other process parameters such as system capacity. However, various hardware tools described earlier are available to process feeds to the desired bulk density while allowing optimum process parameters, such as extrusion moisture, to be employed. A summary of operating parameters of various pelleting, extruded and agglomerating processes is necessary to evaluate and compare the processes. The addition of expanders to pellet mills was intended to further improve pellet quality. Expanders represent additional energy inputs to pelleting by increasing product temperature. Three to five percent steam is usually injected into an expander, in addition to the mechanical energy generated by the main drive motor, to achieve 90 to 130ºC product temperature inside the expander. Product discharging the expander is usually 70 to 80ºC and contains 16-18% moisture (Heindreich and Eberhard, 1994).

To heat product sufficiently to gelatinize the starch and to reach pasteurization temperatures requires a given amount of energy, depending on the efficiency of the processor and the ability of the process to transfer energy inputs to the product. Large electrical motors are used to drive expanders, and up to12 kWh per metric tonne of product is required for the expander process alone. Reported improvements to pellet quality by coupling an expander to a pellet mill have been inconsistent. This may be due to recipe characteristics such as high internal fat levels, but much of this is due to the low moisture levels employed during processing. Extruders and expanders have general similarities in design and function, but they are not the same. Even within the extruder family, there are many not-so-subtle differences that have a major impact on the characteristics of the end product. Extruders can be broadly classified as dry or moist and as single- or twin-screw.

Dry extrusion usually implies process moistures of 18% or less, while moist extrusion generally processes recipes at levels above this moisture level. Dry extrusion does not employ preconditioners, and is therefore limited in its ability to process a wide range of raw materials. The similarities between dry extruders and expanders are very striking, and close examination of the principles involved and effects on final products reveal only subtle differences. Expanders are usually quoted at much higher capacities than dry extruders. This is made possible by imparting less energy into the product per unit of throughput. This fact is reflected in the typical cook values of cereal grains processed through each system. Extrusion imparts more thorough processing of feeds compared to pellet mills or a pellet mill/expanders combination. The major difference is due to the use of more steam and higher levels of moisture (moist extrusion) in the extrusion process. Moist heat is generally regarded as more effective in gelatinization of starch, denaturation of protein and pasteurization of products. Differentiation between dry and moist extrusion is summarized in **Table 2-6** (Hancock, 1992).

Retention time in the extruder barrel can be as low as 12 seconds, and it is this principle of high-temperature/short-time processing that has made extrusion an effective processor of individual ingredients and complete diets in feed manufacturing.

Table 2-6. Variations in complexity and capacity of extruder types.

Extruder Type	Output	Versatility
Single-screw (dry extrusion)	Low	Low
Single-screw (moist extrusion)	High	Moderate
Twin-screw (moist extrusion)	High	High

Post-extrusion processing

For most "dry" feeds, the final moisture content needs to be less than 12% to prevent mold and bacterial growth. Final products with moistures above 12% are sometimes referred to as semi-moist products. This group of products may have moisture levels greater than 30% and represent a category of products that cannot be processed on pellet mills. When considering a soft-moist product, one needs to determine the water activity of the product. Water activity is the critical factor in determining the lower limit of available water for microbial growth. In general, if the water activity of a product is less than 0.65, no microbial growth can occur.

Drying and cooling

The primary purpose of drying is to reduce the level of moisture in an extrusion cooked product. Many extruded products exit the extruder die at moisture levels above 18%, which necessitates product drying for shelf stability. In some cases, the drying process can involve additional heat treatment of the product. One example of this is the drying at elevated temperatures to impart a "baked" or "toasted" flavor and appearance to the product. As mentioned earlier, many feeds are best processed at extrusion moistures between 23-28%. Some of the moisture is lost due to flash evaporation as the superheated product exits the die and expands. Further moisture will be lost through evaporative cooling, as the product cools during conveying or when a cooling step is employed. Pellet coolers will generally result only in a reduction in moisture levels of about 3% and further reductions in moisture levels require a drying step. Pneumatic conveying of products from the extruder to the dryer inlet reduces product moisture content 1-2%. Pneumatic systems help separate sticky products that tend to clump with belt conveyors and improve sanitation around the extruder die.
The two types of dryers used for most feed products are conveyor and vertical style dryers (Plattner, 2001).

Final product applications

Many of the advantages claimed for agglomerated or pelleted feeds are really due to the form in which the feed is presented to the animal, and the fact that the feed has been subjected to a heat treatment. The relatively dry treatment employed during pelleting followed by a pressing step yields a final pellet matrix that may deteriorate during transportation and handling. The process flexibility and the processors' philosophy toward total quality management are the greatest factors in pellet quality.

Low-moisture or dry extrusion has been utilized in the feed industry for many years. Although applications have usually been limited to extrusion of dietary ingredients such as full-fat soy, extrusions of complete diets without a pellet mill have been employed. Extrusion has been used to process the following feeds:
- Full-fat soybeans and other high-oil ingredients;
- Piglet feed and calf starters;
- Hygienic feeds for poultry;
- Protein bypass feeds for ruminants;
- Aquatic feeds;
- Petfoods; and
- Feeds containing high levels of wet byproducts.

Full-fat soy

Full-fat soybeans are thermally processed to destroy anti-nutritional factors and to increase oil availability, while preserving the nutritional quality of the protein. The major anti-nutritional factor of concern in raw soybeans is a trypsin inhibitor. Trypsin inhibitor is a protease that is harmful to most animals and humans, and nutritionists have documented this effect conclusively. This protease enzyme can be inactivated by heat treatment. A reduction of at least 85% of the trypsin inhibitor units is considered necessary by feed technologists to avoid nutritional problems (Schumacher). Pellet mills are unable to process full-fat soya due to the high levels of fat (18-20%) indigenous to soybeans. Expanders are capable of destroying 70% of the trypsin inhibitor by processing at 120ºC. In comparison, moist extrusion destroys up to 95% of the trypsin inhibitor through heat treatment. Higher moisture during heat processing results in more efficient destruction of the trypsin inhibitor and urease activity (McNaugton and Reece, 1980). Additionally, full-fat soybeans can be moist extruded to destroy over 95% of the trypsin inhibitor without damaging lysine (Mustakas, *et al.*, 1964). Evidence indicates that "dry" heat processing is not as successful as extrusion in enhancing subsequent nutritional value of raw full-fat soybeans. It may be concluded that any processing treatment involving moisture tends to have a beneficial effect. Thus steam (moist) extrusion tends to result in higher subsequent nutritive value than dry extrusion and dry roasting (Wiseman, 1990).

Pasteurization and Salmonella control

The feed industry is acutely aware of the possibilities of food-borne illnesses related to microbial contamination—which can occur at any point along the food chain. This is an especially important consideration for animal foods/feeds entering the home, such as petfoods. As early as 1965, widespread testing indicated that moist extrusion was much more effective than pelleting in *Salmonella* control (see **Table 2-7**).

Table 2-7. Effect of extrusion and pelleting on *Salmonella* destruction.

	Extruded	Pelleted
Number of Samples	775	35
Process Temperature, °C	95-120	60-85
Process Moisture, %	25-35	11-19
Salmonella positive, %	0	60

Ruminant feeds

Processing the concentrate portion of beef and dairy rations through expanders and extruders has not been the subject of many studies. However, reports indicate moist extrusion of high-fat dairy feeds increased palatability and milk production by over 2.0 kg per day when compared to the same diets being pelleted (Castaldo, 1995). Extruded feed processing costs were higher, but still netted a 2:1 return on the added feed cost. Several patents exist for extrusion processing of feedstuffs to increase the protected or bypass protein contents. Soybean meal is extruded in combination with rapeseed meal or cottonseed meal under specific process parameters to yield a protein supplement. The moist heat treatment denatures protein, which escapes large-scale degradation in the rumen and thus serves as a protein source for digestion in the abomasum (ruminant stomach).

Complete diets

Complete diets for livestock, such as piglet feeds, calf starters and grower and finishing diets for poultry and swine have been successfully extruded. Moist, extruded swine finishing diets were compared to mash diets in a Texas A&M University study. The studies indicated a 13% improvement in feed efficiency with the moist extruded diet (Herbster, 1991). The extruded diets did not increase the incidence of ulcers or hyperkeratotic activity in slaughtered animals. Moist extrusion and similar agglomeration technologies have been used to produce aquatic feeds for many years. Feeds for shrimp and other aquatic species are among the most expensive feeds on the market today. These diets usually contain high-quality ingredients that are highly digestible and of a high nutrient density. Moist extrusion using single- or twin-screw designs are the most common method of processing aquatic feeds. Feeds are processed to various bulk densities depending on the species being cultured:

- Floating (carp, tilapia, catfish);
- Slow-sinking (trout, salmon yellowtail); and
- Sinking (shrimp, river crab, cod).

Extrusion permits sinking and floating diets via density control that is not possible with pellet mills. Factors that affect product density include the following:

- Starch and soluble protein contents of the recipe;
- Thermal and mechanical energy inputs during

preconditioning and extrusion; and
• Extrusion moisture and retention time.

Aquafeeds are extruded in a wide range of pellet diameters ranging from 0.5 to 60 mm. Single-screw extruders can produce pellets as small as 1.2 mm, while twin-screw designs can extrude pellets as small as 0.7 mm. Extrusion is now preferred over pelleting as the processing method of choice for aquatic feeds because extruded products retain their shape longer in water, exhibit less leaching of nutrients in water and have fewer fines resulting from transportation and handling. There is a strong connection between feed management and the environment with intensively-raised species. Poor quality feeds that are not stable in water can have detrimental effects on water quality and this often results in poor performance, disease and high mortality rates.

The greatest majority of petfoods are processed via extrusion cooking. Petfood categories include dry-expanded, semi-moist, soft-expanded and pet treats. Petfoods are extruded to:

- Render the starch components digestible by cooking;
- Satisfy the physical requirements of density, size and shape;
- Pasteurize the recipe components; and
- Impart desirable textures, flavors and colors.

Dry Expanded Products

The dominant position of dry-expanded petfood in the market is evident in the fact that it comprises the largest share (over 60%) of sales volume. These petfoods usually contain 8-10% moisture and are processed from cereal grains, cereal byproducts or their derivatives, soybean products, animal products, milk products, fats and oils, minerals and vitamin supplements. Dry dog and cat foods usually contain 5-13% and 8-12% crude fat on a dry basis, respectively. Palatability is improved by the higher fat levels and is usually achieved by spraying liquefied fat and/or flavor enhancers on the surface of the final products. Crude protein contents (dry basis) of dry-expanded dog foods are usually 18-30% and, for dry-expanded cat foods, 30-36%.

The ingredients are blended and ground to pass through a 1.2 mm or smaller hammermill screen and fed into the extruder for final transformation into a cooked chunk of whatever size or shape that may be desired. Typical extrusion processes will incorporate some means of conditioning the material with both steam and water as it passes through the extrusion system. In addition, the material will become gelatinized by means of friction, shear, temperature and pressure within the extruder barrel chamber.

Upon exiting the die orifices located on the discharge end of the extruder barrel, the now visco-amorphic mass will expand upon being subjected to atmospheric pressure, will be shaped and sized by the orifice of each die opening and will be cut to a desired length by means of a rotating external knife-cutter device. The injected steam and water (moisture) that have been added to the product must be removed. Typical extrusion moistures of dry-expanded petfood products will range from 22-28%, and that moisture level must be reduced to final moisture of 8-10% prior to packaging or storage. That process is usually accomplished by means of some type of continuous dryer with a separate cooler or a dryer/cooler combination. It should also be noted that typical dry-expanded products will possess a wet bulk density of 352-400 grams per liter prior to drying and 320-352 grams per liter after drying.

Semi Moist Products

The second petfood category is semi-moist products. Semi-moist products are typically extrusion cooked through an extrusion process similar to those utilized with dry-expanded products. There are distinct processing differences and variations in formulation that differentiate semi-moist from dry-expanded products. Semi-moist products involve many of the same basic ingredients as dry-expanded products. In addition to the dry grain mixtures, some sort of meat or meat byproduct liquid slurry is often blended with the dry ingredients prior to extrusion. Ratios of dry-to-wet ingredients will vary from one manufacturer to another, and exact proportions are generally considered to be proprietary information.

Unlike extrusion-cooked dry-expanded products, it is not the intention to “expand” semi-moist products at the extruder die but, rather, to "form" a strand or a shape that is similar in size and shape to the die orifice. The intention is to gain as much cooking as possible during extrusion. Generally, it is not possible to expand the product a great deal due to the higher levels of fats and oils associated with the meat portion of the mix, but when the extruder barrel is properly configured, it is possible to fully cook the mass within the extrusion chamber.

Another major difference between semi-moist and dry-expanded petfood products involves extrusion moistures and final processing to handle those moisture levels. Typical semi-moist products are extruded in the range of 20-30% moisture. Preservatives are included in the ingredients to provide shelf stability, and since it is most desirable for the final product to be soft (similar to meat), the moisture in the product is not removed following extrusion or prior to storage. Bulk densities of both the wet stages of semi-moist products as well as the packaged final stages differ greatly from typical dry-expanded products. Wet densities of semi-moist products will range from 480-560 grams per liter, with final densities very much in the same range, since moisture removal is not required.

Soft expanded products

The third petfood product category is soft-expanded products. This category represents an innovative product type that is similar to semi-moist products. Both products often contain a relatively high percentage of meat or meat byproducts and are typically higher in fats and oils than dry-expanded products. Meat-type ingredients may be introduced into the extruder by either of the means previously mentioned under the semi-moist category. They differ from semi-moist products in that they take on the expanded appearance associated with dry-expanded products after they are extruded. Alterations to equipment required to convert a dry-expanded petfood system to semi-moist production are also required in order to produce soft, expanded-type products.

With soft, expanded-type products, the basic extrusion process is similar to that of dry, expanded products in that conditioning with steam and water must take place prior to extrusion, and the end product is expanded at the die. However, the ingredient characteristics are similar to those of semi-moist products and the final product, although expanded, is soft and pliable, much like real meat.

Semi-moist and soft, expanded dog and cat foods contain moderate levels of moisture (25-32% on a wet basis). Due to the elevated moisture contents, semi-moist and soft, expanded petfoods are stabilized and protected from spoilage without refrigeration. Preservation systems are built into the formulation to adjust the final product water activity (Aw) to a level (0.60 to 0.8) where the growth of microorganisms is prevented or greatly reduced. The Aw is lowered by humectants (sugars, syrups, salts and polyhydric alcohols such as propylene glycol). These petfoods are further stabilized by adjusting the pH to levels (4.0 to 5.5) that are too low to support many microorganisms. The recipes also prevent mold growth by the inclusion of an antimycotic agent such as potassium sorbate.

Common ingredients in this category of petfoods include animal products, milk products, fats and oils, soybean products, cereal grains and their byproducts, marine products, minerals and vitamin supplements. Semi-moist petfoods are heavier in bulk density and usually contain fresh animal products while soft, dry products usually contain dehydrated animal products and possess bulk densities similar to dry-expanded petfoods. Formulations usually reflect dogs' preference for sweetness and cats' preference for acidic flavors.

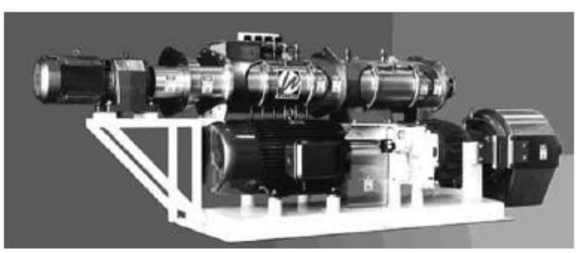
Snacks and Treats

The final market category involves those products often referred to as snacks or treats for pets. These products usually take the shape and appearance of real bones; however, there are other snack-type products for pets that come in a biscuit or variety of other shapes. In recent years, more and more producers of those types of pet snacks, as well as would-be producers of those types of petfood products, are investigating the potential of extrusion cooking. The primary reason for the interest is the potential cost savings that may be realized from the short-time/high-temperature of the extrusion cooking process, the high thermal efficiency of extruders, the floor space saved by the process and reduced labor costs may make production of such products more profitable. A typical extrusion snack petfood system would utilize the same basic principles and equipment arrangements of a typical semi-moist extrusion system. In some instances, a dry-expanded system can be applied to the production of pet treats or snacks. The primary differences would include the final die and cutting apparatus designed for producing a relatively large piece, such as a bone, biscuit or wafer.

Universal Pellet Cooker (UPC)

A patented UPC cooking system and process (see **Figure 2-26**) is an extrusion-based pelleting system (Wenger, 1997; Wenger, 1999). It was designed specifically for the production of livestock feeds; but because of its design, can also be used to make other extruded products such as aquatic feeds and some petfoods. It appears to be more effective, efficient and versatile than the traditional pelleting systems, such as the expander plus pelleting press that are currently used. The UPC also allows the processor to utilize many raw materials that do not process well in a conventional pellet mill, such as those which contain high fiber or high levels of sugar.

Figure 2-26. Wenger Universal Pellet Cooker®.



However, the UPC needs to be considered as an alternative to rather than a replacement of the conventional pelleting process since, from an economic standpoint, it will probably never directly compete in the production of large-volume, low-margin pelleted feeds. Its unique design gives special processing advantages to producers who use raw materials that vary significantly, have high levels of internal oil or high lactose levels. The UPC should also be considered in cases where the animal performance is enhanced by this high-temperature/short-time process.

Raw material specifications

Every feed production facility manufactures a broad range of products. These can include several different diets for a single species (integrators) or several different diets for many species (commercial mills). Broad product assortments require a vast number of available ingredients to meet the nutritional requirements of each specific diet. Since the number of possible ingredient combinations is endless, and selection is normally based on least-cost formulations, demographics or nutritional value, the formulations may change frequently. Therefore, proper attention must be taken to ensure high-quality pellets are consistently produced. Ingredient grind (mean particle size) and formulation play a major role in producing high-quality pellets. These factors similarly affect the UPC as they do other pelletizers.

Many researchers have studied the importance and effect of particle size reduction on animal performance. They have tried to determine the "optimum" particle size to achieve maximum growth rates. The optimum size varies for each species, age group and selection of ingredients. Researchers have found that the common thread in particle size reduction is that a smaller mean particle size will improve animal performance due to an increased surface area available for enzymatic attack. However, there are limitations to how fine one can grind feed before health of the animals becomes a concern.

Not only is particle size reduction important for animal performance, but it is also very crucial for pelleting. Coarse grinds create voids and fractures in pellets, making them sensitive to handling and presumably to end up as fines at the feeder. Evaluating particle size is commonplace in most feed mills. Particle size is usually determined by performing a sieve analysis. The feed particles are separated by size, weighed and the mean particle size is calculated based upon a log-normal distribution. **Table 2-8** shows an example sieve analysis.

If the maximum particle size or foreign matter in the feed is larger than the die opening, it is possible that the opening can be plugged or partially blocked, resulting in a change of appearance of the pellets. In cases of severe blockage, the pelleting die will need to be cleaned before normal operation can proceed. As a rule of thumb, when the desired pellet diameter is 4 mm or less, the suggested maximum particle size should be one-third the diameter of the opening. For larger diameter pellets, the grind size should be less than one-half of the die opening size.

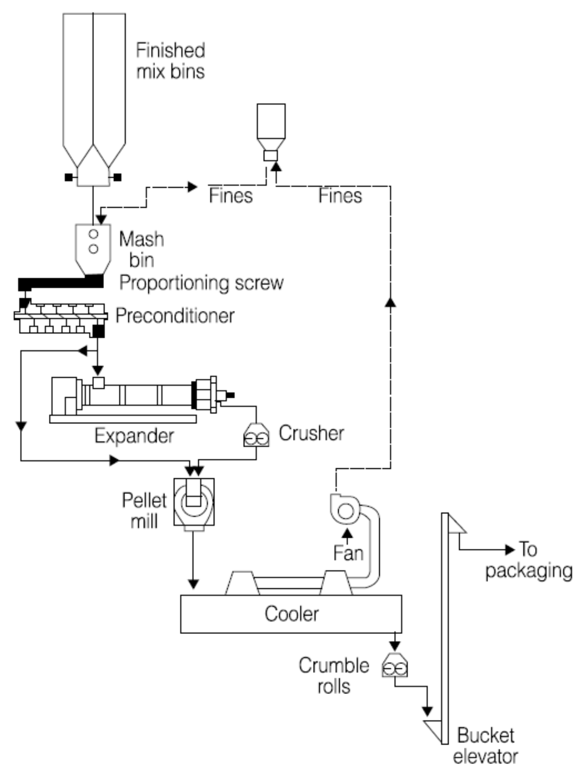
Table 2-8. Example particle size distribution. Three mm grind; sorghum-based ration.

US Sieve	Weight, g	Weight, %
12	0.03	0.02
16	1.64	1.20
20	27.21	19.88
25	43.29	31.64
30	40.33	29.47
40	17.09	12.49
Pan	7.25	5.30
Total	136.84	100.00

The UPC system, which utilizes the natural binding qualities of the ingredient formulations to their fullest extent, does not depend on the use of non-nutritive binding agents to produce a durable, high-quality pellet. These natural binding elements of the raw material are starch, protein and fiber. Starch portions of the mix hold the greatest binding capability. In most formulations enough starch is present to produce the desired pellet durability without giving much consideration to the other two elements.

Starch possesses a unique ability to lose its crystalline structure and becomes a viscous gel during processing. This allows it to disperse through and around structures of other origins. This loss of crystallinity is known as gelatinization. Upon exiting the UPC and cooling, the starch returns to a crystalline state, resulting in a durable structure. Between 50-80% of the starch fraction in most diets can be gelatinized during processing. Protein, like starch, can also function as a binder. Protein denaturation is the modification of a protein's three-dimensional structure when exposed to high temperatures. This three-dimensional structure is modified when the proteins are subjected to mechanical and thermal energy. The re-association, which aligns the protein molecules, occurs during laminar flow and forms a rigid structure. However, not all sources of protein are good binders. Those sources with low amounts of pre-processing, such as some types of blood plasma meals, contain "functional" protein, which has a greater binding ability than heavily processed sources such as meat and bone meal. Functional proteins are those that are not already denatured.

Figure 2-27. Expander-pellet mill flow diagram.

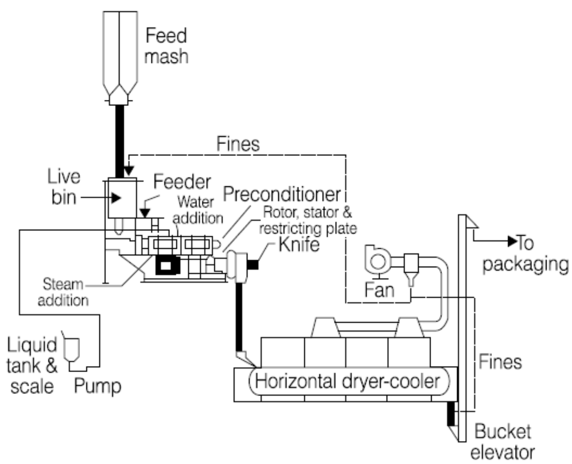


Most sources of fiber strengthen pellets by "melting." The re-association of the lignin present in fiber gives binding power to the pellet. It takes much higher processing temperatures to melt lignin than it does to gelatinize starch or denature protein. Therefore, its influence is often only low to moderate in binding ability; yet high-fiber diets will typically form very durable pellets.

Hardware requirements

Processing principles of the UPC are different from the expander and pelleting press. One machine is designed to do the job of the conventional two. A rotor and stator cook the feed similarly to an expander; however, the feed is formed into dense pellets rather than expanded chunks. With fewer pieces of equipment required and less space needed, the process flow is simplified. **Figure 2-27**, as compared to **Figure 2-28**, shows how the UPC can easily adapt to existing manufacturing facilities without costly modifications.

Figure 2-28. UPC flow diagram.



Preconditioning

The UPC system utilizes an initial cooking zone so that the system depends less on mechanical energy and more on thermal energy. This initial cooking zone, known as preconditioning, is a prerequisite for the production of quality pellets. A previous section of this chapter covers the importance of preconditioning.

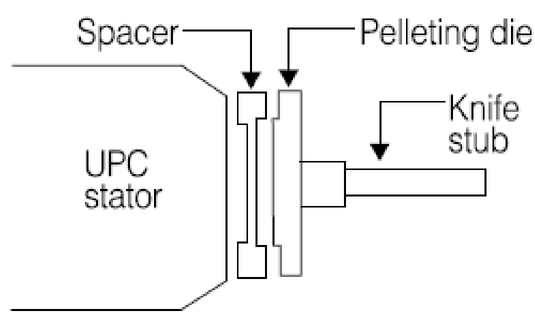
Rotor and stator

The rotor and stator are designed to convey feed through a restricting plate, build pressure and increase the product temperature. The increased temperature is the result of mechanical energy input or shear. This aids in the cooking of raw materials. The rotor consists of a segmented-flighted shaft designed to increase the internal product temperature very quickly. Each segment of the rotor can be removed and replaced according to wear of that particular part. Since the whole rotor does not need replacement, the wear cost is lowered considerably. The stator also consists of segmented parts. Each stator segment has a wear sleeve that requires replacement as needed. It is uniquely designed to aid in the forward conveying of raw material. Shear bolts or stop bolts, which are common in expanders and need frequent replacement and maintenance, are not required for the UPC. These components are designed quite similar to the barrel and screws of an extruder.

Pelleting die

A pelleting die is required to restrict the flow of material and provide the cylindrical shape of the pellet. The number of orifices in the die is determined based on the desired capacity, raw material formulation and final product specifications. Changeover time of various dies is kept to a minimum due to their comparative light weight. When a raw material formulation contains significant amounts of lipids, modifying the pelleting die can increase the pellet durability. **Figure 2-29** shows how a die spacer can be installed between the stator and the die. This additional length increases the retention time of the raw material inside the stator; in turn increases the amount of shear on the product; and thus creates a more durable pellet.

Figure 2-29. UPC pelleting head assembly.



As the pellet leaves the die, a variable-speed rotary cutter controls the pellet length. For example, by increasing the cutter speed, short pellets and crumbles are produced; and by reducing cutter speed, longer pellet lengths are produced. This flexibility eliminates the need for crumbling rolls to produce a crumbled feed.

Cooling/drying

Because heat and moisture are added during processing, extra equipment is required to lower the temperature, remove moisture, prevent mold growth and prolong storage life. This is one of the most significant differences between the UPC process and a traditional pelleting process. The UPC generally operates within the same moisture constraints as other pelletizers. Exit moistures reach a maximum of 18%. This requires a cooler capable of driving off at least 3-6% moisture to achieve final moistures of 12% or less. The pellets must also be cooled within 10°C of ambient temperature. In situations where a conventional cooler will not provide adequate moisture removal, a dryer will be required. A more complete discussion of the drying and cooling requirements appear later in this book.

Process Impacts

To this point, both thermal and mechanical energy have been loosely defined, but it is important to understand how these process variables affect the UPC process. Production of quality livestock feed depends on many processing variables. Pasteurization and production of durable pellets require the addition of steam and/or water in the preconditioner to increase product moisture from 14-18% and a temperature of 70-90ºC. The shear provided by the rotor, stator and the pelleting die can elevate the product temperature to 110-150ºC depending on the die configuration and ingredient formulation.

Pasteurization

The UPC system offers two opportunities to pasteurize pelleted feed products. The first stage is the DDC preconditioner. As previously mentioned, the DDC is capable of holding the feed for up to two minutes and can reach temperatures of 90-95ºC. This combination of temperature and retention time will destroy many microbial populations.

The second opportunity to destroy microbes is in the rotor and stator. The technological concept behind the UPC differs somewhat from the currently-used methods of heat treatment processes. Other methods depend on high-temperature/short-time (HT/ST™) processing, meaning the feed spends a relatively short amount of time (i.e., 20-30 seconds in an extruder and 15-25 seconds in an expander) at conditions of high temperature and high pressure. However, the UPC utilizes high-temperature/micro-time (HT/MT™) processing. This means that the feed spends a much shorter amount of time under these conditions, usually 3-4 seconds and still reaches temperatures of 115-150°C. This ability to cook feed quickly ensures that heat-sensitive nutrients such as vitamins and amino acids are handled more delicately to prevent degradation. However, harmful microorganisms, such as Salmonella, can be completely destroyed.

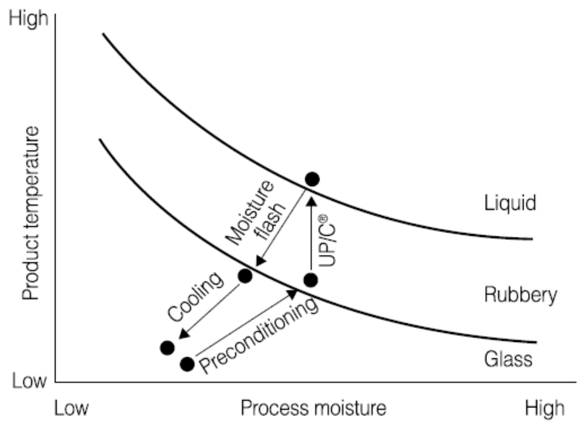
Table 2-9. Nutrient retention and microorganism destruction. Source: Wenger Technical Center Test Data. (1996).

Sample	Vitamin A, IU/kg	Lysine, %	Mold count, CFU/g
Raw Material 1	8,580	0.70	300,000
Processed Sample 1 Lot 1	12,320	0.71	< 10
Processed Sample 1 Lot 2	13,046	0.72	< 10
Raw Material 2	9,042	0.70	300,000
Processed Sample 2 Lot 1	14,278	0.71	< 10
Processed Sample 2 Lot 2	14,190	0.72	< 10
Raw Material 3	n/a	1.36	500,000
Processed Sample 3 Lot 1	n/a	1.41	40

Table 2-9 shows retention of various heat-sensitive nutrients and destruction of microorganisms in feed produced on the UPC. In each case, none of the nutrients were degraded, but the detrimental microorganisms were destroyed. Table 2-14 indicates the results of expanding plus pelleting on

vitamin retention. This data show that the expander does partially destroy some vitamins.

Figure 2-30. State diagram of the UPC process (Strahm and Plattner, 2001; Strahm and Plattner, 2000).

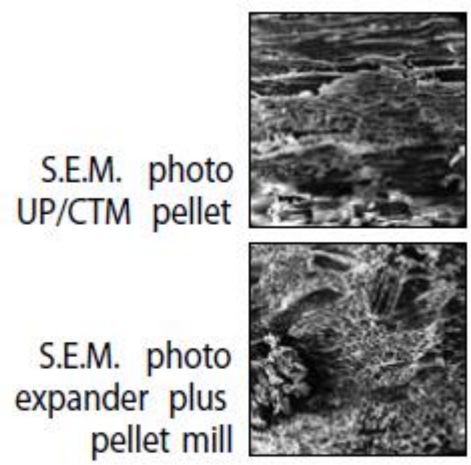


<u>Pellet Durability</u>
The ability for the UPC to produce an extremely durable and dense pellet is illustrated in **Figure 2-30**. This graph shows how the raw material viscosity changes inside the preconditioner and stator as energy and moisture are added. When energy inputs are sufficient and the product temperature moves above the glass transition temperature (T_g), major components of the raw material, such as protein and starch, transform from a highly viscous, glassy state into a rubbery dough. This change begins to occur in the preconditioner.

As the temperature continues to rise inside the stator, the product reaches its melt transition temperature (T_m). When a product is heated above its T_m, the rubbery mass's viscosity declines quickly and becomes a fluid (Strahm, Plattner, Huber and Rokey, 2000). The reduction of viscosity allows the raw material to pass through the orifices of the die with relative ease at low moisture and pressure (i.e., 200-900 psi). Upon exiting the pelleting die, the pellet's temperature declines and some moisture flashes from the surface of the pellet. The pellet returns to a glassy structure. This re-association and hardening of the melt can be witnessed when examining hot pellets exiting the pelleting die. At this point, the pellets seem fragile but after cooling they become very strong and durable. Since each feed mix has a different T_g and T_m, each feed formulation will process somewhat differently.

To help understand the T_g phenomena, consider the feed mix as a mass of wax. At room temperature it is in a crystalline state and breaks when one tries to bend it. As the wax is heated it becomes pliable. The temperature at which the wax begins to show a considerable amount of flexibility could be considered as its T_g. Continuing to heat the wax will eventually convert it into a fluid, so the temperature at which it fluidizes can be considered its T_m. **Figure 2-31** shows photos of a pelleted feed made using a conventional expander plus pellet mill process and one from the UPC system, magnified with a scanning electron microscope. Notice the laminar structure that develops with the UPC process. This structure provides superior strength over the expander plus pelleted product.

Figure 2-31. Scanning electron micrographs of pelleted feeds.



Final product characteristics
Every livestock producer has different ideas for what the appearance and quality characteristics of feed should be. These specifications include: Pellet size, bulk density, durability, fines content, moisture and other various considerations. These product specifications can be controlled by the independent processing variables of the UPC, which include the following:
• Feed delivery rate;
• Knife speed;

• Steam;
• Water;
• Pellet die configuration; and
• Recipe formulation.

Pellet size can be easily controlled. The possible pellet diameters range from 2-18 mm and adjustments are made by a quick and easy replacement of the pelleting head. The pellet length can be varied to any size or even into crumbles when desired by adjusting a variable-speed cutter and/or varying the number of knife blades. Bulk density can also be controlled and varied during operation. However, pellet diameter and length do have a significant effect on the density range. As the diameter and length increase, the bulk density decreases. Typically the bulk density of UPC pelleted feeds is about 550-650 grams per liter. The raw material affects the finished product density to the greatest extent. High-fiber diets tend to have the lowest raw material densities; therefore, one cannot expect to achieve the same finished product density as a feed high in protein or starch. Durability is probably the most important characteristic of pelleted feed. Consumers expect the most durable pellets possible. Poor pellet durability results in the generation of fines. Durability can be predicted by determining the pellet durability index (PDI), which gives reference to how well pellets hold their integrity during packaging and handling (McEllhiney, 1994). The UPC, however, typically produces pellets with a PDI of over 95%.

Benefits of the UPC

The UPC has shown advantages over pellet mills and expanders in several feeding trials with poultry, swine and dairy cattle. **Table 2-10** shows the advantage of a UPC for poultry. Those animals fed pellets produced on the UPC reached grown weight more quickly and needed less feed to reach the target body weight.

Studies with swine have shown that pelleted feeds with 10-15% fines can negatively influence animal performance. The findings show that as the fines content increases, feed wastage, low palatability and lower feed conversion ratios are noted. Fines create waste at the feeder and are not as palatable as whole pellets. Several factors influence the ability of the UPC to prevent the production of fines. Mean particle size, diet formulation and starch gelatinization all affect the production of fines.

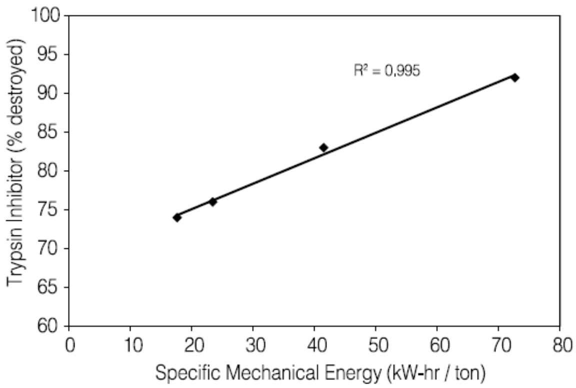
Table 2-10. Poultry feeding trial (40 days). Wenger Technical Center Test Data (2000). Feeding trials by independent third party.

	Body weight, kg	Feed Conversion	Feed Needed to Reach Target Weight, kg
Universal Pellet Cooker	1.95	1.53	2.7
Pellet Mill	1.91	1.65	3.0
Expander + Pellet Mill	1.84	1.75	3.2

Large feed particles can disconnect from the pellets as the cutter shears them to length at the pelleting head. Low levels of cook lead to poor pellet durability, and inevitably lead to the breakdown of pellets. Also, high-fiber diets tend to produce more fines than high-starch diets, since these ingredients have different binding abilities. Other than the mainstream production of compound feed, the UPC can also produce types of feeds that are all but impossible for pellet mills and expanders to produce. Full-fat soy (FFS), soft-moist pellets and feeds high in bypass protein and bypass fat are the most notable.

FFS production has been limited to HT/ST extrusion systems due to the high energy input requirements needed to destroy the anti-nutritional factors that exist in raw soybeans. However, the UPC has shown to be capable of producing equivalent quality FFS. **Figure 2-32** shows the results of four tests run at different specific mechanical energy levels (SME). At the higher SME inputs acceptable, product can be produced. Destruction levels between 80-90% are found to be sufficient for trypsin inhibitor in most livestock feeds.

Figure 2-32. Effect of SME on trypsin destruction (Wenger Technical Center Test Data, 1996).



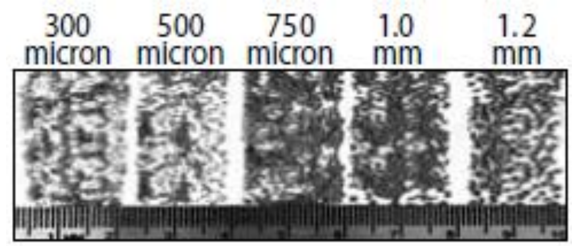
Production of soft-moist pellets is an available option with the UPC, giving feed producers even more flexibility to satisfy consumers and open new markets. With the proper ingredients included in the formula, final moisture and mold growth will not be a concern. The final moisture can vary from 15-20% when humectants and mold inhibitors are included in the ingredient mix to control water activity.

Feed manufacturers have been bombarded recently with technological advances in the compound feed processing industry. As with any technology, however, continuous development brings about major improvements. The UPC is a direct result of the rapid increase in demand for processing equipment required to heat treat and pelletize livestock feeds. The UPC is another option to provide high-quality feed with the ease and simplicity of using one machine. The flexibility provided allows producers to gain greater customer satisfaction by developing new characteristics into existing feed lines at lower cost.

Sphere-Izer Agglomeration System (SAS)

Producing starter feeds (see **Figure 2-33**) for aquaculture has long been a challenge. Traditional single-screw extruders are often limited to pellet sizes of 1.2 mm, while a twin-screw extruder can consistently produce feeds as small as 0.7 mm in diameter. These systems are often difficult to run since any contamination in the feed or hardened, overcooked material that builds up in the extruder barrel will plug die orifices. Production runs are often less than one hour due to plugging of the die orifices.

Figure 2-33. Starter aquatic feeds.



Some producers have resorted to first making a standard extruded pellet of substantial size, normally greater than 4 mm in diameter. The pellets are dried and cooled and then they are crumbled using a roller mill. Then the particles are sifted and classified into size ranges. With this method, typical on-size products are usually in the range of 50% or less, with the balance being smaller and larger particles. These particles often have very ragged and sharp edges, which some believe can cause an increased mortality rate in the fry. An alternate process for producing these starter feeds is the SAS process. This system is much different than the typical extrusion cooking process. The SAS process is designed to produce more uniform and nutritionally homogeneous particles than a traditional crumbling system. A uniformly mixed and pulverized formulation is passed through a low-shear, low-temperature extrusion process where it is conditioned with water as well as other possible liquid additives and then compressed through a special die to form extruded strands. These strands are then transported to the Sphere-izer™. This machine, by cyclonic motion, sizes and shapes the strands into pellets with lengths about the size of the strand in diameter. The SAS™ will produce finished feeds in a size range of 0.3-1.2 mm diameter with >85% “on-size” product. The low processing temperatures required are suitable for minimizing nutrient damage, production of medicated feeds and utilization of other temperature-sensitive ingredients.

Ingredient preparation

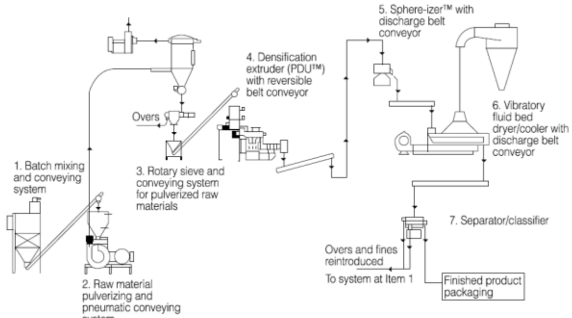
The raw ingredients used in the process can be much different than the requirements for conventional extrusion. In typical extrusion, starch is required to bind the ingredients together in order to form a durable pellet, and contents of 15-20% must be present in the formulation. With the SAS process, low-starch formulations can be successfully used since the starch required for traditional extruded products does little to bind the product together because the temperature of the process is low, usually in the 40-50°C range. The particles are bound by using natural binders from fishmeal, fish soluble, gluten and other organic ingredients.

Preparation of the formulation mixture includes micro-pulverizing to a specified particle size range to prevent die plugging during processing. After grinding, the formulation is passed through a rotary sieve to remove any particle larger than specified for the finished product size. The same particle size rules apply for the SAS system as in a conventional extrusion system. The raw materials should have a maximum particle size less than 1/3 of the die opening. If this criterion is not met, it becomes very difficult to successfully produce a product for any length of time.

Process equipment and parameters

The product agglomeration is accomplished by using a forming extrusion system. The material is metered into a preconditioner where it is moistened with water. Other liquids such as oil or medications can be added to the preconditioner as well. It is essential that all of the liquids be strained before injection and that a proper sized spray nozzle is used to give uniform distribution of the liquid. Even water lines need to contain fine strainers or screens to prevent any particle, such as a hard water deposit which could plug the die, from entering the system. After leaving the preconditioner, the wetted material enters the extruder barrel. The extruder is designed and operated to prevent substantial cooking of the raw material; but instead kneads and forms it into a semi-elastic dough. The extruders typically turn slowly and the length-to-diameter ratio is relatively short. The extruder is capped with a die plate that forms and separates the dough into individual, continuous strands which have a diameter of the desired product. The agglomerated strands are then fed into the Sphere-izer for sizing and forming to the desired size. The Sphere-izer is a spinning disc with a series of radially-symmetrical grooves or corrugations. As the ropes drop onto the disc they are broken into small pieces, which eventually turn into spheres as the pieces roll over the corrugations. Continuous drying of the small diameter starter feeds presents problems when considering the traditional horizontal continuous bed dryers and vertical dryers. The small diameter products cannot be handled in a static bed or moving bed perforated tray dryer because of several factors. The SAS products pack together so tightly that they create a bed of product that does not allow air to pass through. Therefore, the product will not dry completely. To eliminate this problem, a vibrating bed/fluid bed dryer is utilized for drying and cooling these products. The fluid bed dryer forces air through perforations in the vibrating bed with enough velocity to suspend the particles in the airflow and keep the product moving and exposed to the heated air stream. The cooling portion of this unit does the same only using ambient temperature air. A complete flow diagram for the SAS is shown in **Figure 2-34**.

Figure 2-34. SAS process flow.



<u>Advantages and disadvantages of the SAS</u>

Since the SAS is a low-temperature process, it allows the feeds to be medicated. This allows the producers to more easily control disease in their aquatic species. It also produces pellets with a smooth surface; as compared to a crumbing process, which produces pellets with ragged edges and sharp corners. One of the main disadvantages of the SAS process is that the processed feed is not pasteurized. The processors must be careful in cleaning the system and choosing ingredients that are not contaminated. The final products produced by the SAS also tend to have poor water durability. Since relatively low heat is applied, the starches are not cooked, and thus the pellets do not have anything to hold them together. The other option is to use pre-gelled starches, which would give the products much better durability; however, they greatly increase the cost of the operation. The other major disadvantage with this system is that it is only capable of producing sinking feeds. Conventional extruders allow the processor to produce partially-floating feeds down to 600 microns.

The SAS process is designed to produce more uniform and nutritionally-homogeneous particles than a traditional crumbling system. A uniformly mixed and pulverized formulation passes through a low-shear, low-temperature extrusion process where it is conditioned and compressed to form agglomerated strands.

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