INTRODUCTION
Wenger's involvement in the livestock feed and pelleting industry dates back to 1935 when Wenger developed and manufactured mixers, pelleting machinery, and other basic feed milling equipment for the livestock industry. Since this time Wenger has installed its pelleting technology worldwide for use within the livestock feed industry. The UP/C® (Universal Pellet Cooker) is Wenger's latest technology for production of pellets and pasteurization of mash.

In livestock feed processing plants, pelleting has become a primary processing step to enhance the quality of feed. It is a time-proven method of improving feed efficiency and feed quality, which explains its longevity in the field. Pelleting, the agglomeration of ingredients into dense pellets, produces many traits desired by livestock producers. These include:

- Decreased feed wastage
- Reduced selective feeding
- Improved feed efficiency
- Better handling characteristics
- Destruction of undesirable micro-organisms
- Increased bulk density

In the past, livestock producers have come to demand these qualities, but as research reveals the benefits of high temperature processing, feed manufactures are expected to add to this list of desired traits. High temperature/short time processing techniques, such as extrusion and expansion, have added new qualities to livestock feed that producers are requesting such as:

- Complete pasteurization
- Improved pellet quality (better durability and fewer fines)
- Increased liquid inclusion levels
- Improved feed utilization
- Increased starch gelatinization
- Production of by-pass fat and by-pass protein

The UP/C® (Figure 1) helps meet or exceed these expectations. It is significantly more effective, efficient, and versatile than the traditional systems, such as the expander plus pelleting press (Figure 2) that are currently used. Since the UP/C® utilizes fewer pieces of equipment, it is easier to justify because it reduces capital, formulation, operating, and maintenance costs.

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 UP/C® as they do other pelletizers.

GRINDING CONSIDERATIONS
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 1 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 (i.e. maximum particle size of 1333 microns for 4 mm pellets).
BINDER CONCERNS
The UP/C® system, which utilizes the natural binding qualities of the ingredient formulations to their fullest extent, does not depend on the use of nonnutritive 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 become 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 UP/C® and cooling, the starch returns to a crystalline state, resulting in a durable structure. Between 50 to 80 percent 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 reassociation, 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.

Fiber strengthens pellets by “melting”. The reassociation 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 gelatinization 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.

Table 1: Example Particle Size Distribution

<table>
<thead>
<tr>
<th>US Sieve</th>
<th>Grams</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>0.03</td>
<td>0.02</td>
</tr>
<tr>
<td>16</td>
<td>1.64</td>
<td>1.20</td>
</tr>
<tr>
<td>20</td>
<td>27.21</td>
<td>19.88</td>
</tr>
<tr>
<td>25</td>
<td>43.29</td>
<td>31.64</td>
</tr>
<tr>
<td>30</td>
<td>40.33</td>
<td>29.47</td>
</tr>
<tr>
<td>40</td>
<td>17.09</td>
<td>12.49</td>
</tr>
<tr>
<td>Pan</td>
<td>7.25</td>
<td>5.30</td>
</tr>
<tr>
<td>Total</td>
<td>136.84</td>
<td>100</td>
</tr>
</tbody>
</table>

1/8" grind milo based ration

![Figure 3: Expander-Pellet Mill Flow Diagram](image)
HARDWARE REQUIREMENTS

Processing principles of the UP/C® 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 3, as compared to Figure 4, shows how the UP/C® can easily adapt to existing manufacturing facilities without costly modifications.

PRECONDITIONING

The UP/C® 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. Preconditioning initiates the heating process by the addition of steam into the feed. With Wenger’s patented preconditioner (Figure 5), retention times of up to 2 minutes are achievable. The Wenger preconditioner exposes raw materials to steam and water for longer periods of time than other similar types of preconditioners. This allows the steam to fully penetrate the feed particles.

Retention time and temperature of the exiting feed are the two most important processing variables of a preconditioner. These variables, which affect the final product quality, must be monitored properly. For example, when the feed throughput increases both the retention time and the exit temperature will decrease, and fines in the final product can result. Thus to improve pellet quality, additional steam would be required to elevate the exit temperature and to provide an adequate level of cook.

Cook is the percentage of starch that has been gelatinized during processing. Because gelatinized starch has a proportional relationship with the amount of heat exposure, it can be used as an indicator of the final pellet quality. The Wenger preconditioner is capable of cooking from 30 to 40 percent of the starch present in a given formulation.

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 UP/C®

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. Change-over 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 6 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.

PELLET SIZING
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. The heat and moisture are removed from the pellets by drying and cooling them after the UP/C®. 
There are two types of coolers: vertical (counter current) and horizontal (Figure 7). Horizontal belt coolers typically have a higher capacity than the vertical coolers. They convey feed on perforated conveying belts through the dryer. As the product moves through the dryer, air flows through the bed of pellets. This type of cooler is usually fitted with one or two conveyors (single or double pass). The double pass is more efficient than the single, since it requires less airflow per ton of finished feed.

Vertical coolers (counter current or bin) allow pellets to descend opposite the direction of the airflow. This allows the coolest air to pass through the coolest pellets and warmest air to pass through the warmest pellets. This type of cooler requires less floor space than horizontal coolers. Vertical coolers are typically configured with one or two cooling decks depending on the capacity requirements.

The UP/C® generally operates within the same moisture constraints as other pelletizers. Exit moistures reach a maximum of 18 percent. This requires a cooler capable of driving off at least three to six percent moisture to achieve a final moisture of 12 percent or less and cool the pellet to within 10°C of ambient temperature. In situations where a conventional cooler will not provide adequate moisture removal a dryer will be required.

**EXTERNAL COATING**
The advantages of topically coating feeds can include: decreased dust, increased palatability, and increased feed intake. Pellets can be coated with nutritive ingredients such as fat, molasses, lactose, vitamins, enzymes, or a combination of these and other ingredients.
Coating equipment consists of an applicating reel, liquid tank, and a pump (Figure 8). For fat application, the reel can be fitted with steam coils and a shroud to prevent build up of congealed fat and fines.

**SOFTWARE**
To this point, both thermal and mechanical energy have been loosely defined, but it is important to understand how these process variables affect the UP/C® process. Production of quality livestock feed depends on many processing variables. Pasteurization and production of durable pellets requires the addition of steam and/or water in the preconditioner to increase product moisture from 14 to 18 percent and a temperature of 70°C to 90°C. The shear provided by the rotor, stator, and the pelleting die can elevate the product temperature to 115°C to 170°C depending on the die configuration and ingredient formulation.

**PASTEURIZATION**
The UP/C® 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°C to 95°C. This combination of temperature and retention time will destroy many microbial populations. Table 2 illustrates the ability of the DDC to destroy some of these microbes.

The second opportunity to destroy microbes is in the UP/C® rotor and stator. The technological concept behind the UP/C® 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 to 30 seconds in an extruder and 15 to 25 seconds in an expander) at conditions of high temperature and high pressure. However, the UP/C® utilizes High Temperature/Micro Time (HT/MT™) processing, meaning feed spends a much shorter amount of time under these conditions, usually three to four seconds and still reach temperatures of 125°C to 170°C. This ability to cook feed quickly, ensures that heat sensitive nutrients such as

<table>
<thead>
<tr>
<th>Microbe</th>
<th>Raw Recipe</th>
<th>After DDC</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPC (CFU/g)</td>
<td>240,000</td>
<td>9,300</td>
</tr>
<tr>
<td>Coliform</td>
<td>22,600</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Mold Count</td>
<td>54,540</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Clostridium</td>
<td>16,000</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Listeria</td>
<td>Positive</td>
<td>Negative</td>
</tr>
<tr>
<td>Salmonella</td>
<td>Negative</td>
<td>Negative</td>
</tr>
</tbody>
</table>

Table 2: Effect of Preconditioning on Microbial Populations

<table>
<thead>
<tr>
<th>Sample</th>
<th>Vitamin A IU / lb</th>
<th>Lysine %</th>
<th>Mold Count CFU / gram</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Mat'l</td>
<td>3,900</td>
<td>0.70</td>
<td>300,000</td>
</tr>
<tr>
<td>960715-003</td>
<td>5,600</td>
<td>0.71</td>
<td>&lt;10</td>
</tr>
<tr>
<td>960715-004</td>
<td>5,930</td>
<td>0.72</td>
<td>&lt;10</td>
</tr>
<tr>
<td>*Raw Mat'l</td>
<td>4,110</td>
<td>0.70</td>
<td>300,000</td>
</tr>
<tr>
<td>960715-003A</td>
<td>6,490</td>
<td>0.71</td>
<td>&lt;10</td>
</tr>
<tr>
<td>960715-004B</td>
<td>6,450</td>
<td>0.72</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Raw Mat'l</td>
<td>N / A</td>
<td>1.36</td>
<td>500,000</td>
</tr>
<tr>
<td>960820-104</td>
<td>N / A</td>
<td>1.41</td>
<td>40</td>
</tr>
</tbody>
</table>

* Rechecked results
vitamins and amino acids, are handled more delicately to prevent degradation. However, harmful microorganisms, such as salmonella, are destroyed.

Table 3 shows various heat sensitive nutrient retention and microorganism destruction in feed produced on the UP/C®. In each case none of the nutrients were degraded, but the detrimental microorganisms were destroyed. Table 4, shows the results of expanding plus pelleting on vitamin retention. This data shows that the expander does partially destroy some vitamins.

Table 4: Effect of Expanding on Final Vitamin Retention in Boiler Feeds

<table>
<thead>
<tr>
<th>Vitamin</th>
<th>Source</th>
<th>Initial Premix</th>
<th>Without Expander</th>
<th>With Expander</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Beadlet</td>
<td>10,000,000 IU</td>
<td>8,000,000 IU</td>
<td>7,800,000 IU</td>
<td>200,000 IU</td>
</tr>
<tr>
<td>D₃</td>
<td>Beadlet</td>
<td>3,000,000 IU</td>
<td>2,400,000 IU</td>
<td>2,370,000 IU</td>
<td>30,000 IU</td>
</tr>
<tr>
<td>E acetate</td>
<td>Acetate</td>
<td>20,000 IU</td>
<td>17,500 IU</td>
<td>17,160 IU</td>
<td>340 IU</td>
</tr>
<tr>
<td>Menadione</td>
<td>MSBC</td>
<td>2,000 MG</td>
<td>1,100 MG</td>
<td>835 MG</td>
<td>260 MG</td>
</tr>
</tbody>
</table>

Table Values in listed units per ton

PELLET DURABILITY
The ability for the UP/C® to produce an extremely durable and dense pellet is illustrated in Figure 9. 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. 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 to 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 reassociation 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 differently. To further clarify this, consider the feed mix as a mass of wax. At room temperature it is in a crystalline state, but when heated the wax becomes pliable. The temperature at which the wax shows a considerable amount of

Figure 9: State Diagram of the UP/C® Process

![Figure 9: State Diagram of the UP/C® Process](image)
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 10 shows photos of a pelleted feed made using a conventional expander plus pellet mill process and one from the UP/C® system, magnified with a scanning electron microscope. Notice the laminar structure that develops with the UP/C® process. It provides superior strength over the expander plus pelleted product, which does not have this same structure.

**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 UP/C®, which include the following:

- Feed Delivery Rate
- Knife Speed
- Steam
- Water
- Pellet Die Configuration
- Recipe Formulation

Pellet size can be easily controlled. The possible pellet diameters range from 2 to 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 UP/C® pelleted feeds is about 550 to 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 can not 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. The UP/C®, however, typically produces pellets with a PDI of over 95 percent.

Studies with swine have shown that pelleted feeds with 10 to 15 percent 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 UP/C® to prevent the production of fines. Mean particle size, diet formulation, and starch gelatinization all affect the production of fines. 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.

**BENEFITS OF THE UP/C®**

The UP/C® has shown advantages over pellet mills and expanders in several feeding trials with poultry, swine, and dairy cattle. Table 5 shows the advantage of a UP/C® for poultry. Those animals feed pellets produced on the UP/C® reached grown weight more quickly and needed less feed to reach the target body weight.

Other than the mainstream production of compound feed, the UP/C® 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 by-pass protein and by-pass 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 UP/C® has shown to be very capable of producing equivalent quality FFS. Figure 11 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 to 90 percent are found to be sufficient for trypsin inhibitor in most livestock feeds.

Production of soft-moist pellets are an available option with the UP/C®, 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 to 20 percent when humectants and mold inhibitors are included in the ingredient mix to control water activity.

By-pass protein and by-pass fat are characteristics of heat-treated feeds that producers of ruminant animals desire. By-pass protein is the result of denatured protein. The protein’s reduction in solubility, allows the protein to “by-pass” or escape the rumen and be digested in the small intestine. By-pass protein can be measured by determining the Nitrogen Solubility Index (NSI) (Appendix B) of the processed feed. The NSI value represents the amount of protein that is soluble; therefore, the remaining protein is considered insoluble or by-pass protein (i.e., NSI value = 20 percent, by-pass protein = 80 percent).

<table>
<thead>
<tr>
<th>Table 5: Poultry Feeding Trial (40 days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body Weight</td>
</tr>
<tr>
<td>-------------</td>
</tr>
<tr>
<td>UP/C®</td>
</tr>
<tr>
<td>Pellet Mill</td>
</tr>
<tr>
<td>Exp. + Pellet</td>
</tr>
<tr>
<td>Mill</td>
</tr>
</tbody>
</table>
Lipids included in feeds specified for ruminant animals can interfere with fiber digestion and even destroy necessary microorganisms that aid with fermentation in the rumen. However, by-pass fat escapes the rumen without interfering with the fermentation process and is allowed to be digested downstream. By-pass fat is the result of the formation of a complex between fat and starch or protein that occurs during high temperature processing. It can be quantified by determining the difference between the Acid Hydrolysis method (AH) and the Ether Extract method (EE) of fat analysis (i.e., AH - EE = by-pass fat). The ether extract method cannot measure fat that has complexed with starch or protein, therefore, it will be the lesser of the two values.

**CONCLUSION**

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 UP/C® is a direct result of the rapid increase in demand for processing equipment required to heat treat and pelletize livestock feeds.

The UP/C® enables feed producers 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. The UP/C® is the machine of choice for producers looking toward the next generation in pelleting technology.

2. Wenger Technical Center Test Data. 1996