FEED AND BIOFUEL

FEED MANUFACTURING HANDBOOK

ANIMAL FEED

Preface

This Feed Manufacturing Handbook is intended as a guide to feed mill operators, managers, and others interested in the operation of animal feed manufacturing.

We trust this guide will be a real help.

AUTHOR

Nils Lastein
M.Sc Food Science and Technology
Global Application Manager - Animal Feed

ENGINEERED SUCCESS

Pelleting of animal feed

Feed that contains all the necessary nutrients for an animal to live is called compound feed. Supplement feed (or mineral feed) is a feed type which requires additional ingredients to sustain the animal. These ingredients are normally locally grown grains which are added just prior to feeding. Supplemental feed is typically more difficult to pelletize when compared to other types of feed, as it contains less grain and more minerals.

Animal feed is typically destined for poultry, pigs, and ruminants like cows, sheep, and goats. There are, however, other types of game animals for which feed is also commercially produced. Within each animal feed group there is starter, grower and finisher feed, as well a specific feeds for breeder animals, such as meat and milk producing animals.

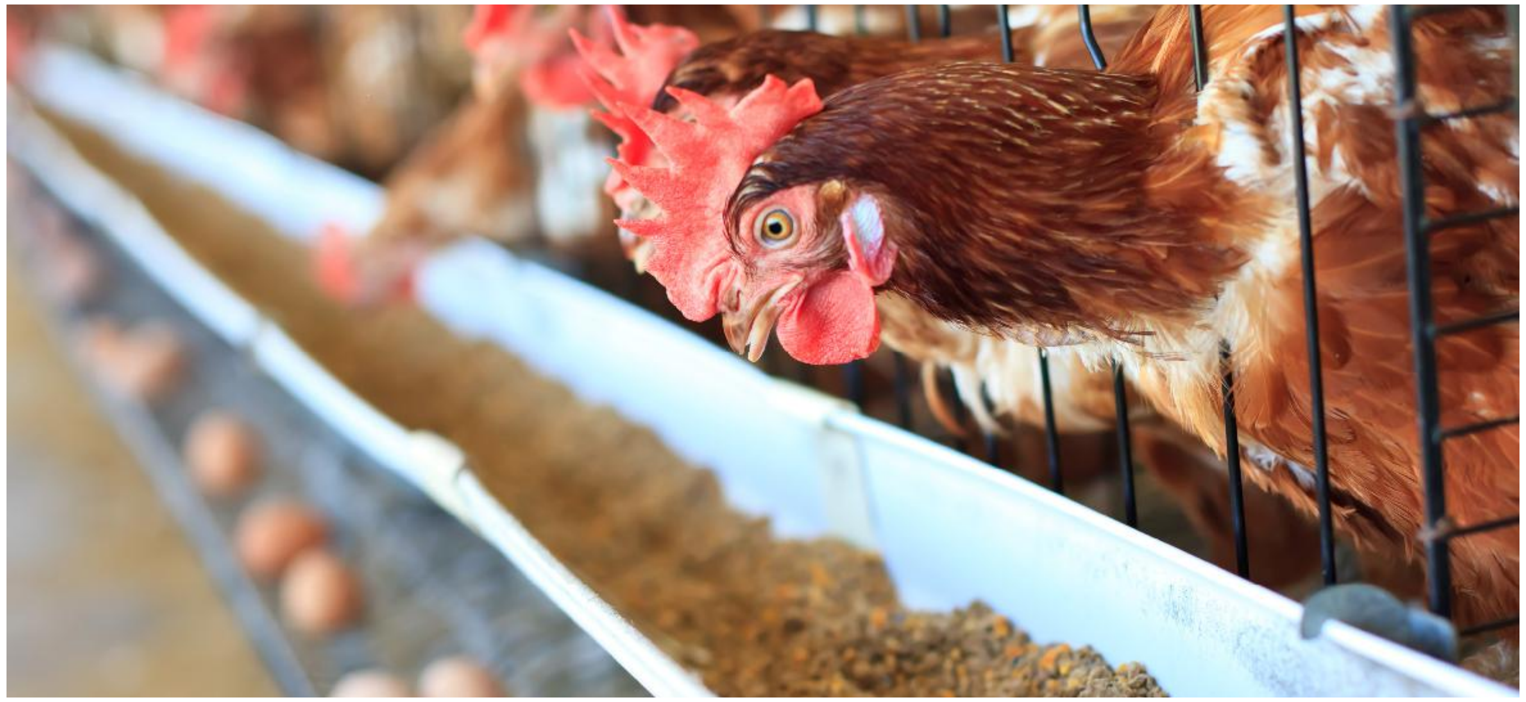
Consistent carcass size is an important factor, especially for broilers and pigs, as slaughterhouse systems are designed with standardized equipment. Animals being under or oversized will not fit the equipment which can cause intestinal ruptures. Ruptures can then leak gut flora onto all subsequent carcasses being processed, causing contamination.

In the pelleting process all ingredients are combined into one pellet which should contain the same ratio of ingredients as the entire lot as defined by the formula (recipe). This ensures that an animal gets the same ratio of ingredients whether the animal eats one, a few, or many pellets as it corresponds to a small or large animal.

For animal feed, just as for human food, the term palatability needs to be introduced. Palatability means the preference an animal has for a specific feed when offered a choice. A good example of making a feed ingredient more palatable would be to increase the molasses content in feed for cows.

Pelleting produces a physically, microbial, and nutritionally stable product which does not deteriorate in quality when being transformed from agricultural crop to animal feed.

Pellets must be hard and stable to prevent them from disintegrating into dust and fines before being consumed. Some animals will only eat the pellets, leaving behind the dust and fines, which increases waste. It is the weaker animals, who tend to eat last, ending up with the leftover dust and fines. Since the dust and fines do not typically contain the same ratio of ingredients as the pellets, these animals will have a harder time surviving.



A hard, stable pellet will be prone to reabsorption of moisture from the air, deteriorating pellet quality and allowing microbial growth of bacteria and molds, which can be lethal to the animals.

THE FOLLOWING ARE THE MAIN ADVANTAGES OF PELLETING FOR ANIMAL FEED:

Improved Feed Conversion Ratio (FCR)
Pelleting is a thermal, mechanical, processing method which heats the material and thereby performs partial or complete cooking of the ingredients.

Cooking is a chemical reaction that results in starch gelatinization (activation) and protein denaturation, thereby increasing the nutritional value of the feed and enabling animals to gain body mass faster.

Prevention of selective feeding
Some animals eat the pellets first (chickens) and some animal eats the entire portion at once (pigs and cows).

Fines are considered waste because they do not include the same ration of ingredients that intact pellets do, but also because the farmer, who sees a substantial amount of fines in the bottom of his troughs, sees the money he paid for pellets being wasted.

Increased bulk density
The rule of thumb regarding density changes from grain to meal to pellet is: Grain: 650 -> Meal: 500 -> Pellets: 700.

Consequently, transportation will be more efficient with pellets as compared to meal.

Prevention of particle segregation
Segregation means de-mixing of particles due to differences in particle shape, density and size. Segregation takes place during material handling that causes vibration, typically, during transport. This causes the small particles, like fine vitamins and minerals, to filter down to the bottom of the storage container while larger particles from gound grain like wheat, barley and corn to stay at the top.

Reduced microbial count
Heat treatment kills bacteria. The higher the temperature, the longer the exposure time, and the more moisture bacteria is exposed to, the more bacteria will be killed. In the feed business, under normal conditions, bacteria will never be completely eradicated. Some bacteria are simply more resistant than others. The most problematic bacteria encountered in the feed business are Salmonella, Campylobacter, E. Coli, and Enterobacter.

Increased microbial stability
The shape of pelleted feed naturally allows for a higher degree of ventilation than stored meal feed. This ventilation allows for the removal of excess moisture and helps to prevent the growth of mold.

Easier handling
A silo filled with meal will only remain free flowing for a short period. Over time, meal settles and becomes compacted, losing fluidity. This causes *ratholing*, a situation where only the center of the silo empties while most of the material is left clinging to the side of the container. Ratholing makes it nearly impossible to discharge meal from a silo. Grain and pellets almost always remain free flowing, even under large silo pressure.

Poultry

Poultry types are named for their primary function and are kept for egg production (layers), meat (broilers) or for breeding (breeders). Poultry feed possess the best pelleting properties of these main animal feed types. Recipes for poultry are composed using local available starch sources either from corn or wheat, with additional protein supplements from soybean meal. The natural low-fat content of the main grain is boosted with the addition of oil. Additionally, protein sources may be by-products from the oilseed crushing industry like rape seed, cotton seed, sunflower, or soybean.

Poultry feed is usually subject to large and varying liquid inclusion in the main mixer where fat, oil, amino acids, water, and acid are added compared to other feed for other species like pig and ruminants.

A bird has a rudimentary tongue that does not have the external function of picking up food; therefore, they cannot eat dust and fines. Consequently, pellet durability is very important because the remaining feed is wasted. For further information please see Aviagen Ross Broiler Handbook:

https://en.aviagen.com/assets/Tech_Center/Ross_Broiler/Ross-Broiler-Pocket-Guide-2020-EN.pdf

Poultry is an attractive source of animal protein all around the world due to it's very high feed conversion ratio, short generation time, and the output of eggs as well as meat.

In poultry production the following subgroups are defined:

- Breeders or parent stock lays the eggs that will hatch into either layers or broilers.
  - Grandparent stock produce eggs for parent stock.
- Broilers are birds for meat production. Taking only 42 days to mature from chick to broiler.
  - These birds progress through the different stages: starter, grower, and finisher.
  - A starter bird comes directly from the hatchery
- Layers are birds for egg production.

For intense farm stable systems, the primary input is the feed. If the feed has a low hygienic standard (not heat treated) it will introduce pathogens into the flock, causing reduced feed conversion ratio, higher mortality, and inequal animal sizes.

STARTERS

Pre-starter and starter feeds are fed in the first ten days of the bird's life and are high in protein and nutrients.

These feeds are usually crumbled/granulated pellets or small pellets (2-2.5mm). Crumble particle size may be anywhere from 1.5mm up to 3mm.

Starter and grower feed may have added coccidiostat that will prevent parasitic infection. Several other animal species are very sensitive to carry-over of coccidiostats.

Therefore, plant design must compensate for this risk to prevent carry-over to shared mixer lines, batch scales, and conveyors. The coccidiostats most commonly found in poultry are Nicarbazin, Monensin, and Salinomycin.

Starters

BROILERS

Broilers are kept for human consumption of meat. Broilers are fed grower feed for 14-16 days and then finisher feed for the remaining time.

Broiler feed is lower in protein and higher in fat energy to promote growth, whereas finisher feed is highest in energy to add weight quickly.

Broiler recipes are composed with supplementary fat/oil for increased energy content of the feed and increased FCR (Feed conversion ratio). Small amounts of oil may also be added post pellet to reduce dust.

Water may be added to the feed in the main mixer to help birds stay adequately hydrated, as they may struggle to drink enough in the hot houses.

The total fat content in the recipe originates from both naturally occurring fats (corn and by-products) and added fat, ranging from 3-4%. Supplement fat and oil, ranges from 5-8%, making total end fat content as much as 8-12%. Fat originates from both vegetable and animal sources and may be in both solid and liquids forms.

Grinding and pelleting capacities vary greatly between regions. Pelleting of broiler feed is considered the easiest product to pelletize due to several factors:

- High amounts of cereal products and low amount of by-products
- High oil and fat content

Finally, there are large global differences in acceptable pellet durability and this, consequently, introduces large variations in pelleting capacities.

Grinding capacity increases with the inclusion of easy-to-grind raw materials and meal by-products.

Of the available by-products, soybean meal is easiest to grind, and sunflower meal is the most difficult, due to their husks.

Broilers

Hot stamping TechCenter

LAYERS

Layers are poultry designed for laying eggs. Layer feed has a coarse structure, medium energy content, good hygienic quality, and a high calcium content.

Layers require more calcium carbonate in their diet to ensure good eggshell quality and less fat/oil than broilers, as they do not need a high FCR. Calcium inclusion may be as high as 10%. As a result, reduced pellet mill capacity can be expected, as the calcium causes significant wear on the hammer mill and pellet mill die and rollers.

Layer feed is characterized by its coarse structure and low supplementary fat. This formula reduces digestion rate, as layers only require enough energy to maintain egg production and base metabolic levels. Layers may be fed a mash (feed that has only been ground but not pelletized). Mash should be prepared with a roller mill to achieve a very coarse and precise particle size. Alternatively, if the feed is processed through a hammer mill, a much finer structure will be produced. In this case, the mash also needs to be sprayed with a small amount of fat or oil and mixed to prevent particle segregation.

The job of a layer is to produce as many eggs as possible in their lifetime. Because infection will affect every single egg produced, it is paramount to prevent bird infection. Regardless of this, some feed manufacturers still chose to produce cold mash which does not take hygiene into consideration.

Mash should be hygienically heat-treated after mixing but prior to storage or some other measures of managing the microbial quality of the feed must be instituted.

BREEDERS

Breeders are birds that lay eggs which are usually destined to become broilers. Feed for breeders is very similar to that of layers but with an increased focus on feed hygiene. Both feed categories are characterized by a coarse structure and small particles. This structure accelerates feeding time and consequently, both layers and breeders may be fed with granulate. It is extremely important that feed for parent stock (and grandparent stock) is hygienically produced and not recontaminated because a Salmonella infection at this stage will be inherited by every chick here after. Retention times may be up to 2-3 minutes at temperatures of 80C. This is dependent on customer demands, and as an example, the Aviagen standard is 86C in 6 minutes.

TURKEYS

Turkey feed is very similar to broiler feed. However, turkeys are prone to selective feeding. making pellet quality a high-priority. The recipes for turkey feed also have a higher total fat content which results in a higher pelleting capacity compared to broiler feed. Turkey feed, like broiler feed, is also subdivided into starter, grower, and finisher recipes, with increased fat content towards the end of life.

Turkeys are very sensitive and may die from foreign substances introduced by carry-over from mixers, bins, and conveyor equipment, as well as bad mixing quality. These foreign substances may originate from conventional broiler feed manufacturing like coccidiostats (Salinomycin).

Ruminants

Cows, sheep, and goat are all ruminants and their feed shares the same characteristics: Fibers

Cows, sheep, and goats are all ruminants and their feed possess the same characteristics: The main ingredients are fiber in the form of cellulose and lignin. These are broken down in the rumen, the first chamber of the ruminant's stomach, by a microbial reaction that releases sugars and other nutrients from the plant cells making them accessible for the animal to metabolize.

Though the term ruminant refers to a whole group of multi-stomached animals, the feed industry is typically referring to cows when speaking of ruminant feed.

The cow is a resilient animal that can eat almost anything. Unfortunately, this means that the feed for cattle may also be composed of almost anything, including human food by-products, some of which can be very difficult to pelletize.

Ruminant feed recipes often include few grains and large quantities of by-products chosen for their low price and high fiber and protein content. Common by-products found in ruminant feed are rape seed meal, sunflower meal and soybean meal.

Dried Distiller's Grains (DDGS), a low-quality, by-product of distilled alcohol for human consumption or as liquid biofuel, is commonly used as a nutritional ingredient in ruminant feed. DDGS are completely exhausted of nutrients like starch and proteins but are included because of their low cost and high fiber content. Many of these by-products may come in the form of a pellet, which requires additional grinding to process.

Feed for cows can be split into two categories. Feed formulated for dairy cows, which contains a little fat, and the feed formulated for beef cattle, which is lean and dry.

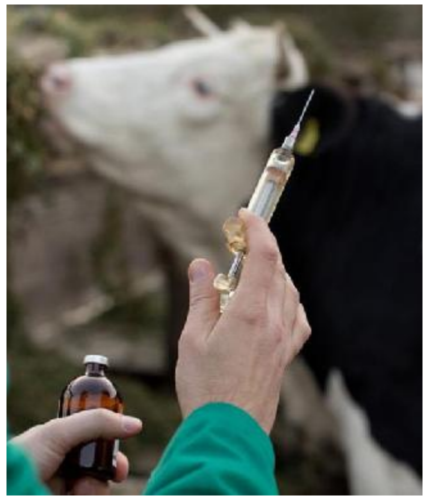
Local ingredient availability and price influence ruminant recipe composition and, in many places, pelleted ruminant feed is merely a supplementary mineral feed, as the primary nutrients are grown by the farmer. A distinction should be made between full feed and supplement feed since the latter contains a high amount of minerals which reduces pelleting capacity (approx. 30% less).

The fiber products from DDGS, human food by-products, and bran products are all difficult to grind and pelletize and reduced capacities can be expected. To increase pelleting line capacity, double pelleting concepts are often applied.

High amounts of molasses, up to 8-12%, as well as meal by products from sugar production (sugar beet pellets) are often added to ruminant feed for increased palatability. They may be added in the main mixer, but it is preferable to add these palatents into the conditioner. As the water content in molasses is around 50%, which limits the amount of steam that can be added to prevent roll slip and pellet mill blockages.

Ruminant feed does not normally contain any added oil as a feed nutrient. Only a small amount of technical oil is added to reduce dust, lubricate in the die and produce a shiny pellet. Ruminant feed is often conditioned at very low temperature, around 50-60C. The primary reason is the high quantity of water that molasses contains. Limiting the amount of water that can be added during conditioning as steam. Adding 6% molasses is equal to 3% sugar + 3% water, meaning there is 3% you cannot add as steam. 3x12C=36C less conditioning temperature (80-36=44C out of the conditioner). Dust in pellets reduces palatability. Therefore, ruminant pellets must be high quality and small amounts of oil may be applied post pellet to bind the residual dust.

Means of Obtaining Feed Safety



In many places, such as the United States, parts of Latin America, and Asia Pacific, antibiotics are still being introduced to feed as a growth promoter. This occurs primarily in the poultry and pig sectors where antibiotics are given to healthy animals to suppress non-clinical (not visible) illnesses, thereby freeing up energy to build muscle mass rather than fighting infection.

The downside of this strategy is that bacteria begins to build a resistance to the antibiotics. As resistance to one antibiotic builds, more and more antibiotic formulas are applied, creating multi-resistance bacteria.

Antibiotic resistance has a fairly nasty side effect in that, resistant bacteria can be transferred from the animal, through consumption of meat to consumer. Then when the antibiotic resistant bacteria infects a human host, doctors are rendered helpless, with no way to effectively treat the infected patient.

Antibiotics were discovered in the mid-1940s and it only took a decade more for the side effects to be discovered. By the 1960s and 70s, antibiotics resistant bacteria were also discovered. Individual countries in EU started introducing bans in the late 1990s and then, in 1999 the EU introduced a full ban. In 2000 the World Health Organization (WHO) issued a similar recommendation.

In the year 2000, the EU introduced a law, mandating the heat treatment of animal feed. Feed would be treated to temperatures up to 80°C to assure animals receive safe and healthy diets and to prevent the introduction of pathogens to farms.

This temperature level is much higher than is mandated by most other places in the world such as United States, where conditioning is only regarded as a mean of achieving higher pellet quality and line capacity, even though this temperature treatment is easily controlled in the pre-conditioning step, prior to pelleting.

Until recently, the EU permitted the use of formaldehyde to treat whole grains that were added to finished feed but the discovery of cancer-causing agents in formaldehyde caused it to be banned by the EU in 2018 to insure the health and safety of feed mill operators. Safe, alternative methods of preventing the overgrowth of dangerous bacteria are currently being developed. These include collection methods or hurdles as well as probiotics and organic acids, amongst others.

- The use of Probiotics is the application of "active and healthy bacteria" that totally outnumber the pathogens.
- Organic acids are introduced to help form a hostile environment (low pH) for the pathogens.

Raw materials

Grains, by-products, rendering products, minerals and vitamins

Raw materials are the ingredients described by the formulation that are required to compose the feed. Compound feed is feed from which the animal can sustain an entire life cycle. Raw materials differ widely in terms of pelletability due to the differences in chemical composition. Pelletability is the ability of the raw material to pelletize. The main pellet binders are starch and proteins which are activated using heat and moisture in the conditioner prior to pelleting. The formulations are optimized to fulfill the nutritional animal requirement. Additionally, raw materials may also be substituted based on chemical composition, cost, and market availability. This method is called, *least-cost-optimization.* The formulations are not optimized with respect to processing in the feed mill: handling, grinding, or pelleting.

Feed Conversion Ratio (FCR) - The ability to convert feed into animal body weight.

$$FCR = \frac{Feed\ eaten\ [kg]}{Increased\ body\ weight\ [kg]}$$

In intense commercial farms animal feed conversion ratios are quite impressive:

- Salmon: 1.2 – 1.3*
- Chicken: 1.7 – 2.0
- Pork: 2.5 - 4
- Ruminant: 5 - 10

*Due to low moisture in feed and high moisture in fish meat.

Raw materials may be divided into subgroups:

CEREALS OR GRAINS

Main ingredient in feed could be

- Corn (maize)
- Wheat
- Barley
- Rice

http://www.fao.org/es/faodef/fdef01e.htm

Different regions around the world have different primary grains.

RENDERING PRODUCTS

Feather meal from poultry, meat and bone, meat meal, and blood meal, from cattle, pig, fish, or poultry processing plants (slaughter houses). Excess fat and moisture are removed to form a dry and stable product (more or less).

https://www.fao.org/3/y5019e/y5019e0g.htm

http://assets.nationalrenderers.org/essential_rendering_overview.pdf

Raw materials

BY-PRODUCTS

Oilseeds like rape seeds, soy beans, cottonseeds, copra, palm kernels, and sunflower contain high amounts of oil and proteins. Oils are often extracted for human food consumption. The residual is high in protein and ideal for animal feed. Soybean meal is the most important protein source of poultry and pig production in the world. However, it is also a high risk source of Salmonella in animal feeds.

Two terms are important to know:

- The term cake is used to define the residual proteins from a pressing process only. It is high in oil, approximately 5-10%.
- The term meal refers to pressing, followed by a chemical extraction, forming a much more lean product with only about 1-2% oil.

https://www.fao.org/3/y5019e/y5019e0g.htm

Oilseed by-products have high protein content which pelletizes quite well in the presence of adequate steam.

By-products can also originate from distilleries and sugar plants. DDG is a by-product from distilleries where alcohol fermentation is based on starch rich products like wheat, sorghum, corn, rice, or barley. The by-product is called dried distiller grain (DDG).

The S in DDGS originates from “with solubles”. DDGS products are high in fiber but also notable amounts of protein. DDGS products are mainly introduced into ruminant feed. DDGS products, in their pure form, are very difficult to pelletize.

Almost all by-products stored in a vertical silo will not flow well and will experience ratholing. A flat storage silo is better long-term solution but transforming these products into pellets solves this problem entirely.

BRANS

Bran is the hull and/or husk separated from grain during the processing of human food products. Grains are the seeds of edible grasses such as wheat, rice, barley, sorghum, and corn. Bran products are very high in fiber, very low in bulk density and have poor flowability.

PREMIX

A premix is a composition of necessary vitamins and minerals specific to the needs of a given animal group and is similar to a vitamin pill, in human terms. The premix reduces the need for a large quantity of small dosing silos in feed factory. Premixes are usually designated for the different stages in the animal growth: pre-starter, starter, grower (fattener), finisher, or described by numbers: I, II, III, IV.

VITAMINS AND MINERALS

Monocalcium phosphate (MCP), calcium carbonate (limestone), salt (NaCl), and many other essential vitamins and minerals are added to animal feed in either fine or coarse consistencies.

AMINO ACIDS

Lysine, Methionine, Threonine, etc., are the naturally occurring building blocks of proteins given to animals as either dry or liquid supplements, as many of these are limiting amino acids necessary for animal growth.

ENZYMES

The natural occurring enzyme phytase is often added to pig and poultry feed to:

- Increase availability of phosphorus to the animal
- Reduce amount of supplemented phosphorus into the feed
- Reduce amount of excreted phosphorus in the manure

Protease is added for enhanced protein digestibility and amino acid utilization. Xylanase and amylase are added for enhanced starch digestibility and utilization.

The enzymes added to animal feed are good and naturally occurring components that already exists in the raw materials but that benefit from being boosted.

The enzymes supplement are normally introduces in liquid form at the post-pellet stage in order to compensate for the losses caused by heat treatment in the pelleting line.

MEDICINE

Specific medicine may be added by hand, dumped straight into the prebin or directly into the mixer on prescription by the vet. Medicines may be antibiotics and coccidiostats.

FATS AND OIL

Feed grade quality of rape seed oil, soy oil, animal fat, palm fat/oil, etc., may be added as a supplement to increase the energy content of feed, which leads to higher animal performance (weight gain). Small amounts may be applied to bind dust and create a shiny pellet.

Customer segments

Animal feed producers are split into two different segments that operate with slightly different agendas: integrators and commercial operators.

INTEGRATORS
Integrators employ the entire value chain, including crop growth, feed processing, animal husbandry, slaughtering, and meat processing. Typically, integrators make use of only a few formulations, using a limited variety of ingredients, while operating with very larger order sizes, running the processing lines continuously on the same types of feed. Integrators are less focused on pellet quality and more focused on capacity, producing for stock. It is for these reasons that they require larger hammer mills, mixers, and pellet mills.

COMMERCIAL OPERATORS
Commercial operators sell feed directly to farmers on the open market producing formulas based on each farmer's custom order. Consequently, commercial operators have frequent starts and stops due to change over on the processing lines as well as many dosing and finished product silos. Typically, commercial operators would require small to medium machines and tend to be focused on quality rather than capacity, as their customer can easily switch to another supplier.

Plant design

Brown field or green field

Only the basic concepts of plant design will be discussed in this document, as there are many more factors that affect plant design than can be covered in this document alone.

The term “brown field” refers to projects conducted inside existing buildings and potentially with existing processing equipment in place. On the other hand, “green field” projects are those designed from scratch on an empty site.

Capacities must be defined so that limiting factors are located at main machine which would be the pellet mill. Therefore, meal preparation includes batching, milling, and mixing sections and must be oversized by approximately 20% as compared to the bottle-necked main machines.

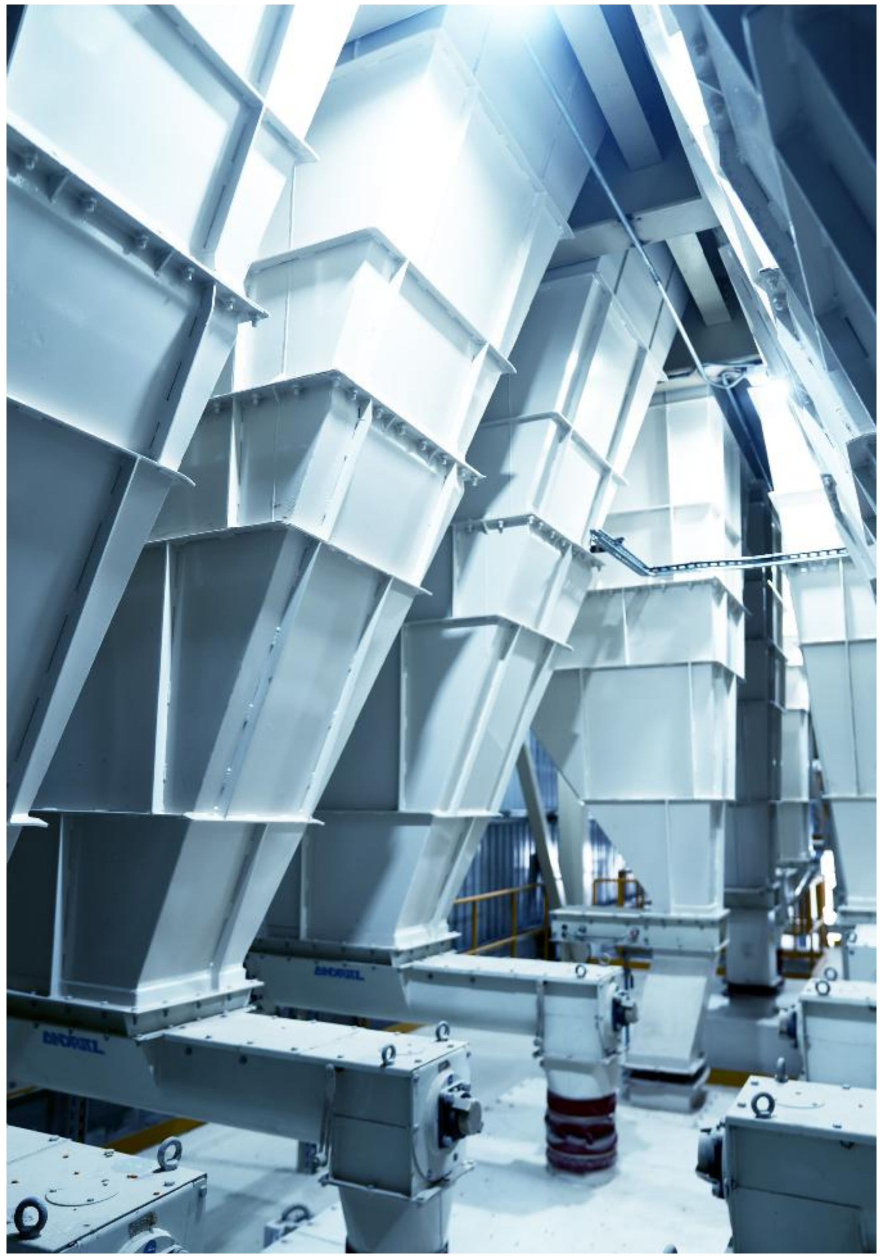
Processing lines can be dedicated to producing feed for a single species or can accommodate production of feed for multiple animal species. A multi-species line will have changeovers from one order to the next and attention must be given to possible carry-over, order planning, and capacity. Having many order changes can have an impact on daily capacity. Carry-over is a very important factor. Some of the components that are major contributors to carry-over are conveyor systems, filter bags, materials hanging in bins, and short-cut clear-out times for conveyors in the control systems. To have a lean and effective plant design, gravity should be employed as much as possible. For example, building a grain elevator a bit higher and allowing to slide into a bin is preferable to conveying materials horizontally using a chain conveyor.

The process of protecting feed from contamination requires a multi-layered defense. It is essential to prevent impurities from entering the plant from external sources such as the ventilation systems, visitors, and contaminated raw materials. By introducing procedures such as entry restrictions, vehicle sanitation, and controlling birds and rodents (F.T. Jones 2011), breaches can be reduced. It is also imperative to maintain hygienic levels inside the plant by taking steps to kill pathogens through heat treating and disinfection. Finally, when considering plant design, keeping “clean” and “dirty” zones separated also helps to reduce transmission of contaminants.

Batching

Batching is where the process begins

Before the batching process can start, raw materials must be transferred from the storage area (silos or flat storage) into dosing silos. Typically, main dosing silos only contain enough raw materials for one day of production. Storage silos may contain months worth of raw materials and may be built in conjunction with drying and cleaning facilities. Mineral bins (salt, phosphorus and calcium) are normally refilled on a weekly basis possibly with a blow line entering directly into the bin from an external truck.



Before the physical batching process starts, the required formulation is selected, a total order size is determined, and a destination silo is selected. Other required processing parameters, such as hammer mill, pellet mill, or cooler settings should be set at this time. The plant control software translates the total order of batches. For example, 40tons into 20pcs at 2tons per batches (or changes). The batch size is determined by the size of the mixer. Therefore, a 4000L mixer traditionally may hold a 2ton batch.

The weigher consists of a weighing unit and possibly a subsequent surge bin with discharge equipment (chain conveyor). This is known as a double deck weigher. In a single deck weigher, the weighing unit also contains the transport equipment. The weigher may be split into multiple sections for increased capacity (one shared transport surge bin with one or more weighers above).

The raw materials are dosed one at the time into the weigher, typically with a frequency-controlled dosing screw, vibration feeder, or a bridge slide gate. The actual frequency drive is shared between screws on the same scale, as they will not operate simultaneously anyway. The dosing method and dimensioning depends on the required dosing precision, capacity and the material characteristics. Silo planning is the process of assigning raw materials to specific silos. This is done using one or multiple formulations (recipes).

THE BATCHING PROCESS

The batching process is started by taring (zeroing) the weight. If the tare is too far away from the calibration set-point, then carry-over might be present in the weigher.

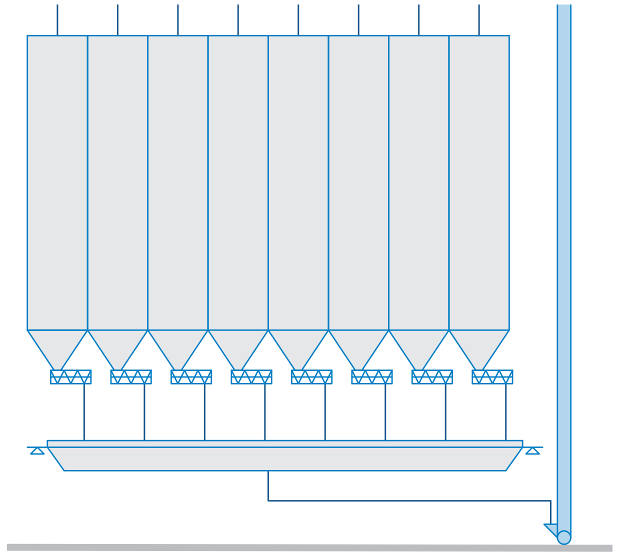
The dosing of an ingredient is done in three steps. First, coarse dosing, followed by medium dosing, and finally, fine dosing. The shift between these steps is done without pause and is done to enhance the dosing precision while increasing capacity. These steps are determined by the remaining dosing amount in kg.

The dosing process stops before the target amount is achieved and the difference is called the tailing. The tailing is the amount of material mid-air that didn't reach the scale yet but must be anticipated falling downwards.

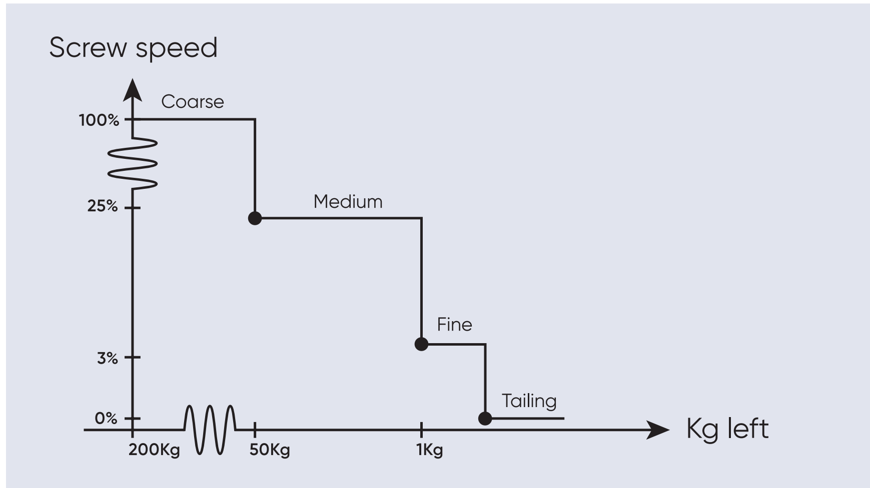
If maximum dosing time is exceeded an alarm is raised. If the weigher signal is not increasing while the dosing screw is operating, a no-flow alarm is raised. The reason could be an empty silo or hanging product.

After the target material has been dosed, the weigher is tared once again and is ready for next ingredient. This is repeated until all the ingredients in formulation have been dosed.

After all dosing steps are complete, either the conveyor inside the weigher starts or the weigher empties into a bin with its own internal conveyor. The latter is faster because it quickly frees up the weigher for the restart.



	Coarse	Medium	Fine	Tailing
Speed	100%	25%	3%	0.1kg
Limit	50kg	10kg	1kg	



Batching

ACCURACY

The dosing accuracy is the sum of the dynamic accuracy plus the static accuracy.

- The dynamic accuracy is related to the characteristics of the screw and raw material.
- The static accuracy is related to the load cells and amplifier.

Both the dynamic and static error contribute to the deviation between the actual amount (realized set point) and the planned amount (set point by formulation). The deviation goes into the order production report and acts as basis for further optimization.

TYPES OF BATCHING SYSTEMS

Often three types (sizes) of scales are used in a feed plant. Scales for the main ingredients, one for minerals, and a third for micro ingredients. All these scales will produce the same number of batches which all converge in the main mixer.

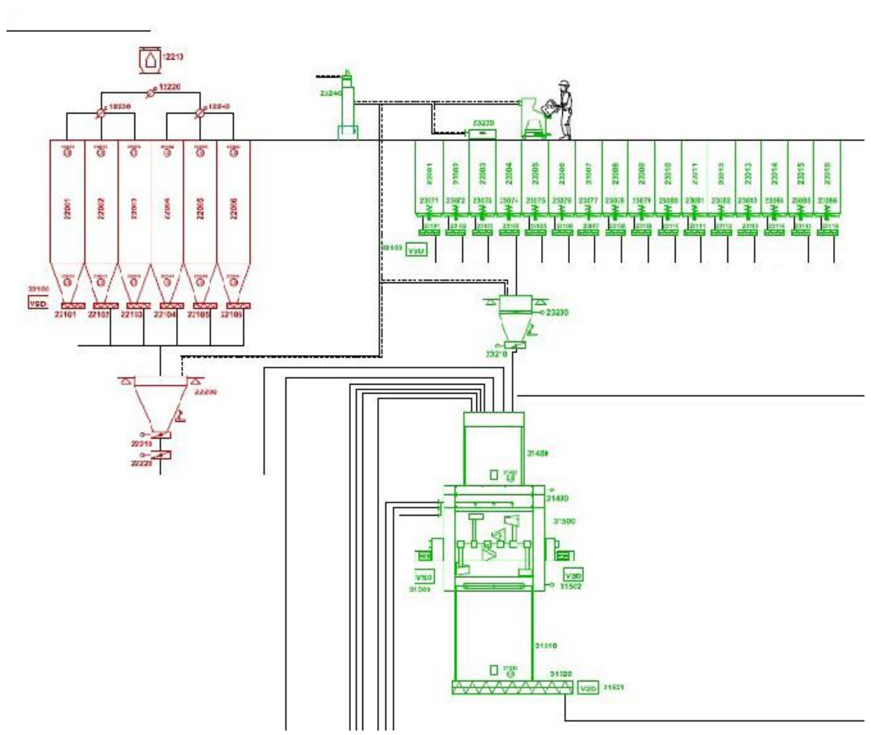
- Main ingredients are normally cereal products but can also be by-products and rendering products, which all require grinding.
- Minerals are normally salt, limestone, and phosphorous. These by-pass the grinding process to protect the hammer mill from extreme abrasive wear.
- Micro ingredients are the remaining and smallest ingredients and include components like amino acids, vitamins, and enzymes.

A hand dump is another way for raw material to be delivered.

Lastly, The liquid ingredients are added. Some are batched into main mixer (fat, oil, water, etc.), and some are added continuously in the conditioner before pelleting or into a continuous or batch coater after pelleting.

Fats and oils may be added either before the pellet mill (in main mixer or conditioner) or after the pellet mill in a coating system (continuous or batch coater). This balance of pre or post pellet coating may be used to balance capacity and quality of pelleting, since fats and oils act as a lubricant in the die and excessive amounts reduce capacity but decrease quality.

A similar approach may be used for balancing the application of enzymes which are destroyed (reduced activity) during the heat treatment process in the pelleting line.



Grinding

Grinding is the process of breaking down grain into meal

The primary purpose of grinding is to break the protective hull of the grain, releasing the nutrients for cooking in the pelleting line as well as making the grain easier for the animal to digest and consequently, grow faster. Grinding also significantly improves the pelleting process.

The hull of the grain protects the endosperm (kernel) from premature degradation. The endosperm is an energy reserve used for seed germination in the spring. By breaking the kernel, the nutritional value of the endosperm is now more accessible to the animal for digestion and feed conversion.

Only raw materials like cereals, brans, by-products, and rendering products that benefits from the grinding process need to be sent through the grinder. The remaining vitamins and minerals must by-pass the grinder due to the risk of carry-over in the filter and increased abrasive wear.

Finer grinds lead to better conditioning and improve the pelleting process in capacity and quality.

However, the feed manufacturer needs to establish an appropriate balance between animal nutritional requirements and process requirements.

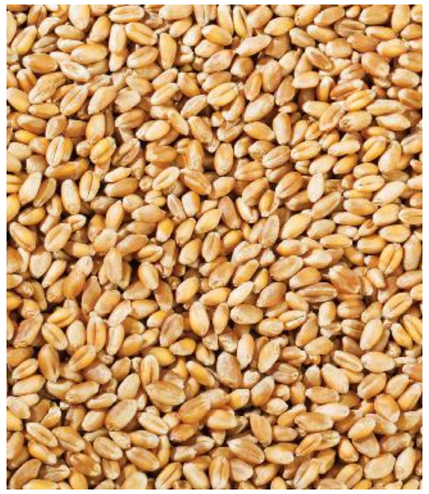
The hammer mill and roller mill may be installed in combination with screeners to by-pass undersized particles directly into main mixer with the purpose of optimizing power consumption and capacity.

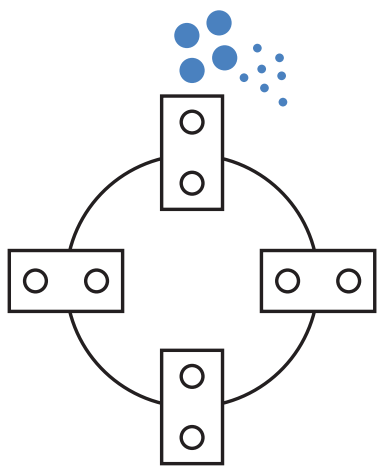
We distinguish between pre-grinding and post-grinding compared to the batching process. Before or after the batching process.

- Post-grinding: All raw materials are ground together after batching – European process
- Pre-grinding: Raw materials are individually ground prior to batching – US process

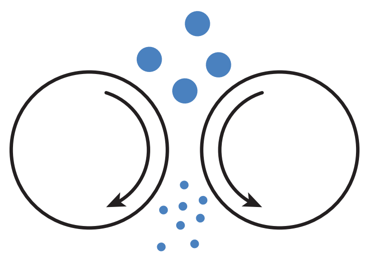
Pre-grinding, as opposed to post-grinding, enables the use of individual screens for individual raw materials, enables better hammer mill utilization (OEE), but also requires more silos and bins.

The grinding process is mainly performed by hammer mills and roller mills however vertical hammer mills and disc mills are also used, with the latter being very sensitive to foreign objects.



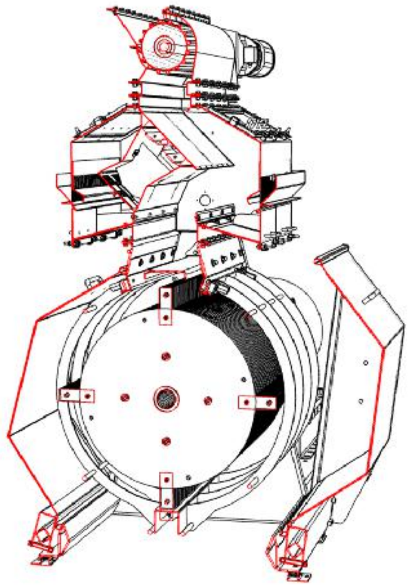


Hammer Mill



Roller Mill

Grinding



HAMMER MILL

The hammer mill works with freely hanging beaters that are mounted on a rotor which pulverizes the grain as it enters the grinding chamber. The air flow produced by the fan evacuates the meal from the grinding chamber through the perforated screen which defines the maximum particle size. Raw materials enter from the top and are moved by the guide plate in the direction the rotor/hammers are rotating. The raw materials are impacted initially by the hammer and secondly upon contact with the screen. The main grinding takes place on the downside screen and the final grinding on the opposite upward facing screen. If material is still not small enough to pass through the screen by air evacuation after a complete circle, it suffers the symptoms of regrinding which results in increased power consumption, heating of meal and reduced air flow. Grinding is mostly efficient when then hammer can accelerate the grain into the clearing in between the hammer and screen. The air flow of the fan pulls the grain into this grinding zone.

Hammer mills should be designed symmetrically in order to reverse rotor operation and wear on both upside and downside screens equally, as well as in all corners of the hammer, while maintaining grinding performance. As the direction of rotation is changed, the inlet guide plate must also change position.

Multimill

Optimill

For fine grinding applications, thin, fragile screens with small perforations are used. To prolong the lifetime of the thin screens, this type of hammer mill (MultiMill) has a grinding bridge in the inlet measuring 200mm long. It is a thick thick plate with corrugations to take the initial impact of the grain and thereby protect the screen. In the bottom of some hammer mills, there is a stone trap. The intension was not to actually trap stones but stones which are not caught in the separator tend to end up there (until they are ground). The stone trap in the bottom slows down the speed of the grain preparing it for reacceleration, a last grinding on the upwards screen. Some suppliers install fixed counter hammers to serve the same purpose.

The hammer mill will grind almost everything, and it is also applied in many other applications other than just feed and biofuel. The hammer mill may grind occasional lumps of wet or fatty material. However, when fat or moisture levels increase, operation may become difficult because product may start to accumulate outside the grinding chamber - between the screen and the door. This will reduce air flow, increase power consumption, and may trip the motor or ignite a fire in the hammer mill. Formulations which include rendering products benefit from being premixed prior to grinding.

FEEDERS

Pocket feeders or screw feeders are used to feed material into a hammer mill or roller mill. For free-flowing grains, or those with small particle sizes, a pocket feeder may be utilized. However, sticky substances such as rendering products will clog pockets and oversized particles such as large wood chips can cause blockages in the rotation. In situations such as these, a screw feeder should be installed.

Pocket feeder

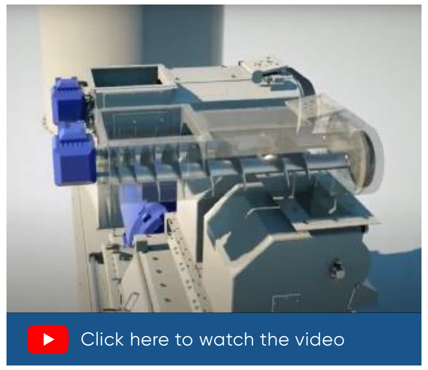
Screw feeder

The speed of the pocket or screw feeder is regulated by the amperage of the hammer mill's main motor. This ensures that the hammer mill is loaded to a desired set point and prevents overload. This regulation is performed by a PID-regulation loop. For roller mills, the electrical load on the lowest and finest layer is typically the highest and therefore used for the regulation loop.

PERFORMANCE TUNING

There are a few parameters that can be fine-tuned so that the hammer mill performance is optimized performance.

- Screen size (large screen => higher capacity but also results in a structure that is more coarse)
- Tip speed (fast => finer grind, slow => more coarse)
  - Limitations (40-60Hz)
- Hammer-to-screen clearing (closer distance => finer grind)
- More hammers => even finer grind
- Capacity (low => fine grind, high => coarse grind)
- Air flow (low air flow => fine grind, high air flow => coarse grind)



Grinding

RAW MATERIALS
Many different factors play a role in how easily certain raw materials will grind.

Crops grows at different rates from one region to the next. The slower a crop grows the higher the fiber content will be. The higher the fiber, the more difficult the product will be to grind.

Storage time and conditions also impact grinding. Grains kept in dry storage, where water content is low due to evaporation, grinds more easily. Additionally, the longer grains are stored the easier they are to grind as starch crystallization causes kernels to become increasingly crisp.

Each ingredient typically requires a specific energy (kWh/t) to grind on a specific screen. When grinding is performed in post-grinding (all ingredients together after batching) the specific energy is the linear combination of the individual ingredients:

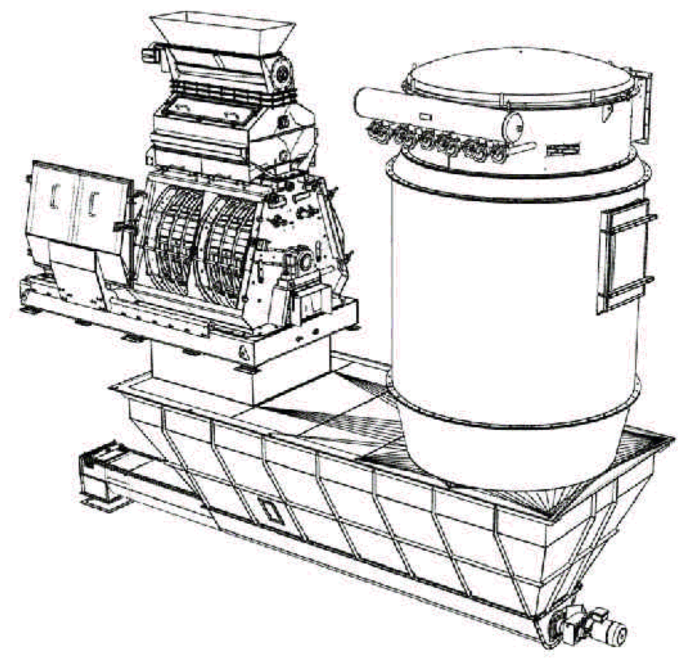
- Ø3mm screen with 50/50 split on wheat and barley
- Wheat at 6,6kWh/t
- Barley at 12,5kWh/t

This boils down to
(12,5+6,6) / 2 = 9,55kWh/t.
The calculation on different ratios like 30/70 wheat/barley split relies on similar approach:
6,6*30% + 12,5*70% = 1,98 + 8,75 = 10,73kWh/t

Eventually, groups of formulations for broiler feed, pig fatteners, or dairy feed, for example, will have their specific energy grinding requirement. As mentioned above, these values would be specific to the region primarily due to the different characteristics of the raw materials that are traditionally available and included in the formulations.

The hammer mill typically increases material temperature by 5-10°C as the energy consumed by the motor goes into heating the air and the material (and the mill itself). The temperature increase leads to moisture evaporation from the material, referred to as shrinkage. If the temperature is higher than expected, it can signify reduced airflow due to clogged screens or re-grinding due to increased fiber content.

AIRFLOW
The airflow of the hammer mill fan is essential not only to protect the machine and process but also to protect the operator. Air enters the hammer mill through the separator inlet. The raw material enters from the feeder into the tray in the separator. As the inlet air blows from below, it lifts the grain up, leaving heavier material, such as stones, behind. The airflow transports the grain into the grinding chamber and when grain is ground small enough, the airflow will evacuate the grinding chamber into the plenum (collection bin). Heavier particles will sediment (fall out) into the discharge screw conveyor, but lighter particles will flow along the air stream to the integrated bag filter. Exhaust air from the filter will be cleaned of particles (<10mg/m3) and exit through the fan silencer.
Though invisible, air flow is an integral part of the grinding process. Often, processing problems are caused by problems with the filter and airflow.
Reducing the airflow reduces



Grinding

the evacuation of meal from the grinding chamber, thus increasing retention time and thereby increasing grinding and power consumption. Less air can make the meal finer and more air makes meal more coarse. Therefore, reduced airflow can cause the meal to become very fine. Additionally, if power is limited, reducing airflow will also limit capacity.

Reducing airflow must be performed in a controlled way, as this will increase dust concentration in the plenum. If the dust concentration reaches an excessive level, there is a potential for a dust explosion to occur. A spark from a foreign object like a stone or metal scrap is typically the cause of an explosion.
Reducing airflow can also lead to unintentional wear patterns. Therefore, one should monitor negative pressure on the system, temperature in the grinding chamber, or the airflow directly in order to secure both the grinding process and safety around the hammer mill.

The integrated bag filter of the grinding unit may be moved away from the hammer mill and into a location where the meal needs to go anyway. In this way, the airflow evacuating the grinding chamber also acts as a means of transport in a pneumatic conveying system (lean phase 0,8-1,2kg/m3). Depending on capacity, it does, however, require a larger fan and filter than the mill itself requires on a collection bin. The latter will be replaced by a pickup pan, reducing the size of the installation significantly.
For fine grinding extrusion applications, a double grinding setup may be installed. It consists of one feeder and one separator on top of the hammer mill and then a transition section to the next hammer mill. The two mills are stacked on top of each other, sharing the airflow. The top hammer mill typically operates with a Ø3mm screen and lower hammer mill with Ø1,25mm screen. Depending on formulation quality the screens can go down to 90-95% < 300ym.

Like the previously mentioned pneumatic transport setup, the double grinding setup can also be installed with a pneumatic discharger, conveniently retrofit for brown field projects.

Grinding

CAPACITY ESTIMATION

Estimating the capacity of a hammer mill for a specific formulation starts with evaluating the required specific energy (kWh/t). For individual ingredients, see the table below.

The power requirement is calculated by multiplying capacity in t/h by specific energy:

$$kW = {}^{kWh}/_{t} * t/h$$

Afterward, select the compatible hammer mill for this motor size.

MultiMills are intended for extrusion applications like aquafeed and pet food which require fine grinding.

OptiMills are designed for animal feed like poultry, pig and ruminant feed which require coarse grinding.

Screen size	Oat	Barley	Rye	Wheat	Corn	Sorghum
1,5	50,0	26,2	18,9	13,9	12,5	10,0
2,0	29,4	20,2	13,2	11,2	9,3	7,7
2,5	24,4	15,0	9,3	8,6	7,2	5,9
3,0	21,5	12,5	8,2	6,6	5,7	4,3
3,5	16,5	10,2	6,8	5,7	4,7	3,7
4,0	13,2	8,9	5,7	5,3	3,8	3,0
4,5	11,8	7,8		4,7	3,3	
5,0	10,6	7,0		4,3	2,9	
5,5	9,7	6,4		3,9	2,6	
6,0	9,0	5,9		3,6	2,4	
6,5	8,4	5,5		3,4	2,2	

kWh/t for different screen sizes, 12% moisture

WEAR PARTS

The primary wear parts on a hammer mill are hammers, pins (bolts), and screens. Additional wear parts include top and bottom wear pieces (grinding bridge, top wear piece, bottom wear piece, stone trap) as well as guide plates. Spare parts are screen frames, rotors, and bearings.

Hammers must be replaced regularly to maintain grinding performance as well as safety. If the hammer has been worn shorter than the original length, it must be scrapped and replaced to withstand the extremely high dynamic stress. ANDRITZ hammer systems for both the OptiMill and MultiMill are very simple and inexpensive compared to other suppliers. Each hammer has two holes, and all 4 corners are usable. With regard to OptiMill rotors, the hammers can be modified very quickly. To use the other hole, lay all the hammers down, aligning with new hole, insert a new pin, and retract the old pin. Pins should not be reused.

A locking collar with set screw prevents the pin from moving sideways into the grinding chamber sides.
The guide plate sits in the inlet of the mill, hidden and difficult to inspect or even to be seen. However, when worn, it will leak material into the wrong side when compared to the rotor direction, causing a significant capacity reduction of up to 10-20%. The edges of the guide plate will be razor sharp, so be careful inspecting if they are not visible. When new hammers are installed, the capacity will not immediately improve. However, after a short

break-in period they will reach optimum capacity. From there they will slowly degrade with use until they again reach an unacceptable level and need rotating or changing.

Some (conventional) hammers are surface hardened. Hammers may also be supplied with a hard facing composed of either a weld seam or an actual hardox material. These are very costly and so long-lived that a thicker hammer pin is required to have the same lifetime as conventional hammers. Hard-faced hammers have a much more consistent grinding performance over their lifetime when compared to conventional hardened hammers.

Screens are replaced when they break due to excessive wear, vibrate, or when a foreign object punches a hole through the surface. Screen perforations can be designed with different patterns and distances between the holes. This gives different open areas on similar screens. Screens should be perforated and rolled so that the metal burrs end up on the inside grinding chamber.

Bearings are either pedestal bearings for the OptiMill or flange bearings for the MultiMill. Regardless of type of bearing being used, bearing maintenance is essential for safe operation as bearing collapse may cause a catastrophic breakdown. Therefore, hammer mills must be supplied with a bearing temperature sensor/ switch. Bearings are normally lubricated on a time schedule and replaced based on elevate bearing temperature or on elapsed time. Bearings should always be replaced when the rotor is replaced. Of the two bearings, the non-drive end must be allowed to move axially, while the drive end is fixed. When installing bearings, each must be adjusted to correct tolerances between the upper ball rows and the outer ring.
The motor is connected to the rotor shaft through a coupling and works to protect the electrical motor from vibrations. The motor and rotor must be aligned correctly to prevent overloading the coupling. The coupling must be inspected on regular basis and maintained (lubricated) accordingly.

SAFETY

Andritz mills have door locks and zero-speed switches on the shaft which interlocks with the control to prevent an open mill from starting but also from opening prematurely when ramping down.

Remember that disengaging the hammer mill from the main circuit breaker and/or through the controls/MCC (motor control center) usually doesn't deenergize the pneumatics, which must be closed and vented to be safe. Bear in mind that the guide plate is pneumatic and may cut a finger/ hand when operated.

Grinding

DUST EXPLOSIONS
Hammer mills are notoriously dangerous machines as they are fast rotating, dust generating, and easily grind stone and nuts, creating lots of sparks. Explosions do not occur under normal conditions, as the dust concentration in the collection bin and filter are too lean to support an explosion. However, if the airflow is reduced significantly, dust may increase to a dangerous level. All possible measures must be taken to reduce the risks of explosion but eventually, you may end up with a risk assessment that indicates you need to prepare for an explosion. The explosion may either be suppressed or vented.

A suppression explosion is very expensive from both a capital and an operational perspective. It consists of one or more pressure transmitters, a high-speed dedicated control system, and one or more powder extinguishers permanently mounted in the collection bin and filter. The systems will then need regular and costly service and inspection.

Venting systems come in two variants. Either simple break-open panels or flameless vents. During an explosion it opens at 0,1bar (Pstat). With the vent open, the pressure will continue increasing to a reduced maximum pressure which is less than 0,6bar (Pred). This is no more than the designed maximum pressure the machine can withstand (Predmax=0,6).

The break-open panel breaks and prevents the explosion from rising above 0,6bar which would demolish the machine and the process and has the potential to kill the operator and destroy the entire plant. When the panel opens, it spits out a flame which is easily 20-25m long and must be safely led to an outside area using a relatively short duct. Ducts normally don't exceed 1,5-2m. The panels are obviously not reusable but are relatively inexpensive.

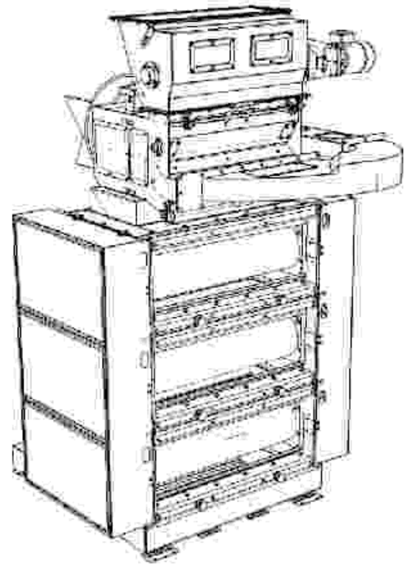
If the explosion cannot be directed through a duct because of the building layout, a flameless vent system can be installed instead. It separates the flame from the combustible material (dust) and vents the positive pressure out of collection bin and filter using the same parameters to open at 0,1bar and prevent pressure building higher than 0,6bar. The vent is reusable and equipped with a switch to indicate activation. The flameless venting system is more expensive than the panel, yet much cheaper than the suppression and allows the grinding installation to be placed freely within the building.

One should never perform work next to an operating hammer mill. Shorter inspections using correct personal protective equipment (PPE) are allowed.

Grinding

ROLLER MILL
The roller mill works with two or three sets of corrugated rollers rotating at the same speed. On top there is a pocket feeder and a separator with an internal recirculating fan. The output particle size is determined by the corrugation size and distance between the rollers. Roller adjustment is supplied either manually or automatically. The roller mill consists of two or three layers of roller sets, each grinding the material finer and finer. Roller fluting and roller gap becomes smaller and smaller down through the layers in the machine.

The roller mill processes dry, lean, cracked cereals grains (split in half) into smaller particles, producing a narrower range of particle sizes than the hammer mill but consuming approximately half the energy.



The roller mill cannot process meal, by-products, or bran. The hammer mill is better at grinding powders, fiber-rich, and fatty materials (rendering products). The hammer mill is a better choice when a fine grind is genuinely required. Still, by utilizing the automatic roller gap adjustment for each tier, the roller mill will process each grain type to the exact nutritional requirements for which the animal feed is being produced.

Factors to consider when selecting/installing a roller mill:

When the coarsely structured meal from a roller mill is pelleted, more power is required to run the pellet mill, it does so at a reduced capacity, and ultimately the results are a lower quality pellet as compared to the pellets formed from meal produced by the hammer mill.

Because there is no airflow in the grinding zone of a roller mill, there is a risk of dust explosion if the collection bin below is not as small as possible.

A roller mill should be installed on small volume collection bin to prevent dust explosion.

The rollers go blunt over time and need to be replaced. Roller bearings and belts should be inspected and potentially replaced at the same time.

The roller mill shares many mechanical components with a pellet crumbler (GM and GRM) and is supplied with a pocket feeder and separator on top.

Mixing

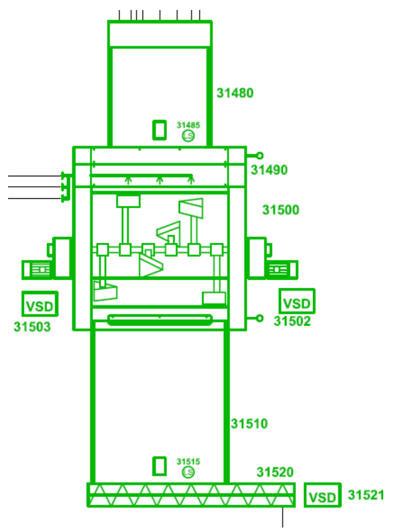
Meal from the mill meets-up with vitamins and minerals in the mixer

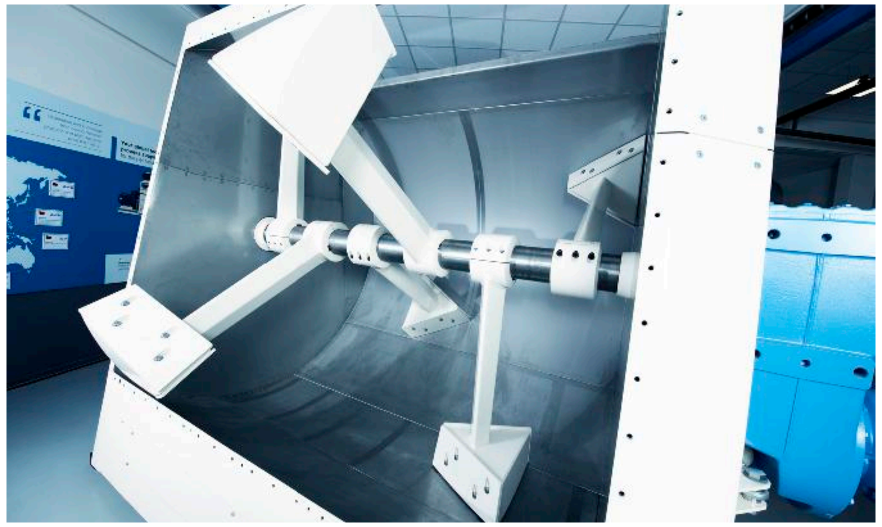
The raw materials that compose compound animal feed come together in the main mixer prior to the pelleting or extrusion process. The mixer typically sits between the grinder and pelleting line (post grinding) but can also sit between the dosing and pelleting line (pre grinding).
The mixing process, regardless of paddle, ribbon, or single/twin shaft, moves the product slowly axially and fast radially. Paddle mixers may operate anywhere from a 25-100% degree of filling.

Through the years, ANDRITZ has made several types of single shaft mixers: HPB (horizontal paddle), FMR (feed mixer ribbon), HB (horizontal ribbon), and most recently, the OptiMix which is a horizontal paddle mixer.

The trough of the OptiMix is completely cylindrical with a tangential inlet and adjustable paddles that wipe the end walls axially with minimal tolerance to the trough. The trough is made of carbon steel or stainless steel. The mixing aggregate consists of a shaft with permanently mounted, bi-directional paddles. The wiring and piping are integrated into the frame, making it easy to clean and maintain the mixer. A ladder is attached to the end of the mixer to provide easy access to the OptiMix. The shaft, arms, and paddles are designed to operate equally in both rotational directions in order to minimize product accumulation caused by liquid applications. The mixer has an integrated, full-length outlet damper with a locking device and optional air seals to prevent carry-over. The mixer comes with an optional, full-length axial inlet damper. Full-length inlet and outlet dampers ensure fast filling and discharging.

To achieve a decent line capacity, any mixer must be installed with a surge bin for discharging and a pre bin for buffering from the hammer mills and the minor scales. The mixing device (shaft and paddles) rotates during filling, as continuously restarting under full load will cause a mechanical failure. Liquids such as molasses, fat, oil, water, acid, enzymes, amino acids, etc. are added through nozzles located in the mixer inlet. An application of fat and oil causes particle agglomeration; therefore, the spraying period should only be initiated after the dry mixing time is complete. In addition, the mixing process is not intense enough to break any lumps formed during the liquid spray period. Therefore, the wet mixing period should only be long enough to capture the liquid nozzle after-run.





Ribbon-style mixers, which have one outer ribbon and one inner ribbon for opposite axial material movement are an alternative option. However, the ribbons are difficult to clean and replace and virtually impossible to adjust. Additionally, they mix slowly and must be filled to capacity to maintain mixing quality.

Both paddle and ribbon mixer come in single and double shaft. Adding another shaft increases mixing speed (cycle time), reduces built-in height, and increases both capital and operational costs.

MIXING QUALITY

The quality of the mix is based on the homogeneity of the dry ingredients in the meal. Bad mixing can result in poor animal performance and carry-over.

Some ingredients are essential to some animals but may be lethal to others (copper to sheep and coccidiostats to turkeys), and carry-over can result in a perilous outcome!

A sound quality control system should include regular mixer testing, such as the Codex Alimentarius mixing quality testing required by the FDA, EU, and WHO. Mixer performance and results are affected by a number of factors.

- Longer mixing times usually result in better mixing, but very fine particles (powders) may segregate with prolonged mixing times.
- Mixer wear and tear
  - You must ensure that the outlet slide of the prebin or mixer is not leaking (carry-over).
  - Paddle-to-trough distance will increase as mixing paddles wear, reducing mixing ability
- Regular cleaning is required when performing wet mixing or mixing that promotes material build up
- Both under, but more frequently, over-filling the mixer will cause bad mixing
- Raw materials change with the seasons, changes from suppliers, and when new recipes are introduced
  - The particle size distribution and shape: ground material, minerals and vitamins
  - Differences in bulk density
- The inclusion of wet materials

SAMPLING

Mixing quality is determined by analyzing a sequence of samples extracted from the mixer surge bin outlet. Samples should also be taken downstream from the mixer. To collect the sample, the product should be taken from a location where it is falling, and it is safe to cut through the product.

The primary sample size should be as large as possible (approximately ½ kg). Usually ten samples are extracted from one batch during emptying. Sampling must start when the mixer post bin emptying begins and stops when emptying ends. Samples must be extracted and handled according to the basic principles of TOS (Theory of Sampling).

SAMPLE HANDLING

Samples must be uniquely marked and stored in double plastic bags in a cool and shady place. The samples are typically handed over to the laboratory, but you should ensure that, the samples are analyzed as soon as possible using appropriate and certified methods for sample handling, sample homogenization, mass reduction, and analytical method.

MARKER SELECTION

It is very important to carefully select appropriate markers. Andritz recommends the use of Microtracers, a product which contains (or consists of) iron particles covered with a dilutable food grade color. For experimental purposes methyl violet may be used, but as this is toxic, the batch must be destroyed and process lines thoroughly cleaned afterwards.

Markers good for routine usage are micro ingredients such as vitamins or amino acids added explicitly in micro dosing. The downside is that the laboratory analysis is expensive. For daily use, NaCl seems suitable even though NaCl is naturally occurring in other feed components and causes an over optimistic CV-value.

Different markers will give different results! No matter your marker selection, it must compose less than 2% of the feed. Therefore, it is a good practice to use a marker which does not already exists in your product. Additionally, the amount of tracer must lead to minimum 1000 particles in each primary sample. If a Microtracer product is applied, a minimum of 100 particles should be found in each sample.
If you choose to use micro ingredients to monitor your mixing quality over time, you can cause weighing errors from your dosing system if you compare CV-values over time.

A good method is described in ANSI/ASAE S303.4 SEP2007 Test Procedure for Solids-Mixing Equipment for Animal Feeds.

COEFFICIENT OF VARIANCE

Mixer performance or mix uniformity is measured using coefficient of variance (CV). The CV value indicates the standard deviation as a percentage of the average value.

CV is defined as:

$$CV\,[\%] = \frac{\sigma}{\mu} * 100\%$$

where mean is:

$$\mu = \frac{\sum_{i=1}^{n} X_i}{n}$$

and standard deviation is:

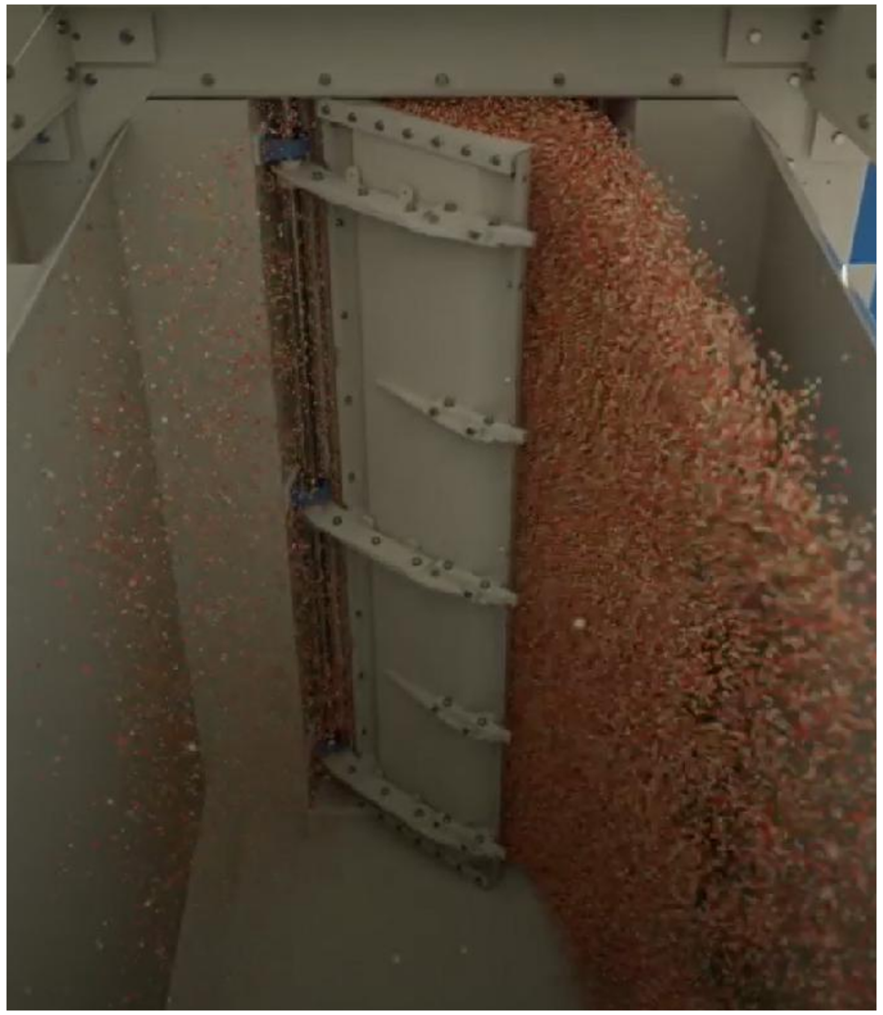
$$\sigma = \sqrt{\frac{\sum_{i=1}^{n} (X_i - \bar{X})^2}{n-1}}$$

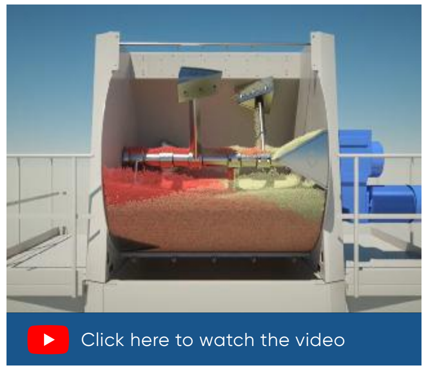
When having **n** samples. The standard deviation describes the random deviations from a mean average.

Calculating the coefficient of variance removes the "unit" from the standard deviation

The minimum CV-value would be 10% whereas the normal market requirement is 5% or 3% depending on the source.

However, as the CV-value is an expression of the accumulated error of mixing, sampling, sample handling, and analysis; 3% may prove very difficult to achieve.





Conditioning

Steam pre-conditioning

The initial processing step in the pelleting line is conditioning. Here steam collects on the surface of meal particles. This increases moisture content and raises meal temperature prior to pelleting. The conditioner is a continuous paddle mixer with paddles mounted on a rotating shaft to lift the meal into the air as steam is injected. With ANDRITZ conditioners, the direction of rotation is always up, and to the right - towards the doors, with a rotational speed from 150-200rpm, depending on the model.

The conditioning process heats the product from 20C to 70C, consuming 3% of the steam and elevating moisture content correspondingly by 3%. As a rule of thumb, adding 1% steam (in relation to meal capacity) increases the temperature from 12-14C, depending on the specific heat capacity of raw materials. Retention time depends on capacity and conditioner volume – but it is usually from 20 to 40 seconds. A high retention time is needed to allow the particles to absorb the moisture entirely and for the pellet mill to operate optimally, ensuring that the meal will be hot and moist but not wet. If the steam flow is too high for the material to absorb or the opposite, the meal absorption is depleted, the conditioner will blow the shaft and door seals and leak steam and dust.

Suppose steam loses energy (temperature decreases) from the boiler to the conditioner, resulting in condensation. In that case, the steam flow will push condensate forward towards the conditioner, potentially overflowing the condensate drains. Eventually, a splash of water may enter the conditioner and generate a lump of wet meal, causing roll-slip and, eventually, pellet mill blockage. Therefore, the boiler must operate at high pressure, pipes must be isolated, and steam traps must be correctly and strategically placed. Finally, pressure may occur in the condensate drain system, preventing the remaining steam traps from operating correctly.

Steam should be transparent and opaque. Foggy steam indicates water droplets and is considered bad quality. The steam pressure in the manifold will usually be close to zero or slightly above. While most materials will pelletize without steam conditioning, they will perform better, and the pelleting process will consume less power. Additionally, the moisture and increased temperature from the steam activates natural binding ingredients:

- Regular feed is bound by primary starch
- Wood and straw pellet are bound by lignin
- DDGS, rape, and sunflower pellets are bound by protein

Higher steam inclusion levels are needed in very cold conditions to achieve proper conditioning (up to 6%). This additional moisture may cause rollers to slip. Similarly, hot environments will cause the grain to be dry and hot, requiring less steam to achieve the temperature set point. In this case, less water is introduced, resulting in quality problems that require liquid addition in the main mixer or conditioner.

Different products require different conditioning temperatures. Selecting the optimal conditioning temperature is a compromise between the requirements for hygiene (eliminating bacteria), local legislation, pellet durability, capacity, and bulk density; consequently, it may vary depending on context, application, and economy. The below list indicates the typical ranges:

- Pig and poultry feed, containing a lot of starch, may be pelletized around 80-85C with approximately 16% moisture
- Ruminant feed containing fiber material may be pelletized at around 60-65C with approximately 16% moisture
- Sunflower husks containing lignin may be pelletized almost cold at a conditioning temperature of 40-50C
- Rape seed meal, sunflower meal, and soybean meal, containing proteins, are pelletized at higher temperatures of 80-90C
- White wood pellets with lignin are usually pelletized using 12-13% moisture and 60-70C consuming 50-60kWh/

RETENTION

Retention time is calculated using the following equation:

- Volume is the effective volume of the conditioner (cylinder minus shaft and paddles)
- Density of the meal
- Degree of filling is determined by the material properties and capacity but mostly paddle settings
- Capacity in Kg/h

Retention time is measured by stopping the conditioner during stable production and weighing the meal inside (E.g., 100kg found inside a conditioner running 15.000kg/h):

$$\frac{100kg}{15000kg/h} * 3600 = 24sec$$

The meal inside the conditioner can also be discharged from the pellet mill dump chute.

The rule of thumb is to include 1% of steam, which increases the temperature by 14C.

An alternative, and more straightforward method, is to stop the feed screw and measure the time it takes for the pellets to stop leaving the pellet mill.

In the conditioner, molasses, fat, oil, and water may be added together. Usually, liquid inclusion in the conditioner happens through the steam nozzle, heating it as the liquid passes through.

Opening the steam nozzles should correspond with the degree of filling, meaning that the nozzles should be fully open where most of the material lies and closed where no material lies (inlet and outlet).

Retention time is calculated using the following equation:

$$\frac{volume[L] \cdot density[kg/L] \cdot degree\ of\ filling[\%] \cdot 3600}{capacity\ [kg/h]} = retention\ time\ [sec]$$

$$\frac{1960L \cdot 0{,}56\ {}^{kg}/_{L} \cdot 30\% \cdot 3600}{73000kg/h} = 16sec$$

REGULATING RETENTION TIME

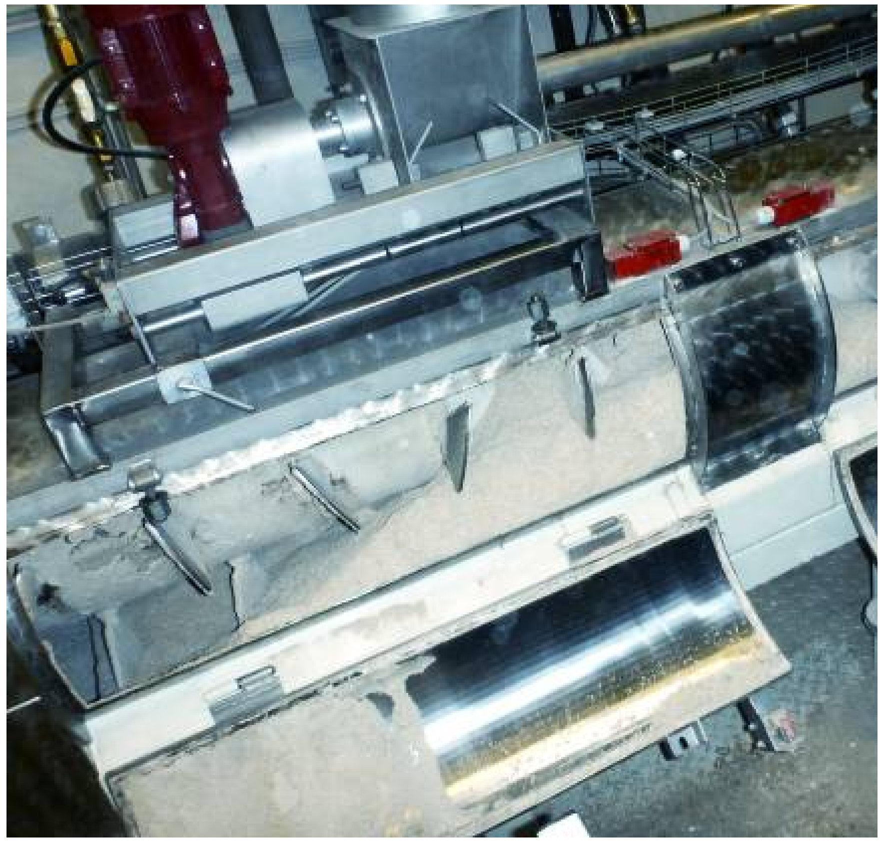
Retention time is increased by adjusting the paddles to throw the material in the direction of the primary material flow. When the retention time increases, the motor's power consumption will also increase. This practice may be used to evaluate conditioner retention without opening the conditioner. However, there may not be a linear relationship.

The practical way of tuning the retention time is by stopping the conditioner in the middle of the process and weighing the material inside. Alternatively, you can measure the material depth at selected spots. A third and more expensive method is to add a tracer, such as the micro tracer Yttrium Oxide, to the inlet and extract samples at equal distances from the outlet.

Because all tracer particles will not discharge at once but will be circulated throughout the retention period, this practice will not only provide an estimate of the retention time but will also indicate the deviations from the mean retention time and answer the questions "How fast are the fastest particles traveling through the conditioner and how slow are the slowest?"

It may be necessary to adjust paddles in pairs to avoid an irregular pumping effect of the material. Additionally, inlet paddles should only move material forward to prevent blocking the feed screw, and the paddle in the outlet section must also only move material into the outlet section.

The same approach used to measure pellet temperature is used to measure meal temperature. First, a large sample is pressed together in a thermo bucket. Then the thermometer is allowed to sit until stable readings can be collected.



Good Conditioner Filling

A PT100 temperature sensor is placed in the meal outlet. The temperature indicator is connected to the control valve through a PID regulation loop in the control system for automatic regulation of outlet temperature - independent of raw material changes such as moisture absorption and initial temperature.

The PT100 sensor must be clean and well placed in the meal outlet stream to quickly and precisely measure the temperature.

STEAM

The steam supply system is unique in the sense, that there is very little condensate return flow. "Normal" steam systems recirculate the water, as it is utilized to transport energy (turbines, heat exchanges, etc.). Because of the large amount of water consumed by a steam system used for animal feed production, water preparation is very important in order to keep steam components operational and the pelleting process running correctly. Many factories operate with reduced capacity due to bad steam quality. Water preparation consist mainly of softening which is the removal of salts that are eliminated during heating but also the preheating of make-up water that will drive out gasses that promote corrosion (oxygen).

The build-up of minerals and the corrosion of components in both the boiler and all the conditioner's steam components may.
The steam components to a conditioner mainly contains the following components:

- On-off valve
- Pressure reduction valve
- Steam flow control valve (regulation valve or modulation valve)
- Steam trap (water separator)
- Optional flow meter
- Manometer (and transmitter)
- Service valves and sight glasses
- Compensator

HOT START AND HYGIENIZERS

When starting up a pelleting line, the initial meal flowing through a conventional conditioner will be insufficiently heated because the process equipment is still cold. Consequently, Andritz has developed a modified conditioner with a hot start: the CM902PH and CM902PH-K.

CM conditioners are insulated with electrical heat tracing, preheating the machine to the required processing levels and resolving most condensational problems. Additionally, steam is applied to a small initial portion of meal, which is recirculated internally with the inlet and outlet gates closed until the desired meal temperature set point has been reached. Afterward, the inlet and outlet gates open, and the conditioner works conventionally.

This hot-start conditioner eliminates the need for a recirculation elevator, which typically delivers inadequately heated material back up into the pelleting line for re-processing. The elevator receives moist material from the conditioner/pellet mill and therefore needs to be made from stainless steel to hold up to the condensation inside. The condensation build-up also means the elevator is very dirty inside and has the potential for mold and bacterial growth.

RETENTION

Heat treatment is a function of time and temperature. Bacteria are killed when exposed to a specific temperature for the required amount of time. So, when the desired temperature from the hot-start conditioner has been reached, it is vital to retain the meal for the required length of time. ANDRITZ designed the CRT (controlled retention time) for this exact purpose. It is a full-flight screw with electrical heat tracing for preheating and insulation. The screw motor is frequency controlled to adjust the retention time within the capacity restrictions.

This thermal treatment may be thought to take place only in the heating and retention sections of the conditioner and is often ignored in the additional processing steps of pelleting, expansion, or extrusion, as the process parameters may vary considerably from one formula to the next.

The hygienizer (or retentioner) consists of a large-diameter screw that slowly conveys the meal from the inlet to the outlet. All contact materials are made out of 316-quality stainless steel. The drive is variable with a frequency drive so that the retention time can be balanced with the capacity. The machine ensures constant heat treatment time, as the first material to enter is the first material to exit (FIFO). The device is always isolated and electrically traced like the hot start conditioner, preheating the machine before operation, preventing condensation from forming wet lumps, and drying the inside environment after operation.

The screw is very slow-moving and can cause surges of material from the CRT. Therefore, a flow equalizer is located in the outlet to create a uniform flow of material and ensure the load on the pelleting machine remains stable.

The screw equalizer speed is variable, employing a frequency drive. It is adjusted according to the filling level in the CRT outlet, which is measured using a lever arm fitted with a transmitter.

Typical conditioner retention time is 40 seconds but for hygienized animal feed, 4-6min is occationally the practice. Hygienized animal feed process lines are typically installed in poultry applications, especially in breeder feed lines where a higher level of hygiene is required.

The CRT's capacity is calculated based on the degree of filling, capacity, meal density, and retention time.

Feed Expander

Expanders knead product prior to pelleting

The feed expander works within the principle of high-temperature short time (HTST), providing high colony forming unit (CFU) reduction; in other words, killing bacteria while preserving enzymes and vitamins.

The feed expander is based on the same process principle as an extruder and is built with similar parts, such as the bearing dock, transmission, and motor base.

The feed expander screw pushes the product towards the restricted outlet, building up pressure and temperature, reaching 40-80 bar and 90-100C, depending on the process requirements.

Usually, the power installed on the expander is similar to that of the pellet mill. The regulation principle is also the same: an amperage is set, and the hydraulicly operated nozzle will open and close accordingly. A distance transmitter gives feedback as to the position of the nozzle. The hydraulic system has two operational speeds; a conventional adjustment speed and a higher speed used in the event of a nearby blockage. A temperature transmitter sits in the outlet giving the operator a reference point for adjustment.

Typically installed above the pellet mill to increase pelleting capacity and quality simultaneously, the expander is fed by the conditioner, operating with similar steam and liquids application that it would have if it were feeding the pellet mill directly.

The feed expander requires well-conditioned, somewhat moist material to prevent plugging and operate smoothly but produces relatively large chunks, making pellet mill operation difficult. Therefore, a wing crumbler is often installed below the expander to reduce particle size. In addition, a force feeder inside the pellet mill door provides better feed distribution than a simple dump chute feeder. The pellet mill can also be bypassed, producing a finished expandate with a light, granular texture, and a large surface area. This product may be served to sows in a wet feeding system.

Open nozzle

Closed nozzle

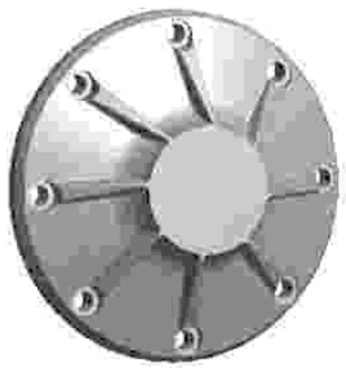
The feed expander is often used in conjunction with a subsequent pellet mill, working as an alternative to double pelleting, where two pellet mills are installed on top of each other. Because of the variable nozzle opening, the amount of energy applied to the product may differ from formulation to formulation. However, when two pellet mills are stacked into a double pelleting setup, the top press applies a fixed amount of energy to the die.

The benefits are the variable energy application and better activation of the natural binding properties of the feed (starch and proteins), resulting in the reduction of fines and the need for recycling, ultimately providing higher pellet quality and line capacity.
For example, European dairy feed producers spend approximately 14kWh/t on conventional pelleting and get 20tph with 96% PDI. On the other hand, installing a feed expander lifts capacity to 25tph and quality to 98%, spending 12kWh/t on the expander and 6kWh/t on the pellet mill.

Click here to watch the video

The primary feed expander wear parts are shown below.

The material is pushed forward by the screw segments. The last segment in the flow direction is the wear screw. It is subjected to high stress as it pushes material towards the nozzle end plate which sits on the outlet of the nozzle ring.



Closed nozzle

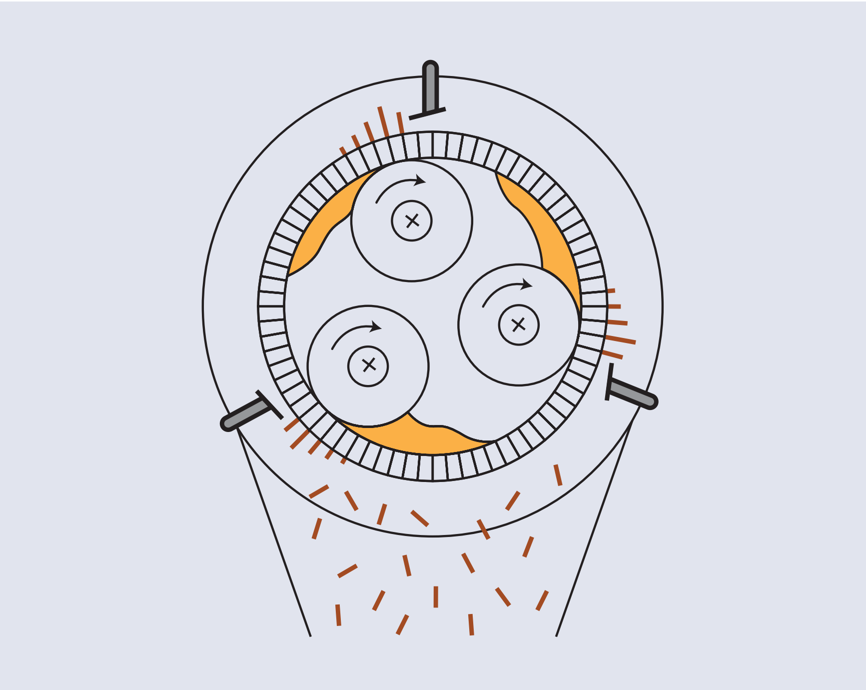
Nozzle ring

Wear screw

Pelleting

The heart of the feed mill

The conditioning process adds moisture and temperature to the meal in preparation for pelleting. The conditioner is a continuous paddle mixing process, where paddles mounted on a rotating shaft lift the meal into the air as dry steam is injected. The meal stays inside the conditioner for approximately 40 seconds, where the steam is added to heat the product to 70-80C and increase moisture content from 12% to 15%.

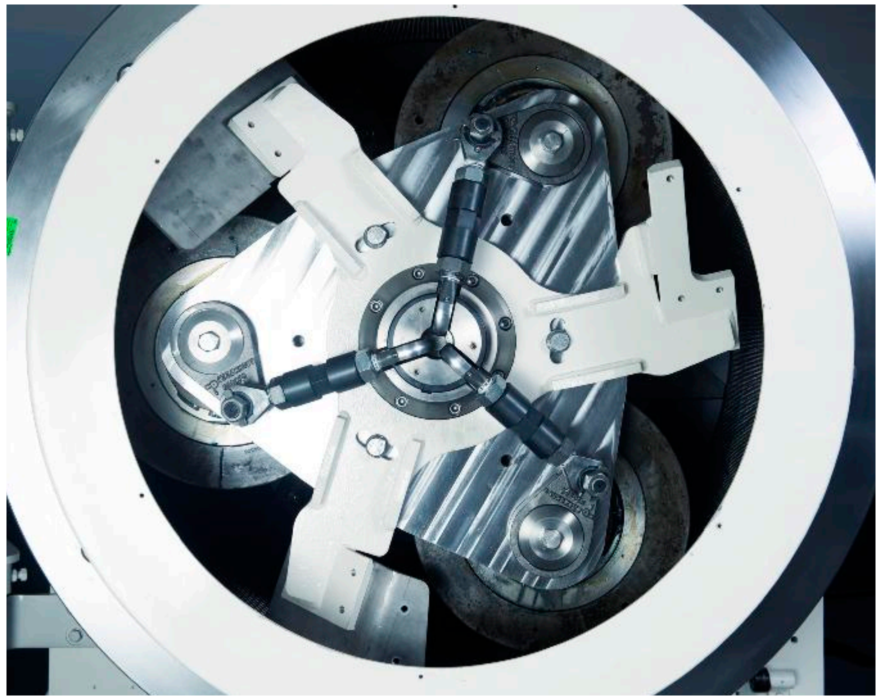


Pellets are formed by feeding the hot, moist material from the conditioner into a perforated ring (die). Here internally located rollers force the meal through the holes of the die. The heat from friction raises the product temperature to 80-100C and forms the pellet. A feed cylinder or feed cone is installed on the front of the die, ensuring that material falling from the conditioner above enters the die inside rather than leaking into the cooler. Scrapers move material from the feed cylinder/cone to the front of the rollers. The cylinder has a rough surface that prevents material from getting inside, distributing material to all rollers. It is possible to adjust the material distribution between the rollers by adjusting the scrapers. An even distribution leads to improved pellet mill operation and higher capacity.

Surrounding the die is a pellet door or pellet chamber with a hole in the front where the mash from the conditioner enters and another hole in the bottom where pellets leave, heading for the cooler. In the door, pellet knives and an optional spray system are installed. The pellet door should be insolated to reduce noise and prevent condensation.

The pellet mill has either two or three rollers. The rollers are eccentrically mounted, enabling roller gap adjustment by rotating the roller shaft as the die rotates clockwise (see from the front). The left roller (in a 2-roller system) is called the leading roller, and the right is called the trailing roller. Traditionally the leading roller takes more of the load and experiences more wear than the trailing roller, but the objective is to load all rollers equally. Rollers can experience uneven wear caused by blockages that cause the overloaded roller to slip. Roller feeding and scraper distribution are aimed at evenly feeding material across the roller (from front to back) to create an even carpet, preferably in front of the roller. The rollers are located on the roller main shaft where the die is mounted. The roller main shaft is fixed in the back end of the machine by either shear pins or hydraulic disc brakes (a Paladin feature).

The die rotates around the roller main shaft on which the rollers sit and rotate individually. In an empty state, the rollers should barely touch the inside of the die so that when the mash gets trapped, the roller rotation begins. If a foreign object is trapped between the roller and the die, it will be pushed into the die. However, the foreign object will try to rotate around the entire roller main shaft. The shear pins or disc brakes will break, protect the machine, and prevent



excessive damage. This kind of overload may also be caused by poor mixing or overload in capacity.

The bearings of the rollers are grease lubricated through a channel inside the roller main shaft from behind. On older, smaller machines, bearing lubrication must be done manually. However, on larger, more modern machines, lubrication is automated.

The mash is intended to be pushed out through the die to form pellets. However, the independent rotation of the die and rollers can sometimes result in mash escaping from the front of the roller. If the mash escapes the die, the rollers will experience roll-slip, an action similar to the skidding of a blocked tire on a car. When the rollers stop rotating, there is an almost immediate and complete blockage, causing the pellet mill to go into overload.
Rollers are usually adjusted by default, using a manual arrangement with an adjustment screw and a lock nut to keep that adjustment in place. However, rollers can also be adjusted automatically or remotely, though they will require an initial manual adjustment and zeroing of the process control software.

The two existing methods for feeding the pellet mill:
1) The dump chute feeder is a simple device where material falls onto a chute and magnet, directing it into the feed cylinder and die. In case of amperage overload, the dump chute may open and dump material onto the floor or bin below.
2) The force feeder is practical when the pellet mill is fed from a feed expander (when particle size needs to be smaller than what the wing crumbler can make) or when the conditioner is installed high above the pellet mill.
In the latter case, it is more challenging to get the mash to reach the trailing roller due to the high falling speed. If mash escapes from the feed cylinder into the cooler without first passing through the die, it is called "leaking."

The die can be mounted on the main shaft in many ways: Bottom-out bolting, conical fit, or clamps. They all have pros and cons; however, bottom-out is the best as it is fast, stable, easy, durable, and bulletproof. On the other hand, the conical fit is slow. The "quick die change" concept involves two rings between the die and the main shaft. One ring is bolted onto the main shaft from behind, and the other is bolted on the die. The idea is that these two rings are bolted together from the front and are easily accessible using a pneumatic wrench for quick and easy die replacement.


Close to die


Away from die

AUTOMATIC ROLLER ADJUSTMENT

Pellet mills can be supplied with either manual or automatic roller adjustment. Auto Roll Adjust (ARA) is a hydraulically driven linkage system that runs through the roller main shaft that is operated and controlled from the back of the machine. The automatic roller adjustment system is interconnected with the roll slip sensors, which measure the speed of each roller.
The automatic system offers many benefits, but an easy restart is probably the biggest. Rollers may also be retracted during idling to prevent die rolling, thereby prolonging the lifetime of the die. Building a layer between the roller and die, known as a "carpet," increases power consumption and pellet quality for easier formulations. This procedure can be utilized to select a die that is best suited for the formulation. More difficult formulations require a longer press channel, but the ARA can compensate for that by retracting rollers and applying more energy – equal to the longer press channel. In combination with roll slip sensors, the rollers can be pushed closer to the die if one is slipping (this typically occurs with the leading roller).

Die speed

Increasing the die speed will reduce the carpet height in front of the roller, making it less likely for the roller to slip and the pellet mill to block. Increasing the die speed will also create a pellet with more layers. At the upper limits of die speed, pellets are subjected to the force of impact when they hit the pellet chamber and break, forming dust and fines.

Traditionally, a high die speed is selected when processing fine materials with good pelletability, whereas coarse materials need a slow die speed. Slow die speeds give pellets a gentler treatment in the pellet chamber, but slow speed prevents layers of material from building up in the pellet.

Two or Three Rollers

Initially, pelleting machines were designed with two rollers, but this configuration caused uneven wear on the die because roller stress was concentrated on the left and right sides. With the advancement of the three rollers system, now the mechanically preferred solution, the pressure on the die is more evenly distributed.

As a result, three roll machines are installed for high-capacity, easy-to-pellet, quality products like poultry feed. In comparison, two roller machines are selected for pelleting fibrous products or when a lot of space inside the die is required.

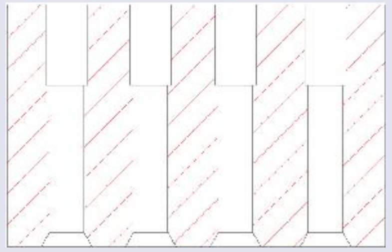
When ideally set up, operating a machine with three rollers will have 50% less material buildup in front of the roller compared to two roller machines, corresponding with a 50% capacity increase. However, this assumes that material is equally distributed to all rollers.

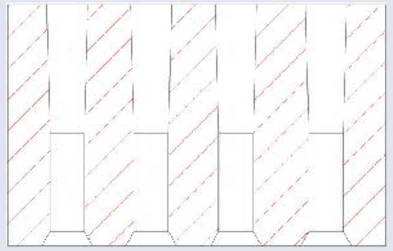
Die retention time will be the same regardless of whether the machine has two or three rollers. However, the pellet will be composed of more layers using three rollers. Additionally, power consumption (kWh/t) is higher on the three-roller system, as most power is consumed by flow initiation in the pelleting channel, occurring twice as often on a three-roller system.

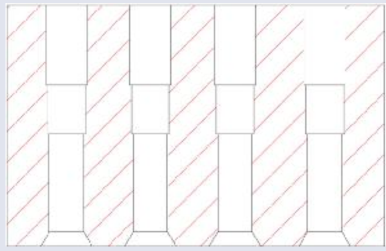
Die Specifications

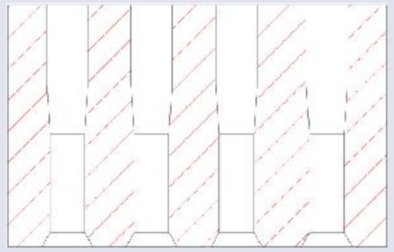
Dies are specified using the hole diameter and die thickness. For example, a Ø3.5x80/50 die would have a hole diameter of 3.5mm and a 50mm Press channel plus a 30mm counter-bore for a total die thickness of 80mm. However, each die has a specified thickness that must be met to prevent breakage during operation. Therefore, the die could be manufactured to 70mm thick, for example, and then counter-bored from outside to an effective die length of 50mm.

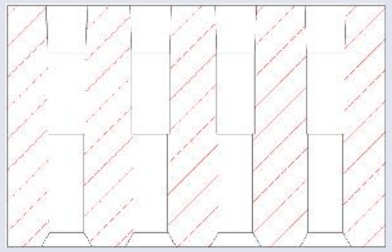
The hole length defines the magnitude of counter pressure between the material and the die. This contact point converts the die's rotational energy into the material's thermal energy. The longer the hole and the higher the counter pressure, the higher the pellet quality. Consequently, this also lowers the capacity. The ratio between the diameter and length is called the L/D ratio.
The die's hole pattern is strongly related to the physical strength of the die. A high open area enables high capacity but is also weaker and more likely to break. Smaller holes mean there will be more of them, resulting in a lower capacity than a die with larger holes. Features like inlets, relief channels, and counter-bores also increase the cost.

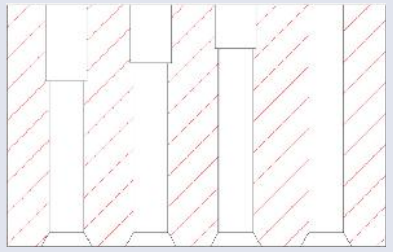

Straight hole design

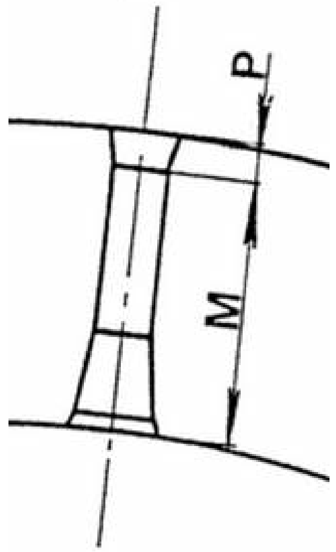

Conical counterbore design


Multiple steps counterbore


Conical straight counterbore design


Straight conical counterbore


Variable relief



Dies have an operational surface area determined by the inside diameter and track width. A similar surface area can be obtained by combining different diameters and widths. Generally, a narrow die is well suited for ruminant feed, but energy requirements and fee rates are lower than poultry feed production, which can handle wider tracks with higher capacities. The risk related to running low capacity and high energy feed on a wide track die is the possibility of the die breaking prematurely. Finally, distributing less material (low capacity) into a wide track die to feed all rollers can take a lot of work.

Die lifetime is measured in tons rather than hours. Die cost is directly correlated with the number of holes and machining hours.

The pelleting process relies on the rollers having traction against the die without actually touching the die surface, as contact would quickly destroy the die, degrading the inlets.

Rollers typically have dimples, which are dead-end holes with a diameter of 6-8mm. These dimples fill with feed and provide that traction. If the rollers were smooth, they would easily slip and stop pushing material through the die, blocking the machine.

Rollers can also be fluted with long grooves. A fluted leading roller may be selected for high-fat formulations. If feed escapes sideways from the rollers, they may be equipped with close-end fluting - hence the open-ended and close-ended terms.

Roller tracking and slipping

behave similarly to the wheels of a car. The deeper the tracks, the more traction the rollers have, but deeper tracks also shorten the lifetime of the roller.

Abrasion from the rollers and feed ingredients wears down the die profile. When this occurs, the rollers and the die must be replaced at the same time. The roller gap must be set so the rollers hardly touch the die. If the roller is pushed into the die, the empty pellet mill produces a distinctive humming sound, indicating the die is being moved by the roller.

Roller wear reveals how the roller is being fed and utilized. For example, the leading roller (left) is usually more worn than the trailing roller. Another common problem occurs when feed is distributed from the front to the back side of the roller, usually caused by a roller no longer rotating due to a flat spot.

Refurbishment includes cleaning, replacing roller bearings, and regrinding the roller working area. Regrinding reduces the roller diameter; therefore, rollers can be refurbished a limited number of times.

Process Parameters

The shape and dimensions of the die holes correspond with the desired capacity, pellet quality, and feed formula, as only minor changes in the recipe or die alter the output. For example, fat will lubricate the die, reducing friction and counter pressure but also reducing pellet quality. Consequently, one may compensate with a roller with a longer press channel to regain quality. The longer press channels with the same hole diameter in the die will:

- Increase counter-pressure
- Increase power consumption
- Increase outlet temperature
- Provide longer die retention time
- Results in better pellet quality
- Reduces pellet mill capacity

Understanding the above process is essential as it is the basis for further troubleshooting.

The following can cause roll-slip:

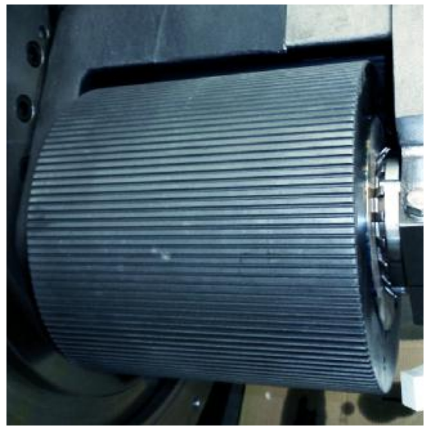
1) Poorly mixed material

2) Material overly saturated by condensate injected with the steam

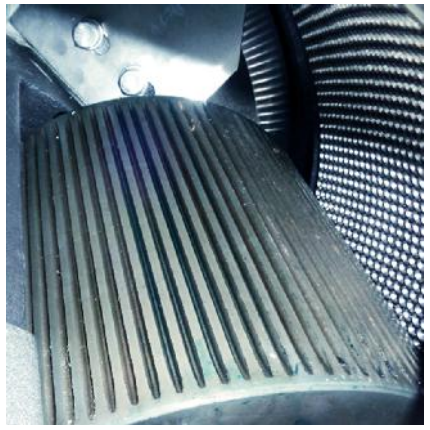
3) The material layer in front of the die becomes too thick, causing capacity overload

As capacity increases, the layer of mash in front of the die also increases. If this layer gets thicker than the radius of the roller, the mash will pass over the roller rather than under it. It will also eventually cause a blockage. As capacity increases, the die retention time (baking time) is reduced proportionally, and pellet quality lessens.

Dimpled



Fluted open ends



Fluted closed ends

Pellet knifes

Pellet knives sit inside the doors after each roller and work like a breaker bar. When the pellet grows long enough, it contacts the knife and is broken off. The closer the pellet knife comes to the die, the shorter the pellets will be. A knife should be installed after each roller as the pellet only grow longer during the roller rollover process.

Pellet length and quality are the primary contributors to bulk density. A 5-10% reduction in bulk density can be seen when comparing long and short pellets. Usually, a pellet length of 2-3 times the diameter will produce maximum bulk density. The pellet knife increases the amount of fines from the pellet mill and, consequently, results in reduced pelleting line capacity and increases the amount of material to be recycled. If a pellet knife is not installed, the pellets will eventually fall off by themselves. However, this can cause the pellet chamber to overfill, blocking the machine and making it difficult to open the pellet chamber.

Die wear

The die and rollers should wear evenly and be replaced together as the roller often take on the wear profile of the die. Both the die and rollers can be refurbished. Die refurbishment involves cleaning, removal of foreign objects, regrinding the inside surface, and inlets. The die can only be refurbished two to three times, as it gets thinner with each regrinding.

A certain amount of natural wear is to be expected. However, some raw materials or formulations will increase abrasive wear, such as those containing minerals like salt and calcium. A die can also be exposed to abrasive wear from unintended foreign objects like rocks, metal, and sand.

Corrosive wear is introduced when formulations contain fat/oil with fatty acids or if a formulation contains acids (ruminant feed). Corrosion can also occur when the die sits unmounted or idle for long periods. Increased friction from corrosion in the press channels can make the die very difficult to restart. However, corrosion can be reduced by replacing feed with a non-corrosive material prior to long-term storage or using dies with a higher alloy content (stainless).

The repeated stress of loading and unloading the die with the rollers can cause metal fatigue which can be identified by flaking inside the die.

Foreign objects not captured by the magnets, like those made of stainless steel, tend to end up pushed into the surface of the die. It is easy to identify the problem of tramp metal embedded in the die because no feed will pass through the die holes in the location of the embedded metal. However, the roller will still push material against the plug, causing a bumping sound as it passes over the spot. Tramp metal can be removed by punching them out with a cylindrical drift punch.

Both new and partially blocked dies may be "run-in" or cleaned by running a mix of raw materials high in oil or a combination of oil and sand through the die. This mixture will pass through the die, grinding away burs and easing die startup or restart. This is done by manually shoveling the mix through the pellet mill. New dies offered as "broken in," or "run-in" have been put through a similar process.

Suppose you find pellets that are off in color (brown or darker) on the backside of the die (towards the drive system). In that case, these pellets are likely to have been sitting in the die for longer than the ones on the front side of the die, indicating that an inspection of your feed distribution is needed.

RAW MATERIAL CHARACTERISTICS

The ability to pellet different materials depends on their binding effects. For example, feed pellets are held together by starch (gelatinization), and wood pellets are bound by lignin.

Fat will lubricate the die, reducing friction and counter pressure and reducing pellet quality. Liquid water added to the conditioner or main mixer has a similar effect. Increasing fiber (cellulose, husks, and hulls) will decrease capacity and pellet quality.

Large particles require longer conditioner retention times because it takes longer for the steam to penetrate them. Coarse grinding reduces total surface area, lessens the effects of steam conditioning, and consequently reduces line capacity and quality. Therefore, a finer grind, resulting in smaller particles, clearly results in higher capacity and quality in the pelleting line.

Pellet Quality

The quality of pellets is based primarily on their durability, but bulk density, pellet length, and appearance are also important. Shorter pellets have a higher bulk density than long pellets, which are more likely to break when packed into bulk quantities, such as bags, for shipping.

The pellet durability index is a measurement of the durability of the pellets when exposed to a standardized durability test. The number of pellets surviving the tumbling process indicates the pellet's durability. There are several tests, but the most commonly used is the ASAE S269.4 which entails tumbling pellets for 10 minutes at 50rpms and then measuring the amount of dust generated.

Pellet samples are extracted from the cooler outlet. They are sieved to remove dust/fines. Pellets are then tumbled and sieved again. For example, Ø3,5mm pellets would be sieved on a Ø3mm mesh. Material passing through the mesh is considered dust/fines, and the calculated fraction indicates pellet durability.

Example:

500g Ø3,5mm pellet sieved from initial dust had 12g passing through the Ø3 mesh. 12/500 would correspond to a PDI of 97%.

Alternative methods:

- Holmen Tester by Borregaard
- Amandus Kahl has a single pellet tester for hardness which measures the force it takes to break the pellet in two.

Example:

A customer runs 20t/h at 92% PDI using a Ø3.5 P55 and wants to increase PDI through die modifications.

- Increasing from P55 to P60 will increase die counter pressure, reducing capacity and increasing durability
- Increasing from Ø3.5P55 to Ø4.5P70 with the same L/D-ratio of 15,7 will increase capacity and consequently reduce quality

Pellet tester

Cooling

Removes exceess moisture and reduces temperature

Source: Geelen

Geelen triple grid cooler

The purpose of cooling is not only to cool the pellets but to remove residual moisture and prepare them for long-term storage.
When the pellets leave the pellet press, they are very soft, moist, and unstable and need immediate cooling. Therefore, the cooler is located directly underneath the pellet press.

In the counterflow cooler, pellets flow down as air flows upwards. This way, the coolest pellets meet with the coolest air, and cooling occurs through evaporation and convection, with evaporative cooling doing the majority of the work.

The steam moisture added to the meal in the conditioner is transferred from the process into exhaust air as it evaporates. The cooling air comes from outside directly into the cooler. The outlet air contains a lot of fines, which are separated in a cyclone before the clean air is let out. A fan located on the clean side of a cyclone or filter moves the air inlet, inside the cooler, through the pellets, up to the cyclone, and finally outside.

The degree of cooling is obtained by regulating the airflow and pellet retention time (layer height). Either the Variable Feed Drive (VFD) on the fan or the regulation valve can be used to control the airflow. Retention time is regulated through the position of a level sensor. The cooler usually operates between two level sensors – stopping and starting the discharge grid, respectively. A high-level sensor in the cooler hood stops feeding the cooler by stopping process equipment upstream at the pellet press or dryer. In the lower part of the cooler, there is a low-level (or empty level) sensor that allows the cooler grid to go into complete discharge (emptying).

The cooled pellets are discharged through either a reciprocating table or a series of swiveling and perforated valves on which all pellets lie. These two discharge grids are called the triple grid and swivel valve, respectively. The discharge mustn't crush the pellets during release. Additionally, when the grid is closed, it must support the pellets while allowing the air to pass through the pellet layer. In feed applications, the cooler is usually placed beneath the pellet mill to prevent unnecessary transportation of pellets that can cause them to be damaged. In addition, a rotary valve is placed in between the pellet press and the cooler to prevent the cooler from taking false air from the press. Sometimes, there are cut-outs in the wings of the flights of the rotary valve to remove a little bit of flash-off from the press and keep the air lock clean.

The selection of a suitable counter-flow-cooler discharge system is essential to the cooler's operation (no build-up of product). Specific solutions exist for pellets (RS), expandate, and meal (KL). Below are examples of Geelen discharge types:

Geelen discharge types

RS	Triple grid discharge	Pellets
RW	Triple grid wide range with enlarged pitch	
RB	Triple grid small pellets	Small pellets
RP	Triple grid pulp pellets	Pulp and alfalfa pellets
KL	Swivel valve (perforated grid)	Meal and fragile pellets
KM	Swivel valve meal (perforated grid)	Meal and fragile pellets
TK	Double deck gate non-perforated (deprecated)	
TP	Double deck with perforations	
TM	Double deck meal perforated (current)	
TB	Double deck batch	

Cooling

DOUBLE DECK COOLERS

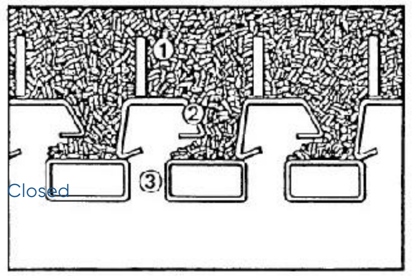
Double-deck coolers increase pelleting line capacity. To understand how they work, it helps to be familiar with single-deck coolers.

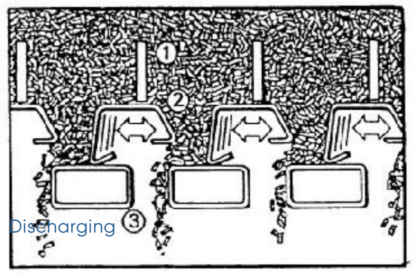
The single-deck cooler must be completely empty before the pellet mill can restart to prevent cross-contamination from different production orders, but double-deck coolers separate different orders by closing the intermediate deck when the pellet mill prebin is empty (plus a constant time), allowing for a faster pellet mill restart. When the cooler discharges the last pellets from the previous order, the intermediate deck, a swivel valve grid, will open.
When the intermediate deck is closed, and the pelleting line is processing the next order, fines from the previous order lodged in the screener and cooler cyclone may contaminate the order. These fines may be sent to a dedicated recycling silo to prevent cross-contamination or may be returned to the finished product. The latter has the potential to elicit complaints from farmers who see dust in their pellets.

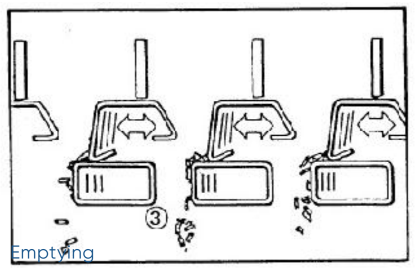
Triple Grid Discharge

The triple grid is the most common type of discharge system used for feed and, as the name suggests, is composed of three grids. These three grids include a stationary top grid, middle discharge grid, and lower emptying grid. The triple grid has the following states:
- Closed position - Only cooling air is allowed through the pellets from above and below
- Discharging - Pellets are discharged carefully by small movements in the middle grid
- Emptying - All pellets are discharged from the cooler by moving the lower and middle grids, resulting in complete opening and total discharge.

Source: Geelen







HYGIENE

The cooler hygiene and pellet outlet temperature are the primary veterinary inspection points for microbiology and Salmonella.

Employ the following measures to ensure hygienic cooling:
- Proper and regular cleaning of the cooler
- Cooling air is taken from a dust-free environment, preferably outside, high above the plant, from the shady side of the building
- The cooler bottom and air intake are placed in an enclosed room
- The cooling inlet air is processed using HEPA-filters

Safeguard against condensation inside the cooler by insulating the cooler, exhaust piping, and cyclone/filter. Condensation will cause liquid water to flow back into the cooler and the pellets but can also reach the cyclone/filter and travel down through the fines outlet airlock, causing blockages. Therefore, ducting should be insulated and installed with as few horizontal pipes as possible to avoid accumulating fines.

SIZING

AAirflow requirements range from 1.2m3/kg to 1.6m3/kg, depending on pellet size. See Table 1, Air flow requirements.

Pellet size	Air flow	Retention time
Ø2-4mm	$1.2m^3/kg$	15min
Ø5-7mm	$1.4m^3/kg$	19min
Ø8-11mm	$1.5m^3/kg$	22min
Ø12-16mm	$1.6m^3/kg$	25min

Air flow requirements for feed. Source Geelen

Retention Time Calculation

$$retention\ time\ [min] = \frac{mass\ of\ pellets\ in\ cooler}{hour\ capacity} * 60 = \frac{8000kg}{30.000\ kg/h} * 60 = 16min$$

Example:
30t/h with 4mm pellets density $600kg/m^3$ in a 28x28 cooler ($1.2m^3/kg$ and 15min (0.25h) retention time). The cooler has a surface of $2.8m x 2.8 = 7.8m^2$

Required air flow in cooler:
$1.2m^3/kg * 30.000kg/h = 36.000m^3/h$
Air velocity:
$36.000m^3/h / 7.8m^2 / 3600 = 1.3m/s$
Pellet layer depth:
$30.000kg/h @ 600kg/m^3 = 50m^3/h$ pellets

PARAMETERS INFLUENCING COOLING

Good cooling = complete cooling + even cooling.
- Pellet fat content - When pellet fat content exceeds 5-6%, cooling efficiency will be reduced.
- Pellet size - It takes longer to reach the center of a large pellet, large pellets require more air and longer retention times (see Table 1 below).
- Pellet temperature - Hot pellets contain more energy than cooler pellets and take more time to cool.
- Pellet density - Dense pellets hold a more significant amount of heat
- Pellet moisture content - Dry pellets don't have as much moisture to evaporate and will take longer to cool.
- Cooling air properties:
- Temperature
- Relative humidity
- Volume

Pellets are sufficiently cool when they are cool to the center. Verify pellet temperature by placing a sample (5-10kg) of the pellets in a thermo bucket and monitoring them for the desired temperature. If the temperature rises, the pellets are not sufficiently cooled.
Uniform cooling is more difficult to determine, but even layer depth is the key and can be obtained by tuning the distributor in the inlet section.

When cooling expandate, meal, or other very low-density products, it is essential to maintain a low and constant airflow, so the product is not sucked into the exhaust air.

Meal Coolers

Since cooling meal is a batch process, it differs from cooling pellets. Meal cooling uses a double-deck, swivel valve cooler. The operation is mainly based on timers. The top deck retains the hot meal from the hygienization line above, and the lower deck performs the actual cooling. Effective cooling occurs in the top and bottom sections, although the primary control is in the lower section. The airflow is adjusted, so the meal is fluidized in both layers during operation.
With pelleting, the pellets follow the principle of first-in-first-out. This is not the case with fluidization in the meal cooler, which mixes the meal completely within the cooling batch. Due to the fluidization process, the cooler is equipped with rotating rakes to remove craters caused by the upwards airflow and relatively heavy meal.

Crumbling

Particle size reduction - pellets into starter feed


Mash


Crumble


Pellets

Crumbling or granulation is a process performed to reduce pellet size without having to change the pellet mill dies. It is a typical practice for poultry feed, specifically chicken starter feed, as newly hatched chicks cannot swallow the 3-4mm pellets meant for fully grown chickens.

Crumble, also called cross or starter feed, in no way resembles the pellets from which they originated. To process starter feed, newly pressed and cooled pellets are forced through a crumbler equipped with a set of rotating corrugated rollers similar to the ones found in the roller mill. One coarsely corrugated, slow-moving roller holds the pellet, while a finer, faster-rotating roller, with oppositely mounted teeth, cuts the pellet. A combination of corrugation size and roller gap determines the size of the crumble.

The crumbler is usually located under the cooler hopper with a built-in distribution roller and bypass diverter.

A noteworthy characteristic of crumble is the absence of intact pellets and dust. However, worn rollers force operators to push them closer together. The smaller roller distance combined with worn or absent flutings leads to an accumulation of dust as pellets are crushed rather than cut.

The distance between the two rollers is fixed by an adjustment mechanism, which may be manual or controlled remotely. When overloaded with either pellets or foreign objects, the roller distance may momentarily stretch the spring tensioning that holds the two rollers together, activating the overload switch. It usually will not stop the operation but warns the operator that rollers are overloaded.

For the crumbler to operate correctly, the rollers must be parallel and are measured with a feeler gauge application placed across the roller sets measuring the left and right roller adjustment. The rolls are adjusted to a factory default distance of 2 mm. However, a space equal to 1 to 2mm is considered an acceptable initial roller gap with the final adjustment performed during production, in conjunction with lab screening analysis to determine output particle distribution.

Like conventional feed pellets, the crumbled end product should not contain dust and fines.

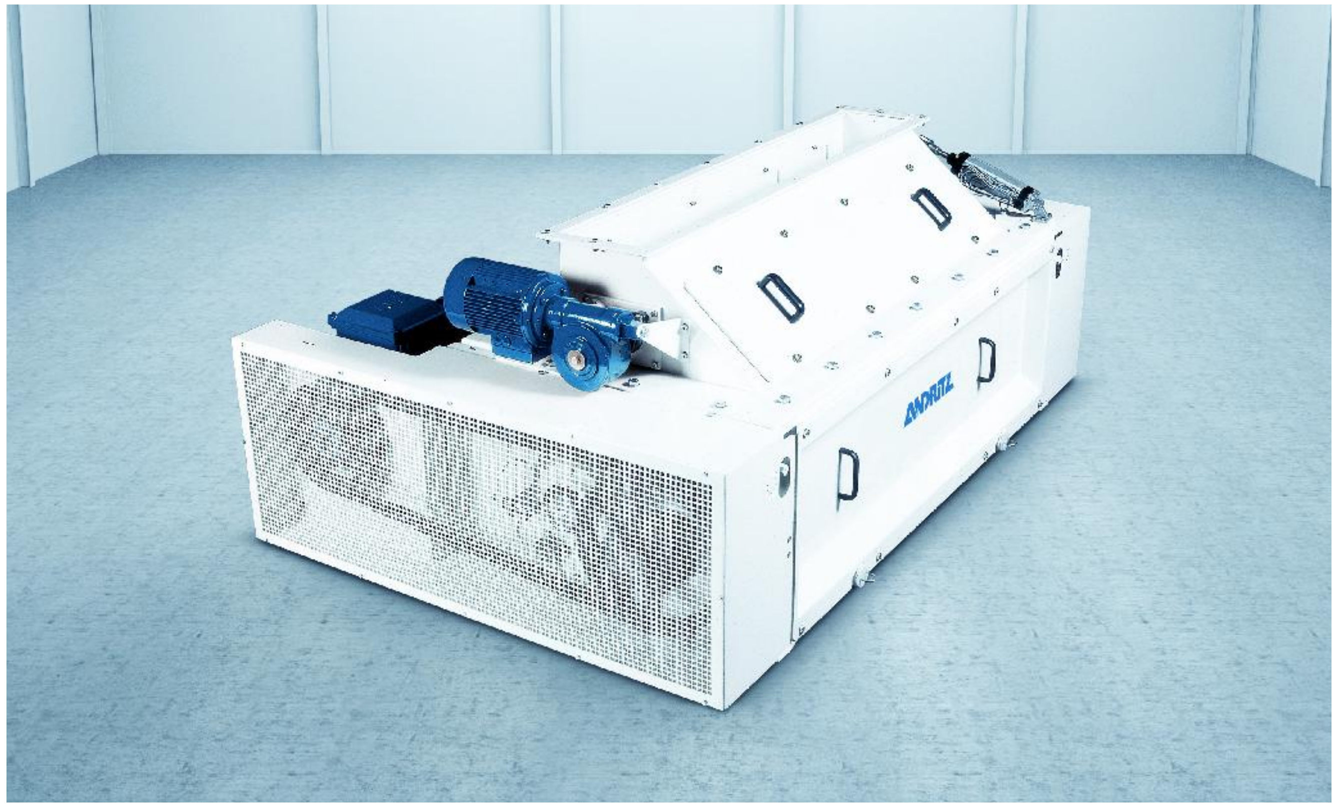
GM-series crumblers have Ø220mm rollers and coil spring-loaded rollers. GRM-series are reinforced versions of GM, have Ø300mm rollers, and use stronger disc springs.

Distribution Roller

It is recommended that the crumbler is installed with an integrated distribution roller and bypass. The purpose of the distribution roll is to feed the material over the rollers' entire width and regulate the crumbler motor's load. The bypass flap allows the pellets to circumvent the roller set and leave the crumbler intact.

The distribution roll can be placed directly under the cooler hopper outlet with the speed set as slow as possible so the distribution roller can disperse the pellets over the entire width of the crumble roller. Therefore, the speed of the distribution roller should be adjusted using a frequency drive. If the feeding speed is too high, the crumbler will become overloaded, crushing pellets and creating fines. The speed should be so slow that the cooler hopper above only becomes empty when a new surge of pellets is fed in from above. The material moves through the distribution roll, dispersing a batch into the crumbler. If no processing is required, the material/pellets may be diverted directly into the stock by setting the flap in its bypass position. This position also guarantees the cooler hopper is totally empty at a change of recipe.

GRM Crumbler



Screening

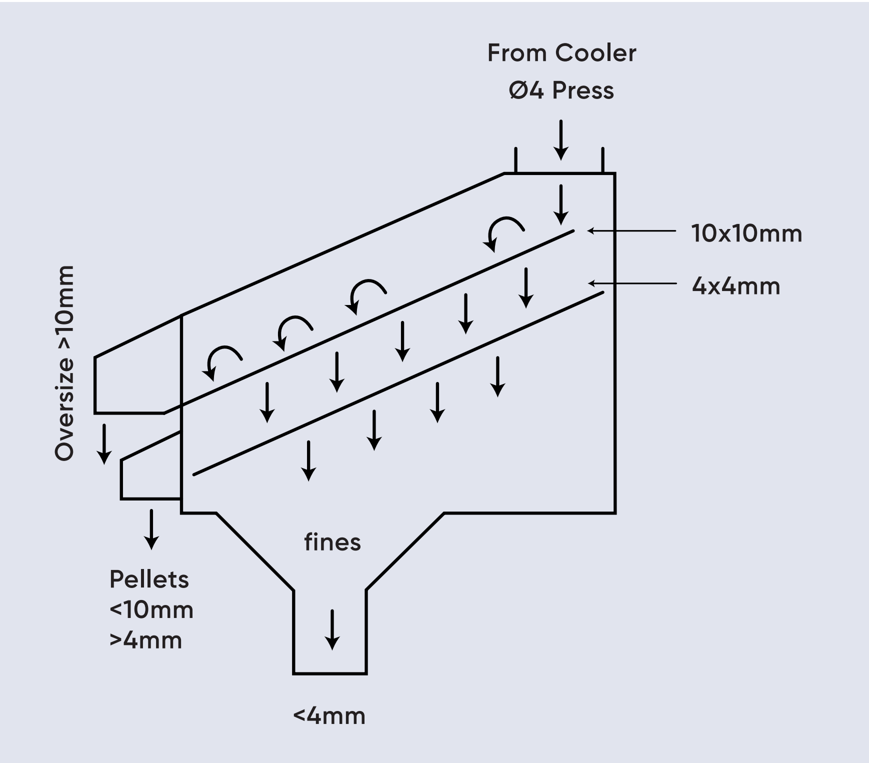
Removal of fines, dust, and particles

The primary purpose of the screener is to remove dust and fines from a finished product as it leaves the cooler. It is a simple process that splits the flow into two groupings: pellets and undersize particles. Undersized particles are normally recirculated back to the pelleting process line. The screener may have a larger mesh layer above the pellet mesh that removes oversized "particles." Oversized particles are typically pellet agglomerates from the pellet chamber, cooler, or cooler hood. These could be as large as a brick and are challenging to cool due to their large size. These lumps must be removed or recirculated back into pelleting line along with the undersized particles to maintain a hygienic finished product.

A two-deck screener typically has three outlets: Fines, good pellets, and oversized lumps. For a Ø3,5mm pellet, the top mesh could be 20x20mm to remove lumps, followed by pellet mesh at 3,3x10mm, and then anything passing through this mesh would be considered dust/fines.

Typically the screens will have a mesh with square holes. Although rectangular mesh may have the same particle cut size properties as pellets, the rectangular holes will allow sphere-shaped particles to pass through at a higher capacity.

Screening crumble (starter feed for chicks) may require splitting the screening process across two meshes with slightly different mesh sizes and then combining the flow, either in the outlet end of the screener or in piping below the screener. With the second technique, a higher utilization can be achieved inside a physically smaller machine.



The screener is equipped with one or more declining meshes. The screener operates through one or two vibrating motors that regulate the screening intensity by adjusting the stroke length of the eccentric counterbalance. Too short a stroke length may overload the mesh, introducing a screening error. An overloaded pellet mesh will cause dust and fines to be transported along with the pellets into the finished product silo.

On the last part of an order, when the cooler goes into complete discharge, carry-over may be introduced if the product output flow is not handled correctly. This problem is amplified when double-deck coolers are set to restart the pelleting line as quickly as possible. Flow redirection occurs when a two-way diverter is located below the screener, becoming a complicated web of pipes that makes flow inspections difficult. Fines returning to the pelleting line originate from the cyclone, a filter that cleans the exhaust from the cooler. This collection of dust and fines is composed of ingredients that don't pelletize well, such as husks, flakes, brans, and fiber, and recycling them back to pelleting line result in the introduction of low-quality mash in the pellet mill.

Coating

Addition of fat, oil, or enzymes

There are many advantages to coating pellets. Fat and oil are added to increase the energy value of feed, so animals gain weight faster. Additionally, pellets can be coated with small amounts of fat and oil to reduce or bind dust and create a shiny, appealing pellet.

The amount of applied liquids is defined by the set point of the formulation. Deviations from this set point (actual consumed) must be documented and kept in an order report together with the finished feed.

Several types of process equipment are traditionally used for coating:

- Continuous spray systems or a flow coater (Micro Fluid Spray MFS)
- Batch coating system (Vacuum Coating VAC)
- Drum coater (COT)
- Fat on die

Coating applications apply liquids after pelleting and are referred to as Post Pellet Liquid Applications (PPLA).

Micro liquids such as phytase enzymes may be added to pellets to enhance the phosphorous uptake in poultry and pig diets; consequently, the phosphorous release into manure results in environmental pollution.

Enzymes are destroyed by high temperatures and are therefore applied after pelleting. An alternative to spraying after pelleting is to apply a larger amount of enzymatic materials to the formulation to compensate for the percentage lost to heating in pelleting line.

Oil and fat can also be sprayed after pelleting to prevent the oils from lubricating the die and reducing pellet quality. Oil and fat application may be balanced between the main mixer and the coater to balance pelleting capacity and pellet quality.

Coating

MICRO FLUID SPRAY

The Micro Fluid System (MFS) is designed to apply a continuous mist of micro liquids like enzymes onto pellets. However, it may also apply a coating of fats and oils.

- 0,01 to 0.1% to 1% enzymes
- 1-5% fat or oil

When an MFS is installed, a screener must be installed upstream to remove dust, and a retention bin is also necessary for the pellets to have a place to adsorb the applied liquids. Additionally, the pellets must be cooled before being processed in this machine.

The fats and oils are preheated before application, improving handling, ensuring the correct spray pattern, and guaranteeing the pellets adsorb properly.

The ability of the pellet to effectively absorb fat and oil is directly related to the pellet's durability and porosity. Preheating fat is an important step in achieving maximum absorption. If the correct temperature is not reached, the fat will harden on the pellet's surface and not soak into the pellet particles. Therefore, the fat melting point, pellet temperature, and porosity with adsorption requirements must be carefully balanced to optimize the application and prevent leakage.

The MFS is used primarily to add micro liquids, but also macro ingredients to animal feed pellets. The MFS consists of a prebin, cellular feeder, weighing plate, spraying chamber, and retention bin.

The MFS can be installed with a bypass system and an additional spraying chamber. The pre-bin feeds the spraying system so a smooth and constant pellet and liquid flow can be achieved. When the two ingredients come together at an identical speed, precision is much higher than in a stop-start operation. The surge bin (retention bin) retains the pellet until complete absorption (micro) or hardening (macro oil) has occurred.

The pellet speed over the weighing plate and the signal from the load cells are combined to calculate the gravimetric pellet flow. This signal is sent to the liquid pumps to spray the desired amount of liquid onto the pellets.

The benefits of adding micro ingredients post-pellet include pelleting line flexibility and increased capacity, as multiple feed variants may be produced without restarting the pelleting process.

Flat fan nozzles are installed for macro liquids according to the required flow rate. Two-matter nozzles with compressed air are applied for micro liquids. A conventional nozzle would not produce a satisfying spray pattern at low flow rates. Consequently, the micro liquid nozzles are air pressure assisted (two-matter nozzles) to

Coating

produce the required fan pattern and low flow range.
Increasing the air pressure does not modify the flow rate but only the spray pattern shape and distance. Nozzles have a wide flow range in which they operate (produce a required spray pattern). By fitting multiple nozzles with different flow rates for the same liquid, it is possible to obtain a much broader overall flow than having only one nozzle.

Both nozzle types are selected based on the required flow rate. However, increased liquid viscosity and temperature may change the actual flow rate, requiring subsequent modification to the configuration. The nozzles must operate within the designed flow range, as fan patterns (pattern width) will change, and spray patterns and pellet carpet width must correspond. No surplus liquids or build-up should be left hanging in the interior of the spray chamber after processing.

The overall challenge with the MFS is applying a precise and constant liquid spray, regardless of the variations in pellet flow from the cooler, discharge surges, and deviations in pelleting line capacity.

VAC

Liquid type, amount, and absorption rate significantly impact the quantity of fat and oil added using a continuous flow coater. Exceeding the limit of pellet absorption will cause pellets to leak oil, creating a mess on conveying equipment, in finished product

silos, and trucks, as well as ruining packaging by soaking through bags.
Vacuum coating is a much more effective system for applying large quantities of fats and oils. This technology originates from the extrusion application, where it has been used to deep coat pellets for aqua feed, and to a lesser degree, pet food, with up to 30-40% oil.

The process line of vacuum coating consists of a prebin, potentially a weighing bin, the vacuum coater itself, which requires liquid pumps and flow meters, possibly weighing tanks for the liquids, and a vacuum pump. A surge bin is located underneath the vacuum coater to quickly remove the product from the coater, enabling a faster restart. Water-based ingredients should be sprayed first and then oil. Multiple fat-based ingredients may be mixed and sprayed together or sprayed individually, forming coating layers – an excellent method for enhancing palatability. Vacuum coater technology is a very accurate coating process when combining the batch process with load cells.

Coating

FAT ON DIE

The Fat on Die System is mounted in the pellet door (chamber) and sprays fat or oil on the outside of the die through a spray nozzle placed immediately after each pellet knife. When the pellets reach the ideal temperature, they readily absorb the equally hot fat or oil.

The Fat on Die System utilizes the knowledge of the flow rate throughout the pelleting process to spray the precise amount of fat or oil. This process step is a considerable advantage over post-pelleting coating systems, as it eliminates the need for extensive measuring of the flow rate of pellets. Post-pelleting systems installed after the cooler will struggle to buffer the surges of pellets as the cooler discharges and measure the pellet flow rate to adjust the liquid flow.

A Fat On Die system requires the pellet chamber to be cleaned regularly, as the combination of fines and fat causes heavy residue build-up. Subsequent equipment like ducts, rotary valves, and coolers also require intensified cleaning to maintain a good level of hygiene.

Pelleting Process Control

The process control software for pelleting regulates everything from the prebin and feedscrew to the cooler. The pelleting process control software is supplied as a Process Control Management System or Master Panel System (PCMS or PCPS), respectively. In addition, a process control system is often integrated into the overall plant control system, which communicates with formulation software (like Format), resource planning software (ERP) for accounting, inventory, and finished product management.

The software adjusts the feed screw speed until a desired amperage load set point has been achieved on the pellet press motor. Additionally, the conditioner's steam flow control valve features a second, independent regulation loop that maintains constant meal outlet temperature independent of the capacity. The process control software also controls the feed expander or secondary pellet mill in double pelleting setups.
The purpose of the pelleting process control is to safely protect operators, equipment, and process, enabling equipment suppliers to give capacity and quality guarantees with confidence.