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Application Example

Handling Plant Protein Powders in Food Production Processes

Introduction

The value of the global plant protein market, at $29.4 billion in 2020, could surpass $162 billion by 2030, which would make up 7.7% of the global protein market, according to a recent report released in August 2021 by Bloomberg Intelligence. At the heart of these plant-based products are the protein-rich powders and blends which are used as the primary ingredients.

While pea and soy proteins have traditionally been the main staples, today's processes increasingly include a wider variety of protein sources, such as lentil, mung bean, canola bean, fava bean concentrates and isolates, as well as goji berries and even mushrooms and other funghi.

Figure 1 - Plant protein powders vary widely in flow characteristics.

The material characteristics of these powders can be challenging. Whether transferring soy protein powders for plant-based milks, or handling and extruding the various proteins used in plant-based meat production, or simply providing prepackaged blends for the production of these items, the material handling requirements of many of these poorly flowing powders require added attention in overall engineering and design.

Due to the challenges presented in handling these powders, it is important to work with equipment and system suppliers who are not only familiar with the overall plant protein processes, but who are also knowledgeable in exactly how to handle the varied ingredients that are utilized in those processes.

Coperion's capability to provide complete systems (from conveying to feeding and extrusion) offers manufacturers of plant protein products optimal efficiency by having one supplier. Based on decades of experience in the industry, some of our newest product innovations in extrusion technology and material handling are focused on developments within the plant-based food market.

This application sheet will focus on the challenges of handling these powders and will outline a variety of design options for optimal material transfer, batch weighing and feeding of these powders in mixing, extrusion and packaging operations.

Defining Material Characteristics

In order to choose the best method for transporting, feeding and weighing the wide variety of plant-based protein (PBP) powders available, it is critical that several key characteristics be determined which will determine the ingredients' flowability. Several of these critical characteristics are defined

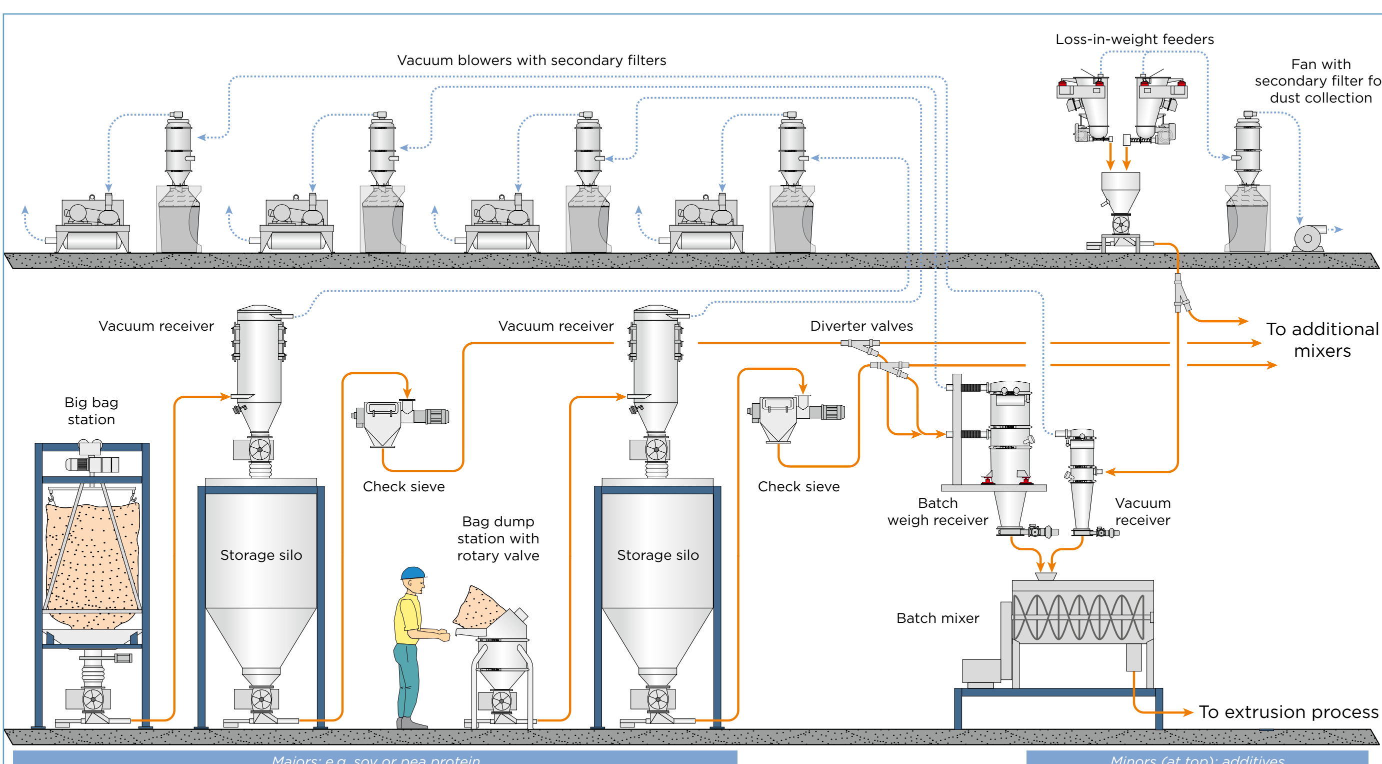


Figure 2 - Material handling from receipt to mixer

Handling Plant Protein Powders

Material Characteristics	Definition	Effects
Bulk Density – Loose	Material weight per unit volume (e.g. kg/liter or lb/cuft). Loose bulk density is measured in a “poured condition”.	Bulk Density can affect a number of design details for material handling systems. These details include flow rates for volumetric feeding and storage capacity of hoppers, silos and receivers.
Bulk Density – Packed	Same as above after applying pressure to product, such as via vibration or compaction.	Affects hopper volumes but also important for refill options for continuous feeding. Bulk density can change with applied pressure. If pressure changes affect the bulk density, a potential for flow problems may exist. Can be very relevant to material left at bottom of storage silo, or after it has been transported and may indicate requirement of additional fluidization.
Particle Size	Actual size of individual particles (e.g. mesh or micron).	Particle size distribution often defined in percentile values, D90, D50, D10. These values indicate the size below which 90%, 50% and 10% of all particles are found.
Angle of Repose	Angle to the horizontal that a bulk solid makes as it flows, unconstrained onto a flat, level surface.	A higher angle of repose indicates a more cohesive product. It is an indication of the friction exerted between material particles. Important for sizing hopper angles to minimize buildup. Angle of repose is also important for sizing any storage bins/receivers to allow for void above heap. In general angles <38 degrees indicate free-flowing, 38-45 is fair/passable flow, >45 degrees is poor flowing.
Slide Angle	Minimum slope, measured in degrees from the horizontal, at which loose solid material will start to flow.	Important for hopper angles, as well as indication of flowability. Aids in design of hopper angles as it determines how steep the sides of the hopper must be to ensure the material will discharge when it is not compacted. Also important for designing transition chutes.
Can Velocity	Upwards air velocity inside a filter housing.	Important in sizing filter receivers and bin vent filters. Fabric filter housings must be large enough so as to stay below the maximum can velocity for the material being filtered.
Terminal Velocity	Actual velocity of the material at the end of the conveying line before receiving vessel.	Value indicates the willingness of the material to be conveyed in a vertical direction. Important in the sizing and configuration of the pneumatic convey system.

Table 1 - Defining material characteristics

Material	Angle of Repose (poured) in degrees
Canola Protein	53
Fava Bean Protein	45
Mung Bean Protein	50
Pea Protein 1	51
Pea Protein 2	45
Soy Protein	45

Table 2 - Flowability of protein powders

Loose Bulk Density kg/dm³ [lb/ft³]	Packed Bulk Density kg/dm³ [lb/ft³]	Slide Angle	D90 in µm	D50 in µm	D10 in µm	Can Velocity m/min [ft/min]	Terminal Velocity m/min [ft/min]
0.31 [19.35]	0.43 [26.78]	68	600	250	125	71.6 [235]	305 [1000]
0.32 [20.25]	0.44 [27.24]	45	500	250	62	35.4 [116]	122 [400]
0.33 [20.3]	0.44 [27.69]	47	250	125	<62	32.9 [108]	183 [600]
0.37 [23.19]	0.48 [30.23]	52	150	125	<62	32.9 [108]	183 [600]
0.39 [24.6]	0.51 [32.11]	52	250	125	<62	58.2 [191]	152 [500]
0.5 [31.1]	0.66 [41.01]	32	150	100	<62	58.2 [201]	152 [500]

Table 3 - Comparative material characteristics of various pea protein powders

in Table 1. As shown in Table 2, most of the plant protein powders are not free-flowing, as evident by their angle of repose values being greater than 45 degrees. Further compounding these challenges, the flowability properties of nominally identical products can differ from supplier to supplier due to the variety of methods which exist to process these powders. This is illustrated in Table 3 where several samples of pea protein were evaluated, resulting in a wide variety of measurements. Although some of the characteristics may be similar, a slight difference in particle size distribution, slide angle or packed densities, can greatly affect how that material flows in a convey line, fills a storage hopper or silo, or behaves in a feeding device. The correct selection of the optimal technology for each of these critical aspects in a process can greatly affect overall flow through the process, as well as critical aspects such as ingredient batch accuracy, blend uniformity, segregation and process efficiency. It is imperative to work with a supplier who has extensive experience in the handling of a wide variety of difficult flowing PBP powders.

Bulk Material Source

As shown in the process flow diagram in Figure 2, raw ingredients for typical plant protein processes can be received in boxes, bags, and bulk bags or supersacks. Typically, protein powders such as pea protein are delivered in 25 kg [50 lb] bags. Bag dump or sack tip stations such as shown in Figure 3 include a small capacity hopper into which sacks/bags of material are opened. These devices usually include a shelf for resting sacks while the operator cuts or tears them open. In addition, when dealing with dusty powders they are often supplied with a dust extraction unit and bag disposal system to protect the operator.

When dealing with blends or powders with a cohesive nature, as is the case with most PBP powders, it is important that the filters used in these devices as well as other equipment such as the pneumatic receivers have quick release properties (such as PTFE coatings) to avoid product build-up on the filters which would affect filtration efficiency.

Conveying Powders

After exiting the bag dump station, the powders are pulled into a powder conveying system. The arrival and transfer of dry ingredients to a production line can be achieved via a number of different types of conveying systems. The mode of transfer of ingredients is dependent upon a wide variety of process parameters, including material characteristics, distance to be transferred, required rate of transfer, and the type of container in which the ingredient is originally received. Pneumatic conveying systems are used to transfer dry materials from one process to another via either positive modes (pressure) or negative conditions (vacuum).

Typical systems include an air source, a material feed device, a convey line and some type of air material separator, such as the Coperion K-Tron vacuum receiver shown in Figure 4.

Pneumatic systems operate in a fully enclosed line, which greatly improves hygienic operation and also minimizes product loss. Vacuum sequencing systems, such as that shown in Figure 2, are often the most economical for small to medium rates up to 7500kg/h (15,000 lb/h). The loader or receiver is placed above the destination, such as above the storage bin in Figure 2 or above the loss-in-weight feeder in Figure 7. Material is conveyed under vacuum until the loader/receiver is filled. Vacuum is then interrupted and the discharge valve is opened to discharge material, hence creating a batch mode of operation. Coperion K-Tron's vacuum sequencing product lines include a variety of sizes and executions, such as sanitary designs for ease in cleaning and product changeover.

In some cases a combined feeder-receiver as shown in Figures 5 and 11 may be the optimal solution for feeder refill. The hybrid unit uses a volumetric screw feeder base unit as the discharge device for a P-Series vacuum receiver. Originally designed for applications with restricted head room requirements, this unit has been used successfully for direct loss-in-weight feeder refill where sticky or fluidizing powder could cause problems with refill valves. Thanks to the modular design any combination can be chosen between feeder and receiver in terms of screw type, receiving volume, and filter area to optimally serve the process.

It is important to note that optimization of the material handling system, particularly with difficult flowing powders such as proteins, is critical for the overall process. As shown in the pea protein example above, conveying factors can also differ greatly, therefore each

Figure 3 - Bag dump station

Figure 4 - Vacuum receiver

Figure 5 - Feeder-receiver hybrid

process step must be tailored specifically to the bulk material to be handled. The system engineers at Coperion and Coperion K-Tron have extensive experience with such materials and will ensure that all required options will be recommended to ensure uninterrupted material flow.

Dilute Pneumatic Conveying

Vacuum (negative pressure) systems are often used for lower volumes and shorter distances. One of the advantages of vacuum systems is the inward suction created by the vacuum blower and reduction of any outward leakage of dust. This is one of the reasons why vacuum systems are often used in higher sanitary or dust containment applications. Another advantage of vacuum systems is the simple design for multiple pickup points. It should be noted, however, that the distances and throughputs possible with a vacuum system are limited due to the finite level of vacuum that can be generated.

As an alternative to the pneumatic conveying options, mechanical conveying is sometimes also worth evaluating. A mechanical conveying system uses a mechanical device (such as conveyor belt, flexible screw or bucket elevator) that physically moves the material from source to destination. Conversely the previously described pneumatic conveyors utilize gas (typically air) to transfer the material through the convey line in a suspended state. A distinctive difference between the two modes is that pneumatic conveying systems have almost no moving parts in contact with the material, resulting in less downtime for cleaning and maintenance than their mechanical counterparts. When dealing with PBP powders, flowability within the mechanical device can be a concern, with cohesion properties resulting in build-up on the hardware.

Additional advantages of pneumatic conveying for food applications include the following:

- Lower maintenance
- Increased operator safety due to fewer moving parts
- Increased product safety due to enclosed convey line minimizing product contamination
- Less product loss and dust leakage – this is especially true in vacuum systems where the material stays within the line due to the negative pressure

Efficient Storage and Convey Designs

If the material conveyed from the source is to be stored in a storage silo or storage bin, a variety of options exist which are useful in maintaining a sanitary and dry environment. Typically all material contact surfaces are stainless steel. However, as an alternative lower cost option, large-volume silos, storage hoppers and bin vents on silos can be supplied as painted with an FDA approved white epoxy paint. These components are also available in stainless steel, but this may become costly depending upon their size.

If moisture is a concern, especially in a high humidity climate, a desiccant bed dryer (DBD) is installed and connected to the silos by a separate line. With the DBD's ability to produce dry air at an extremely low dewpoint, a cushion of air is blown into the top of the silos, guarding against moisture in the material.

In addition to drying the air within the silos with a DBD, the silos or hoppers may also be fluidized by exclusive blowers or a compressed air source. Introducing air (or other gas) into a dry bulk material such that gas is entrained in the void spaces between particles of the material can aid gravity flow of some materials. (Such fluidization devices are shown on the hopper section of the bag dump station in Figure 3).

Material in a highly fluidized state tends to behave more like a fluid than a solid bulk material. In the case of protein powders which have a tendency to be cohesive and often pack, the use of fluidization devices in storage silos, bins or hoppers will help to promote material flow into the pneumatic convey line below.

Finally, when dealing with difficult flowing powders such as PBP's, all hoppers, storage bins, etc. should also include steep hopper angles and flow aids to facilitate flow through the system and avoid any bottlenecks during transport.

Inline Screening

Another key component of the pneumatic convey system specific for food safety is the inline check sieve or screener. This device can be installed directly in the pneumatic convey line and is typically used to sieve bulk materials and powders and remove unwanted material such as string, packaging, plastic, insects and other undesirable items from the process stream. They will also remove any hard lumps of agglomerated product, which may adversely affect the blender operation or additional processes downstream.

Batch Weighing

The manufacture of any blended food product typically involves the intermediate process steps of transfer and weighing

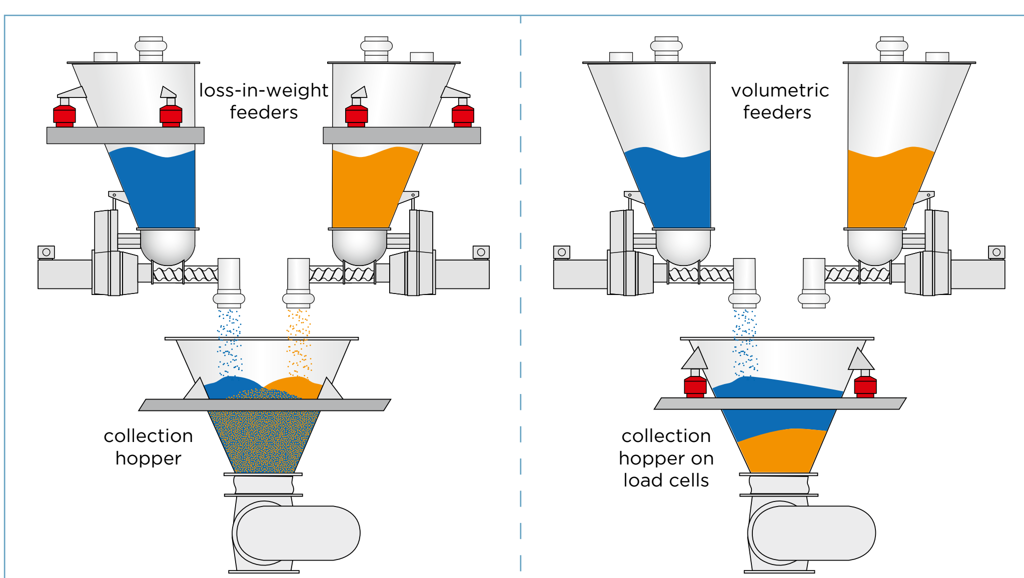


Figure 6 - LIW (left) & GIW (right) batching principles

or batching of individual ingredients based upon their weight percentage in a blend. Depending on this percentage, materials are usually categorized as majors, minors and micros. In many cases, the transfer and weighing of these majors, minors, and micros to the blending step can be a manual and labor-intensive process. In a typical PBP process, the majors are the protein powders while minor can be additional additives.

In an effort to improve process efficiency and product quality, the complete batching process can be automated. This includes the automated transfer of the raw ingredients to the batching system and the use of Gain-in-Weight (GIW) or Loss-in-Weight (LIW) batch systems to accurately and efficiently deliver the individual raw ingredients to the process (see Figure 6). By utilizing automated transfer conveying methods for the raw ingredients via either vacuum or pressure as well as highly accurate weighing systems, the manufacturer can realize lower overall manufacturing costs as well as more savings on individual ingredients, and reduce the time required for manufacture.

In a batching process the ingredients are transferred from the material source to the batching station. In a GIW batching system the batching station would either consist of a pneumatic receiver mounted on load cells or volumetric feeders mounted over a weighed collection hopper. In a LIW batching system the batching station would consist of loss-in-weight feeders mounted over a collection hopper.

As outlined below, in some cases where small amounts of micro ingredients are required for a total overall batch, both methods are employed: LIW feeders for the micros and minors, and GIW batchers for the major ingredients. In the process shown in Figure 2, the major components are sent to a receiver on load cells for batching into the mixer, while LIW feeders are used to batch minor ingredients such as additives.

Gain-in-weight Batching with Scale Hoppers

Scale hoppers are pneumatic receivers suspended on load cells for ingredient batch weighing, as shown in Figure 7. Coperion K-Tron offers a variety of systems for batch weighing of pneumatically conveyed food ingredients, whether the application requires a single ingredient to be delivered to multiple destinations or multiple ingredients to be delivered to a single destination.

One or more materials are sequentially transferred to the scale hopper as required. The material resides in the scale hopper until the precise weight and/or combination of materials is achieved. With the scale weighing system, ingredient accuracies of +/- 0.5% of the full scale capacity can be expected. After accurate weighing, once the mixer calls for material a butterfly valve opens and the material in the scale hopper is discharged into the mixer.

Gain-in-weight Batching with Feeders

In GIW feeder batching volumetric feeders sequentially feed multiple ingredients into a collection hopper mounted on load cells. Each feeder delivers approximately 90% of the ingredient weight at high speed, slowing down towards the end of the cycle to deliver the last 10% at a reduced rate to ensure higher accuracy. The GIW controller monitors the weight of each ingredient and signals each volumetric feeder to start, increase or reduce speed, or stop accordingly. Once all the ingredients have been delivered, the batch is complete and the mixture is discharged into the process below. It should be noted that this type of batching method is sequential for each ingredient, and therefore generally results in a longer overall batching time than with LIW batching (outlined below) if the number of ingredients is high.

Loss-in-Weight Batching Principle

LIW batching is used when the accuracy of individual ingredient weights in the completed batch is critical or when the batch cycle times need to be very short. Gravimetric feeders operating in batch mode simultaneously feed multiple ingredients into a collection hopper. Adjustment of the delivery speed (on/off, fast/slow) lies with the feeder controls and the smaller weighing systems deliver highly accurate batches for each ingredient. Once all the ingredients have been delivered, the batch is complete and the mixture is delivered to the process below. Since all

Figure 7 - Scale hopper with Aeropass valve

Figure 8 - Twin screw feeder with ActiFlow

Figure 9 - Cohesive powders often do not flow well, forming ratholes in a hopper.

ingredients are being delivered at the same time, the overall batch time as well as further processing times downstream are greatly reduced.

Keeping Powders Moving

Coperion K-Tron consistently strives to provide innovative solutions for a wide variety of food processing applications, with an emphasis on efficient material handling techniques for even the most difficult to handle ingredients. The poor flow characteristics of plant protein powders make them difficult to handle and deliver accurately to the process. Cohesive properties can cause bridging and rat-holing in feeder hoppers and affect overall performance. To address these issues and improve the ease of cleaning the feeder and hopper, Coperion K-Tron has developed the ActiFlow™ bulk solids activator, a smart flow aid device which operates in conjunction with the LIW feeder controller and its load cells. Figure 8 shows a twin screw feeder equipped with ActiFlow for handling difficult powders.

ActiFlow eliminates the need for traditional vertical or flex wall agitation in LIW feeders. This unique device eliminates head-room concerns, reduces cleaning and product change-over times and in turn lowers overall production labor cost. It works in conjunction with the LIW feeder controller and digital weighing system to determine by weight when a change in material flow is occurring, before it becomes a problem such as a rathole forming in the feeder hopper as shown in Figure 9. Once the ActiFlow controller detects a potential problem with material flow, the vibration applied to the hopper is automatically adjusted to get the material moving efficiently without impacting feeder performance. In addition, it avoids compaction of the ingredient or ingredient blend because only the necessary amount of vibration is applied to the material to ensure uniform material flow. This type of smart vibration device is critical for feeding PBP powders, as they have a tendency to pack if too much force is applied

Figure 10 - Coperion ZRD rotary valve with optional FXS extraction device

Rotary Valves with Easy Clean Design

In many conveying applications, Coperion K-Tron high efficiency and easy clean rotary valves are utilized. Rotary valves are volumetric feeding devices capable of feeding material across a pressure difference, for example into or out of a pneumatic conveying system. These valves can be provided as blow through or drop through valves at the bottom of feed bins, such as that shown at the bottom of storage silo in the system diagram in Figure 11. Coperion supplies a wide variety of valves in different executions.

For example, the ZRD rotary valves produced by Coperion are specially designed for sanitary food applications where contamination is a concern and frequent disassembly and cleaning is required, such as in the processing of allergen products like soy protein powder. The ZRD hygienic rotary valve can be outfitted with a full access extraction system as shown in Figure 10 as well as a large inlet for high filling efficiency. Without removing the valve from the system, the ZRD hygienic can be easily disassembled, cleaned and reassembled.

The full access extraction system also fully supports the rotor as it is removed for cleaning, making it an ideal method for facilitating endplate and rotor removal. In addition, the expanded inlet design ensures high capacities with minimal bridging which is critical when dealing with poor flowing powders.

It should be noted that these

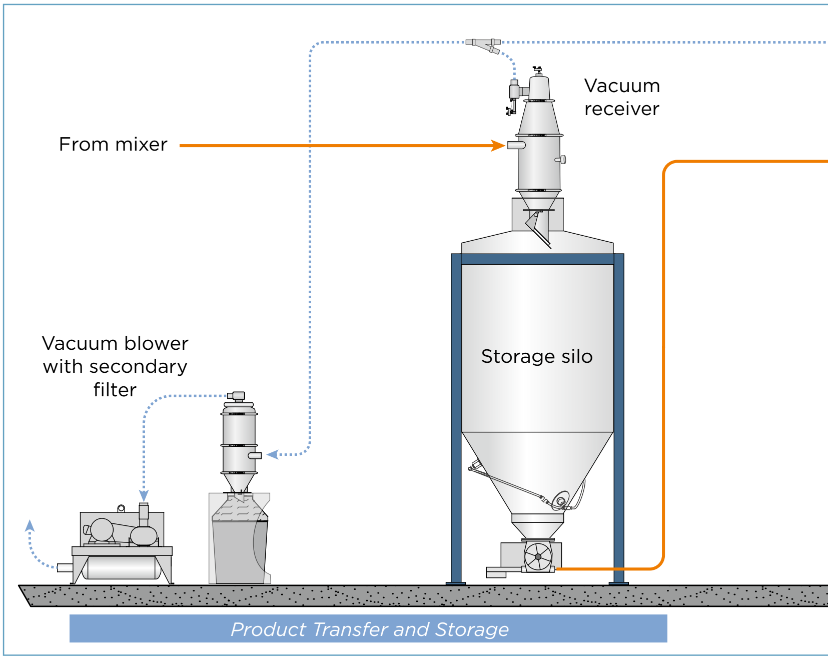


Figure 11 - Delivery of premix to the extrusion process

valves are also used at the outlet of spray dryers when producing plant protein powders, due to their ease in cleanability as well as optimal accessibility.

As an added benefit for food safety, the Coperion rotary valves can also be equipped with the innovative Rotorcheck™ design option, which detects any metal to metal contact in the valve, as a function of electrical resistance between the rotating vanes and housing. This detection system is ideal for avoiding contaminant metal in the product as a result of wear and can be instrumental to ensure safe operation.

Finally, Coperion also has a variety of system and component options which are designed to address poor flowing products. A perfect example of this is the new Smart Glide Finishing (SGF) anti-stick surface treatment option for rotary valves, which prevents sticking and build-up of difficult ingredients directly on the valve surfaces. This treatment is ideal for PBP powders, due to their extremely cohesive nature.

Conveying from the Mixer to the Extruder or Packaging

After mixing, the blended protein powder can be sent on to packaging systems, or in the case of Figure 11, directly to an extrusion system for the production of texturized vegetable protein (TVP) or high moisture meat analogues (HMMA). The same product transfer techniques as outlined earlier will apply. In this case the material is conveyed to continuous loss-in-weight feeders, which accurately control the supply of the ingredients into the twin screw extruder.

It should be noted that accurate and continuous feeding of the bulk vegetable protein as well as water and other possible liquid components and steam to the extrusion process is crucial to the product quality, process stability and reliability. At any stage of the production process undetected feed rate and proportioning errors waste ingredients and add to overall ingredient costs. For example, within the very sensitive high-moisture extrusion process, feeding inaccuracy can easily cause shut-downs of the line, so that the extruder and special die head which creates the fibrous material characteristics need to be cleaned and restarted again. This means the accuracy of the feeding and weighing equipment is critical to this step in the process.

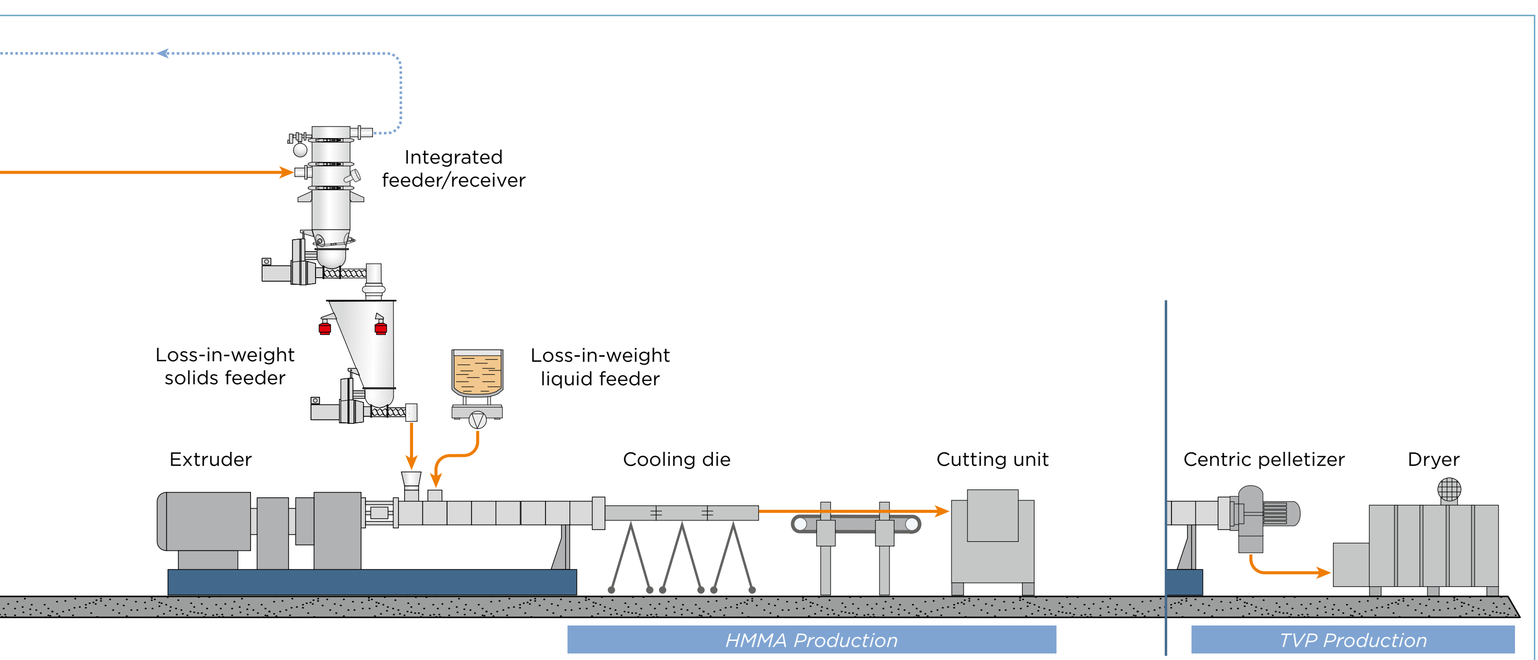
For further design options for feeding and refilling LIW feeders for production of TVP and HMMA see Coperion K-Tron Application Example A-800321, "Feeding, Material Handling and Extrusion in the Manufacture of Meat Analogues".

Options in Cleaning Design and Safety

One of the most important factors in processing plant proteins that is often overlooked is the high percentage of powder handling required in plant protein operations. Since many of these ingredient powders are organic, there is also a higher safety risk for the presence of combustible dusts. Conditions and the material's nature can influence the risk of explosion (including the material's ignition temperature, potential for chemical reaction with oxygen, particle size distribution, dust concentration, etc.). In addition, the Minimum Ignition Energy (MIE) can change significantly when dealing with the same material but smaller powder particle sizes.

Explosion control devices such as explosion vents, suppression systems, containment, sensors and isolation valves must be considered when designing the system. It is important when configuring a system for the transfer of these powders, whether from the spray dryer to the packaging line or from the bulk bags to the feeders above a mixer and/or extruder, that all the possible design parameters are considered to ensure safe operation.

Proper attention must also be paid to how the system is to be cleaned and maintained. It is important when designing the overall functions of the equipment that key attention be paid to making sure that the processing equipment designs



not only adhere to the FDA Food Safety Modernization Act (FSMA) standards and cGMP manufacturing guidelines, but also that the final layout of the system includes as much added versatility and ability to do quick product changeovers as possible.

Depending upon the ingredients to be batched and/or conveyed, a variety of design executions can be provided for the equipment to reduce the overall cleaning or changeover steps. Stainless steel is generally used for the product contact components, but sometimes FDA approved epoxy can also be used for large volume scale hoppers or silos to reduce overall equipment costs. Conveying receivers can be designed with retractable spray balls for wash-in-place cleaning to ensure quick changeover and minimal contamination between material runs.

Conclusion

As outlined above, the material transfer and feeding of plant-based proteins can present many manufacturing challenges. Optimized automated systems for weighing and accurate delivery of all the ingredients for the plant-based protein process without manual intervention can result in a number of process advantages, including fewer mistakes, better accuracy, lower bulk costs, improved product quality and savings in manufacturing costs. In addition, systems and components which are specifically designed to handle these difficult flowing materials will reduce downtime and increase operational efficiencies. Operational and product safety are also key elements of design which should be reviewed. The highly experienced personnel of the Coperion K-Tron can provide a wide variety of design and layout options in both ingredient transfer and delivery to help manufacturers to not only lower process costs but also to improve efficiency and product quality.

Coperion Advantage

- Complete system integration of the plant protein manufacturing process for one source supply.
- Global systems engineering group with extensive application experience for the entire processing line ensures optimal design with an emphasis on product safety, process stability, quick product changeover, and increased efficiency.
- Extensive material handling knowledge in a wide variety of ingredients by the engineers at Coperion and Coperion K-Tron ensures the most efficient means of product transfer.
- Engineered material handling and feeding solutions from both Coperion and Coperion K-Tron reflect extensive experience in hygienic and sanitary design standards, including CIP/COP, EHEDG, FSMA, GFSI, USDA, and 3A where applicable
- The Coperion K-Tron line of feeders provides for the highest degree of accuracy in ingredient and product delivery in order to optimize ingredient cost savings, process stability and reliability as well as constant product quality.
- Coperion K-Tron rotary valves and Aeropass valves are available in a variety of sizes and design options.
- Coperion K-Tron Weigh Scale Hoppers and Batch Weigh Receivers are designed to provide batch weigh accuracies of ± 0.5% of the full scale capacity.
- The Coperion K-Tron line of pneumatic receivers are designed for cleanability and ease of access, with all materials of construction FDA approved.

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