Plant-Based Meat Substitutes

An expert guide to the best practices in the production of TVP (Texturized Vegetable Proteins) and HMMA (High Moisture Meat Analogues)

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confidence through partnership

Executive summary

The market for plant-based meat substitutes is growing rapidly as consumers seek to adopt healthier lifestyles and more environmental viability. As a result, there is an opportunity for existing TVP and HMMA producers to expand their production and for new companies to enter the market.

There are many challenges to plant-based protein processing. Some protein powders have difficult flow properties, and several factors contribute to the quality of finished products. Technology plays a major role in the successful production of TVP and HMMA products.

Gravimetric feeders with intelligent vibration systems help to overcome the challenges of powder flow. Modular food extruders that allow for flexibility in process conditions enable designers to optimize production and improve end product quality. An innovative hybrid extruder also allows manufacturers to switch easily between TVP and HMMA production.

Considering all these factors and choosing an experienced technology partner that offers expert advice and test run support, helps manufacturers to develop and expand their production with confidence.

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1. Introduction

Plant-based meat substitutes are products made from plants but manufactured to look like their meat equivalents. The demand for these products is driven by consumers seeking to reduce their meat intake for personal health reasons, animal welfare concerns, and a desire to limit climate change.

The market for plant-based meat substitutes is increasing at exponential rates. Economists predict the demand for alternative proteins to reach between $77 billion and $153 billion by 2030 from a base of $5 billion to $10 billion in 2021[1]. As a result, many new and existing manufacturers are seeking opportunities to develop and expand their production capability.

The primary plant-based meat substitutes are TVP (Texturized Vegetable Proteins) and HMMA (High Moisture Meat Analogues). TVP products are dehydrated pellets, small flakes or chunks and must be soaked in water before further processing and consumption, while HMMA products contain more moisture and have an equivalent texture to meat products. Soy, pea, and wheat proteins are some of the most common ingredients for many plant-based meat substitutes, but there is a wide range of other viable alternatives.

Browsing the supermarket shelves will yield a wide range of plant-based products already available to consumers, including vegan mince, vegan nuggets, and products with similar texture, appearance, and taste to traditional meat products such as shredded chicken, pulled pork, or fish fingers.

[1] https://www.ey.com/en_us/food-system-reimagined/protein-reimagined-challenges-and-opportunities-in-the-alternative-meat-industry

2. Production of TVP and HMMA - Overview

The heart of both TVP and HMMA production is the twin screw food extruder. Both products are manufactured using protein powder and water as the main ingredients, but the process conditions inside the extruder are quite different. The temperature profile within the extruder, screw speed, moisture content, and the die design at the discharge all play a significant role in the manufacturing process and the product quality of TVP and HMMA.

Extrusion is a continuous process, which means that conveying systems and feeders automatically supply the raw materials at the required rate. Gravimetric bulk solid feeders provide a steady supply of protein powders, while liquid feeders add water to the melt.

After intensive mixing and cooking within the food extruder, the melt passes through a die plate of the centric pelletizer for TVP production, but for HMMA products the melt passes through a specialized cooling die. Both products emerge as intermediate products. Further processing is necessary before they are ready for the consumer.

HMMA products have dense, fibrous structures similar to muscle meats. They contain 50 to 70 percent moisture and should be stored chilled or frozen. HMMA products can be used to create ready-to-eat dishes.

TVP products have expanded fibrous structures due to gaps left when water vaporizes at high temperatures. They are extruded with 10 to 30 percent water addition and are shelf stable after drying. TVP must be soaked in water before further use in products such as burgers, chicken strips, mince, or sausages.

3. Raw material handling: conveying and components

Raw material handling is a significant challenge for TVP and HMMA manufacturers. Some protein powders like pea and lupine-based ingredients are notorious for their difficult flow characteristics. Static electricity or high fat content can cause powders to stick together and cling to the surface of the conveying lines and feeders. Organic powders can also pose a safety risk due to combustible dusts. All of these challenges must be considered when choosing the appropriate equipment for powder handling and pneumatic conveying of the materials.

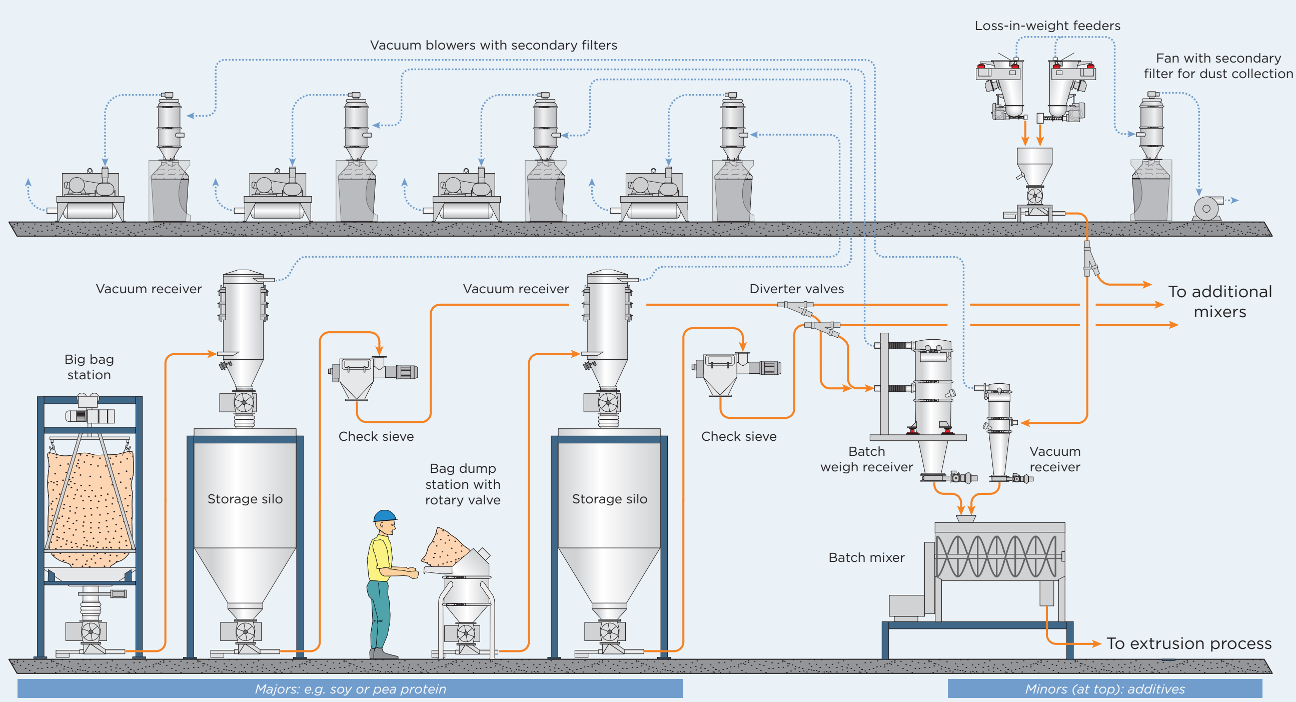
It is important to note that material handling and conveying process steps are critical for the overall production process of TVP and HMMA, particularly with difficult flowing powders such as proteins. The continuous supply of raw materials to the extrusion process is crucial to ensuring consistently high-end product quality.

Care must also be given to the material handling system's design with respect to cleaning and maintenance. Systems should allow for rapid switching between products, easy maintenance access, and provide for wet or dry cleaning depending on the application.

Several standards and regulations cover raw material handling systems used in food manufacture, including European Hygienic Engineering and Design Group (EHEDG) certification and the EU 1935/2004 directive. All processing equipment designs must adhere to the FDA Food Safety Modernization Act (FSMA) standards and current good manufacturing practice (cGMP) regulations.

a. Powder handling and pneumatic transfer

Raw ingredients for plant protein extrusion processes can be received in boxes, bags and bulk bags or super sacks. Typically, protein powders such as pea protein are delivered in 25 kg (50 lb) bags. Bag dump or sack tip stations include a small capacity hopper for receiving the material. These devices usually have an integral shelf for resting sacks while the operator cuts or tears them open. In addition, when dealing with dusty powders such as some plant proteins, they are often supplied with a dust extraction unit and bag disposal system to protect the operator.



Typical set-up for powder handling in TVP and HMMA production processes

When dealing with blends or powders with a cohesive nature, it is important that the filters used in hoppers and on the pneumatic receivers are supplied with quick-release properties (such as superior non-stick fluoropolymer coatings) to avoid powders clogging the filters.

After exiting the bag dump station, powders used for TVP and HMMA production are typically entrained into a powder conveying system. The arrival and transfer of dry ingredients to a production line can include several different types of conveying systems. Selecting the best mode of transfer for ingredients depends 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 conveying line and some type of air material separator, such as the Coperion K-Tron filter receiver.

Pneumatic systems typically operate in a fully enclosed line, which greatly improves hygienic operation and minimizes product loss. Vacuum sequencing systems are often the most economical solution for small to medium rates up to 7,500 kg/h (16,500 lb/h). The loader or receiver is placed above the destination, such as above a storage bin or a loss-in-weight feeder. The material is conveyed under vacuum until the loader or receiver is filled. Vacuum is then interrupted, and a discharge valve is opened to release the material into the vessel below, hence creating a batch mode of operation. Coperion K-Tron's vacuum sequencing product lines include a variety of sizes and executions as well as sanitary designs for ease in cleaning and product changeover.

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, which reduces any outward leakage of dust. This is one of the reasons why vacuum systems are typically 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 throughput possible with a vacuum system are limited due to the finite level of vacuum that can be generated.

If the material conveyed from the source is to be stored in a silo or bin, a variety of options exist to maintain a sanitary and dry environment. Typically, stainless steel is the preferred material of construction for all product contact parts. However, as a more cost-effective option, epoxy coatings with an FDA approved paint may be used for large silos or storage vessels.

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

In addition, the silos or hoppers may be fluidized by exclusive blowers or a compressed air source. Powders 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 pack, this type of device in storage silos, bins or hoppers will help to induce material flow into the pneumatic conveying line.

When dealing with difficult flowing powders, 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.

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

> Bulk material is fed into the process via bag dump stations with rotary valve.

> Coperion offers a wide variety of vacuum receivers, that efficiently help convey bulk solids.

b. Material handling components

Raw material handling systems for TVP and HMMA production can be very complex and often consist of a variety of components, including conveying pipes, airflow control units, gate valves, rotary valves and diverter valves. Each component must meet the sanitary requirements of the food industry, be designed for excellent functionality, and be easy to clean.

In cases where components must meet the highest hygiene standards, it is advisable to adopt a Clean-In-Place (CIP) design, which allows for complete cleaning without removing the component from the processing system. This saves time when switching between products in the manufacturing process.

> Coperion ZRD Rotary Valve with RotorCheck

Flowability of protein powders

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

> Flowability of different protein powders - depending on particle size, ph level and moisture content.
Angle of Repose describes the angle to the horizontal that a bulk solid makes as it flows, unconstrained onto a flat, level surface.

4. Feeding

Feeding systems continuously supply the ingredients to the extruder at a rate consistent with the product recipe. They include bulk material and liquid systems for raw materials such as protein powders, flavors, additives and water or oil. In some cases, several ingredients are premixed and fed to the extruder as a blend or slurry.

Both volumetric and gravimetric feeders are widely used in the food industry. Volumetric feeders measure the volume flow of the ingredients and are suitable for feeding materials with a constant bulk density. However, in the production of TVP and HMMA, heterogeneous properties of the ingredients can quickly lead to irregularities in their flow behavior. Gravimetric feeders are highly accurate when feeding heterogeneous products.

Material characteristics that cause flow challenges in raw material handling also affect the feeding of an extruder. Bridging and ratholing in feeder hoppers are a sign of material flow problems and can impact overall production performance and end product quality.

Many feeders seek to overcome these difficulties using vertical agitation or flexible liner agitation. However, adding vibration to the feed system introduces some other challenges. Vibration can influence the accurate measurement of the mass flow, causing inaccuracy in following the recipe. Variables like vibration amplitude and duration are also tricky to determine without advanced measurement and control.

ActiFlow™ from Coperion K-Tron is a smart bulk solid activator that overcomes the challenges of vibrating a feed hopper. The control system detects changes in material flow, which can be caused by powder sticking. It applies vibration to the hopper from outside without product contact and slowly increases this vibration until the material returns to a normal flow rate. ActiFlow's integration with the control and weighing system prevents the vibration from interfering with flow measurement, and the vibration returns to standby levels as soon as the flow returns to normal. This approach avoids compaction of the material. ActiFlow works without direct contact with the bulk material, thus reducing cleaning effort and resulting in quicker product changeovers.

a. Gravimetric feeders

Gravimetric feeders are standard devices in the plant-based meat substitutes industry. They offer higher accuracy and control of feeds than mass flow meters for plant protein production. Thanks to a weight signal, they measure exactly how much bulk material is being fed into the process and as a result, they react to fluctuations in mass flow caused by changes in bulk density or flow disturbances. In addition, their feeding performance is precisely documented. For recipe changes, it is critical that feeders are accessible and can be cleaned very quickly.

Gravimetric screw feeders are available in both single screw and twin screw configurations. Single screw feeders are suitable for free-flowing powders or granular ingredients. Twin screw feeders are used for sticky and poorly flowing ingredients.

The most common gravimetric feeder is the loss-in-weight (LIW) feeder. LIW feeders consist of a hopper and feeder mounted on load cells or a weigh scale. They are entirely isolated from the extruder via flexible connections so that the feeder weight can be independently measured. As the feeder discharges, the system weight decreases. A controller adjusts the metering device speed based on the measured flow versus the setpoint.

Refilling LIW feeders is critical to ensure continuous production. The refill process uses vacuum sequencing to perform a series of operations:

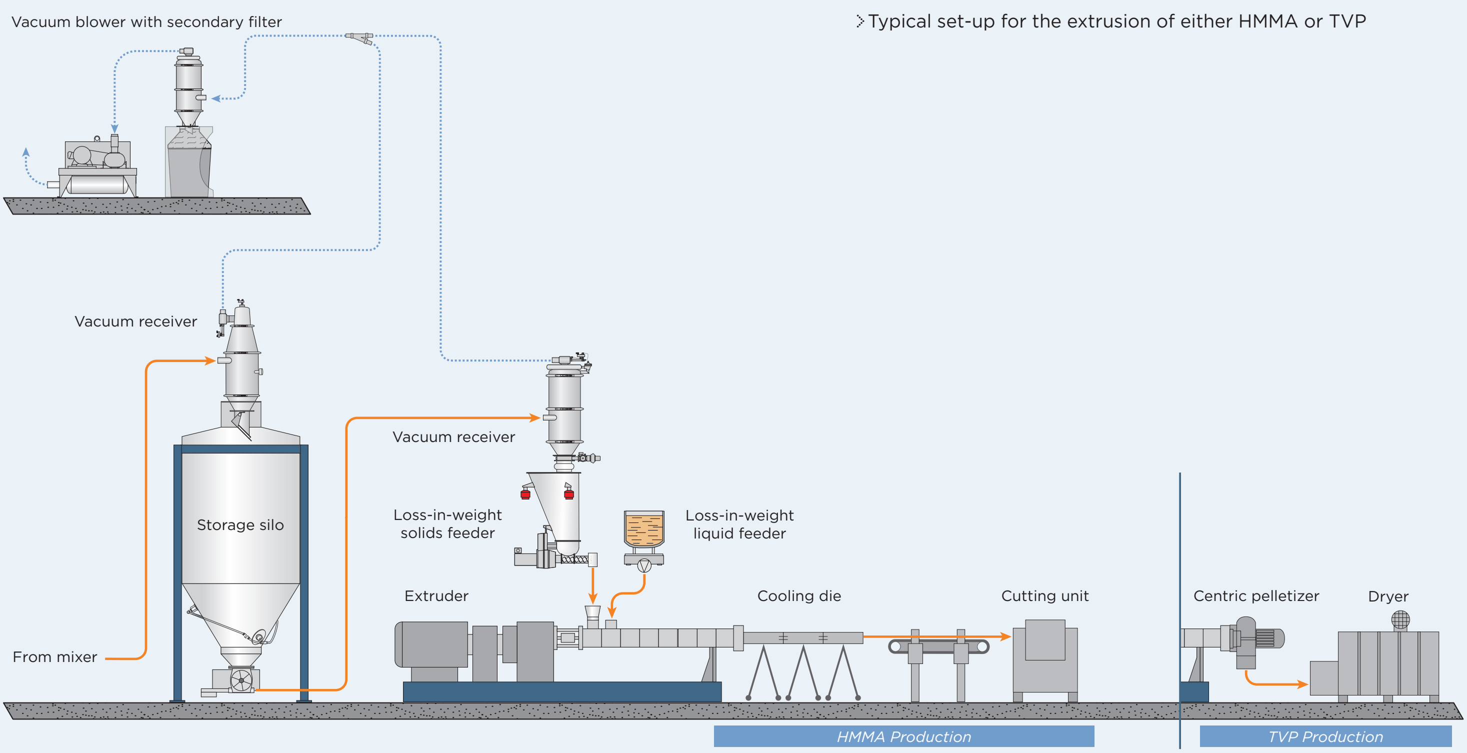
- A receiver mounted above the LIW feeder receives raw material using the dilute phase vacuum transfer principle.
- The vacuum receiver fills to a set level and holds the ingredient until requested by the LIW feeder.
- On request, the receiver contents discharge into the feeder hopper, while a gas pulse releases particulates from the filter mounted inside the vacuum receiver.
- Once the discharge is complete, the discharge valve closes, and the process begins again.

In some cases, a combined feeder-receiver 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. This unit is especially useful for direct loss-in-weight feeder refill, where sticky or fluidizing powder could cause problems with refill valves.

b. Liquid Feeders

Liquid feeders also use the principle of loss-in-weight measurement. A liquid tank mounted on a weigh scale measures the mass flow of an ingredient into the process. Liquid materials are usually transferred into the extruder using a pump with a variable speed drive. The type of pump is determined by the characteristics of the liquid. A controller changes the pump speed or stroke to adjust the fluid flow rate to match the setpoint.

Coperion K-Tron Screw Feeders (left) and Liquid-Loss-in-Weight Feeders (right) ensure high-accuracy ingredient supply consistent with the product recipe.



5. Extrusion

Extrusion is a thermo-mechanical process using moisture, pressure, temperature, and shear forces to transform raw materials into the desired product.

Co-rotating twin screw extruders consist of two screws coupled together and rotating inside a closed barrel. The system is divided into segments so that several screw elements make up the total screw length. At the same time, multiple barrel elements are joined together along the length of the screws. This construction allows for feed supply or heat input at any point in the extrusion process.

A wide variety of screw elements are combined along the screw shafts so that the individual process steps are carried out step by step, resulting in an end product with the desired structure.

Conveying screw elements keep the product moving through the extruder, while mixing elements homogenize the mixture. Left-hand elements resist against the flow and increase the degree of fill in the system, while kneading elements disperse the material to create shear.

TVP and HMMA use different extruder set-ups to form the required product. At the end of the extrusion process, the product is either pelletized to form TVP or passed through a cooling die to create HMMA.

Extrusion of HMMA

- **LIW feeders for protein powder premix**
- **Water**

→ **ZSK Food Extruder**
- homogenous mixing
- hydration
- kneading/plastification
- denaturation

→
- cooling
- laminar flow
- fiber formation

→ **to further processing**

Extrusion of TVP

- **LIW feeders for protein powder**
- **Water/steam**

→ **ZSK Food Extruder**
- homogenous mixing
- kneading
- plastification
- denaturation

→
- texturizing
- forming
- cutting

→ **TVP extrudate to drying/milling**

Extrusion processes for TVP and HMMA production are similar, but use different extruder set-ups and process parameters and differ in terms of product treatment after the extruder discharge.

a. Extrusion process for TVP

Several actions take place within the extruder for TVP production. First, the raw materials are mixed to form a homogenous melt. Then there is the kneading or plasticizing step and finally, denaturation, where the protein molecules unfold and reform in the required structure for the specific product design.

The melt is heated by dissipation. This means that the mechanical energy introduced by the rotation of the extruder screws is converted to thermal energy. Additional thermal energy required can be brought in via heated barrels. TVP extrusion is designed to allow the expansion of water into steam at the die exit so that the material forms a porous fiber structure.

The TVP product exits the extruder through a die plate which aligns the product fibers and through a centric pelletizer which cuts the melt strands into granules. The die plate also provides back pressure on the extruder, which is necessary for the energy transfer within the extruder itself. When the material passes through the orifices of the die plate, the pressure drop results in a release of water vapor, causing the material's expansion into a porous, foamy structure. The granules then need to be dried for stable long-term storage.

b. Extrusion process for HMMA

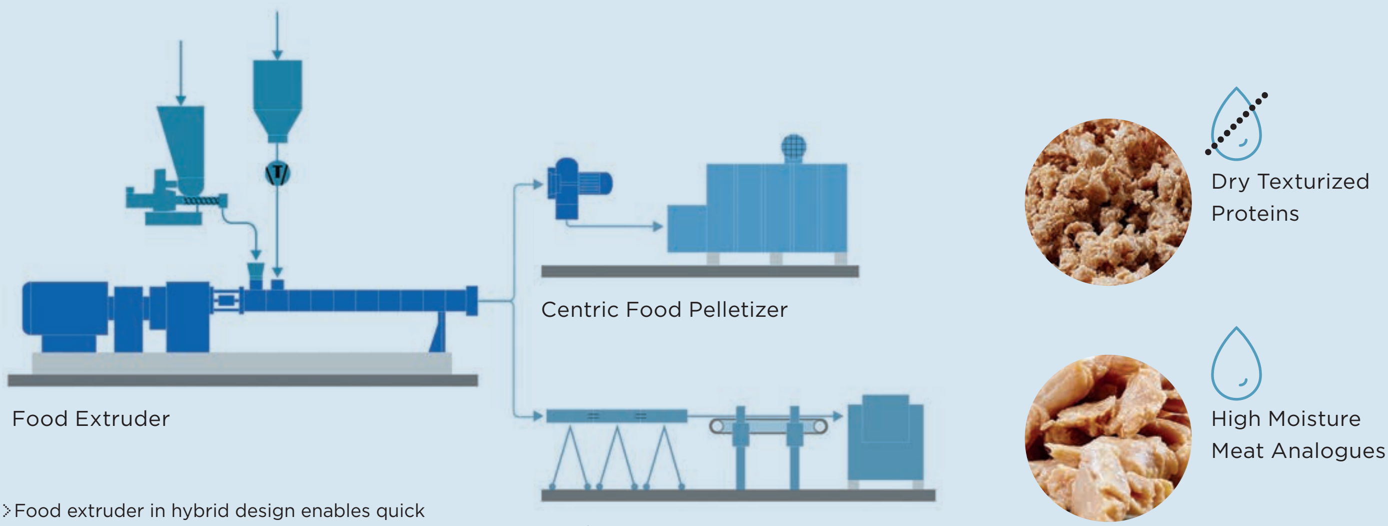
Similar actions take place within the extruder for HMMA production. However, water content necessary for HMMA products is higher than for TVP. In addition, the extruder process section needs to be longer to introduce enough energy for HMMA processing. Protein molecules denature and unfold. Protein agglomerates are separated.

At the end of the extrusion process, a cooling die cools the product down and forces it into a laminar flow. The product exits the cooling die as a rubbery strand or ribbon, which is conveyed to further processing. Transformation to solid-phase happens as fibers are built through freezing the laminar flow profile into meat-like structures.

TVP and possible endproduct

HMMA and possible endproduct

Feeding and Conveying Equipment



> Food extruder in hybrid design enables quick changeover from TVP to HMMA and vice versa.

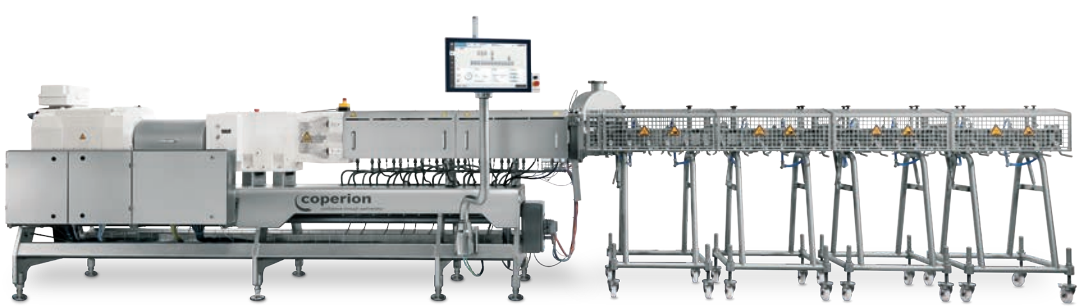
c. Hybrid extruder for rapid switching

Coperion has a hybrid extruder design which offers manufacturers the benefit of rapid switching between TVP and HMMA production. Both processes use the same twin screw extruder, but final product structure is achieved either via a pelletizer for TVP or a cooling die for HMMA. Depending on the recipes, it may not be necessary to change barrels or screw segments when switching products. Using an adapter solution, the food extruder's discharge can be changed over from a centric pelletizer to a cooling die in as little as one to two hours. The same principle functions just as quickly in reverse when performing product changeovers from an HMMA process to TVP. The machine's operator personnel can perform the changeover without support from an electrician.

These hybrid extruders are most useful for small to mid-scale operations, research units and start-ups in particular as they offer an ideal opportunity to enter the rapidly growing market for plant-based products. Until now, the production of TVP and HMMA required two different production systems – and thus high investments.

If the plants become larger, the space required for downstream operations also increases significantly. TVP products need pelletizers and dryers, and HMMA needs chillers and freezers. The higher the production rates, the bigger these downstream elements need to be, and it becomes impractical to have both in one facility. However, for R&D or pilot plants, hybrid extruders are ideal for testing multiple recipes and different product types.

Cleaning of the hybrid extrusion system is important when switching products due to the risk of contamination. The extruder's twin screws have a self-cleaning profile. The screws are intermeshing and self-wiping. Therefore, there are no stagnant zones over the whole length of the process section and product conversion is completed in a few minutes.



> ZSK Food Extruders in Hybrid Design allow manufacturers to rapidly switch between TVP and HMMA production.

> Wide range of possible TVP shapes - depending on process parameters such as energy input

6. Factors affecting product quality

In addition to know-how for the entire process, there are four main factors affecting product quality in the extrusion process for TVP and HMMA:

- Recipe
- Process moisture
- Energy input
- Discharge

Of the four, the recipe is the most influential. With the appropriate recipe, including the quality of raw materials, it is possible to optimize the extrusion process for high-quality TVP and HMMA products. However, it is impossible to produce high-quality products without the right recipe, no matter how much you adjust the other factors. It is also vital to note that changing any one of the factors affecting quality also influences the other factors, making quality control a challenging process.

a. Factors affecting TVP quality

Several characteristics of the product define TVP quality. Fiber texture, length, and strength should all be as similar as possible to the meat equivalent. Bulk density, shape, and extrudate surface are also important features.

The properties of the protein source will impact the achievable quality of TVP. Protein content should be between 50 and 80 percent. Higher protein content can create a gummy product that will not meet the quality requirements.

Protein powders also have a limited capacity to bind water. Adding too much moisture to the extrusion process causes a lighter color, a softer and mushy texture, and less visible fibers. This happens because the mixture has a lower viscosity. The temperature and pressure in the extruder also decrease due to the extra water. The correct amount of moisture results in a firm texture and visible fibers.

Mechanical energy comes from screw speed and screw configuration. Changing these parameters alters the energy input into the process. Higher energy input means the product gets warmer and expands. But too much heat can also brown the product, which affects its appearance. If the energy input is too low, there is no expansion in the product, and the TVP texture is poor.

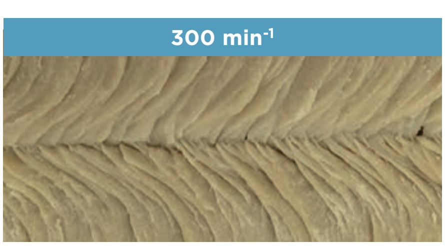
On the discharge, it is the die plate that orients the fibers and creates a pressure drop that contributes to expansion and increased porosity of the product.

b. Factors affecting HMMA quality

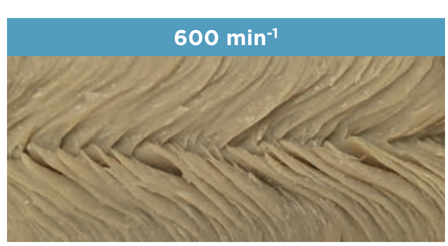
Fiber length and strength are features of HMMA quality, as well as the texture of the product and the firmness of the extrudate. Flavoring and colors are also quality parameters for HMMA as these products are used in ready-to-eat meals.

HMMA contains 50 to 70 percent water and 30 to 50 percent protein, with less than 10 percent fat content. Higher fat content causes mushy fibers with a low fiber strength. Process moisture is a critical parameter for HMMA quality, which is determined by water addition, raw material moisture content, and water binding. If the protein source does not bind well with water, adding starch or fibers to the recipe could help to improve product quality. Too much water gives the product a brittle texture and lighter color.

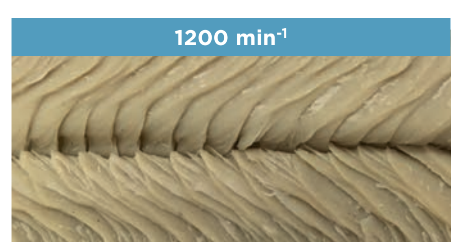
Mechanical energy for HMMA production comes from the screws and thermal energy from heating in extruder barrels. Screw speed and configuration are controllable variables that affect the fiber quality and texture. Thanks to the wide range of screw speeds possible with Coperion's ZSK Food Extruders, raw materials with the most diverse properties can be processed. Depending on the properties of the ingredients, slow speeds (~300 min^{-1}) can create HMMA with a soft texture that is dough-like and brittle. Its fiber layers break easily. Medium speeds (~600 min^{-1}) can create products with a consistent texture and fiber layers that are easy to separate. High speeds (~1200 min^{-1}) create a strong HMMA product texture with hard to separate layers. If the raw materials change, the screw speed can be adjusted to meet the desired product structure.



- soft texture, dough-like and brittle
- fiber layers break easly



- consistent texture
- fiber layers easy to seperate



- strong texture, gum-like
- fiber layers harder to seperate

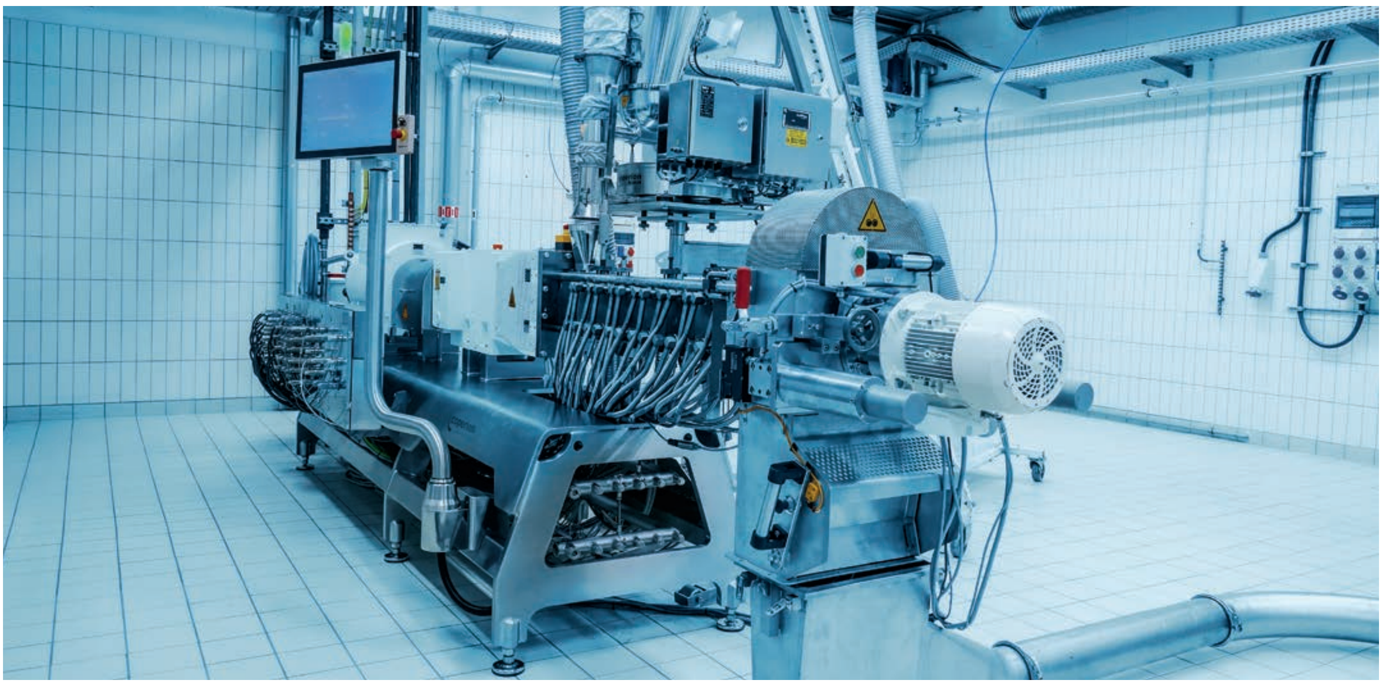
> Screw speed has a significant impact on the HMMA fiber texture - as can be seen here in the example of HMMA based on soy protein concentrate.

HMMA discharges through a cooling die, which defines the formation of fibers in the final product. Flowrate through the cooling die as well as temperature profile play a role in the product quality. HMMA products are not porous like TVP. They have a dense fibrous texture similar to their meat equivalents.

HMMA exits the cooling die as an endless strand. Post extrusion such as cutting allows a wide variety of forms and shapes.

c. Test runs
Performing test runs for new product recipes or new production lines is one way to solve product quality issues before making a significant capital investment and thus reducing investment risk.

Coperion offers global food test centers to customers for the development and testing of feeding, conveying, and extrusion with several ingredients, including the most difficult ones. A team of experts is available to test recipes, material characteristics and properties and provide input to the technical design options for optimal process quality and safety. Coperion also partners with several universities that use the company's equipment and offer locations to develop plant-based products within GMP environments.



> Global test centers, like this Food Test Center in Stuttgart, Germany, allow customers to perform test runs for new product recipes or new production lines before making a significant investment.

7. Special raw materials

Soy, peas, and wheat are the most common ingredients for plant-based meat substitutes, but various alternatives are already in use or are under investigation.

Tests have been done to study the possibility of replacing soy protein isolate (SPI) with ingredients such as hemp protein concentrate (HPC) as there are challenges associated with cultivating soy in colder climates like Northern Europe. In addition, demand for alternatives to soy is growing due to allergen concerns. Results show that it is possible to extrude a mixture with up to 60 percent HPC for HMMA products.

Other investigations center on the idea of sustainability:

- Side streams such as spent grain from breweries and oil cakes can serve as raw materials for wet and dry extruded products.
- Single-cell organisms like dunaliella, spirulina, or chlorella contain up to 70 percent protein. Cultivating these microalgae can reduce pressure on land use and have properties that make them an ideal ingredient for more fish substitutes.

Fortunately, nowadays a lot is known about handling various raw materials, including some with poor flow characteristics. LIW feeders equipped with ActiFlow along with specially designed pneumatic conveying systems can be a solution for new raw materials with their distinct properties.

8. Coperion offering at a glance

Coperion is an industry leader in compounding and extrusion, feeding and weighing, bulk material handling, and service. Extruder integration with the conveying system, feeder and pelletizer or cooling die is critical to the operation as a whole. The company offers complete systems to produce TVP and HMMA, which is a significant benefit compared to piecing together a solution from different suppliers.

The Coperion ZSK Food Extruder has an outer to inner working screw diameter ratio of 1.8, making it the highest free volume extruder on the market. This ratio remains constant for the different extruder sizes, which is vital for scale-up. The similar geometry of the various models means that the higher capacity extruder will produce the same product quality at a higher rate using the same recipe. ZSK extruders have higher capacities than competitive products within a lower overall space footprint and reduced energy profile. This is due to the industry-leading screw speed of 1800 min^{-1}. HMMA production rates range from 50 g/h to 500 kg/h, and TVP production can reach up to several tons per hour. Coperion's ZSK Food Extruder in hybrid design makes it easy to set up production for both product ranges and switch between the two with minimal effort.

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 offers numerous solutions in hygienic and quick-clean designs for ease in changeovers and increased efficiencies. The feeders range in capacity from 32 g/h to multiple tons per hour. In addition, gravimetric feeders can be outfitted with ActiFlow, a smart vibrator that communicates with the controller to automatically adjust activation when it detects material flow issues. Coperion K-Tron loss-in-weight feeders are designed for the rate and accuracy requirements of continuous feeding processes. The state-of-the-art digital weighing systems feature high-resolution measurement at 1:8,000,000 in 20 ms.

Coperion ZRD rotary valves are specially designed for sanitary food applications where contamination is a concern and frequent disassembly and cleaning is required. This is typical in the processing of allergenic products like soy protein powder. The ZRD rotary valve in hygienic design includes a full access extraction system (FXS) and a large inlet for high filling efficiency. The FXS 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.

As an added benefit for food safety, Coperion rotary valves can also be equipped with an innovative RotorCheck option, which detects any metal to metal contact in the valve. This detection system is ideal for avoiding contamination of the bulk material through metal filings from improper operation of the valve.

Finally, Coperion offers 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 Finish (SGF) anti-stick surface treatment option for Coperion's rotary valves, which prevents sticking and build-up of ingredients on valve surfaces.

> Coperion's ZSK Food Extruder in Hygienic Design with high-accuracy gravimetric feeder of Coperion K-Tron

9. Conclusion

The market for plant-based meat substitutes is growing. This rapid growth is putting pressure on existing manufacturers to increase their production capability and creating an opportunity for others to enter the market. It is vital for new and existing manufacturers to consider the technology factors that make for a successful TVP and HMMA production process.

Raw material handling is an essential component of TVP and HMMA production. Such systems should handle raw materials with challenging flow characteristics safely. They should also integrate seamlessly with the extruder so that the system can be optimized as a whole.

Coperion is a globally represented supplier of complete systems for the production of TVP and HMMA. Coperion's systems engineering group has extensive application experience for the entire TVP and HMMA process and ensures optimal design with an emphasis on product quality, process stability and reliability. The systems comply with all hygienic and sanitary design standards, including CIP/COP, EHEDG, FSMA, GFSI, USDA, and 3A where applicable.

Coperion is familiar with the properties of a wide variety of raw materials and their handling - regardless of the protein type and its source. With this extensive knowledge, Coperion not only understands these differences but also has the expertise in equipment design to address them.

Coperion's extruder range offers the highest throughput capacity on the market. They scale easily from laboratory to full production scale, and their modular design allows for maximum flexibility and versatility in process design.

Additionally, Coperion has food test centers available for customers to develop new recipes and test the performance of new raw materials. Extensive industry experience puts Coperion in an ideal position to offer expert advice and engineering support for TVP and HMMA production processes.

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