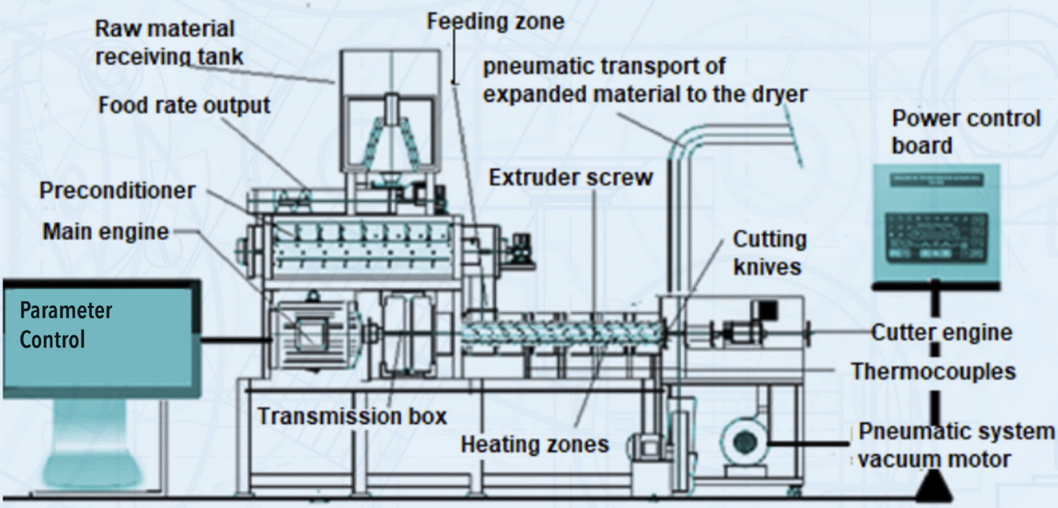
THERMOPLASTIC FOOD EXTRUSION

QUESTIONS AND ANSWERS

A SIMPLIFIED APPROACH

JOSÉ LUIS RAMIREZ ASCHERI



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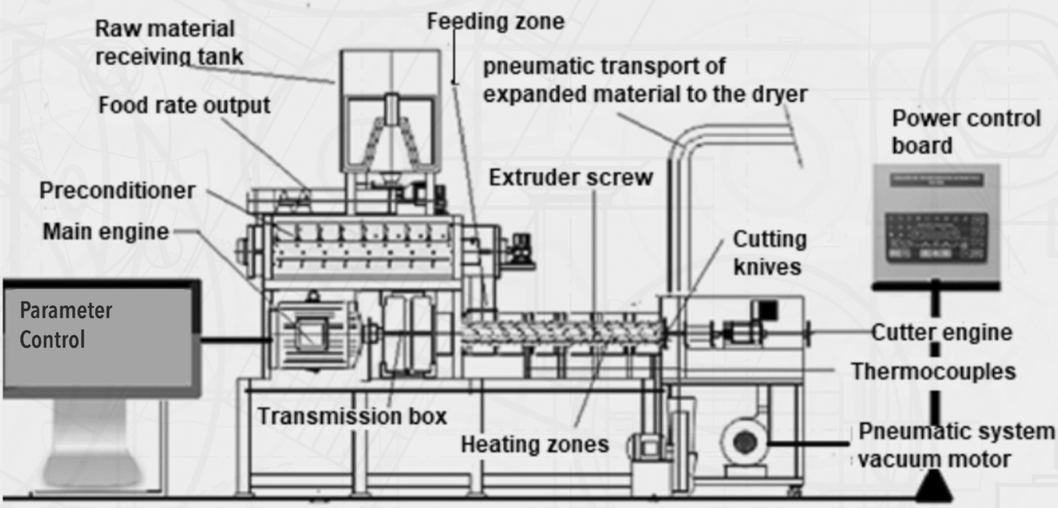

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CIÊNCIAS AGRÁRIAS

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Thermoplastic food extrusion, questions, and answers – A simplified approach

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PREFACE

During my professional activity, as a researcher in the food extrusion field, I have served numerous external customers during more than 30 years of activity in this area. Precisely to answer, with the main answers, the main doubts of most of these customers, the idea of publishing this small treaty was born, with the intention of clarifying as far as possible, in a simplified way, for your better understanding. Most of these entrepreneurs have heard about the extrusion process, and they want to produce some type of product, however, when consulting the manufacturer, they find that there is a very large diversity of equipment available on the market, many of them with high budgets. The question then arises of defining which one would be the most appropriate, or even whether it would be feasible to produce a particular product.

On the other hand, a certain agro-industrial producer realizes that he has large volumes of by-products resulting from a particular manufacturer and that he believes it would be interesting to add value through extrusion. Of course, different by-products can be used, however, not all material is able to pass through the extrusion system, or not everything that is available would be viable.

The characteristics of the raw materials to be processed can also direct the type of equipment that must be considered, that is, an extruder can be very useful for a certain product and without great effect for other types of materials. This is related to the configuration of the extrusion system.

In this sense, the objective of this book is to try to answer, as far as possible, in a simple way, to the entrepreneur, or to those interested in the technique, the main doubts related to extrusion technology. It is hoped that, with this reading, the reader has understood the different nuances presented, and the ways to differentiate the equipment, parameters, and products, since extrusion technology is one of the most versatile in the industrial production of food for both human and animal consumption.

SUMMARY

INTRODUCTION

Thermoplastic extrusion is a technological process for pre-cooking or cooking various raw materials derived from cereals, grains such as legumes, pulses, starches from different sources, agro-industrial by-products, etc. The raw material is previously prepared according to the need for particle size, packaged with the amount of water sufficient to cause the expected degree of cooking, by passing through a screw with a defined configuration inserted in a cannon or barrel with sufficient temperature in its heating zones, in order to modify its characteristics caused by the heat and shear produced inside the barrel in order to gain new organoleptic characteristics, such as texture, taste, odor and nutritional and functional properties. Many commercially available foods are prepared by this process: snacks, breakfast cereals, pre-cooked or instant flour, and cookies, among other foods for human consumption. On the other hand, in livestock, a wide variety of rations are used for different species as well as their stages of growth according to nutritional needs, in the same way for pets (pet food), food of different types according to the requirements in each case. Another sector with high production values is aquaculture, with the delivery of feed for different species and levels of growth, which together involve large revenues for these sectors.

In this sense, entrepreneurs from different areas emerge with the desire to use this technology with the available resources, in order to add value and consequent income improvement. Due to the existence of a wide variety of extruders, from the simplest to the most complex, with single or double screws and different accessories, the entrepreneur will need to evaluate which is the most appropriate, both from an economic and technological point of view. A decision that needs to be studied in order to guarantee investment and success with the productivity of the production line.

For the reasons described, this little book of questions and answers has been created for those who want to preliminarily know the circumstances of the thermoplastic extrusion process.

HOW IS EXTRUSION DEFINED?

There are several definitions for food extrusion, one of them is: Extrusion is a heat treatment process of the H.T.S.T high-temperature short time), which through a combination of heat, moisture, and mechanical work, modifies profoundly the raw materials, providing new shapes and structures with different functional and nutritional characteristics.

WHAT ARE THE MAIN APPLICATIONS OF THE EXTRUSION PROCESS?

The efficiency in continuous production, combined with the ability to produce shapes that are not easily realized with other production methods, has led to the extensive use of extrusion in the food industry. An indication of some applications is shown in Table 1

For human consumption	
Breadcrumbs (breadcrumbs)	Spice Degermination
flavor encapsulation	
Anhydrous decrystallization of sugars to make candy	Enzymatic liquefaction of starch for fermentation in ethanol
Chocolate shell for quick-cooking pasta	Treatment of oilseeds for further oil extraction
Pre-treated malt and starch for fermentation	Gelatin gel confectionery
Rice bran stabilization	Vegetable protein gelling
Preparation of pre-cooked pasta	
Partial destruction of aflatoxins in peanut meal or gossypol in cottonseed meal	Preparation of sterilized baby food (Porridge and baby food)
Caramels, licorice, chewing gum	Elimination of soybean trypsin inhibitor in feed use
Corn, rice, sorghum and potato snacks, etc.	Production of textured pulses
Co-extruded snacks with internal fillings	Pre-cooked flours of cereals, pseudocereals, grains in general, and tuberose
Restructuring of minced meat	Crispy bread, cookies, crackers
instant rice puddings	Modification of starches by reactive extrusion
For animal consumption	
Pet food (dogs, cats, etc.)	Livestock feed (poultry, swine, dairy and beef cattle, goats, sheep, etc.)
aquaculture feed	horse feed
For industrial use	
Pregelatinized starches for the textile industry	Pregelatinized starches for the mining industry
Pregelatinized starches for the oil extraction industry	Manufacturing Bioplastic materials for and packaging utensils (cutlery made from starchy materials)
Manufacture of paper money	Manufacture of biodegradable packaging material (styrofoam replacement)

Table 1. Main applications of the extrusion process

Font: Adapted from James G. Brennan, 2006.

WHAT HAPPENS TO THE MATERIALS INTRODUCED IN THE EXTRUDER?

During extrusion, numerous functions take place, among which we can mention: transport, grinding, hydration, shearing, homogenization, mixing, compression, elimination of gases, heat treatment, starch gelatinization, protein denaturation, partial or total destruction of microorganisms and toxic compounds, compaction, agglomeration, pumping, partial melting and plasticization of the mixture, the molecule's orientation of or aggregates, molding, expansion, formation of pores or fibrillary structures, partial drying, etc.

WHAT ARE THE PARTS OF THE EXTRUSION SYSTEM?

Figure 1 shows a typical schematic extrusion system.

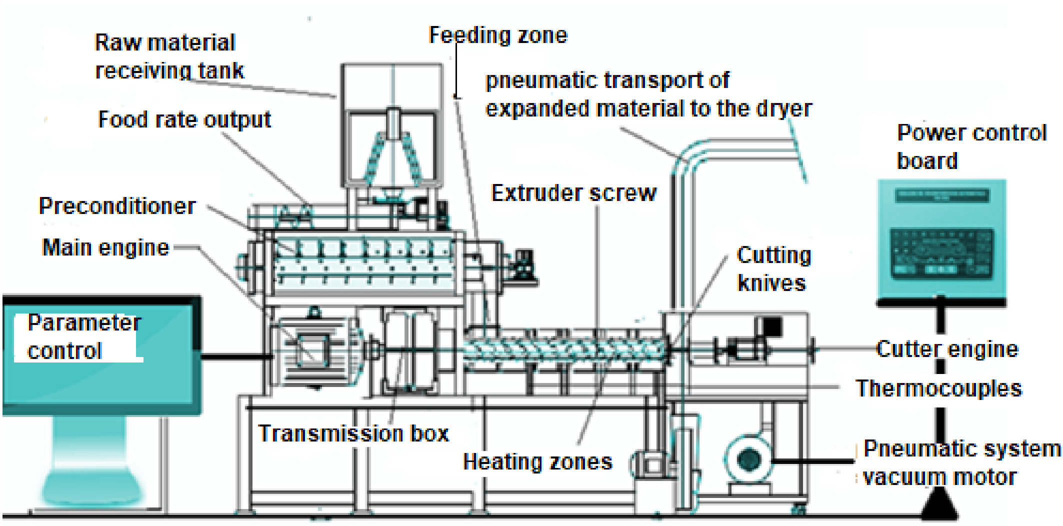


Figure 1.- Schematic of a typical extrusion system.

A brief description of the different parts of the extrusion system follows.

1. RAW MATERIAL RECEIVING HOPPER

Pneumatic or gravity conveying systems pour raw material into a tank, in which, in general, they have a conical rotating system to improve the homogenization of the particles and provide a regular feed to an adjustable speed screw conveyor. From here, the material is fed to the pre-conditioner. In order to transport the dry raw material to the extruder barrel, volumetric (Fig. 2) and gravimetric (Fig. 3) feeders are generally used. The volumetric devices have single and double screws, which transport the material, there are also vibrating feeders and belt feeders. In all of these feeding mechanisms, it is assumed that the density of the feed material remains constant over time and therefore a constant volume of feed will result in a constant mass flow rate. Gravimetric feeders are more expensive and more complex than volumetric feeders. They are usually microprocessor controlled to monitor the mass flow rate and adjust the feeder speed as needed.

Figure 2- Brabender® Volumetric Feeder.

Source:https://www.directindustry.com/pt/prod/brabender-technologie-gmbh-co-kg/product-14639-1892079.html

Figure 3- Schenck-process® volumetric and gravimetric feeder.

Source:https://www.directindustry.com/pt/prod/schenck-process-holding-gmbh/product-14361-1945549.html

2. PRECONDITIONER

Equipment in which the raw material is packaged with the amount of water required for processing. These preconditioners are closed horizontal cylinders, containing one or two axes, provided with adjustable pallets- these allow the variation of the angle of inclination to increase or decrease the time of permanence of the product inside the conditioner, allowing better process control. On the other hand, the shafts rotate with adjustable speed control, either clockwise or counterclockwise, in order to homogenize the material with water, either in the form of steam or liquid water, or even both. The residence time of the material inside the pre-conditioner must be ideal, in order to guarantee the homogeneity of the mixture and sufficient distribution of the water added to the particles of the material, and consequent positive effect during extrusion cooking. There are different types of preconditioners on the market, from the simplest to the high-performance ones, according to the needs of the process and the desired final product. Preconditioners are subject to different factors that can improve or decrease their performance, such as the size, shape, and density of the raw materials; sequence and flow of the added ingredients; beaters configuration; preconditioner format; format and inclination of the palettes; speed of the axle or axles, either in the clockwise or anti-clockwise speed differential thereof; retention and distribution time; energy distribution; component wear; flow rate (feed rate), according to the configurations of the models in which they were designed.

Depending on the rotation speed of the preconditioner, the mixing efficiency can be improved: With the increase in speed, the mixing of the ingredients with the conditioning water or steam improves; on the other hand, with the increase of the differential speed between the mixers, the mixing and hydration significantly improve; in the same way, increasing the mixture reduces the formation of agglomerates (pellets); in contrast, reducing speed increases retention time In figures 4 and 5, the preconditioning elements can be seen.

Fig. 4 CLEXTRAL®

Preconditioner

Fig. 5 Internal part of the CLEXTRAL® preconditioner
showing the palettes and mixing axes.
Source: https://www.clextral.com/technologies-and-lines/equipment/the-preconditioner/

Preconditioner models: Single-shaft cylindrical (SC); Cylindrical with two axes (DC); Two-diameter cylindrical (DDC); High-Intensity mixing Preconditioner (HIP); High Shear Preconditioner (HSC).

According to patent number PI 0710500-2 A2, by inventors Lavon Wenger, Marc Wenger, and Galen J. Rokey, published in 2012, it deals with the improvement of the pre-conditioner having two independently driven high-speed shafts. Preferably, the speed differential between the axles is at least about 5:1. The mechanisms are operationally coupled to a digital control device to allow speed and direction of rotation control. The preconditioner is supported by load cells also coupled to the control device to allow for point-to-point changes in material retention time within the preconditioner. It is particularly useful for preconditioning and partial gelatinization of starchy formulations, reaching about 50% of cooking during preconditioning.

EXTRUDER SCREWS, SINGLE TO TWIN-SCREW

The function of the extruder screw or screws consists of the first step of transporting, melting, and homogenizing the raw material through rotary motion. Due to the intrinsic properties of each raw material and/or formulations, such as surface hardness of the granules, melting temperature, shear coefficient, the viscosity of the molten material, and others, it is necessary to develop different thread constructions to achieve better results and cooking conditions. In practice, however, due to cost issues, both for single and twin screw extruders, what is noticeable are standard screws that seek to meet groups of materials with similar rheological behavior. Geometrically, it is divided into three distinct zones (Fig. 6): Feeding Zone, whose function is to transport the raw material to the compression zone. In this zone, in general, the pitch is larger or the thread core has the smallest diameter, remaining constant. This part of the thread must ensure a supply pressure and preheat the material. (b) Compression Zone, is the zone where pre-cooking begins, due to the decrease in the distance between the steps or the constant increase of the thread core, which will compress and shear the material.

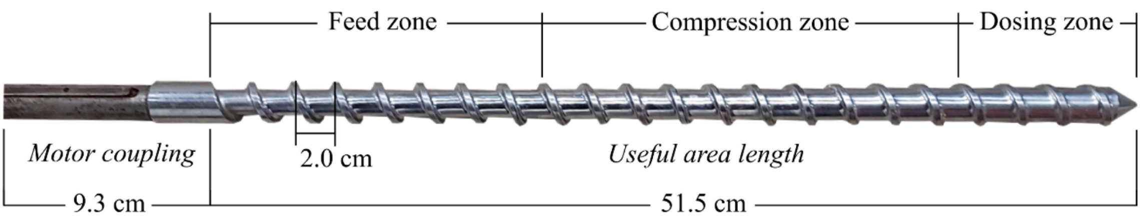


Fig. 6. One-piece Brabender® Extruder Screw 3:1 compression ratio

Source:https://www.brabender.com/en/food/products/extruder/single-screw-extruder/single-screw-extruder-test-extrusion-properties-of-various-materials/

The decrease in the volume available between the threads of the screw, in addition to providing compression and helping precooking, tends to homogenize the dough that begins the transformation of the material, eliminating the air initially transforming the starch and/or proteinaceous material in the pre-cooking stage. -Fusion. (c) Dosage Zone, in this zone the screws have threads with less depth, this is because the diameter of the thread core has been growing, reaching its largest dimension here and remaining constant. It is in the dosing zone that the cooking is completed, and maximum homogenization is carried out, also defining the pumping of the molten mass to the outlet in the matrix.

In extruder screws (Fig. 7) with the same depth, what changes is the distance between the threads, being much smaller in the dosing zone. Another way to cause and/or improve the shear rate is to place elements with a reverse position, or elements that have a horizontal cut of the fillets, in each case these elements play a role in improving the melting and/or cooking of the material.

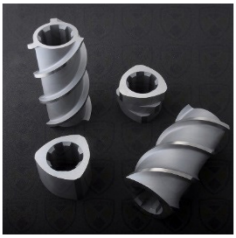
		
Extrusion System Elements with the same depth, low shear rate, and different flow restrictors	Flow restrictor (or reverse position) and high shear rate elements	Elements normally used in the assembly of the feed zone, with low shear rate steps

Figure 7. Screw elements with different configurations.

Source: https://www.promaxx.com.cn/Screw_element.html?gclid=Cj0KCQjwpdqDBhCSARIsAEUJ0hP_7Ckfr6aPNredq-e4A6noBYVlqM49dkcnptIQww3Pxl1GO2bg46gaAiwBEALw_wcB

WHAT IS EXTRUDER SCREW CONFIGURATION?

There are a wide variety of formats in the manufacture of screws for extruders, some are integral, that is, from a single piece of specific alloy steel, in which it was machined. Most single-threaded equipment is manufactured for direct expansion products- in general for making corn chips- are high shear rate solid screws as shown in Figure 8 below.

Figure 8.- One-piece high shear rate short barrel extruder, normally used in the extrusion of corn grits.

On the other hand, extruders with higher performance have interchangeable elements, as shown in the figure prepared by WENGER®, the screw has a central axis, in which the different elements that form part of the screw are fitted. Both for twin screw (Fig. 9) or single (Fig. 10) extruders.

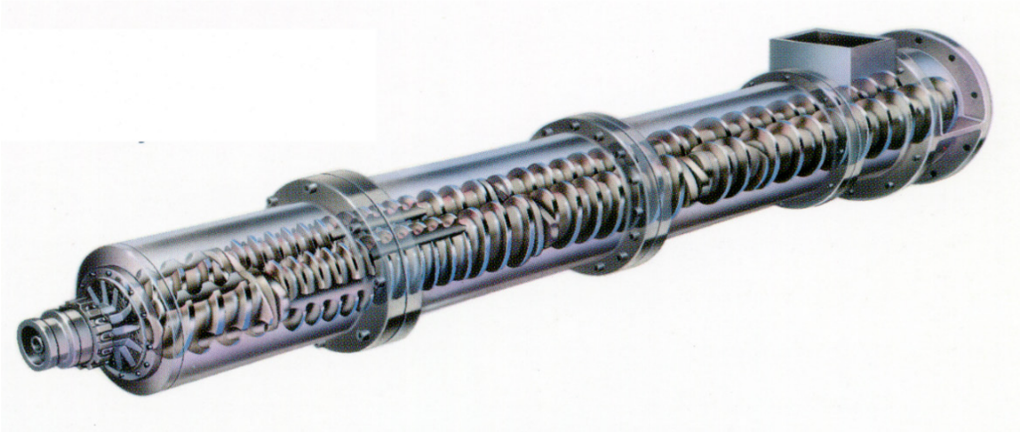


Figure 9. Schematic of a three-section, feed-section twin-screw extrusion system from Wenger® Manufacturing, Inc.

Source: Sort course of food extrusion FPR&D-TAMU, Center and Wenger Manufacturing, Inc.

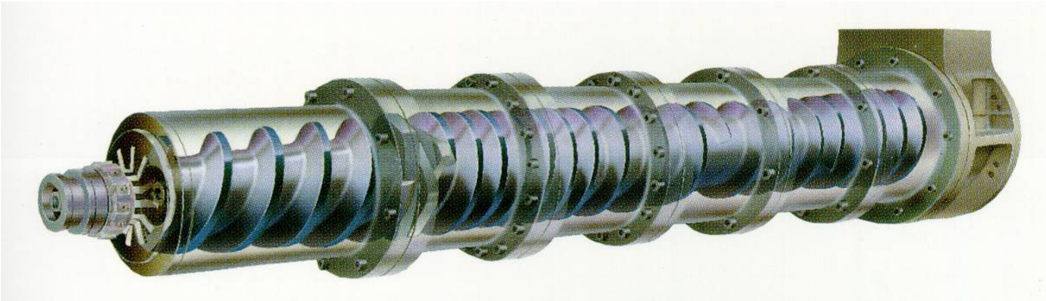


Figure 10. Schematic of a six-section single-screw extrusion system

Source: Sort course of food extrusion FPR&D-TAMU, Center and Wenger Manufacturing, Inc.

Depending on the configuration in the fitting of the elements, the extruder can be prepared for low, medium, or high shear rates.

Figure 11 shows a sectional element of a twin screw extruder barrel.

Figure 11. Sectional element of a barrel system or also called jacketed elements of a twin screw extruder.

Source: Sort course of food extrusion FPR&D-TAMU, Center and Wenger Manufacturing, Inc.

Figure 12 shows different elements of a BRABENDER® twin screw extrusion system.

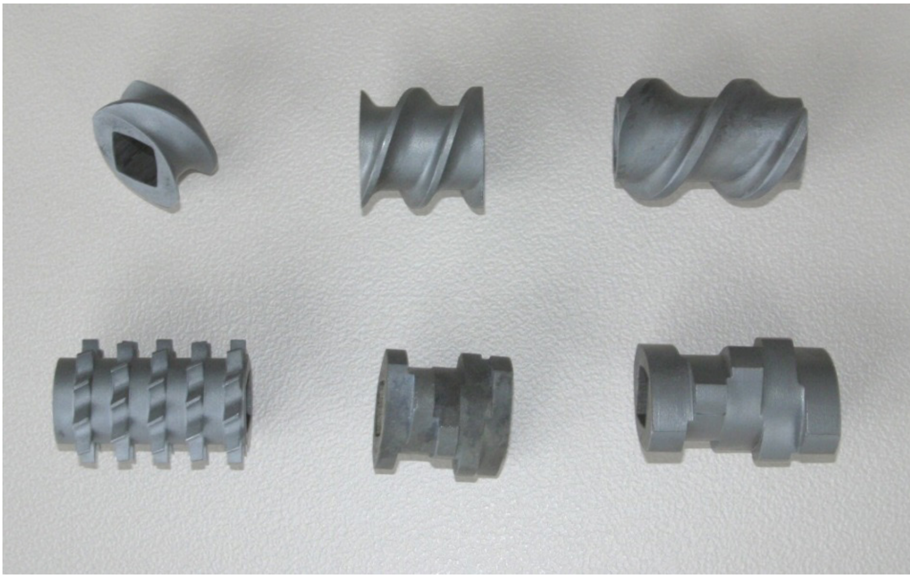


Figure 12. Sectional elements that make up a screw of a twin screw extrusion system. Source: Brabender® GmbH & Co.

Figure 13 shows the different ones already assembled, containing elements of different helixes, including one of counterflow (a), or of cut helices (b) to promote better mixing of the material.

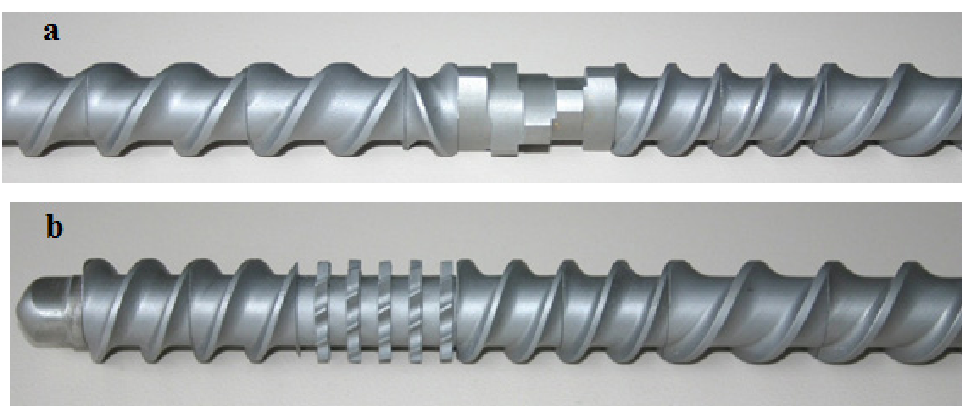


Figure 13. Assembled elements of a twin screw extruder

Source: Brabender® GmbH & Co.

EXTRUSION SYSTEMS

There is a wide variety of extruder types for food processing, whether for human consumption or for the manufacture of animal feed. In recent years, there has been a significant evolution in the modernization of equipment available to the industrial market, facilitating the production of new foods with increasingly complex raw materials and innovative final products.

An extrusion system is basically composed of a one-piece barrel or joined by modules forming sections according to the length foreseen in the extruder project. The characteristics of the barrel may differ according to the expected nuances. Some are equipped with jackets so that steam or hot oil can be added for heating. Likewise, according to the project, the jacketed sections can have a helical system, either clockwise or counterclockwise to the screw rotation thus causing additional friction to the extrusion force. There are also extruders that have systems for direct injection of steam or water into the barrel, so there will be differences in the cooking degree, according to the handling of the extrusion parameters.

The screw, or screws, depending on whether the extruder is constructed, is one of the most important elements of the extrusion system. Depending on the format, that is, one-piece, or formed by interchangeable elements, of short, medium, or long size, the performance of the same will be in accordance with the assigned purposes.

For example, a twin screw extruder, with interchangeable elements, will be able to work in conditions of low, medium, or high shear rate. In this way, high expansion products can be developed as well as intermediate products, or pellets (third generation snacks), without expansion, but with a degree of cooking suitable for the product. Extruders used in research have temperature control systems in the different sections of the extruder barrel, achieving adequate cooking degrees, according to the needs of the formulation used. Likewise, accessories allow being added that differentiated processes, such as co-extrusion and/or application of supercritical CO_2, among other accessories such as those for fibrillation/texturing of the material.

On the other hand, there are single short screw extruders, generally produced for the manufacture of corn derivatives, mainly grits, used for expanded products, and snacks. This equipment may be more limited. Most of this equipment have fixed screw speed, that is, they do not have a speed regulation system, which can be improved with the incorporation of a frequency variation allowing screw speed control. In these extruders, the temperature of the barrel can be with or without electrical resistance, generally without a jacket for recirculation of cooling water, which makes it difficult to control the heating in the barrel. The ones that have a cooling system, it is done only through the circulation of running water. However, higher-performance extruders have a cooling system with the circulation of cold water in the different zones of the extruder barrel, controlled by a Chiller[1], in order to promote greater efficiency in the distribution of the heat needed for each zone of the extrusion system. In these systems, each zone is jacketed, that is, it allows the passage of cold water, controlled by the action of solenoid valves, previously adjusted when determining the temperature profile to be used in a given process.

1. Chillers are basically water coolers. The refrigerated water produced by them is used in order to lower the temperature, when necessary, in the jackets of the extruder barrel sections, whose power is measured in tons of refrigeration (TR), and they are capable of working with a wide temperature variation, which can even be negative when additives are used.

IS IT POSSIBLE TO USE THE SAME EXTRUDER MACHINE TO PRODUCE DIFFERENT FOODS?

Yes, as long as the extruder has enough features and accessories to achieve different configurations. Preferably if the equipment has a co-rotating twin screw with the possibility of exchanging elements in order to determine the required shear rate. Machines of this type are normally used for product development, as they have the necessary accessories for the variations that the new product requires. Everything is related to the needs of the producer. If there are high production volumes, for example working in three shifts, of a particular product, in this case the equipment will be configured only for that factory condition, so the fact that the extruder has different interchangeable configurations would not be useful. On the other hand, with the possibility of different configurations in the extrusion system, it can be justified, for specific cases, production volumes of high added value, which justifies the assembly and disassembly and consequent stops for this purpose. Hence the importance of dimensioning the equipment according to the desired production. Part of this problem can be solved by purchasing additional screws with specific configurations for certain products, in this way, the exchange of the same can be more accelerated.

Various extrusion processing parameters are considered, these can be classified into three categories: (a) independent parameters or input parameters, such as raw material properties, operating parameters, such as feed rate, speed, and configuration of the screw, type, die dimensions, the temperature profile of the different zones of the barrel, etc. (b) system parameters or dependent parameters, residence times, specific mechanical energy, engine torque, system pressure, melt viscosity, and (c) product properties or output parameters, such as physical properties (expansion, density) and chemical (amino acid profile, lipid content, etc.), sensory properties (texture, crispness), etc.

WHAT TYPES OF RAW MATERIALS ARE LIKELY TO BE USED IN EXTRUSION?

One of the advantages of the extrusion system is related to the possibility of using a large number of raw materials. Among those of vegetable origin: are all types of grains and cereals, pseudocereals (quinoa, amaranth, kiwicha, etc.) available, and their versions of wholemeal flour or not, and their respective starches. Starchy derivatives of roots and tubers (potatoes, cassava, taro, yams, etc.), by-products (co-products of oilseed extraction such as soybean cake or soybean meal, lupines, or lupine beans), corn bran, wheat, rice, bagasse resulting from the extraction of fruit juices, etc.) among others, resulting from the agro-industry, these, depending on the type of final product, must be subjected to dehydration and/or enzymatic stabilization for better hygiene/sanitization conditions and preservation for future applications. Of animal origin: meat, meat and bone meal, fish meal, crustacean meal, insect meal, poultry feathers, bovine blood, powdered egg, skimmed milk, gelatin, etc.

HOW DO RAW MATERIALS INFLUENCE PRODUCT QUALITY?

Certainly, each ingredient, alone or together, in a formulation will have its inherent typical differences, generating a degree of cooking, texture, and sensory properties, related to that composition. That is, the proportions of protein, carbohydrates, lipids, total, soluble and insoluble fibers, among other secondary components, that will give the final product its unique sensory property. The developer of food products, whether for human consumption or for animal feed, who manages to manage the proportionality of ingredients from different sources, will then have great results in consumer acceptability.

The nutritional value of raw material is not limited to its chemical composition (protein, energy, fiber, and mineral values). There are raw materials that are more or less digestible (more or less easily broken down by their constituents) and also the presence of anti-nutritional compounds (compounds naturally present in foods that will make their digestibility difficult, for example, tannins in the grains of some sorghum varieties, gossypol in cottonseed meal, the soybean trypsin inhibitor, etc.). This relative digestibility of each raw material can also vary according to the species of animal (for example, the digestive system of birds is different from the digestive system of cattle). The anti-nutritional factors themselves are substances that, even in a vestigial state, reduce or totally prevent the use by the animal of a nutritive element (both at the digestive level and at the metabolic level). Best-known anti-nutritional factors: anti-vitamins, mineral cation-chelating organic acids, anti-enzymes (such as soybean antitrypsin), condensed tannins (present in sorghum grains), lectins, saponins (quinoa), as described by Marcos Duarte: https://www.infoescola.com/zootecnia/materias-primas-da-nutricao-animal/.

Considering the case of processing corn grits to obtain expanded or snack foods, these grits generally obey a quality standard, coming from a variety of hard or semi-hard grains, a fundamental characteristic to exert that resulting crunchy and crispy effect during extrusion, pore formation, therefore the expected texture.

On the other hand, in the elaboration of feed, there is an interest in delivering a portion of food that is as complete as possible from a nutritional point of view. That is the proper balance of proteins, carbohydrates, lipids, minerals, vitamins, bioactive, and attractants, among others. In this sense, there is an important demand for high-quality formulations and ingredients. However, a fundamental aspect is related to the cost of ingredients, especially with protein sources. A particular example can be placed in the formulation of fish feed, in countries where the high-quality fish meal and oil are of high price, it is sought to replace with proteins from vegetable sources such as soybean meal as the main protein ingredient, under these conditions, the other ingredients added as sources of carbohydrates must have properties that facilitate the binding of the pellets produced. In addition to nutritional quality, several physical properties must be considered as pellet quality requirements, such as texture, density, size, etc. High fiber contents can cause brittle products, impairing physical quality, buoyancy, and integrity in the proper time in the water, among other factors. The amount of starch present in the formulation may improve the binding/cohesion characteristics of the ingredients and may form starch-lipid-protein complexes, which in addition may also increase the susceptibility to enzymatic hydrolysis.

In this sense, proteins derived from plant sources such as soybean meal, legumes, wheat gluten, and corn gluten, among other cereals, have good functional properties, in the formation of cohesive structures. These are low-cost with an adequate amino acid profile. Among the protein sources of animal origin, such as meat, fish, chicken, blood meal, gelatin, meat, and bone meal, these do not provide an adequate structural-functional property, evidently, the cost of these ingredients is higher and provides an excellent profile of amino acids.

DOES PARTICLE SIZE INFLUENCE THE FINAL QUALITY OF THE PRODUCT?

Depending on the desired final product, the size and homogeneity of the particles entering the extrusion system are of significant importance. Considering, for example, a short barrel extruder, prepared for the expansion of products derived from corn grits, the particle size or its distribution among them will be of significant importance, as the texture and pore formation of the expanded product will depend on this. For this case, for example, the companies that manufacture grits have made different types of grits available for commercialization.

Tables 2, 3, and 4 below show the granulometric variations of three products sold to snack manufacturers (corn snacks): SnackMix 400, SnackMix 300, and SnackMix 200, (Company: Milhão-Indústria Alimentícia, S.A.)

Granulometry	*SnackMix* 400/Corn Grits	
% Retention in the sieves (ABNT)[1]:		Standard
	14 (1,410 mm)	Max. 15.0
	16 (1,180 mm)	Max. 40.0
	20 (0,850 mm)	Max. 40.0
	25 (0,710 mm)	Max. 10.0
	Pan	Max. 1.0
Moisture		Max. 13.0 %
Lipids		Max. 0.8 %
Acid (ml sol. 1N of NaOH/100g)		Max. 3.0 %
GMO		Absent
Deoxynivalenol		Max. 750 ppb
Fumonisin (B1, B2)		Max. 1000 ppb
Zearalenone		Max. 150 ppb
Ochratoxin A		Max. 10 ppb
Aflatoxin (B and G)		Max. 20 ppb

Table 2. Granulometric and physicochemical characteristics of SnackMix 400 grits from the *Milhão Food Industry®*.

1. Brazilian Association of Technical Standards

Granulometry	SnackMix 300/Corn Grits	
% Retention in the sieves (ABNT):		Standard
	16 (1,18 mm)	Max. 1.0
	20 (0,850 mm)	Min. 60.0
	25 (0,710 mm)	Max. 30.0
	40 (0,425 mm)	Max. 10.0
	Pan	Max. 2.0
Moisture		Max. 13.0 %
Lipids		Max. 0.8 %
Acid (ml sol. 1N de NaOH/100g)		Max. 3.0 %
Specific weight		650 a 750g /L
GMO		Absent
Aflatoxin		Absent

Table 3 Granulometric and physicochemical characteristics of SnackMix 300 grits from the *Milhão Food Industry®*.

Granulometry	SnackMix 200/Corn Grits	
% Retention in the sieves (ABNT):		Standard
	20 (0,850 mm)	Max. 2.0
	25 (0,710 mm)	20,0 – 40.0
	40 (0,425 mm)	Min. 50.0
	50 (0,300 mm)	Max. 10.0
	Pan	Max. 3.0
Moisture		Max. 13.5 %
Lipids		Max. 0.8 %
Acid (ml sol. 1N of NaOH/100g)		Max.. 3,0 %
GMO		Absent
Deoxynivalenol		Max. 750 ppb
Fumonisin (B1, B2)		Max. 1000 ppb
Zearalenone		Max. 150 ppb
Ochratoxin A		Max. 10 ppb
Aflatoxin (B and G)		Max. 20 ppb

Tabela 4. Granulometric and physicochemical characteristics of SnackMix 200 grits from the *Milhão Food Industry®*.

Source: https://milhao.net/industria-alimenticia/grits-de-milho-snack200/

WHAT ARE THE MAIN PARAMETERS OF THE EXTRUSION PROCESS?

Depending on the screw or twin-screw configuration, the main parameters include: moisture, temperature, screw speed, type, and die diameter, feed speed.

The moisture, in which the raw material was placed to start the process, is one of the most important factors for the conversion of the processed material into the final product ready for consumption. The amount of water added will define the degree of shear within the extrusion system. In this way, if we want an expanded product, for example using corn grits, the moisture can be between 14 and 18% approximately, as it can vary according to the type of ingredient placed as well as the configuration of the screw or screws. If the objective is pellets, or also called half products, the moisture processing to be used can vary between 28 to 32% depending on the quality and type of flour to be used.

The diameter and type of die are those that restrict and shape the product at the exit of the extruder. The smaller the diameter, the more restricted the output of the product (this obviously increases the pressure of the system) which must be in agreement with the other parameters (mainly moisture and temperature). There are very small dies, around 1mm in diameter, others maybe 2, 4, 6, or 8 mm, depending on the type of product and in accordance with the extruder configuration conditions. In the preparation of snacks, the format is important, in this case, in order to achieve the correct figure, the appropriate adjustment in the speed of the cutting knife of the product at the exit of the extruder must also be considered.

Temperature is another important factor in extrusion processing. Depending on the length of the cannon, the temperature profile must be carefully controlled, in its different available zones, to avoid overcooking and or even burning the product. Let us consider a short barrel extruder, that is, with three heating zones, for expanded products, in this case, the temperatures could be approximately 90, 100, 140°C; or 100, 120, 160°C, depending on the type of raw material, speed and screw configuration of the extruder. If the extruder has 10 heating zones, the temperature profile for expanded cereals can be approximate: 80, 90, 90, 100, 120, 120, 130, 130, 140, and 140 °C., this profile is obviously tentative, and subject to modifications according to the type of raw material and/or formulations that were introduced into the extruder.

Speed of the screw(s), depending on whether it is an extruder, single or double screw. As the speed increases, the greater the shear rate, consequently, the greater the rate of conversion of the material cooking degree and increasing expansion. This happens up to a limit, as this speed does not imply a linear progression of the expansion. It reaches a certain speed value, the material more, and on the contrary it does not expand at a certain speed value. Under these conditions, the product undergoes a much greater degradation, breaking, the structures are responsible for the texture, taste, color, and odor in the product and even impair the quality.

Feed speed also has an influence on the expansion quality of a given product. As the increase in expansion increases, there can be a measure of the increase in expansion. This is due to the feed rate, which must be adjusted according to the granulometry and type of raw material, density, specific weight, and/or a formulation to be fed into the extruder.

An important accessory of extruded products is an accessory that is connected to an adjustable speed motor, because with a knife it is possible to cut or expand the pellets at the exit of the die, according to the desired size and shape. Figure 14 shows the bearing of a cutting system, containing several blades made of stainless.

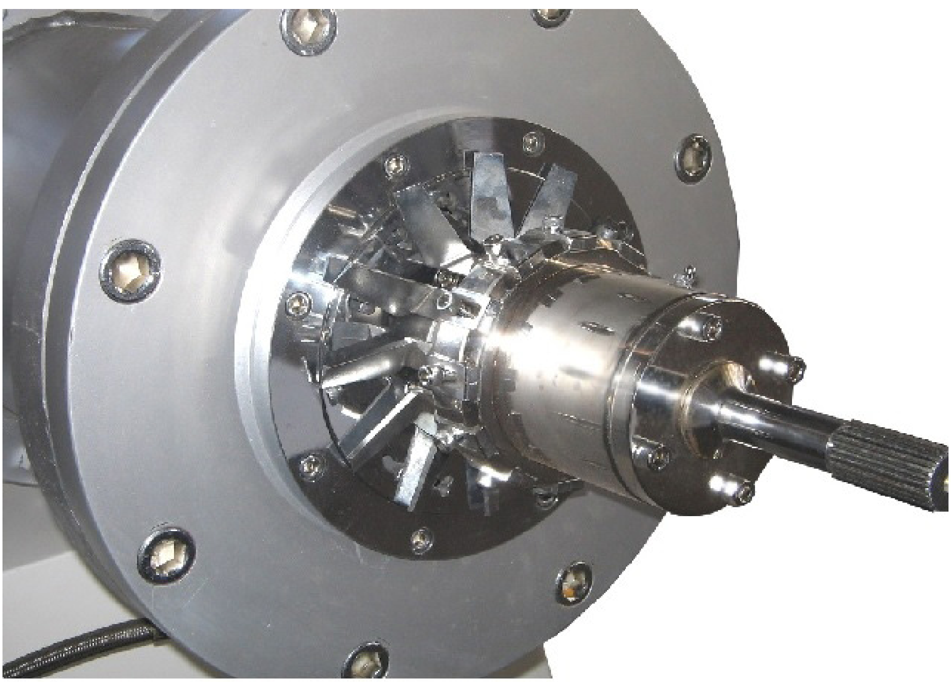


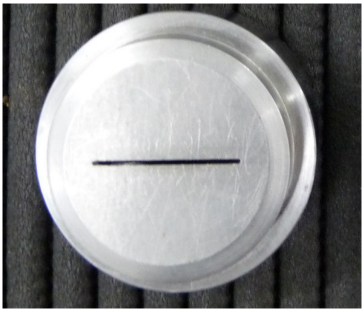
Figure 14. – Bearing of a cutting system, Ferraz® brand.

Source: http://www.ferrazmaquinas.com.br/conteudo/mancal-suporte-facas-extrusora.html

WHAT IS THE DIE?

A die is a part located at the exit of the extruder with one or more openings where the material to be processed passes through pressure. The hole, or holes, of the die is for modeling products in different sizes and structures. They can be designed differently and according to the characteristics of the product to be processed. Its opening determines the material outlet pressure, so the more closed the die, the greater the pressure exerted by the system, in figure 15 a, b, and c. different die types are presented.

a) Die of different formats



b) Laminar die of 1mm opening.

c) Multiple dies with the same diameter

Figure 15. Different die types a) shapes of figures of animals and objects; b) laminar die, for the product to come out as a ribbon; c) multiple dies with the same diameter, typical in the use of pellet processing.

WHAT ARE THE DIFFERENCES AND/OR ADVANTAGES BETWEEN USING SINGLE-SCREW AND TWIN-SCREW EXTRUDERS?

In general terms, it is important to note that each equipment, whether single-screw or twin screw extruders, can be sufficient for a particular product to be manufactured. The question is when a certain additional product wants to be manufactured and that, for reasons of raw material category, the final product does not have the expected quality, since the extruder may not be adequate, or the production costs are not compatible with the producer's expectations. Whatever the configuration of a single screw, the product flow is directly proportional to the screw speed, since the extruder must be filled with mass to perform its function. This implies that the extruder flow rate and the feeder speed are fully linked.

The single-screw extruder conceptually operates by friction (between the dough and the module, ie the dough adheres to the wall of the module). This generates a "drag flow" due to screw rotation within a static module. Each fluid particle has a different velocity according to its position in the module: the closer to the center, the faster it goes, which implies a relatively important dispersion of the residence time of each particle inside the extruder. In this sense, there are some limiting factors for single-screw extruders, for example, a considerable interaction of process variables, ie, a dependence between feed rate and screw speed; poor mixing capacity, and inefficient mechanical energy generation, this implies the need to use between two to four more moisture percentages to gelatinize the starch, which then has to be removed in the drying process, implying energy costs in this operation.

Since the single-screw extruder does not work as a positive pump, it must be monitored in the processing of raw materials and/or formulations with a high lipid content, because, due to the lubricating action of fatty acids, the degree of cooking may be impaired. The same can happen when working with high moisture content.

Over time, the space between the top of the screw and the wall of the module increases, due to screw wear generated by abrasion and corrosion of the mass. This generates leakage of increasingly important flows, with a strong impact on the quality of the product: it can reach a loss of 10 to 20% of the flow over the life of the screw.

It is important to consider that using single-screw extruders, intermittent interruption of the raw material feed flow can lead to clogging of the die or dies. This is due to the fact that, depending on the type of material, mainly starchy, it can quickly retrograde, going from the molten state to the solidification state quickly. The result is that the machine stops rotating, and the screw must be removed for cleaning as well as the dies.

On the other hand, a co-rotating extruder (i.e. the two axes rotate in the same direction and are together) with a double screw works as a positive displacement pump, allowing to process of viscous, oily, sticky, or very wet material with the same pumping efficiency. This pumping capacity (with efficient mixing) allows the continuous addition of elements (steam, fat, dyes, ingredients, etc.) to the extruder modules. A very intense mixing occurs in the areas of co-penetration of the screws (macro and micro-mixing). From this mixing, ability comes its power to incorporate mechanical energy and a high rate of heat transfer. This makes it possible to obtain homogeneous cooking of the dough, with an excellent degree of starch gelatinization, protein denaturation, and lipid cohesion. Expansion at the matrix level is done consistently, resulting in a product with uniform density, texture, shape, and color. It is evident that there is a need to consider that to reach this level, factors such as feed rate, particle size and homogeneity of the material and/or formulated mixture, degree of hydration/pre-cooking in the pre-conditioner, screw configuration, temperature profile, screw speed, die diameter/shape, knife cutting speed must be fully adjusted.

WHAT IS FOOD CO-EXTRUSION?

Co-extrusion is an extrusion process used to obtain a product that combines two textures: one material is extruded and continuously filled with another to form a single product. In figure 16, it can be seen that the blue component corresponds to the extrusion of a material that can be, for example, expanded cereal, in the final part of the matrix, indicated in red color, corresponds to a duct that serves to feed the second component, which can be, for example, a jelly or savory sauce. In this way, a given expanded in the form of a cylinder would have the jelly filling in the central part.

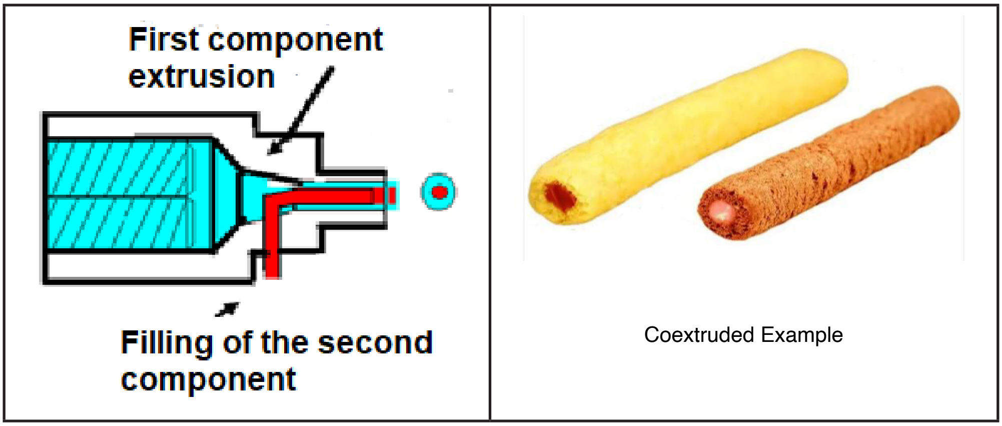


Figure 16.- Schematic of a co-extrusion system and the resulting product.

Source: https://pt.made-in-china.com/co_saibainuochina/product_Core-Filling-Snack-Food-Processing-Line-CO-EXTRUDED-SNACK-FOOD-MACHINE-_hhyyerygu.html

WHAT IS PELLETING?

Pelletizing consists of transforming formulations and/or floury raw materials subjected to thermal treatments (temperature and humidity) and high pressure into pellets (Pellets) using a pellet machine. In figure 17, different types of pellets can be seen.

Figure 17.- Different types of pellets.

Source:https://www.portaldoagronegocio.com.br/agroindustria/nutricao-animal/noticias/conheca-os-fatores-que-impactam-a-durabilidade-do-pelete-e-a-eficiencia-produtiva-no-processo-de-peletizacao-de-racoes

This process aims to compact the mash ingredients, which is done through multiple dies, which at the exit are cut according to the required size. It should be considered that pelleting can be carried out using extrusion or pelletizing equipment. A pelletizer basically consists of a system that has a plunger that has the function of compressing the crumbled portion, previously packed with correct moisture, which, with the proper temperature, is able to compact and format the pellets. The use of these two production systems, extrusion and/or pelletizing has its advantages and disadvantages, as described in Table 2.

Regardless of the manufacturing process, it is known that balanced rations have numerous advantages when compared to traditional mash and/or seed mixes, such as: standardization and adequate balance of nutrients, elimination of food selection, greater digestibility, and partial or total pathogenic organism's destruction, according to the pelleting method adopted.

The most used processes in the manufacture of animal feed are extrusion and pelleting. Both processes result in balanced foods, but there are considerable differences between the products. The extrusion process is characterized by the cooking of ingredients under high pressure, moisture and temperature, in a short time. This process provides greater digestibility of the feed, in addition to improving the palatability of the feed. Another advantage is the versatility in terms of controlling texture, density (related to the expansion degree) and food format. Extruded products can be offered in different shapes and sizes, which also brings advantages in terms of attractiveness. This set of factors highlights the extrusion process as advantageous, in relation to more traditional processes in the manufacture of animal feed. All feed, granulated or in sticks, are produced by extrusion, as it allows offering the animals the best nutrition, and consequently, even more health and well-being.

In summary, pelleting consists of compacting ingredients into small units called pellets. For this transformation, moisture, pressure, and temperature are also involved, but to a lesser extent, resulting in a reduced degree of cooking. This process is used in the manufacture of approximately two thirds of the world's animal feed, due to the low cost of production and the ease of handling the equipment. When faced with the extrusion process, pelleting has disadvantages in terms of digestibility and palatability. Source: https://racoespassaroforte.com.br/2019/09/06/post3/

WHAT ARE THE ADVANTAGES OF EXTRUSION-COOKING AND PELLETING SYSTEMS IN FEED PRODUCTION?

Table 5 shows the main comparisons between the extrusion and pelleting processes in the production of feed.

Extrusion-cooking	Pelleting
The versatility of extrusion equipment - allows the production of feed with different densities (floating, fast or slow submersion)	Pelletizing equipment allows the production of a limited range of pellets (fast sinking pellets)
Flexibility - many formulas can be extruded into acceptable foods for fish, shrimp, pork, chicken, pets, etc.	Formulations are restricted to some types of food (chicken and pork included)
High digestibility of raw ingredients, mainly the starch fraction (cereal grains), therefore the high feed conversion rate	Better digestibility of raw ingredients, but not as efficiently as extruded ones, and lower feed conversion rate
Maximum moisture content up to 55%. Can use wet ingredients	The maximum moisture content of 16 to 17%
The baking rate is ≥ 90%	The baking rate is around 50% using various pre-conditioners
Minimal risk of bacterial contamination due to high temperature and pressure	Risk of bacterial contamination in the final product. The cooking temperature is too low to be suitable for the destruction of anti-nutritional factors, pathogenic organisms and viruses in the feed.
Pelletizing equipment allows the production of a wide range of pellets (low and fast sinking pellets)	Water stability pellets require binder additives and good operator skills. Formulations are restricted to some types of food (chicken and pork included)
	The ingredients are compressed and can decompose, generating fines. The nutrient content may differ in the pellets.
Better digestibility of raw ingredients, and high feed conversion rate.	Low digestibility of raw ingredients, but not as efficiently as extruded ones, and lower feed conversion rate. It is difficult to increase the amount of plant-derived ingredients in formulations, therefore expensive raw materials such as fishmeal must be employed.
High pressure and temperature increase starch gelatinization, generating un high-quality quality products with almost no fines.	Foods are prepared at lower temperatures and pressures, so fines are often present in the food.
Low-cost formulations	Formulations are limited by machine design, requiring expensive fishmeal to meet protein requirements.
The formulation may contain fat levels of up to 22%	Fat levels are limited to 4-5%, otherwise, pellet production is impractical
Requires grinding raw material mesh size of 20	Requires finer grinding of raw material, mesh size of 60

High capital investment	Lower capital investment
Long utility usage	Shorter utility usage

Table 5. Comparison between feed processing technologies.Fonte: Arturo Melendez Arevalo, Jose Luis Ramirez Ascheri, Eliana Monteiro Soares de Oliveira, Jose de Jesus Berrios, Aquaculture feeds: a review of raw material, manufacturing process and product quality, ***Journal of Food, Agriculture and Environment***, Issue 3&4, Pages 10-17. (https://www.wflpublisher.com/Abstract/5530). DOI:10.1234/4.2018.5530.

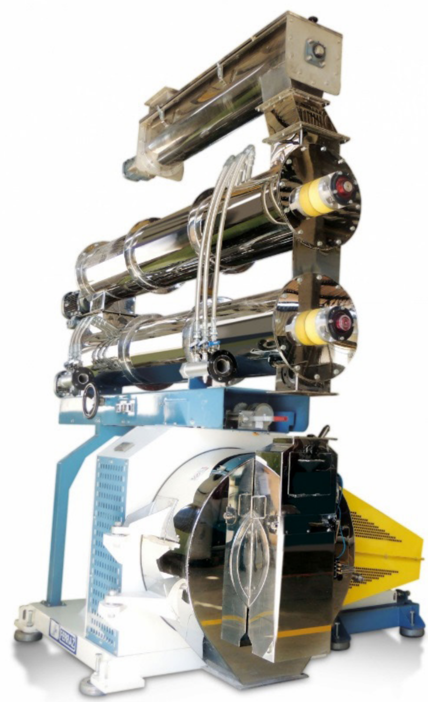


Figure 18.- Ferraz® brand pelletizer, Ribeirão Preto, SP, Brazil.

Source: http://www.ferrazmaquinas.com.br/conteudo/peletizadoras-de-racao.html

Figure 19.- Ferraz® brand twin screw extrusion system, Ribeirão Preto, Brazil.

Source: http://www.ferrazmaquinas.com.br/conteudo/extrusoras-dupla-rosca.html

WHAT IS THE IMPORTANCE OF GRANULOMETRY IN PELLET PRODUCTION?

The particle size, depending on the use of the formulation, is significantly important, especially in the production of pellets for animal feed, as it is responsible for the quality of the pellets in different aspects. Finer particles in the formulation allow greater penetration of moisture and heat into the ingredient particles, due to the greater surface exposure area. This is related to the water diffusivity principle, where smaller particles tend to absorb more water faster than larger particles. Hence the need to consider, as far as possible, the homogeneity of the particles in the formulation.

However, the best granulometry for the species for which the feed is intended should always be taken into account.

With coarser particles, it can result in the production of brittle pellets, as a larger particle inside or on the surface of the pellets can form a fragile region, functioning as a breaking point. In addition, there is a higher percentage of fines when working with larger particle sizes.

The results of adequate particle size can lead to better product appearance; reduction of the incidence of clogging in the holes of the die; ease of cooking the ingredients; reduction of fine powders and reduction of pellet breakage; greater stability in the water; better fluid retention during coating due to small cell structure.

In general, the particle of the formulated mixture should have about 1/3 of the matrix opening, not exceeding 1.5 mm. Figure 20 shows the effect of particle size in rations made with particles of 800 and 1.5 microns.

Figure 20.- Pellets are made with formulations with particle sizes of 800 μm and 1.5 μm, respectively.

Source: Sort course of food extrusion FPR&D-TAMU, Center and Wenger Manufacturing, Inc.

SINCE THE EXTRUSION PROCESS IS A COOKING METHOD, HOW CAN THE DEGREE OF COOKING OF A GIVEN SAMPLE BE EVALUATED?

Considering that the main ingredients to be processed have high amounts of starch or starch-protein-lipid mixtures, some ways to determine the changes that have occurred are:

Indices of absorption and solubility in water.- Assuming that native starch is insoluble in water, and its contribution to viscosity is practically zero. However, extruded starch absorbs water quickly, forming a paste at room temperature, without any heating. This paste is formed by the solubilized macromolecules and also includes water-swollen (gel) particles. These properties are strongly influenced by particle size: the smaller the particles, the greater the speed and degree of solubilization. The Water Absorption Index (WAI) is the weight of the gel obtained per gram of dry sample, and is generally determined by the method of Anderson et al. (1969). The WAI value correlates well with cold paste viscosity because only damaged starch granules absorb water and swell at room temperature, resulting in increased viscosity. After reaching a maximum, with respect to the degree of damaged starch, the WAI decreases with the start of dextrinization.

On the other hand, the Water Solubility Index (WSI) expresses the percentage of dry matter recovered after evaporation of the supernatant from the determination of water absorption (ANDERSON et al., 1969). The WSI is related to soluble molecules in the dry sample and measures dextrinization. The water solubility of starch is also related to expansion and follows the same variations with extrusion conditions. The “sticky” characteristic of some extruded starch products is related to their high solubility. This problem can be reduced by complexing the soluble amylose with fatty acids or monoglycerides, which act simultaneously to delay the retrogradation of the extruded material.

Paste viscosity method.- The pasting behavior of starch-based products is generally characterized by measurements of consistency and viscosity. Consistency can be measured using, for example, the Botwick consistometer, which measures the length of the flow of the hydrated suspension over a horizontal plane. However, currently, the most, common method is related to the use of the Rapid Visco Analyzer (RVA), whose advantages in determining consistency are significant, both in terms of the shorter analysis time (approximately 10-14 min.) for the small amount of sample (1-3 g) required (WALKER et al., 1988).

The behavior of extruded starches during heating, in excess of water, as can be observed with the RVA, is characterized by the absence of a gelatinization peak during heating, the high viscosity in cold (before heating), by continuous decline in viscosity from

50 to 96ºC, and by the strong decrease in viscosity in the range of 90-96ºC with an inflection point (Figure 21). Cold paste viscosity mainly depends on the degree of gelatinization of the starch granules and the extent of their molecular breakdown during the extrusion process. Cold paste viscosity refers to the viscosity of the starch-water suspension at room temperature, without the need for heating. It was observed that the initial cold viscosity increased until reaching a maximum value, and ten decreased with increasing extrusion severity.

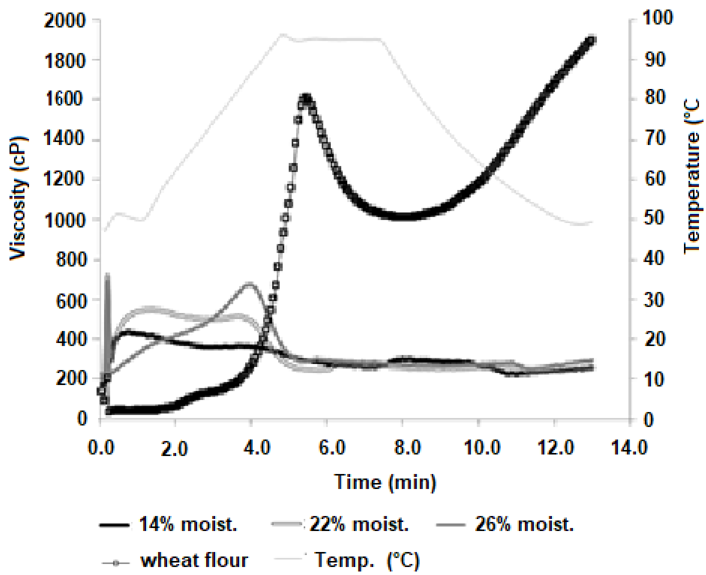


Figure 21. Influence of extrusion conditions on the viscoamylograms of wheat flour and wheat flour extrudates at 14, 22, and 26% moisture in the same processing condition (screw rotation speed at 300 rpm, solids feed rate at 11 kg/ h, and temperature of the last heating zone at 170°C). Source: Carvalho, (2001).

DIFFERENTIAL SCANNING CALORIMETRY (DSC).- WHAT IS DSC?

According to MENCZEL, et al, (2009) is the most popular thermal analysis technique, the “workhorse” of thermal analysis. This is a relatively new technique; its name has existed since1963 when Perkin - Elmer marketed their DSC - 1, the first DSC. The term DSC simply implies that during a linear temperature ramp, quantitative calorimetric information can be obtained on the sample. According to the ASTM standard E473, DSC is a technique in which the heat flow rate difference between a substance and a reference is measured as a function of temperature, while the sample is subjected to a controlled temperature program. Such measurements provide qualitative and quantitative information about physical and chemical changes that involve endothermic (heat absorption), exothermic (heat release), or heat capacity changes. The test method consists of heating or cooling a sample at a controlled rate, under the action of a specific purge gas with controlled flow, and continuous monitoring with a suitable detection device to observe the difference in heat input between the reference material and test material. What is it for? It is one of the most important, used, and widespread techniques for the characterization and identification of polymers. In a DSC analysis properties can be obtained as described in Table 6.

Glass transition temperature (Tg)	Heat of fusion and reaction
Melting temperature (Tm)	Heat capacity (Cp)
Boiling temperature (Te)	Thermal and oxidative stability
Temperature (Tk) and crystallization time	Reticulation degree
Crystallinity degree	kinetics Reaction

Table 6. Properties that can be determined in the calorimeter

Fonte: https://afinkopolimeros.com.br/dsc-o-que-e-e-para-que-serve/

The DSC technique can also be used to detect frozen stresses in finished parts, contamination and/or material mixing, oxidation time (OIT and OOT), some quantification for mixing materials, etc.

Some factors that can directly affect the final result of the analysis are: heating and cooling rate, gas used, type of sample port, sample mass and shape, etc.

A typical DSC curve can be seen in Figure 22.

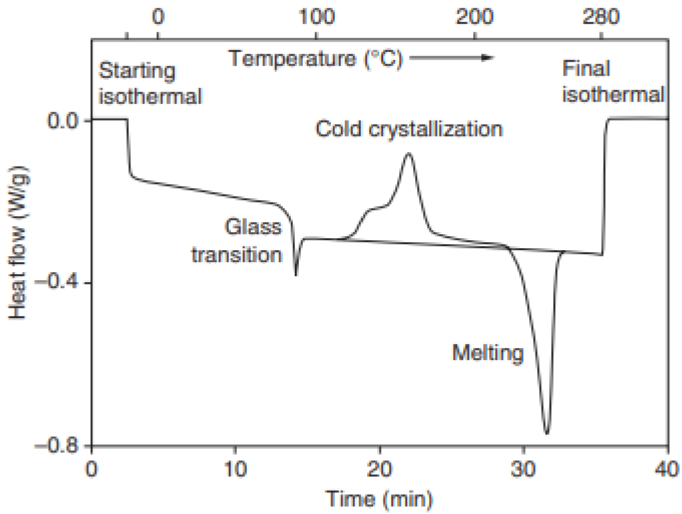


Figure 22. Typical Graph of a DSC analysis. A full DSC curve of quenched (amorphous) poly (ethylene terephthalate) was recorded at a heating rate of 10 ° C/min; the glass transition (at ~ 80 ° C) is followed by cold crystallization and melting of crystals formed in no isothermal cold crystallization. The baseline during the transition was drawn to show that the crystallization process lasts until the beginning of melting. Endotherm is down. Source: MENCZEL, et al., (2009).

AS THE EXTRUSION PROCESS IS HEAT TREATMENT, IS THERE A LOSS OF NUTRIENTS AND/OR MICRONUTRIENTS?

Yes, in the case of amino acids there may be a loss of about 30%. Therefore, to complement, in the case of processing and animal feed, for example, industries use synthetic amino acids, such as lysine, methionine, and tryptophan, among others. In the case of vitamin C, it is heat-labile and should preferably be added after the process, thus avoiding the loss of this important ingredient. In the case of other vitamins and pigments, the loss will depend on the formulated raw material, the temperature of the process, the moisture used, and the retention times, both in the pre-conditioner and in the extrusion system, this loss can reach, average, between 10 and 15%. This implies that there must be an equation between retention times and degree of mixing and homogenization and extrusion parameters, mainly moisture content and cooking temperature, in such a way that their optimization results in pellets with quality not only from the point of physical and appearance (texture, density, brittle or crumbling pellets, etc.) but also with preserved nutritional requirements.

WHAT IS THE EFFECT OF THE MICROBIAL LOAD EXTRUSION PROCESS?

In general terms, extrusion significantly reduces the presence of pathogenic microorganisms. Table 7 shows the main microorganisms counted in samples of a particular formulation before and after the extrusion process. This will be related to the temperature profile adopted in the process, a number of zones in the system, residence time in the barrel, and formulation, among others.

Type of microorganism	Formulation before the extrusion process	Formulation after the extrusion process
TPC (CFU/g)	240.00	9.300
total coliforms	22.600	<10
Counting fungi and yeasts	54.540	<10
Clostridium botulinum	16.000	<10
listeria sp	positive	negative
salmonella sp	negative	negative

Table 7. Effect of extrusion on the microorganism's population of raw material formulated.

Source: Sort course of food extrusion FPR&D-TAMU, Center and Wenger Manufacturing, Inc.

WHAT ARE THE CONSIDERATIONS IN USING AGRO-INDUSTRIAL BY-PRODUCTS IN EXTRUSION PROCESSING?

Among the main factors to consider:

(a) preparation of the raw material, this implies, if the original condition is of high moisture content, it must be dehydrated, conditioned to the conditions required for formulation, for example, milling/sieving according to the final product required, adapting the particle size, maintaining good processing/manufacturing practices, governed by current health standards, that is, food grade.

(b) Under the conditions expressed in item (a) it necessarily implies costs in the operations (energy for drying, grinding, sieving, etc.) which may also reflect on the permanence of the nutritional components that supposedly make the processing of this co-product worthwhile.

(c) The availability of the material in order to consider production scales should be considered, for example, orange peel by-product of industries of concentrated orange juice, grape, cashew, rice bran, cotton, wheat, etc.

(d) Another important aspect refers to the extrudability of the material resulting from co-products, that is, not every product is feasible to put in the extruder and have a satisfactory resultant product. A typical case is to try to extrude rice husk, high silica content material, and cellulosic material.

WHAT IS REACTIVE EXTRUSION?

The reactive extrusion process uses an extruder as a continuous reactor (primarily a co-rotating twin screw extruder), with exceptional mixing capabilities at the molecular level. This extruder-reactor design is ideally adapted to provoke chemical reactions with medium viscosity (viscosity >100 Pa.s and/or variable viscosity), with adequate control of parameters such as temperature and time. Using a twin screw extruder as a reactor, the reactions can occur both in the homogeneous phase and in the heterogeneous phase.

(a) Homogeneous phase reactions, bulk polymerization which may include chemical modifications of the polymers: grafting, cross-linking, functionalization, depolymerization, etc. Liquid phase reactions in classical organic chemistry.

(b) Heterogeneous phase reactions, aqueous two-phase systems, including casein to caseinate processing, saponification (increase in viscosity according to conversion rate)

(c) Two-phase liquid-solid systems, including alkaline digestion of lignocellulosic, pulp bleaching, solid-liquid separation, etc.

(d) Enzymatic reactions - Hydrolysis of biopolymers (starch and proteins)

FINAL CONSIDERATIONS

Undoubtedly, extrusion technology can be used by entrepreneurs of small, medium and large companies. Just adapt to the different alternatives available in the extruder manufacturers' market. The choice of the right equipment is very important for the entrepreneur because his results of economic return with the expected products to be manufactured will depend on it. This treatise has been limited only to the extrusion-related aspect, but there are well-established pre- and post-extrusion technological processes that have not been addressed in this book. Pre-extrusion involves everything related to the preparation of the raw material to be processed. One of the main activities is related to the milling sector. The choice of these types of equipment must be judicious according to the needs in order to obtain good results during extrusion. Post extrusion equipment is related to the completion of the extruded product depending on whether it is food for human consumption or animal feed, for example drying, coatings with oil or seasonings, or addition of fortifiers, etc. as well as packaging systems.

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ABOUT THE AUTHOR

I, **JOSÉ LUIS RAMÍREZ ASCHERI**, was born in Tingo Maria, Peru, a region known as the gateway to the Peruvian Amazon. There I made studios from the early years until I graduated, in 1981, a Food Engineering, at the National Agrarian University of the Jungle, in the same city. My first job was as a hired teacher at the same university, an interesting experience for a recent graduate. In Lima, Peru, I got a job as a research assistant at the company Maltería Lima, where I worked in chemical analysis of the malt samples used in the breweries of the Peruvian capital, my time there was short because soon I was called and hired as Plant Manager of a soft drink factory, then La Loretana Drinks, in Pucallpa, Peru. After two years of working in this activity, as a personal challenge, I decided to travel to Brazil in order to pursue an academic master's degree at the Faculty of Food Engineering (FEA) of the State University of Campinas (UNICAMP), obtaining the Master degree in Food Technology in 1987. During my stay at the FEA, still as a Master's student, I was hired as a Senior Technician by FEA, a position I held for about two years. At the same time that I held the position, continue my studies by enrolling in the doctoral course at FEA-UNICAMP. At the end of 1989, there was a public contest for a researcher at EMBRAPA, in the area of Cereal Technology, in which I participated and was incorporated as such in March 1990 after I left as an employee of UNICAMP. At Embrapa Food Technology (CTAA), with the aim of carrying out my doctoral thesis, I traveled to the USA, with an Embrapa grant, as a visiting researcher at the Food Protein R&D Center at Texas A&M University, which, after 18 months, I managed to finish the part of my Thesis, which I defended at FEA in 1994, to obtain the title of Doctor in Food Technology. By joining the research activities at CTAA, I joined the group of researchers in the area of Cereal Technology, in which I work so far, which in 2022 has already passed 32 years of intense teamwork with great results. At the same time, as a result of an agreement between EMBRAPA and the Graduate Program in Food Science and Technology (PPGCTA) of the Federal Rural University of Rio de Janeiro (UFRRJ), I have been a permanent professor in this program since 1995 to the present, where I have contributed as a permanent professor, advisor/supervisor, until now, of students, with 25 Dissertations for obtaining a Master's degree and 16 Theses for obtaining a Doctor's degree granted by UFRRJ. On the other hand, in order to support a new graduate program, I was invited to participate as a permanent professor in the Graduate Program in Nutrition and Health (PPGNS) at the Federal University of Espírito Santo (UFES). As a result of research at CTAA and postgraduate guidance, I have published as author and co-author about 190 publications in national and international technical-scientific journals, as well as participation in congresses related to Food/Cereal Technology. More information on academic results can be viewed on Curriculum Lattes, http://lattes.cnpq.br/1891994321882753, or on Google Scholar, as Jose Ascheri, and ORCID: https://orcid.org/0000-0001-7449-8815.

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QUESTIONS AND ANSWERS

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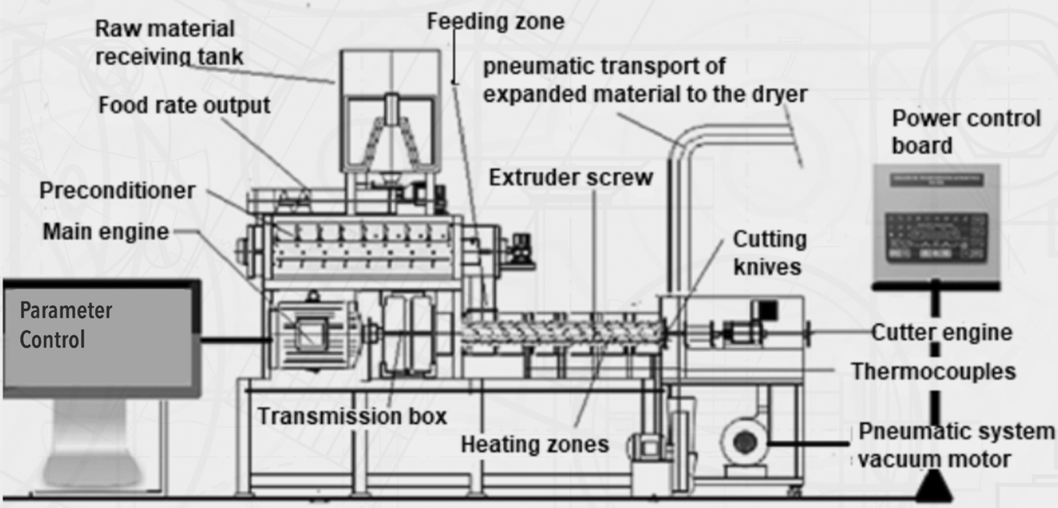

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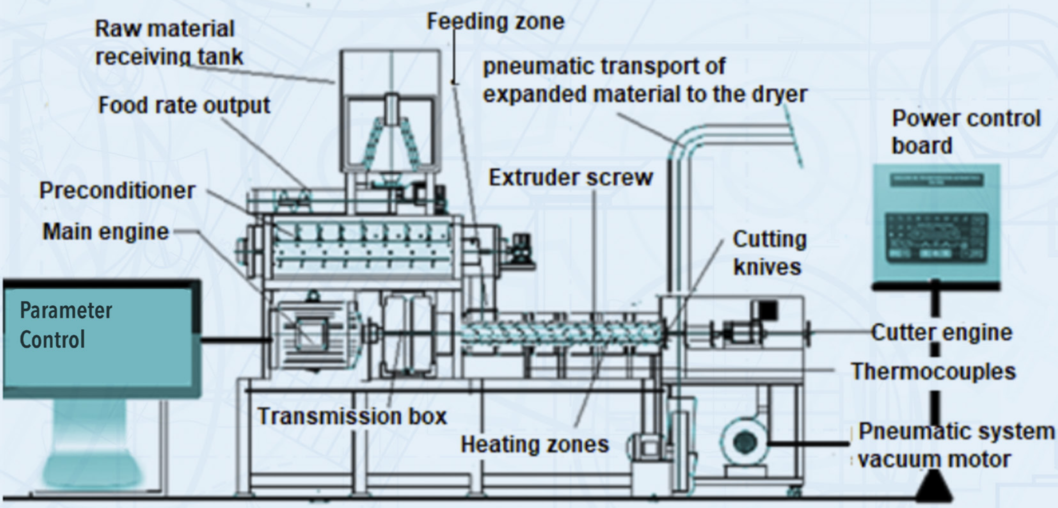

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