# FOOD EXTRUSION

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**Contents**



**Summary**

The process of screw extrusion is used in the food and agricultural industries to make a variety of products. The process combines many operations as one, is flexible, can be used to make different types of products, and produces few or no effluents. This article gives an overview of the status of food extrusion research and applications.

## 1. Introduction

Extrusion is defined as a process in which material is pushed through an orifice or a die of given shape. The pushing force is applied using a piston or a screw. In food applications, screw extrusion is predominant.

Historically, one can trace the use of a screw as a conveying device to the Greek philosopher Archimedes, who used a single screw in a cylindrical open channel to pump water uphill. Today's extruder consists of one or more screws encased in a metal barrel, attached to a drive motor. A hopper at one end is used to feed raw materials, while a die on the other gives shape to the product. Extruders were developed in the 1870s to manufacture sausage. Application of the single-screw extruder evolved during the 1930s, when it was used to mix semolina flour and water to make pasta products (see *Food Mixing*). It was also used in the process of making ready-to-eat (RTE) cereals to shape hot, precooked dough. In both of these applications, the level of shear rate was low. During the late 1930s and 1940s, directly expanded corn curls were made using extruders, which were characterized by extremely high shear rates. The first patent on an application of twin-screw extrusion technology was filed in the mid-1950s. Since then, the application of extrusion technology has widened and grown dramatically.

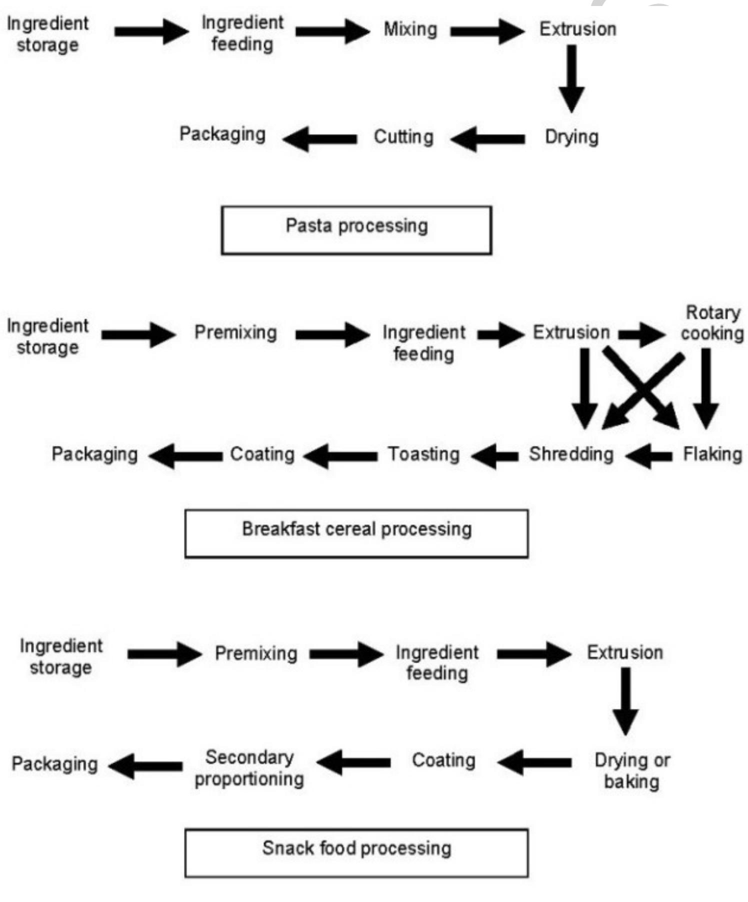


Figure 1. Role of extrusion in manufacturing of pasta, breakfast cereal, and snacks

Extrusion processing of food materials has become an increasingly important manufacturing method, and its applications have broadened substantially in the last two decades. From the point of view of transport phenomena, extrusion processing can be thought of as a combination of several processes, including fluid flow, heat and mass transfer, mixing, shearing, particle size reduction, melting, texturizing, caramelizing, plasticizing, shaping, and forming (see *Food Process Engineering*). Depending upon the product, one or many of these processes will take place in an extruder. For example, in pasta manufacturing, the main objective of the extrusion process is to partially gelatinize starch, compact the dough, and give it the desired shape. In the case of chocolate manufacturing, the extruder is used as a reactor to generate key flavor attributes. In the case of corn puffs, the extruder is used to develop the desired expanded, porous structure. Today, a variety of products such as breakfast cereals, pasta, snacks, candy, confectionery products, and pet foods are made using screw extrusion processes. Figure 1 shows the key role of extrusion in the manufacture of pasta, breakfast cereals, and snack products. An extrusion facility consists of many components, as shown in Figure 2.

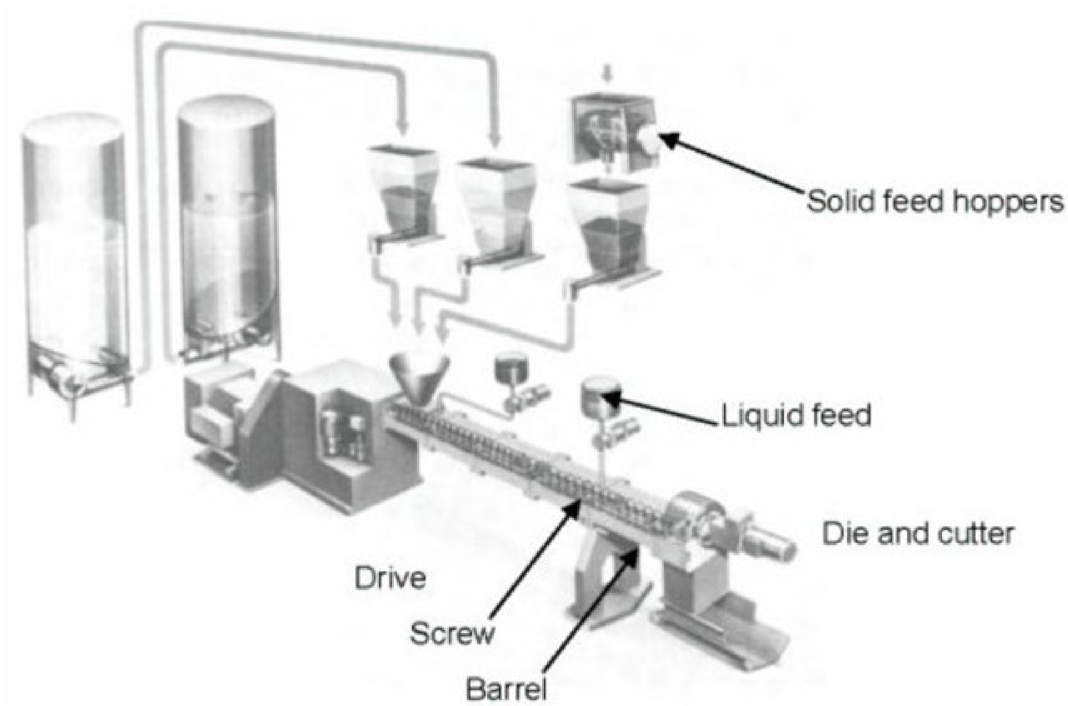


Figure 2. Typical twin-screw extrusion facility (courtesy of Krupp Werner & Pfleiderer Corp.)

There are many advantages of extrusion processing over other conventional cooking processes (see *Conventional Thermal Processing*). Extrusion is a continuous process. It is flexible because on-line process adjustments can be made to achieve desired product characteristics. In addition, the same extruder can be used to manufacture different types of products. The process has no effluents and is energy-efficient. It can be used to process relatively dry, highly viscous materials as well as moist or wet materials. Recent advances in the basic research and development of better process control strategies have made it possible, to a large extent, to control the thermo-mechanical changes during extrusion to achieve desired product properties (see *Engineering Properties of Foods*).

Food extrusion is a high-temperature–short-time (HTST) process. Figure 3 shows a comparison of the food extrusion process with other processes, on a diagram with temperature and residence time as axes. It can be seen that during extrusion, the food material may be exposed to temperatures as high as 200 °C. However, the exposure to such high temperatures lasts only 1–10 seconds. In a typical corn cooker, the operating temperature is about 100 °C, and exposure time is about an hour. Figure 4 shows a flow diagram for the production of cornflakes using the conventional process and using an extruder. One can see that several steps that are used in conventional cooking are eliminated by using an extruder. Though there are some differences in the products obtained from the two processes shown in Figure 4, several manufacturers have adopted the extrusion process because of the advantages discussed earlier.

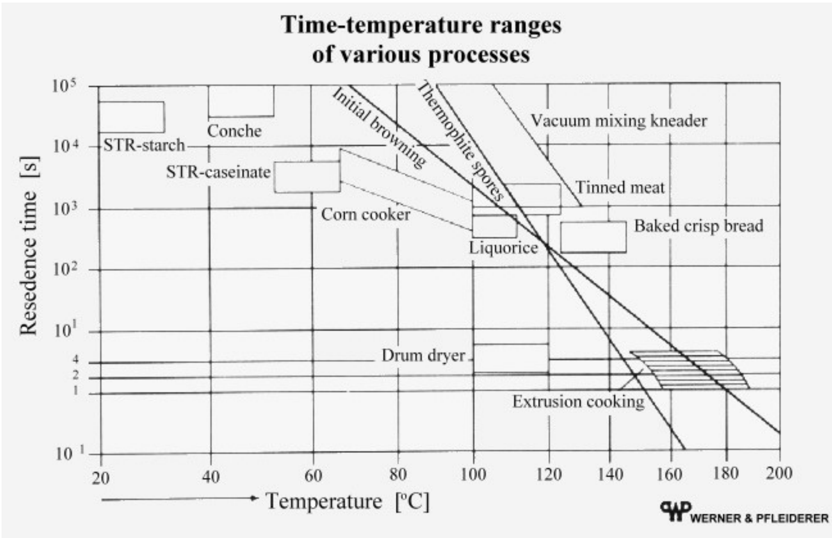


Figure 3. Time–temperature behavior of various food processing operations (courtesy of Krupp Werner & Pfleiderer Corp.)

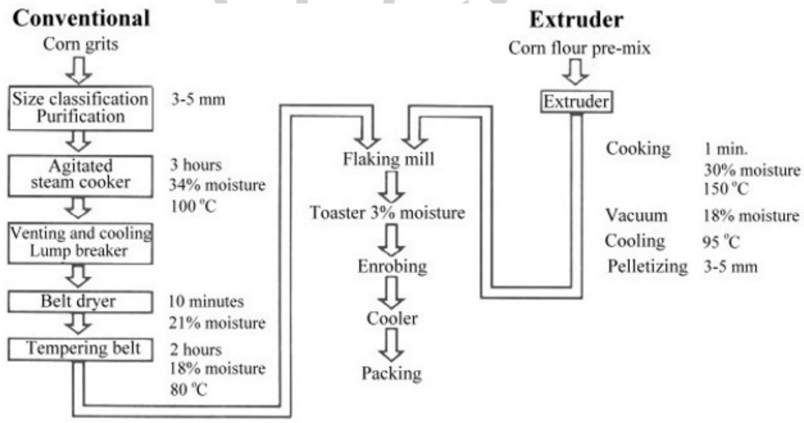


Figure 4. Flow diagram for the production of corn flakes using conventional & extrusion processes
From: Wiedmann W. (1992). Improving product quality through twin-screw extrusion and closed-loop quality control. *Food Extrusion Science and Technology* (ed. J.L. Kokini, C.-T. Ho, and M.V. Karwe), pp. 539–570. New York: Marcel Dekker.

## 2. Extruded Products

Today, extruders are used in a variety of applications, such as the manufacture of breakfast cereals, pasta, meat analogs, filled snack products, and pet food. They are also used in the mechanical de-boning of meats, as well as hops processing. Extruded products can be broadly categorized into products for human consumption, products for animal consumption, and biodegradable, non-consumable materials.

### 2.1. Products for Human Consumption

Some examples of extruded products for human consumption are listed in Table 1.

| **Type** | **Example** |
|---|---|
| Directly expanded | Breakfast cereals, corn curls |
| Unexpanded | Pasta |
| Half-products | Potato pellets |
| Co-extruded | Fruit-based cereal, jelly-filled cores |
| Modified | Starches, fat mimics |
| Texturized | Meat analogs |
| Candy | Licorice, chewing gum |

Table 1: Extruded products for human consumption

For directly expanded products, extrusion is carried out under high shear, high temperature, and low moisture conditions. For pasta, extrusion is carried out at moderate (~40 percent w/w) moisture and a low (~50 ºC) temperature. In half-products such as potato pellets, an extruder is used to make a dense, semi-cooked product, which is stored under appropriate conditions in a warehouse for further processing as needed. Because of its high density, a half-product occupies less space than a puffed product. These pellets are processed further, when required, to make puffed or expanded product by frying or baking. To make co-extruded products, a special die is designed to pump semi-solid material into the core. Modified starches and fat mimics are made by extruding under optimum time, temperature, and shear conditions. To make texturized meat analogs, plant proteins such as soy proteins are used along with a long die to impart a fibrous, meat-like structure to the extrudate.

### 2.2. Pet Food and Animal Feed Products

Extrusion cooking was used to manufacture pet foods during the early 1950s. Today, extrusion is used to make semi-moist and dry expanded pet foods, aquatic food, milk foods, and foods for laboratory animals. Extrusion offers a way to cook, shape, and pasteurize these products. It permits better utilization of available cereal grains, as well as vegetable and animal proteins, in manufacturing cost-effective and nutritionally balanced diets with unique and improved characteristics. Since this article focuses mainly on products for human consumption, extrusion of pet foods and animal feed will not be discussed in the sections that follow.

Even though the applications of extrusion technology in food processing and manufacturing have broadened over the last two decades, the science and fundamental understanding of the process have always lagged behind the technology. The complex, multi-component, irreversibly reactive nature of food materials, combined with complex screw and die geometries, make complete deterministic analyses of extrusion processes extremely challenging. Issues related to the predictability and control of the flavor and texture of extruded products still need more research and development. In the area of nutraceuticals (health-promoting compounds found mainly in plants), extrusion might offer a way to improve their extractability, enhance their bioavailability, and deliver them effectively.

## 3. Extrusion Equipment

Extruders come in several designs, dependent upon their application. Some extruders are designed simply to convey the raw materials, while others are designed to mix and knead them; most, however, are designed to impart mechanical and thermal energy to the raw materials to bring about desired physico-chemical changes. Extruders can be broadly categorized on the basis of the number of screws. The most commonly used extruders are single- and twin-screw. Extruders with more than two screws have been used in the plastics industry but not in food processing.

### 3.1. Single-Screw Extruders

Single-screw extruders contain a single rotating screw in a metal barrel, and come in varying patterns. The main design features are shown in Figure 5. The most commonly used single-screws have a constant pitch. Single-screws usually consist of three sections: (1) *feed*, (2) *transition* or *compression*, and (3) *metering*, as shown in Figure 5. The raw materials are fed in a granular form at the hopper located in the feed section. The rotating action of the screw conveys the material to the transition section. In the transition section, the screw channel becomes shallower and the material is compacted. A major portion of mechanical energy is dissipated in this section, which results in a rise in temperature of the material. Starch becomes gelatinized, and the material becomes more cohesive. It is transported further by the metering section and pushed through the die opening. The barrels of single-screw extruders usually have helical or axial grooves on the inner surfaces. This helps to convey and mix the material more effectively.

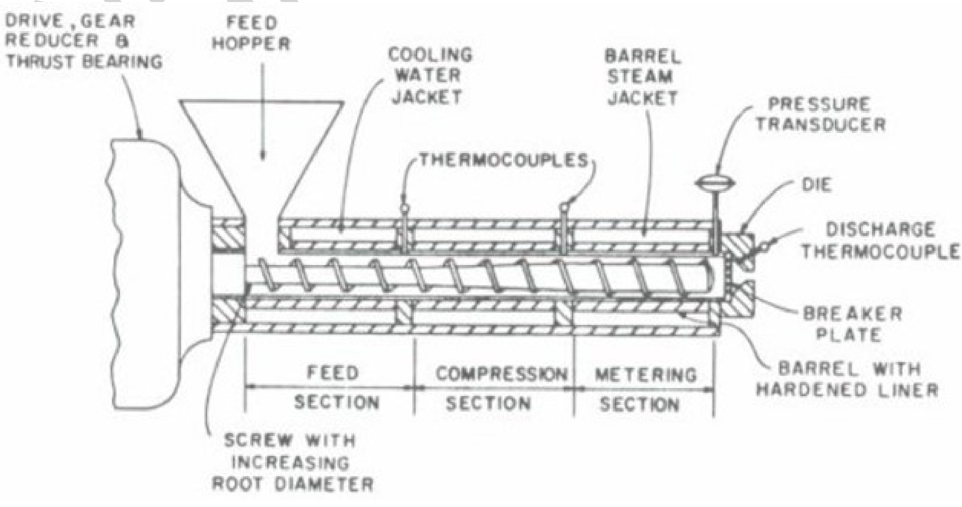


Figure 5. Schematic diagram of a typical single-screw food extruder
From: Harper J.M. (1981). *Extrusion of Foods*, Vol. I. Boca Raton, FL: CRC Press.

Single-screw extruders are usually characterized by their length to diameter (L/D) ratio and their compression ratio, which is the ratio of the maximum channel depth to the minimum channel depth. The most commonly used compression ratio is 3 to 1. The throughput (mass flow rate) capacity of a single-screw extruder is linked to screw speed, screw geometries, and material characteristics.

Single-screw extruders can be further characterized depending upon the degree of shear they apply. Table 2 shows how single-screw extruders are categorized according to their shearing ability and the associated operating variables. The amount of shear applied results in different product properties. High shear levels cause disruption of starch and protein molecules, affecting their functionality, such as solubility, viscosity, and water-holding capacity. Today, approximately 70 percent of the extruders in the food industry are of single-screw type.

| **Operating variable** | **Low-shear forming extruder** | **Moderate-shear cooking extruder** | **High-shear cooking extruder** |
|---|---|---|---|
| Feed moisture, % wb | 25–35 | 20–30 | 12–20 |
| Maximum product temperature, °C | 50–80 | 125–175 | 150–200 |
| Length to diameter ratio | 5–8 | 10–20 | 4–12 |
| Diameter to channel height ratio | 3–4.5 | 5–10 | 7–12 |
| Compression ratio | 1:1 | 2–3:1 | 3–5:1 |
| Screw speed, rpm | 3–4 | 10–25 | 30–45 |
| Shear rate, $s^{-1}$ | 5–10 | 20–100 | 100–180 |
| Net mechanical energy input, $\frac{kW-hr}{kg}$ | 0.03–0.04 | 0.02–0.04 | 0.10–0.14 |
| Heat transfer through barrel jackets, $\frac{kW-hr}{kg}$ | –0.01 | 0.0–0.03 | –0.03–0.0 |
| Steam injection, $\frac{kW-hr}{kg}$ | 0.0 | 0.0–0.04 | 0.0 |
| Net energy input to product, $\frac{kW-hr}{kg}$ | 0.02–0.03 | 0.02–0.11 | 0.07–0.14 |
| Product types | Macaroni, RTE cereal pellets, 2nd generation snacks | Soft moist pet foods, pregelatinized starch, drink and soup bases, textured plant protein, RTE breakfast cereals | Puffed starch, dry pet foods, modified starch |

Table 2. Operating characteristics of single-screw extruders
From: Harper J.M. (1992). A comparative analysis of single- and twin-screw extruders. *Food Extrusion Science and Technology* (J.L. Kokini, C.-T. Ho, and M.V. Karwe eds.), pp. 139–148. New York: Marcel Dekker.

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**Biographical Sketch**

**Mukund V. Karwe** is currently Associate Professor of Food Engineering and Undergraduate Curriculum Coordinator in the Department of Food Science at Rutgers University. He is also the coordinator of an industrially funded research project on Health Promotion and Safety through Processed Foods in the Center for Advanced Food Technology at Rutgers University. His research is focused on mathematical modeling and numerical simulation of transport phenomena associated with food extrusion and baking processes. His work in extrusion has led to an understanding of fluid flow and mixing within the complicated geometry of twin-screw extruders. He has also worked in several multidisciplinary research areas, such as the generation of flavor, texture, and key physico-chemical changes affecting the quality of extruded products. His current research projects include application of the extrusion process to enhance nutraceutical potential of selected food grains such as quinoa and buckwheat, fortification of foods with omega-3 fatty acids, and hybrid jet impingement microwave baking. He is co-editor of the book *Food Extrusion Science and Technology* (1992, Marcel Dekker, Inc.). He has taught short courses and conducted workshops on extrusion technology in the United States and in India.