Chapter 3
Food-Processing Equipment

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3.1 Introduction

The present-day food industry has its origins in prehistory when the first food processing took place to preserve foods in case of famine or to improve their eating quality. For example, meat was roasted to improve its quality, and grain was ground to obtain flour for baking bread (Fellows 2009). Equipment was developed to facilitate the operations and to reduce the time taken. Water, wind, and animal power were harnessed. At first the equipment used was on a domestic scale, but later on, as society developed, trade establishments such as bakeries and breweries sprang up. These were the forerunners of the present food industry.

A food process is a set of sequential operations that leads to a product. Every step, which, in most cases, corresponds to an individual piece of equipment, has its own influence on the final properties of the processed product. The design of this equipment is based on a knowledge of transport phenomena, which are at the center of food engineering. This is often defined as "the application of engineering principles to food products." One important cornerstone of food engineering is the unit operation. This concept, which was developed in the 1950s and 1960s, forms the background for studies of individual operations such as distillation, cooking, evaporation, and extraction. For each of these unit operations, transport phenomena underlie the basic mechanisms of operation.

This chapter will cover an introduction to food manufacturing (today and a vision for the future). Some principal types of food processing, packaging, and end-of-line equipment will also be described.

3.2 Food-Processing Equipment in a Production Plant

3.2.1 Today

The food industry in Europe in the year 2011 is:

- The largest manufacturing sector with production worth close to 956.2 billion euros (accounting for 16 % of the turnover of manufacturing in the 27-member bloc).

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- Direct employment in the food and drink sector in the EU accounts for 4.1 million jobs and many more jobs indirectly—making the industry the leading employer in the manufacturing industry in the European Union. The industry remains highly fragmented with 274,000 companies (99.1 % of which are small or medium sized).
- One that employs wide-ranging production methods, covering both first- as well as second-stage processing.
- A sector displaying relatively stable overall growth of around 2 %, albeit with significant variations between the various branches that make up the food and drink industry.

In Sweden, the food industry:

- Is the fourth largest branch of industry on the basis of production value
- Is the second largest on the basis of turnover
- Is the third largest on the basis of number of employees
- Employs about 500,000 people within food production, distribution, and handling

With these data as a starting point, it would be quite logical to assume that the food industry today is effective, clean, and employs high technology, including the widespread use of computers in production and process control. You might believe that there are highly competitive enterprises keen to incorporate the latest research and development findings into their production methods. You might also believe that the industry has a high turnover; that its employees are highly motivated, well educated, and highly productive; that its manufacturing processes "pump out" products consistently with the required exacting specifications; and, finally, that production skills are held in high regard. It may also be believed that new products with highly desirable characteristics are often developed, that new business concepts encourage company growth, and that new investments are made when needed.

Most of the above attributes are found in the chemical process industry but not in the food industry. What then do you find when you visit a large, modern food factory of today? Frequently, you will see an expensive production unit, manually operated and very inefficient. In many other manufacturing industries you can observe development, innovation, rationalization, and improvement but not in the food industry (Hesselman 2012). Many of the numerous staff engaged in food production are to a large extent uneducated. Brands are taken care of tenderly; sophisticated marketing and distribution skills are employed. However, staff training is rare. Frequently, operatives are not experienced in working with food. Many of them started with summer jobs and stayed on. Their salary is low and their IT and computer experience is minimal. We see an industry that needs staff with a higher level of higher education and knowledge about their functions in the production units.

Moreover, in the case of food, the consumer is reluctant to drop the old-fashioned approach. We prefer the vision of our mothers stirring the contents of a stew to the picture of a hygienic plant with stainless steel equipment that produces safe food! There are few areas around that are so filled with contradiction as food manufacturing. We want a wide range of quality products with a long shelf life that are, at the same time, inexpensive. Ideally, they should be produced from locally sourced, organic ingredients.

Unfortunately this is the same all over the world. Charming handicrafts and art are applied. The old craftsmen that used to manage the production do not exist any longer. We have neither absorbed their knowledge nor employed compensating technology. A lot of food factories are still run like a home kitchen. That, at least, it is the image that is portrayed—homemade is safe, tastes good, and is cheap!

But who is cracking 700,000 eggs an hour? Who bakes 12,000 loaves of bread an hour? Who is making 5,000 tons of hamburgers an hour? At home or in the restaurant kitchen or. . .?

At the moment, the food industry is exposed to enormous pressure for change. The competition has already increased significantly, deregulation has occurred, and customs barriers have been removed.

A great deal of structural rationalization is in progress, and consumers are less well protected. Over the past 60 years, food manufacturing has been transformed from a handicraft to a process industry. The resulting changes have been particularly intense during the last 8–10 years. As most people are aware, the food industry is under severe scrutiny by the media, which also touches all of us who are consumers. It is bombarded by questions relating to ethics and hygiene. Demands by the consumer are increasing every day. The trends are towards safer, fresher foods, without additives and at a lower price.

Unfortunately, as discussed above, the education level of many food industry employees is low, and they have little interest in higher education. In 1995, a study of the Swedish food industry found that only 30 companies out of 2,300 employed one engineer or scientist having more than 3 years at university (Björk 1997). In total, around 800 engineers or scientists were employed in the food industry, mainly by the large international corporations. In 1994 the number was somewhat higher. The industry is regarded as having a low status, and this is not good for its employees.

There is also an entrenched conservatism within the food industry, which limits its ability to implement modern techniques and production methods employed in other sectors. This is perhaps due to the fact that few young people have an education in food processing or that there are too few opportunities for education at a higher level.

The above issues are as "hot" in the USA as in Europe. In the States, there is low inflation (as in Europe), low consumer prices, and relatively low unemployment. Published data show that both food industry sales and profits have increased. For example, operating margins increased by 0.6 % during the period 1993–1996, profit margins by 0.2 %/year, and net profits by 1.3 % over the same period. However, there are still ongoing pressures to lower costs, increase market share, and provide more competitive salary packages. Moreover, to meet competition from large-scale imports of cheaper food, the industry has been forced to find ways to increase its productivity.

In the home market, it is becoming more and more important to produce a greater variety of products with a high turnover rate in order to meet consumer demands and, at the same time, to reduce the time between ordering and delivery. The trends towards fresher food with no additives continue. The current attention on food safety issues (e.g., dioxin contamination in Belgium and mad cow disease) puts an increased focus on hygiene and traceability. A mistake can mean the difference between life and death.

Automation occurs in some branches of the industry, for example, the dairy sector. Online sensors to control quality and safety are few. Computers and other IT tools that can be used for planning, simulation, and decision support are rare. Here there is a great potential for development. Where automation occurs, it is normally in the storage and packaging parts of the production process.

In general one can say that the equipment in the food industry is of a very high standard. The design is hygienic and the equipment is well suited for the production of small volumes of product, i.e., the processes are very flexible. New innovative equipment and processes are few and far between. However, the industry has a good record of importing techniques from other industries (e.g., microwave and NIR techniques).

3.2.2 Vision for the Future

Let us visit a small town in Europe. The year is 2020. There are both households and industries located in the town. One of the companies is a small enterprise called "Local Foods." It produces fresh bread and ready-to-eat meals based on bread. About 400 different articles are manufactured. Most of the products, filled French rolls, crepe, pies, Quiche Lorraine, and pizza, are distributed to households close to "Local Foods." New products are developed now and then. Customers can order and buy their food via a TV screen in their homes. The products are dispatched to the customer immediately after preparation, within 1–2 h. If a particular request is made regarding the filling, quality, or size of the product, it can be specified via the screen. The order goes directly into the production computer that controls the processes. The raw materials are based on frozen dough and different fillings such as prawns, minced meat, shellfish, rice, cod, clams, champignons and other types of mushrooms, vegetables, chicken meat, and boiled egg. Storage rooms for raw materials are located at one end of the production unit. There are facilities for both cold and frozen storage of fillings and dough.

The plant and the processes are fully automated, and the line is completely flexible and can be tailored to individual products. Equipment for sterilization, blanching, pasteurization, boiling, deep fat frying, and baking are available. New heating techniques (microwaves, NIR, ultra high pressure) are tested and used when appropriate. Minimal processing, i.e., nonthermal processing or minimum heating, is also used. On the production line, a computer is installed to provide decision support for the operators and to control the processes. The computer programs are easy to use, and the graphic interface and hardware are specially designed to be user friendly to the operators. Online sensors measure the quality properties, such as the color of the crust, GI, health properties, texture, and aroma, and aid traceability. The raw materials are characterized using sensors. When the product is finished, the process stops and the product is packed and sent directly to the customer.

The company has developed relationships with different skilled contractors to keep it updated with the latest tools to improve production efficiency. A robot handles the logistics and assembly of the products. The ventilation for the buffer in which the raw materials are stored before use is of the highest quality and is clean room approved. Energy use within the production unit is optimized, and the production is certified according to ISO standards.

3.3 Description of Food Processes and Equipment in Different Sectors of the Industry

The food industry is divided into several sectors depending on what kinds of raw materials are to be processed (grain, vegetables, fish, meat, etc.). In Sweden the food industry is divided into 13 different sectors or branches; in the European Union, it is divided into nine different branches.

In Sweden:

- Slaughterhouses and meat processing
- Dairy products and ice cream
- Processed fruit and vegetables
- Processed fish products
- Oil and fat
- Grain mill products and starch processing
- Bakeries
- Sugar
- Chocolate and confectionery
- Other food products
- Wine and spirit
- Malt beverages
- Mineral and soft drinks

In the EU:

- Processed meat
- Fish products

- Processed fruit and vegetables
- Oils and fat
- Dairy products
- Grain mill products and starch products
- Animal feed
- Other food products
- Beverages

Table 3.1 shows the different process steps/unit operations employed in each sector of the food industry (Claesson and Skjöldebrand 2002). As can be seen in this table, a number of unit operations are used in all types of production, regardless of the process objectives or the raw materials employed. These are raw material handling, mixing, cooling, filling, packaging, storage, and transportation. Unit operations involving heat treatment comprise 75 % of all processes in the food industry.

3.4 Raw Materials

The demand for processed food tends to be seasonal in nature (Brennan 2006), and supplies of many raw materials are subject to variations in both quantity and quality throughout the year. Such variations may be buffered by sales forecasting, but providing regular supplies of raw materials of a seasonal nature, such as fruits and vegetables, presents problems.

Considerable progress is being made in improving the suitability and the supply of raw materials for food processing. The main directions in which such progress is being made are:

1. Selective breeding of varieties specially for processing
2. Growth programming and contract buying of raw materials
3. Improvement in raw material transportation and storage
4. Improvements in mechanization

Any improvement in the suitability of the raw material for its intended purpose, or in the spreading of the season over which it may be harvested, results in improved processing efficiency and plant utilization. The development of varieties for food processing involves consideration of all those attributes of the raw material, which are reflected in the quality of the finished product. The attributes of importance in this respect are color, shape, function, texture, and maturation characteristics. The development of suitable varieties for processing requires close cooperation between breeders, research stations, and processors.

3.5 Mixing and Emulsification

Mixing may be defined as an operation in which a uniform combination of two or more components is effected (Brennan 2006). The degree of uniformity attainable varies widely. With miscible liquids and soluble solids in liquids, very intimate mixing is possible. With immiscible liquids, paste-like materials, and dry powders, the degree of uniformity obtainable is invariably less.

The materials are fed to a mixer and may vary from low-viscosity liquids to highly viscous pastes or dry powders. Mixing equipment is conveniently classified on the basis of the consistency of the materials that it will handle successfully. The most commonly used form of mixers for handling low or moderate viscosity liquids is the impeller agitator. This type of mixer consists of one or more

Table 3.1 Process steps and unit operations employed in different parts of the food industry (from Claesson and Skjöldebrand 2002)

	Branch unit													
Operation	Meat	Dairy, ice cream	Preserved fruit and vegetables	Preserved fish	Oils and fats	Mill starch	Bakery, pasta	Sugar	Chocolate confectionery	Finished food	Wine and spirits	Malt, beer	Soft drinks (including water)	Other foods (spices, coffee, tea, powdered products, sauces)
Raw material storage	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Cleaning raw materials		×						×						×
Sorting	×		×	×	×	×		×		×				×
Raw material classification	×	×	×	×	×	×	×	×						
Mixing	×	×		×			×		×	×	×	×	×	×
Filtration								×			×	×		
Centrifugation		×						×						
Fermentation	×						×				×	×		
Homogenization	×	×		×						×				
Crystallization		×			×			×	×					
Heat treatment														
Preservation														
Sterilization	×	×	×	×						×				
Pasteurization	×	×	×	×						×				
Blanching			×							×				
Radiation			×											×
Conversion														
Conching									×					
Boiling	×									×				
Baking							×							
Frying	×									×				
Smoking	×									×				

Tempering	×		×	×										
Reheating	×									×				
Warm holding	×									×				
Cooling	×	×	×	×	×		×	×	×	×	×	×	×	
Water activity														
Drying	×	×	×	×		×	×	×	×				×	
Concentration		×												
Phase change														
Freezing	×	×	×	×				×		×				
Thawing (defrosting)	×		×	×						×				
Extrusion		×				×			×	×				
Mounting							×			×				
Filling	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Packaging	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Storage	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Transport	×	×	×	×	×	×	×	×	×	×	×	×	×	×

impellers fixed to a rotating shaft, which create currents within the liquid. These currents should travel throughout the mixing vessel. It is not sufficient simply to circulate the liquid; turbulent conditions must be created within the moving stream. When this comes into contact with a stationary or slow-moving liquid stream, shear occurs at the interface and low velocity liquid is entrained in the faster moving streams. In order to achieve mixing within a reasonable time, the volumetric flow rate must be such that the entire volume of the mixing vessel is swept out in a reasonable time.

A new exciting mixer has been developed by a Swedish company, QB Food Tech AB. It consists of a cubic tank mounted on one of its corners and rotated about a vertical axis. The company claims that the unique flow pattern created within the device makes it capable of mixing powders and liquids faster, to a better quality, and with a lower energy consumption than conventional mixers (QB Food Tech 2012). It can handle batches of 30–4,000 l and continuous in-line mixing up to 50,000 l/h.

When mixing particulate solids, the probability of obtaining an orderly arrangement of particles is virtually zero (Brennan 2006). In practical systems the best mix attainable is that in which there is a random distribution of the ingredients. However, the degree of mixing necessary in any mixing operation depends on the use to which the mixture is to be put and the method of control that is applied. Solids mixing is generally regarded as arising from one or more of three basic mechanisms. These are convection, i.e., transfer of masses or groups of particles from one location to another; diffusion, i.e., the transfer of individual particles from one location to another arising from the distribution of particles over a freshly developed surface; and shear, i.e., the setting up of slipping planes within the mass. Most mixing devices employ all three mechanisms.

Examples of mixers for particulates are tumble mixers, horizontal trough mixers, vertical screw mixers, and fluidized bed mixers. Texts devoted to mixing operations include Harnby et al. (2000), Paul et al. (2004), and Cullen (2009); the latter is specific to foodstuffs.

3.6 Filtration

Solid–liquid filtration, hereinafter termed filtration, may be defined as that unit operation in which the insoluble solid component of a solid–liquid suspension is separated from the liquid component by passing the latter through a porous membrane or septum, which retains the solid particles on its upstream surface or within its structure or both (Brennan 2006). When a suspension of particles is passed through a filter, the solids initially become trapped in the filter medium and, as a result, reduce the area through which liquid can flow. This increases the resistance to fluid flow, and a higher pressure difference is therefore necessary to maintain the flow rate of filtrate (Fellows 2009).

There are different kinds of filtration equipment on the market. Some of them will be briefly mentioned here (Brennan 2006; Sutherland 2008). Filtration equipment can be divided into two types—pressure filters and vacuum filters. In pressure filters, a pressure exceeding atmospheric is maintained upstream of the medium to induce the flow of filtrate through the system. This upstream pressure is achieved by pumping the feed slurry into the filter. Pressure filters may operate at constant pressure throughout filtration or the pressure may gradually increase so as to maintain a constant flow rate of filtrate. Various combinations of these two basic methods may also be used.

In vacuum filters, a subatmospheric pressure is maintained downstream of the medium and atmospheric pressure upstream. Because the pressure drop across the filter is limited to one atmosphere, they are not suited to batch operation. Some types of leaf filter, tube filters, and edge filters are operated batchwise, but continuous vacuum filters are far more common.

3.7 Centrifugation

Centrifugation may be defined as a unit operation involving the separation of materials by application of centrifugal force, which is generated when materials are rotated. The magnitude of the force depends on the radius, the speed of rotation, and the mass (or density) of the centrifuged material. In the separation of immiscible liquids, the denser liquid moves to the bowl wall and the lighter liquid is displaced to an inner annulus. The density of the liquids, the thickness of the layers, and the speed of rotation determine the pressure differences across the layers.

Centrifuges are classified into three different groups (Table 3.2) for:

1. Separation of immiscible liquids
2. Clarification of liquids by removal of small amounts of solids (centrifugal clarifier)
3. Removal of solids (desludging and dewatering centrifuges)

3.7.1 Liquid–Liquid Centrifuges

The simplest type of equipment is the tubular bowl centrifuge. It consists of a vertical cylinder or a bowl, typically 0.1 m in diameter and 0.75 m long, which rotates inside a stationary casing at between 15,000 and 50,000 rpm depending on the diameter. Feed liquid (e.g., animal and vegetable oils and syrup) is introduced continuously at the base of the bowl wall. The two liquids are discharged separately through a circular weir system into stationary outlets (Fig. 3.1).

3.7.2 Centrifugal Clarifiers

The simplest solid–liquid centrifuge is a solid bowl clarifier. This consists of a rotating cylindrical bowl 0.6–1.0 m in diameter. Liquor with a maximum of 3 % w/w solids is fed into the bowl, and the solids form a cake on the bowl wall. When this has reached a predetermined thickness, the bowl is drained and the cake is removed automatically through an opening in its base.

Feeds that contain a higher solids content are separated using nozzle centrifuges or valve discharge centrifuges (Fig. 3.2).

Table 3.2 Applications of centrifuges in food processing (adapted from Fellows 2009)

Centrifuge type	Range of particle sizes (μm)	Solids content of feed (% wb)	Application							
			A	B	C	D	E	F	G	H
Disc bowl										
Clarifier	0.5–500	<5	×	×	×					
Self-cleaning	0.5–500	2–10	×	×	×	×	×			×
Nozzle bowl	0.5–500	5–25	×	×	×	×	×		×	
Decanter	5–50,000	3–60	×	×	×	×	×	×	×	
Basket	7.5–10,000	5–60					×	×		
Reciprocating conveyor	100–80,000	20–75					×	×		

A liquid–liquid extraction, *B* separation of liquid mixtures, *C* clarification of liquids, *D* concentration of slurries, *E* liquid–solid–liquid extraction, *F* dehydration of amorphous substances, *G* dewatering of crystalline substances, *H* wet classification

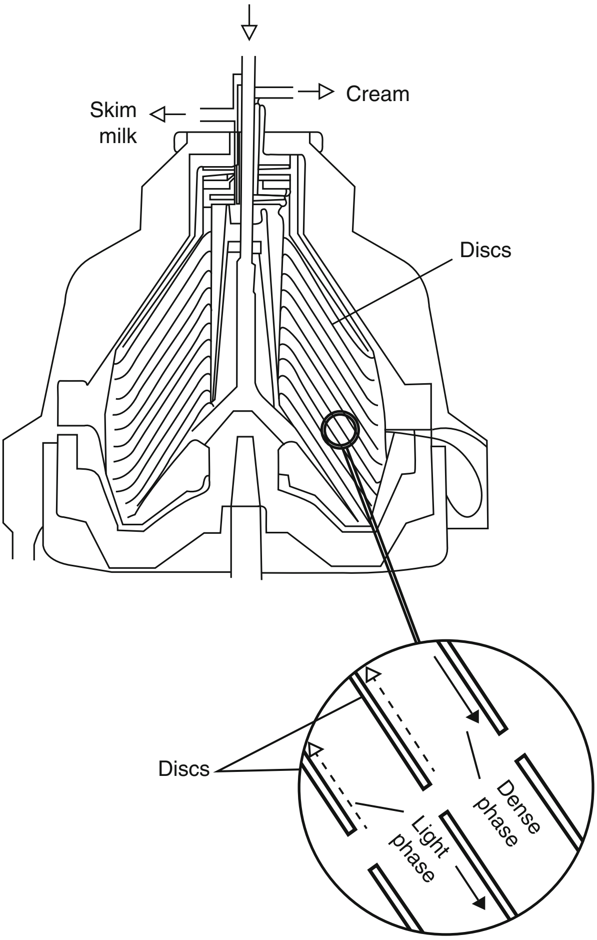


Fig. 3.1 Tubular bowl centrifuge (after Fellows 2009, reproduced with permission from Woodhead Publishing Limited)

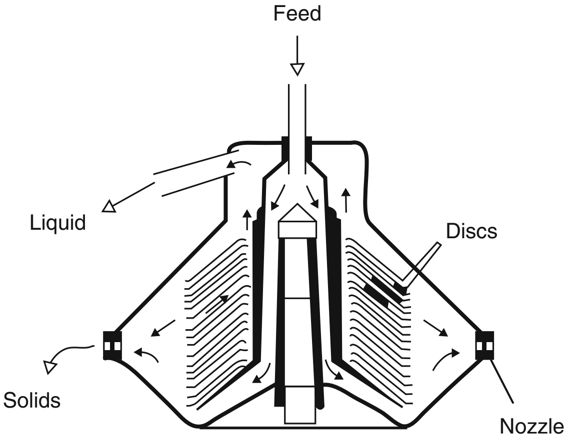


Fig. 3.2 Nozzle centrifuge (after Fellows 2009)

3.7.3 Desludging, Decanting, and Dewatering Centrifuges

Feeds with high solid contents (Table 3.2) are separated using desludging centrifuges (Fellows 2009). A number of designs are available including conveyor bowl, screen conveyor, basket, and reciprocating conveyor centrifuges. In the *conveyor bowl centrifuge*, the solid bowl rotates at up to 25 rpm faster than the screw conveyor. This causes the solids to be conveyed to one end of the centrifuge whereas the liquid fraction moves to the other, larger diameter, end. The solids removed from this equipment are relatively dry compared with other types of equipment. The *screen conveyor centrifuge* is of a similar design, but the bowl is perforated to remove the liquid fraction. This type may have the bowl and screw assembly mounted vertically with liquor fed from the top of the casing.

The *reciprocating conveyor centrifuge* is used to separate fragile solids. Problems caused by buckling of the cake are overcome in a modification of this design called the *multistage reciprocating conveyor centrifuge*. This equipment has a series of concentric reciprocating baskets. The *basket centrifuge* has a perforated metal basket lined with a filtering medium, which rotates at up to 2,000 rpm.

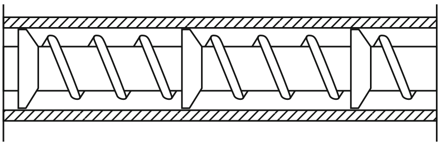
3.8 Extrusion Cooking

Extrusion cooking is a relatively recent form of food processing. Extrusion involves forcing material through a hole (Camire 2002). Sausage extruders were developed in the nineteenth century as simple forming machines. Eventually pasta was produced in extruders. Flour and water were added at one end of the machine, and a screw mixed and compressed the dough before extruding it through numerous holes or dies that gave the pasta its shape. During the 1930s, equipment was developed in which heat was added to the barrel containing the screw; puffed corn curl and other snacks resulted. The pressure developed as the dough moved along the screw; this, together with the heating under pressure, caused the corn to puff as it exited the dies. Specialized extrusion cookers were developed to process more types of food.

The feasibility of cooker extruders, as a form of heat-transfer equipment, has not yet been thoroughly investigated. Knowledge is often lacking on flow phenomena and mixing characteristics in combination with physical properties (viscosity, thermal conductivity) of the food product and how these change during processing (Hallström et al. 1988). Two types of extruders are considered here, the twin-screw extruder and the single-screw extruder (Fig. 3.3). Some general data are given in Table 3.3. There are variants of the single-screw extruder, which can be classified as high-shear cooking extruders.

Considering only the mechanical action of these two types of extruder, the major difference between them lies in how the products flow through them. The single-screw extruder can, in this respect, be characterized as a friction pump, as it is the viscous forces between the barrel and the product, with the aid of the rotation flights that transport the product. The twin-screw extruder, on the other hand, is characterized as a displacement pump in which the “closed” C-shape chambers, formed by the intermeshing screw channels, transport the product.

For further details on the use of extruders in the food industry, see Riaz (2000).



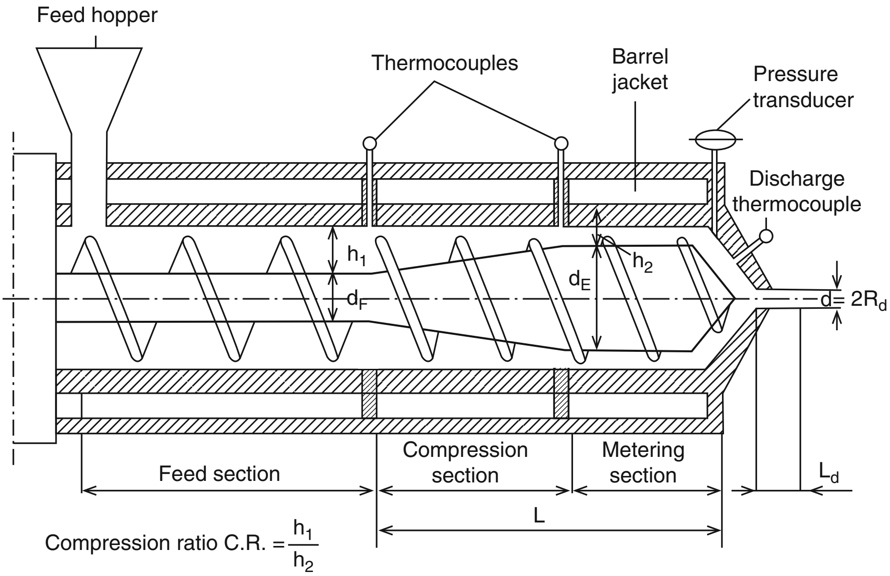


Fig. 3.3 Schematic diagram of a screw extruder (after Hallström et al. 1988)

Table 3.3 Typical data for twin- and single-screw cooker extruders

Characteristic	Type of extruder Twin-screw low-shear cooker extruded	Single screw Collet extruder	High-shear cooker extruder
Feed moisture (%)	28	11	15
Product moisture (%)	25	2	5
Product temperature (°C)	150	200	150
Ratio of screw diameter to flight height	7–15	9	7
No. of parallel screw channels	1	2–4	1–3
Screw speed (rpm)	60	300	450
Mechanical energy input (MJ/kg)	0.4	0.8	1.3
Energy dissipated as product heat (MJ/kg)	0.1	0.4	0.4
Heat transfer from barrel jacket (MJ/kg)	0.2	0	−0.1
Total heat transfer to product (MJ/kg)	0.3	0.4	0.3
Shear rate (s^{-1})	22–47	140	165

3.9 Heat Processing

By far the most important group of processes is those associated with heat processing. An increase or decrease in temperature is employed in 75 % of all process steps in food production. There are a great number of ways of performing such treatments, resulting in a wide variation in equipment for this purpose.

These may be based on convection, conduction, infrared radiation, microwave radiation, electrical resistance, and friction. In conventional practical processes, only convection and conduction are responsible for the equilibration of temperature gradients once they are created by internal heat generation or external heat supply.

Heat treatment processes and equipment are described below. The aims of such processes are summarized in Table 3.4.

3.9.1 Thermal Preservation Processes

There are three main methods of preserving food by heating. These are blanching, pasteurization, and sterilization. Holdsworth (1997) describes both thermal and nonthermal preservation methods.

3.9.1.1 Sterilization and Pasteurization

Heat sterilization is the unit operation in which foods are heated at a sufficiently high temperature and for a sufficiently long time to destroy microbiological and enzyme activity. Heat sterilization of food in containers is an old technology largely attributed to the work of Nicolas Appert in the 1800s. From Appert's work, a substantial industry has developed. For example, the estimated sales of canned products in Europe are around 26,000 million/year (Richardson 2000). Sterilized foods have a shelf life in excess of 6 months. The severe heat treatment during in-container sterilization produces substantial changes in nutritional and sensory qualities of foods. Developments in processing technology therefore aim to reduce the damage to nutrients and sensory components, by either reducing the time of processing in containers or processing food before packaging (aseptic processing).

Pasteurization is a relatively mild heat treatment, usually performed below 100 °C, which is used to extend the shelf life of foods to several days (e.g., milk) or to several months (e.g., bottled fruits)—Fellows (2009). It preserves foods by inactivation of enzymes and destruction of relatively heat-sensitive microorganisms (e.g., non-sporing bacteria, yeasts, and molds) but causes minimal changes in the sensory characteristics or nutritive value of a food. The severity of the heat treatment and the resulting extension of the shelf life are determined mainly by the pH of the food. In low-acid foods ($\mathrm{pH} > 4.5$), the main purpose is the destruction of pathogenic bacteria, whereas below pH 4.5, the destruction of spoilage microorganisms or enzyme inactivation is usually more important.

When pasteurized or sterilized, the products are either heated in a package or directly heated before being packed. Liquid products are often (but not always) heated before being packaged in a continuous flow process. Solids are normally heat treated after packaging. The equipment used in these processes is described below.

A number of different types of equipment can be used for sterilization and pasteurization of liquid foods before they are packed. These are:

- Tubular heat exchangers
- Plate heat exchangers
- Scraped surface heat exchangers
- Cooker extruders
- Boiling pans and kettles
- Microwave heaters
- Electric resistance heaters

Table 3.4 Heat treatment processes and equipment

Unit operation	Products	Objectives	Wanted changes	Unwanted changes
Preservation processes				
Sterilization	Milk, meat, meat products, fruit, vegetables	Heated to >100 °C	Destruction of sporulated microorganisms	Color, vitamins, nutritional value, quality
Pasteurization	Milk, beer, juice, meat, eggs, bread, convenience foods	Heated to 75–95 °C	Inactivation of sickness bacteria	Color, nutritional value, sensory properties
Blanching	Vegetables	Heated to 90–100 °C using water/steam	Inactivation of enzymes, reduction of oxygen, reduction of bacteria, reduction of raw and bitter taste, change of consistency	Nutritional loss, color, leakage
Conversion processes				
Boiling	Vegetables, meat, fish	Heated to 100 °C using water vapor or water	Inactivation of enzymes, texture, protein changes, starch changes	Nutritional loss, color, leakage
Baking	Bread	Heated to >200 °C	Crust, protein changes, destruction of microorganisms	Nutritional loss, water leakage, mutagens
Oven cooking	Meat, fish	Heated to >200 °C	Crust, protein changes, destruction of microorganisms	Nutritional loss, mutagens, acrylamides, leakage
Frying	Meat, fish	Heated to 150–180 °C	Crust formation, color	Nutritional loss
Tempering processes				
Tempering	Meat	To a temperature about 10 °C	Temperature increase and some phase change	Structure
Reheating	Potatoes, meat and ready-to-eat products	Heating to a temperature >60 °C	Temperature increase to make product suitable for eating	Nutrition, texture, water losses
Warm holding	Potatoes, meat and vegetables	Hold the product at eating temperature (60 °C)	No changes should occur	Nutrition, texture, leakage
Cooling	Meat, fruits, vegetables, fish, potatoes	To a temperature below 10 °C	Temperature drop	Nutrition, texture, water losses, microorganism growth
Water activity				
Drying	Vegetables, meat, potatoes, milk	Remove water at around 100 °C	Reduce weight, reduce microorganisms	Nutrition, chemical changes, structure
Evaporation	Milk, juice	Remove some water at 50 °C	Reduce water	Nutrition, chemical changes
Phase changes				
Freezing	Vegetables, berries, fruit, meat, bread	To a temperature <−18 °C	Water changes to ice, reduce microorganisms, prolonged storage	Structure
Thawing	Vegetables, fruit, meat	To a temperature about 5 °C	Ice changes to water	Structure, nutrition

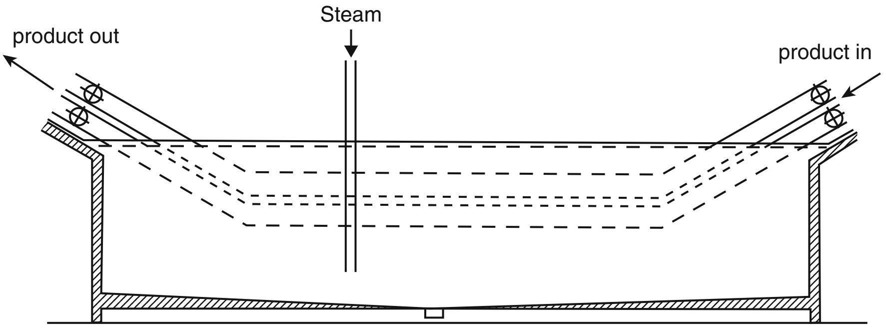


Fig. 3.4 Immersion blancher (after Hallström et al. 1988)

For more details about these techniques, see Fellows (2009), Hallström et al. (1988), and Holdsworth (1997).

The Swedish company Pastair AB has developed a cold process for the pasteurization of liquid foods such as dairy products, fruit juices, and egg white (Pastair 2012). In this process, ozone, which is produced from air in an ozone generator, is injected into the product and maintained in contact with it for a fixed length of time. The product is then heated up to 60 °C for a short period to expel the residual O_2 and O_3. In contrast to thermal processes, minimal changes to the taste and nutritional value occur and enzyme inactivation is minimal. The reduction of microorganisms, however, is comparable to that achieved with conventional pasteurization, i.e., up to 99.9 %.

Retorts using steam for sterilization and pasteurization of food products in cans, bottles, and polyethylene bags may be of the following types:

- Batch retorts, without agitation
- Rotating retorts, without agitation
- Continuous process retorts
- Hydrostatic retorts
- Hydrolock retorts

Again, further details are given by Fellows (2009), Hallström et al. (1988), and Holdsworth (1997).

3.9.1.2 Blanching

Blanching is used to destroy enzyme activity in vegetables and some fruits prior to further processing (Fellows 2009). As such, it is not intended as the sole method of preservation but as a pretreatment, which is normally carried out between the preparation of the raw material and later operations (particularly heat sterilization, dehydration, and freezing). Blanching is also combined with peeling and/or cleaning of food, to achieve savings in energy consumption, space, and equipment costs. The principle types of blancher are described below.

In *water blanchers*, the product is transported through hot water by means of a rotary screw or a rotary drum or on a belt conveyor. One of the simplest designs, an immersion blancher, is illustrated in Fig. 3.4. The water is normally heated by the injection of steam. This design has certain drawbacks. With regard to the heat sensitivity of the product, rapid cooling is important. Furthermore, energy consumption is high. Both of these factors are improved in a design that includes a cooler. Water used in the cooling section is passed through heat exchangers that are used to heat the water for preheating the product. In this way, only a minor part of the heat treatment takes place in hot water heated up by the live steam. The principle is illustrated in Fig. 3.5.

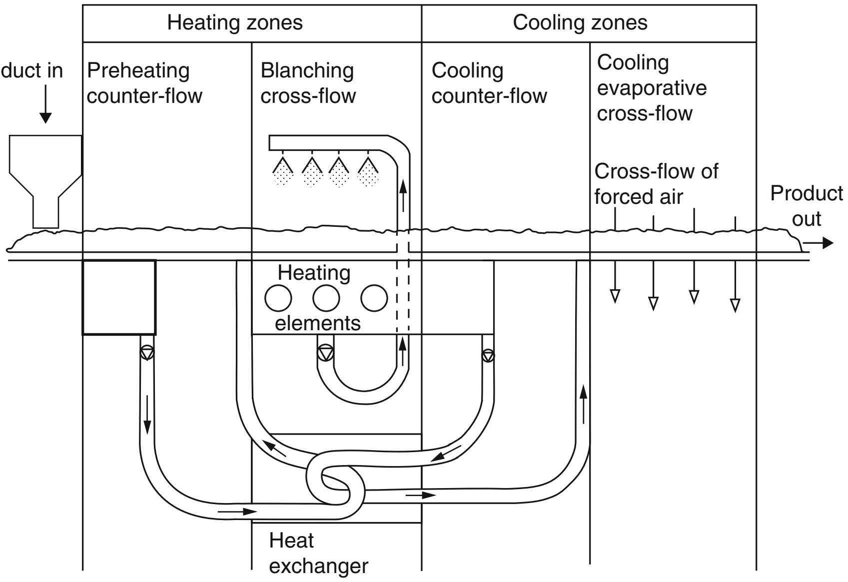


Fig. 3.5 Continuous water blancher using cooling section (after Hallström et al. 1988)

In *steam blanchers*, product transport through the equipment takes place in the same way as in water blanchers. Steam is injected onto the product surface and rapid heating occurs in this environment. Heating time and heat economy may be improved by means of different design features such as reduced thickness of the product, improved steam injectors, rotary valves or seals for minimizing steam losses, and heat recovery systems. In a special design, a vibrating screw transports the vegetables inside the blancher. It is claimed that, in this way, the products move around and heat-transfer efficiency is improved. Spiraling or stacking in the conveyor also results in a much more compact design.

For blanching of large products, the required heating time at the geometric center of the product may be rather long in the equipment described above. Other designs are available; for more information, see Hallström et al. (1988).

3.9.2 Conversion Processes

The manufacture of foods involves two broad types of conversion—those concerned primarily with physical changes and those in which irreversible chemical changes are the main purpose of the activity (Brennan 2006). This part of the chapter deals with processes that aim to change the product chemically. Examples include boiling, baking, frying, and roasting.

3.9.2.1 Boiling

As shown in Table 3.4, boiling means heating of the food at 100 °C using water or steam (Hallström et al. 1988). The aim is to inactivate enzymes and to bring about desirable texture and protein changes.

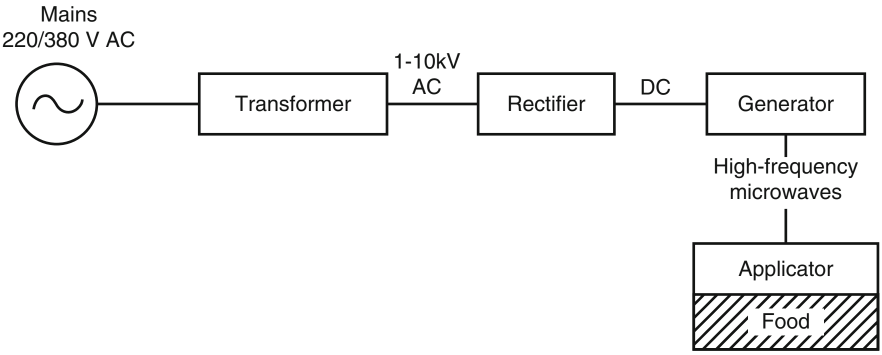


Fig. 3.6 Microwave heating equipment (after Hallström et al. 1988)

3.9.2.2 Baking and Roasting

Baking and roasting are essentially the same unit operation in that they both use heated air to alter the eating quality of foods. The term *baking* is usually applied to flour-based foods or fruits and roasting to meats, nuts, and vegetables. A secondary purpose of baking is preservation by destruction of microorganisms and reduction of the water activity at the surface of the food. However, the shelf life of most baked food is short unless it is extended by refrigeration or packaging (Fellows 2009; Hallström and Skjöldebrand 1983).

Ovens are used in the food industry for the baking of bread and potatoes and for roasting meat (Hallström et al. 1988). They are also used for reheating ready-made frozen and chilled meals. In very few cases they may also be used for boiling; in such cases steam is generated in the oven. The oven consists of either a compartment with one or several shelves for the product or a long tunnel through which the product is transported on a conveyor belt. In the oven, the heat-transfer medium is usually air, which is sometimes mixed with steam. The air may be circulated using a fan. Consequently, the heat-transfer mechanism is either natural or forced convection. To some extent, heat is also transferred via radiation from the walls and via conduction from the shelves.

Forced convection tunnel ovens (Hallström et al. 1988) are very similar to natural convection ovens but have a fan, which may be placed, in different positions. The oven may be divided into a number of sections with one fan in each or have a single fan, which accommodates the whole oven.

Microwave and near-infrared ovens (NIR) are also used to a limited extent on the industrial scale. Equipment for microwave heating consists of a microwave generator (magnetron), which operates at either 2,450 or 915 MHz, a transformer, a reflector, a rectifier, and a device for controlling the supply of microwave energy to the food (see Fig. 3.6). The magnetron needs a direct current of a few kilovolts to operate. At 2,450 MHz, magnetrons are available at output power levels ranging from 400 to 5,000 W. Industrial equipment is mostly based on 2,500 kW modules. The efficiency is between 50 and 65 %, calculated from the supplied electric power. At 915 MHz, only high-power 25–450 kW magnetrons are available. Their efficiency is about 75 %. The microwave power is transferred from the magnetrons to the food by means of an applicator. Many different designs of applicators are available from purpose-built cavities to designs for special applications.

The basic characteristics of near-infrared radiation are high heat-transfer capacity, heat penetration directly into the product, and a fast regulated response (Ginzburg 1969; Skjöldebrand 2000, 2002). These qualities indicate that infrared radiation should be an ideal source of energy for heating purposes. In contrast to microwave heating, the penetration characteristics are such that a suitable balance between surface and body heating can be reached, which is necessary for an optimal processing result. The work of Ginzburg (1969) may serve as a background for heat penetration calculations.

3.9.2.3 Frying

The simplest and most common type of equipment for industrial frying is the frying table. Equipment for continuous griddling or shallow frying of hamburgers, meatballs, steaks, fish fillets, and sausages has been developed from frying tables. Straight in-line systems of this type also exist, with transport rods or moving pans. Continuous systems utilizing Teflon belts as the frying surface with overhead electrical heating elements have been developed in order to avoid burning and to reduce the fat absorption.

In deep fat frying, heat is transferred via convection from oil to the product. The heat-transfer coefficient has been found to vary during the process. This will govern the rate that heat is transferred to the product. Water from the product is evaporated causing turbulence in the fat, resulting in an increased heat-transfer rate (Hallström et al. 1988).

During recent years contact frying of foods has gained increasing interest for industrial purposes as an alternative to deep fat frying. In the case of single-sided contact frying, the product has to be turned over during the process in order to treat both sides. With double-sided contact frying, the necessary frying time can be reduced to less than 50 % compared with single-sided frying for a product of normal thickness. Obviously only flat products like hamburgers, cutlets, bacon, meat cubes, breaded products, and potato products can be fried using this technique. A continuous double-sided Teflon belt grill has been investigated by Dagerskog and Bengtsson (1974) who studied the relationship between crust formation, yield, composition, and processing conditions.

3.9.3 Processes Effecting a Temperature Change

3.9.3.1 Tempering

Tempering is often used to raise the temperature of frozen products, especially meat, to a value at which it is not yet defrosted but is easy to cut into pieces or easy to handle.

Electromagnetic radiation in three different frequency regions is used for tempering purposes. Very low frequencies (<50 Hz) are used to temper blocks of fish (Jason 1974). At such low frequencies, the impedance of fish (or meat) is almost entirely resistive, and the procedure is sometimes called “resistive heating” (Hallström et al. 1988).

When frequencies in the range 300 kHz to 300 MHz are used, the method is called “dielectric heating.” Here the product is immersed in either water or air as it passes on a conveyor belt between two parallel-plate electrodes. This can be compared to microwave heating (300 MHz to 300 GHz) where the material is passed through a multimode cavity, which is coupled to a magnetron by a waveguide.

3.9.3.2 Cooling/Chilling

Cooling or chilling is the unit operation in which the temperature of a food is reduced to between -1 and 8 °C. It is used to reduce the rate of biochemical and microbiological changes and to extend the shelf life of fresh and processed foods. It causes minimal changes to the sensory characteristics and nutritional properties of foods, and as a result, chilled foods are perceived by the consumer as being “healthy” and “fresh.” Chilling is often used in combination with other unit operations (e.g., fermentation, irradiation, or pasteurization) to extend the shelf life of mildly processed foods.

3.9.4 Processes Involving Phase Transitions

3.9.4.1 Freezing

Freezing is a commonly employed means of preserving food products (Skjöldebrand 1990). Most of the water within the food changes to ice. The phase change of the water molecules occurs gradually depending on the degree of binding within the food structure. An American, Clarence Birdseye, founded the modern frozen food industry in 1925. As a fur trader in Labrador, Birdseye had noticed that fillets of fish left by the natives to freeze rapidly in arctic winters retained the taste and texture attributes of fresh fish better than fillets frozen in milder temperatures.

Depending on the cooling medium used, the available equipment for freezing may be grouped as follows:

- Convective (air) freezers
- Conductive (plate) freezers
- Liquid nitrogen and Freon freezers

Convective (air) freezers: Traditionally, convective (air) freezers have been used to freeze food products. In the original and simplest type, the foodstuff is placed in a cold store and surface heat transfer occurs through natural convection. This method is still commonly employed today, especially in small food factories. However, it suffers from the deficiency that the rate of freezing is slow, which on occasion may be detrimental to product quality. Moreover, other products in the store may deteriorate as a result of temperature fluctuations as the doors are opened and closed and as fresh unfrozen product is added.

In blast freezing, cooled air is forced over the product (Hallström et al. 1988). The velocity of the air is of importance as it determines the net heat-transfer coefficient. In air freezing, the low temperature is generally effected by means of a heat pump. However, to some extent, liquid nitrogen is also used.

Conduction freezers: Conduction freezers (also called plate freezers) were developed to improve heat transfer for regularly shaped solid food. The foodstuff is pressed between metallic plates containing channels in which the refrigerant is circulated. The design may vary in the degree of sophistication. A special design for freezing liquid food into pellets is also available. The liquid is poured into small cavities in a rotating drum cooled from the inside.

Cryogenic (nitrogen and Freon) freezers: The original direct-fluid freezers employed some form of brine in which the foodstuff was immersed. For a variety of reasons, mainly hygiene, this method is seldom used today. Rather, liquid nitrogen (LN_2) is often used either for immersion of the product or for spraying on to the product. Due to its low boiling point ($-196\ ^\circ$C) and the highly effective contact between the liquid and the foodstuff, freezing is very fast. As a result, cryogenic freezers are well suited to freezing products having a low solid content (e.g., soft fruits and seafood).

3.9.4.2 Thawing

During thawing, energy has to be transferred into the product in order to both raise its temperature and to melt the ice. This energy may be transferred in different ways. The most common methods are by means of air, water, or microwaves. Other methods such as vacuum and infrared radiation may also be used. The thawing method chosen depends on the thermal properties of the foodstuff, the rate of heat convection from the product, or the dielectric or resistive properties. The thermal conductivity is 2–3 times lower in a thawed product than in a frozen one due to differences in the properties of water and ice.

Table 3.5 Principal differences between thawing in air and thawing in water

	In water	In air
Advantages	– High heat-transfer coefficients – Low flow rate adequate – Uniform heating of product surfaces – Batch and continuous flow operation possible – Low labor cost	– Low capital cost for batch operation – Versatile—can be used for dry products – Batch and continuous flow operation possible – Little mechanical maintenance possible
Disadvantages	– Leaching of flavor components – Water logging with some products – Bacterial contamination a possible hazard – Recirculation and careful filtration necessary to conserve water demand – Corrosion difficult to prevent – Continuous flow operation employs expensive mechanism requiring much maintenance – Cleaning difficult – Cannot be used for dry products	– Large flow rate and high turbulence necessary – Risk of oxidizing some fatty products – Risk of drying moist products – Bacterial hazards with some products – Cleaning difficult – Odor problems – Uniform heating difficult – Continuous flow operation expensive

Nearly all problems encountered in thawing arise from carrying out the process too rapidly. These are connected with:

- The rate of convective heat transfer to the product surface
- The rate of thermal conduction
- The rate of thermal damage

A variety of equipment is used for thawing. The most common methods are convective thawing in which heat is transferred from air or water, vacuum thawing, and dielectric thawing. These methods are described briefly below.

Table 3.5 shows the principal differences between thawing in air and thawing in water. At present, air blast thawing is the most widely used method, largely as a result of its low capital costs. Even though it is a relatively slow method, it may be used for all kind of products. Convective heat transfer in an air thawer is accomplished either by condensation of water on the cold surface or by evaporation. In practice, condensation from a nearly saturated atmosphere can contribute considerably to the fraction of total enthalpy change required for thawing. The relative humidity has to be high in order to prevent the surface from drying out. Control of relative humidity is unnecessary for packaged materials, but it should be maintained between 85 and 95 % for unwrapped products. In an air thawer, the surface heat-transfer coefficient is in the range 10–60 W/m^2 K.

Vacuum thawing is inevitably a batch process, and the capacity of commercially available equipment is seldom greater than 2 tons. However, this poses no problem for relatively thin materials (<5 mm thick) as very rapid rates of thawing can be attained, and this enables the unit to perform a large number of operating cycles in a working day. The APV Torry Vacuum Thawer is one example of this type of process. Figure 3.7 shows the principle of the method. The equipment consists of a large number of vacuum vessels containing the product, which is supported on the open mesh trays stacked on trolleys.

Dielectric (radio frequency and microwave) thawing, which employs similar technology to dielectric tempering, is the most rapid and most versatile method of thawing. The required energy is produced as a result of dielectric losses when a product is subjected to an alternating electric field. Apart from its rapidity, dielectric heating offers the following advantages:

- Uniform heating to a temperature, which need not exceed a few degrees above 0 °C.
- Continuous conveyor operation.

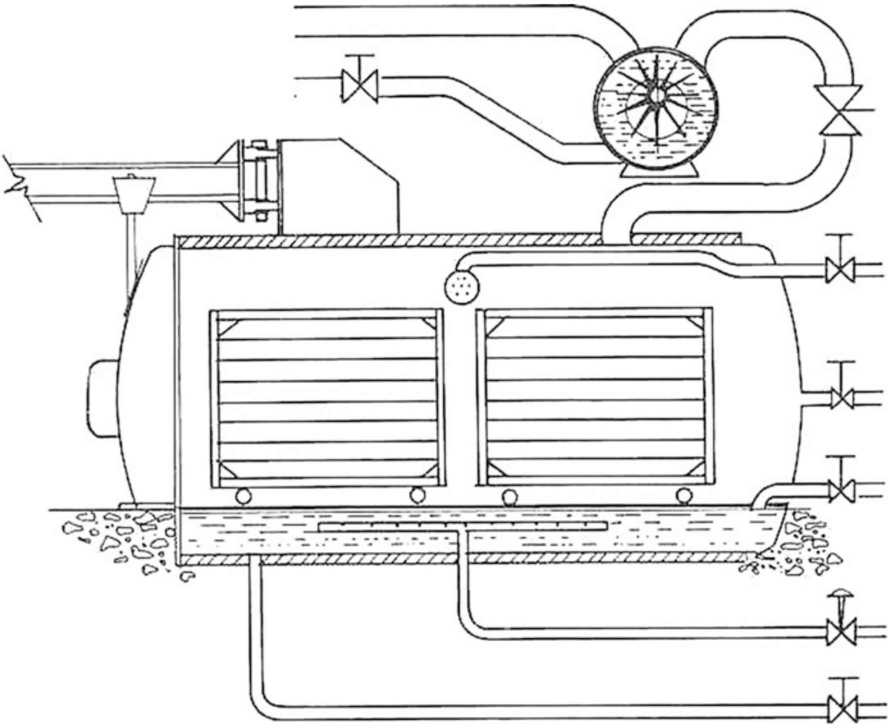


Fig. 3.7 Vacuum thawing equipment (after Hallström et al. 1988)

- Minimum drip loss and no evaporation loss.
- High level of hygiene.
- Thawing can take place within the package.
- No need to be in contact with the product.
- Negligible water consumption.
- Versatility.

There are, however, disadvantages associated with this method. For example, the dielectric properties of the food are dependent on the temperature, especially between −10 and 0 °C, and there is a substantial risk of local overheating. Microwave thawing may only be used for 30–60 mm thick products.

3.9.5 Removal of Water

3.9.5.1 Evaporation

Evaporation—the concentration of a solution by boiling off a solvent (normally water)—has three major applications in the food industry:

1. To pre-concentrate a liquid prior to further processing, e.g., before spray drying, drum drying crystallization
2. To reduce liquid volume in order to cut storage, packaging, and transportation costs

3. To increase the concentration of soluble solids in food materials as an aid to preservation, e.g., as in sweetened condensed milk manufacture

Industrial evaporator systems normally consist of:

- A heat exchanger to supply sensible heat and latent heat of evaporation to the feed. In the food industry, saturated steam is usually used as the heating medium.
- A separator in which the vapor is separated from the concentrated liquid phase.
- A condenser to effect condensation of the vapor and its removal from the system. This may be omitted if the system is working at atmospheric pressure.

Climbing-film and falling-film evaporators in which the residence time of the feedstock is only of the order of a few seconds are widely used for processing heat-sensitive products such as fruit juices and milk. Other types have been described by Ranken et al. (1997).

3.9.5.2 Dehydration

The object of drying (dehydration) is to remove water, most often by means of heating, to increase the keeping quality of the food, and to bring down the cost of storage and transportation (Skjöldebrand 1990). The water content is linked to another entity called water activity, which describes the availability of water for biological reactions and microbiological growth.

Modern drying equipment is based on technologies that come from traditional methods that have been used for hundreds of years. Methods based on convection have their origins in sun and wind drying. However, today the air velocity is controlled as well as the temperature and humidity. Conduction drying used to be carried out in vessels. Nowadays, this is undertaken by controlling temperature as well as pressure, e.g., in vacuum dryers.

Dryers are available in a wide variety of designs and sizes for both batch and continuous operation. For further details, see Baker (1997). Broadly speaking, dryers may be classified as convective, contact (conductively heated), and special types. Some of the more commonly used varieties are described below.

Bin (deep-bed) dryers: Bin dryers are cylindrical or rectangular containers fitted with a mesh base. Hot air passes up through a bed of food at relatively low speed. These dryers have a high capacity and low capital and running costs. They are mainly used for finishing (to 3–6 % moisture content) after initial drying in other types of equipment.

Cabinet (tray) dryers: These consist of an insulated cabinet fitted with shallow mesh or perforated trays, each of which contains a thin (2–6 cm deep) layer of food. Hot air is circulated through the cabinet at 0.5–5 m/s. A system of ducts and baffles is used to direct air over or through each tray to promote uniform air distribution.

Conveyor (belt or band) dryers: Continuous conveyor dryers are sized up to 20 m long and 3 m wide. Food is dried on a mesh belt in beds 5–15 cm deep. The airflow is initially directed upwards through the bed of food and then downward in later stages to prevent dried food from blowing out of the bed (Fellows 2009).

Fluidized bed dryers: These consist of vessels of rectangular or circular cross section with mesh or perforated bases that contain a bed of particulate foods up to 15 cm deep. Hot air is blown through the bed (Fig. 3.8) causing the food to become suspended and vigorously agitated (fluidized). The air thus acts as both the drying and the fluidizing medium. Conventional fluidized bed dryers are limited to small particulate foods that are capable of being fluidized without excessive mechanical damage (e.g., peas, diced or sliced vegetables, grains, powders, or extruded foods). However, vibrated types may be used to dry larger or difficult-to-fluidize particles.

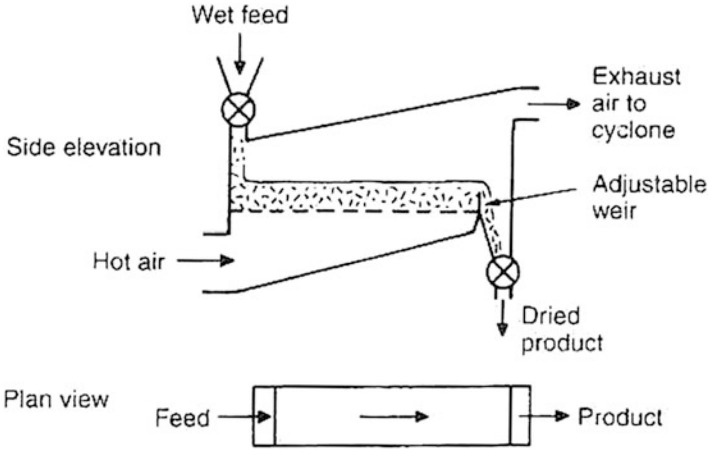


Fig. 3.8 Fluidized bed dryer (after Baker 1997)

Kiln dryers: These are two-storey buildings in which a drying room with a slatted floor is located above a furnace. Hot air and products of combustion from the furnace pass through a bed of food up to 20 cm deep. These dryers are used traditionally for drying apple rings, hops, and malt.

Pneumatic (flash) dryers: In pneumatic dryers, powders or particulate foods are continuously dried in a vertical or horizontal metal duct. A cyclone separator is used to remove the dried product. The moist food (usually less than 40 % moisture) is metered into the ducting and suspended in hot air. Pneumatic dryers are often used after spray dryers to produce food, which has a lower moisture content than normal.

Rotary dryers: A slightly inclined rotating metal cylinder is fitted internally with flights to cause the food to cascade through a stream of hot air as it moves through the dryer. Airflow may be parallel or countercurrent. The agitation of the food and the large area of food exposed to the air produce high drying rates and a uniformly dried product. Rotary dryers are used for the drying of, for example, sugar crystals and cocoa beans.

Spray dryers: The pre-concentrated liquid foodstuff is first “atomized” to form droplets (10–200 μm in diameter) and sprayed into a current of heated air at 150–300 °C in a large drying chamber. The feed rate is controlled to produce an outlet air temperature of 90–100 °C, which corresponds to a wet-bulb temperature (and product temperature) of 40–50 °C. Complete and uniform atomization is necessary for successful drying. Spray dryers are widely used, for example, in the drying of milk. Masters (1985, 2002) provides extensive and detailed descriptions of the technology.

Trough (belt-trough) dryers: Small uniform pieces of food (e.g., peas or diced vegetables) are dried on a mesh conveyor belt, which hangs freely between rollers, to form the shape of a trough. Hot air is blown through the bed of food, and the movement of the conveyor mixes and turns it to bring new surfaces continually into contact with the drying air. These dryers exhibit high drying rates, high efficiency, good control, and minimal heat damage to the product. They are not suitable for sticky foods.

Tunnel dryers: Thin layers of food are dried in trays, which are stacked on trucks programmed to move semicontinuously through an insulated tunnel. Different designs use different airflow configurations (see Fellows 2009).

Sun (solar) drying: Sun drying (without equipment) is the most widely practiced agricultural processing operation in the world; more than 250 million tons of fruits and grains are dried annually

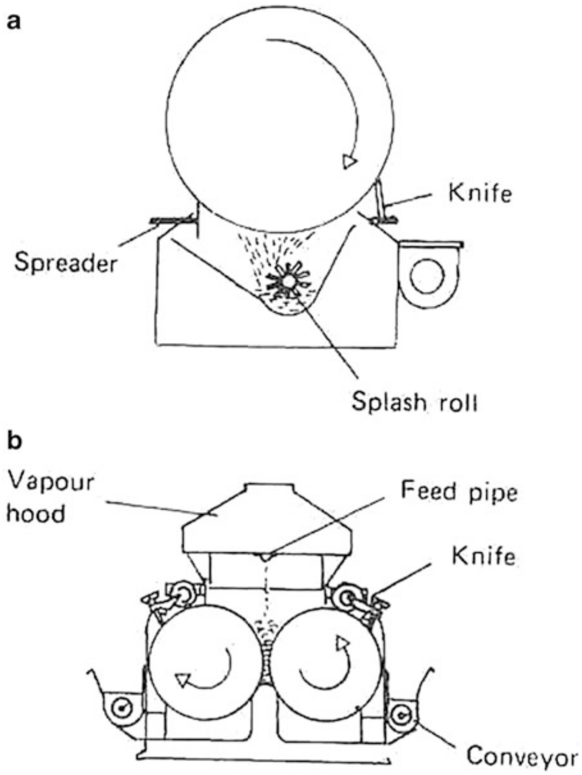


Fig. 3.9 Drum dryers: (**a**) single drum, (**b**) double drum (after Fellows 2009)

using this technique. In some countries, foods are simply laid out on roofs or other flat surfaces and turned regularly until dry. A range of solar drying equipment, which gives improved control and hygiene, is also available. For details, see Imre (1997).

Dryers in which heat is supplied to the food by conduction have two main advantages over hot air drying:

1. It is not necessary to heat large volumes of air before drying commences; the thermal efficiency of contact dryers is therefore higher than that of convective dryers.
2. Drying may be carried out in the absence of oxygen to protect components of foods that are easily oxidized.

Two examples of contact dryers are described below.

Drum dryers: Slowly rotating hollow steel drums are heated internally by pressurized steam to 120–170 °C. A thin layer of food is spread uniformly over the outer surface by dripping, spraying, or spreading, or with the aid of auxiliary feed rollers. Before the drum has completed one revolution (within 20 s to 3 min), the dried food is scraped off the drum by a sharp blade, which is in contact with the surface uniformly along its length. The dryer may feature a single drum, a double drum, or a twin drum (Fig. 3.9). Drum dryers are used to produce potato flake, precooked cereals, molasses, some dried soups, fruit purée, whey, and distillers soluble for animal feed formulations.

Vacuum-band and vacuum-shelf dryers: A food slurry is spread or sprayed onto a steel belt (or band), which passes over two hollow drums within a vacuum chamber at 1–70 Torr. The food is dried first by a steam-heated drum and then by steam-heated coils or radiant heaters located over the band. This technique is used for heat-sensitive food.

Table 3.6 Legislation concerning food irradiation

European Union clearances
Only for dried aromatic herbs, spices and vegetable seasoning; Austria, Bulgaria, Cyprus, Denmark, Estonia, Finland, Greece, Hungary, Ireland, Latvia, Lithuania, Luxemburg, Malta, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden
Dried aromatic herbs, spices and vegetable seasoning and other specified items: Belgium, Czech Republic, France, Germany, Italy, Poland, The Netherlands, and United Kingdom
Non-EU countries in Europe
Clearance: Croatia, Czech Republic, Hungary, Norway, Poland, Russian Federation, Switzerland, Turkey, Ukraine, Former Yugoslavia
Other countries with clearances
Asia/Pacific: Australia, Bangladesh, P.R. China, Republic of China (Taiwan), Indonesia, India, Iran, Japan, Korea, Pakistan, Philippines, Thailand, Vietnam.
Africa (Including Middle East), Egypt, Israel, South Africa, Syria
Latin America (Middle and South): Argentina, Brazil, Chile, Costa Rica, Cuba, Mexico, and Uruguay
North America: Canada, United States of America

3.10 Irradiation

In this process, food is sterilized by ionizing radiation (Ehlermann 2002; Arvanitoyannis 2010). Soon after the discovery of radioactivity and X-radiation, it was noticed that ionizing radiation could induce biological effects. From the multitude of atomic particles known, only gamma rays from nuclear disintegration and accelerated electrons are used for food processing. Electrons may be converted into X-rays by stopping them in a converter or target. Other particles such as neutrons are unsuitable because induced radioactivity is produced. The interaction of ionizing radiation with matter takes place by means of a cascade of secondary electrons carrying enough kinetic energy to cause ionization of atoms and molecules and the formation of free radicals. In addition to these direct effects and primary chemical reactions, chain reactions of secondary and indirect transitions take place. In systems as complex as food and for biological systems that are usually high in water content, most primary reactive species are formed by the radiolysis of water, and the pathways of further reactions largely depend on composition, temperature, dose rate and relative reactivities.

The irradiation process is basically very simple. The goods are brought by a transport system into the irradiation cell, which is essentially a concrete bunker shielding the environment and the workers from radiation. A tunnel system allows free access for the goods but prevents radiation leakage; adequate guarding prevents unintentional access by anything or anyone when the radiation is turned on.

In its standard on food irradiation, the Codex Alimentarius does not restrict the use of irradiation to individual foods or to groups or classes of foods. Most countries have preferred to regulate by this approach. Table 3.6 summarizes the legislation relating to food irradiation.

3.11 Food Storage

Food being stored may become spoiled by three mechanisms:

1. Living organisms (e.g., vermin, insects, fungi, or bacteria) may feed on the food and contaminate it.
2. Biochemical activity within the food itself (e.g., respiration, staling, browning, and rancidity development) may in time diminish its quality and usefulness.

3. Physical processes (e.g., bursting and spoilage of the contents of packages or recrystallization phenomena in sugar confectionery, fats, and frozen products) may have the same effect.

The three main factors of the storage environment, which influence the storage life of a particular commodity, are the temperature, humidity, and composition of the store atmosphere. In addition, rough handling, careless packing, or unsuitable packaging can reduce storage life.

3.12 Packaging

Packaging is an integral part of food processing. It performs two main functions: to advertise foods at the point of sale and to protect foods to a predetermined degree for the expected shelf life (Fellows 2009). The main factors that cause deterioration of food during storage are:

- Mechanical forces (impact, vibration, compression, or abrasion)
- Climatic influences that cause physical or chemical changes (UV light, water vapor, oxygen, temperature changes)
- Contamination (by microorganisms, insects, or soils) and pilferage, tampering, or adulteration

In addition, the packaging should not adversely affect the product, for example, by migration of toxic compounds, by reaction between the pack and the food, or by selection of harmful microorganisms in the packaged food. Other requirements of packaging are smooth efficient and economical operations on the production line, resistance to breakage (e.g., fractures, tears, or dents caused by filling and closing equipment, loading/unloading, or transportation), and minimum total cost.

The main marketing considerations are:

1. The brand image and style of presentation required for the food
2. Flexibility to change the size and design of the containers
3. Compatibility with the method of handling distribution
4. The requirements of the retailer

There are two main groups of packaging materials:

1. Retail containers (or consumer units), which protect and advertize the foods in convenient quantities for retail sale and home storage (e.g., metal cans, glass bottles, jars, rigid, and semirigid plastic tubs; collapsible tubes; paperboard cartons; and flexible plastic bags, sachets, and over wraps)
2. Shipping containers, which contain and protect the contents during transport and distribution (including wooden, metal, or fiberboard cases, crates, barrels, drums, and sacks)

See Campbell (1997) for further details of packaging and other end-of-line equipment.

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