Chapter 2
Design and Selection of Food Processing Equipment

2.1 Introduction

The principles of mechanical design and construction of food processing equipment are similar to those for the equipment of the chemical and process industries. The basic engineering requirements of process equipment are the containment of the material, the strength of the components, the efficiency of the operation, and the transfer of energy during processing. The equipment should be resistant to corrosion and be cost effective, and its operation should not present occupational hazards to the operators. In addition, the food processing equipment must comply with strict standards and regulations, which are necessary for securing the quality and safety of the food products to the consumers.

Hygienic (sanitary) design of food processing equipment involves selection of appropriate materials of construction and design, fabrication, and operation of the equipment that will ensure the safety of the food products from microbial and other contaminations and preserve the food quality. The equipment should be easily cleaned and sanitized by continuous (CIP; see p. 65) or noncontinuous techniques and be adapted to integrated systems of process control and automation.

Plant and equipment maintenance in food processing are of paramount importance. Due to stricter regulations and more or less fluid products, mechanization and automation are more advanced in dairy technology than in other food processing plants (Tannine and Law 2001).

Equipment used in the processing of seasonal products, such as tomatoes, oranges, and sugar beets, requires special maintenance. All equipment, remaining idle for a substantial time, should be examined thoroughly and repaired, if needed, before starting the new processing period. Equipment failure during the busy processing period can result in significant losses of raw materials, due to spoilage. The quality of processed food products is affected significantly by the processing equipment (Kostaropoulos and Saravacos 1995).

G. Saravacos, A.E. Kostaropoulos, *Handbook of Food Processing Equipment*,
Food Engineering Series, DOI 10.1007/978-3-319-25020-5_2

2.2 Sizing and Costing of Equipment

The sizing of food processing equipment is based on material and energy balances around each process unit. The process block diagram (PBD) and data tables obtained in process design (Chap. 1) are essential. Shortcut (simplified) equations are normally used for preliminary sizing of process equipment. Food engineering properties and databanks, especially transport properties, are needed for the calculations (Rao and Rizvi 1995; Rahman 1995; Saravacos and Maroulis 2001). Sizing calculations yield preliminary data on the dimensions of the equipment and the requirements for utilities (steam, water, refrigeration, power).

An oversizing capacity of 10–20 % is normally used to account for production problems, e.g., breakdown of a critical unit, and to meet production peaks. Oversizing is also advisable, when operating or environmental conditions change substantially, e.g., higher capacity of an air-cooling unit to account for increased humidity of cold storage rooms or for higher temperature and humidity of ambient air.

Equipment sizing also depends on the manufacturing plans of the food company. Thus, if greater flexibility is desired, two smaller units are better than a larger one. Splitting the capacity of process and utility units may also be advantageous for a more steady and flexible operation and for a reduction of the maintenance cost of the whole processing plant.

The cost of materials is the major component of the cost of the processing equipment. Typical costs of metallic materials, converted to year 2000 (M&S index), are carbon steel \$430/t, SS 304 \$2000/t, SS 316 \$3200/t, and aluminum \$1600/t (Sinnott 1996). The cost of construction also depends on the type of material used, i.e., raw, rolled, extruded, plate, and alloy, and the precision of workmanship in fabrication.

The price of standardized or “off-the-shelf” equipment is, in general, considerably lower than the price of custom-made equipment. Whenever possible, such equipment is preferred.

Cost indices and Guthrie charts of *Chemical Engineering* magazine (M&S, CE) can be used for general processing equipment (Table 1.3 and Fig. 1.2). Published cost data for various food processing plants and equipment are very limited, e.g., Bartholomai (1987). These data are useful in preliminary equipment and plant design and in economic evaluation of a proposed food processing plant. Of course, more realistic cost data on specific equipment can be obtained from price quotations of equipment suppliers.

Cost data were collected in Europe for certain food processing equipment for the period 1960–1990 (Kostaropoulos and Saravacos 1997). Typical diagrams of cost versus capacity for food tanks, plate heat exchangers, and centrifuges, used in the dairy, edible oil, and juice/beverage industries, are shown in Figs. 2.1, 2.2, 2.3, 2.4 and 2.5. The material of construction is food-grade stainless steel, and the cost in USD (US dollars) was converted to year 2000, using the M&S equipment cost index. The “2/3” rule (1.3) was applicable to most equipment, except for tanks of

Fig. 2.1 Cost of storage tanks for liquid foods (year 2000). Data from Kostaropoulos and Saravacos (1997)

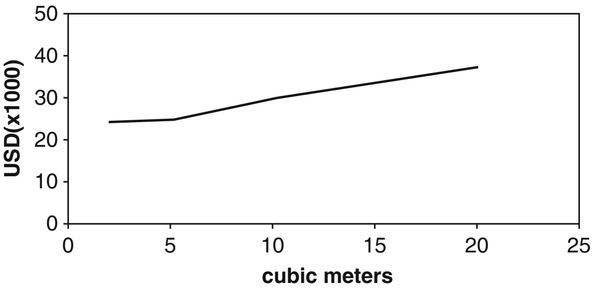


Fig. 2.2 Cost of plate heat exchangers (year 2000). Data from Kostaropoulos and Saravacos (1997)

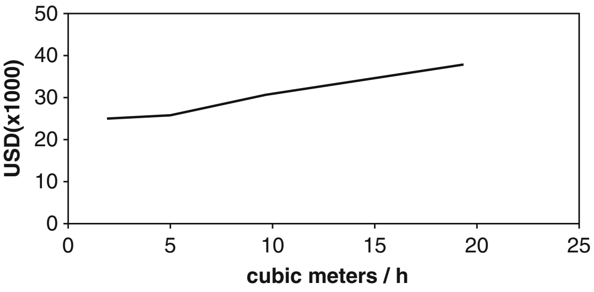


Fig. 2.3 Cost of centrifugal pumps for liquid foods (year 2000). Data from Kostaropoulos and Saravacos (1997)

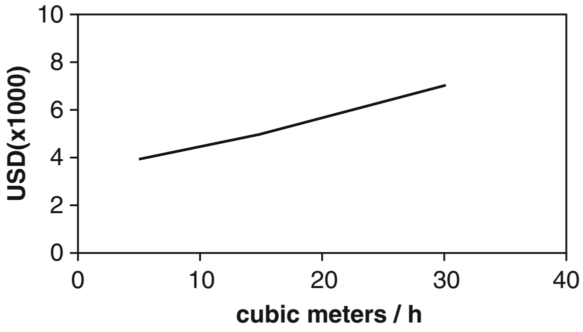
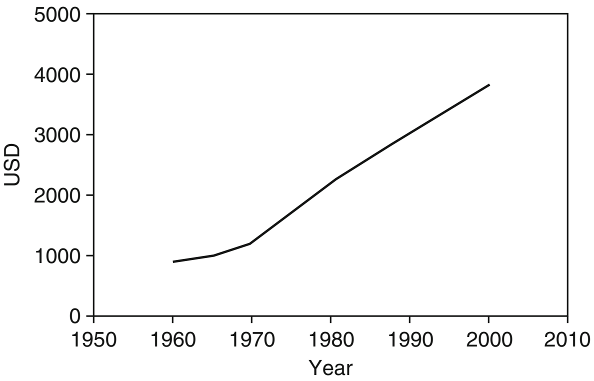


Fig. 2.4 Cost of centrifugal pumps (5 m^3/h) in the period 1960–2000. Data from Kostaropoulos and Saravacos (1997)



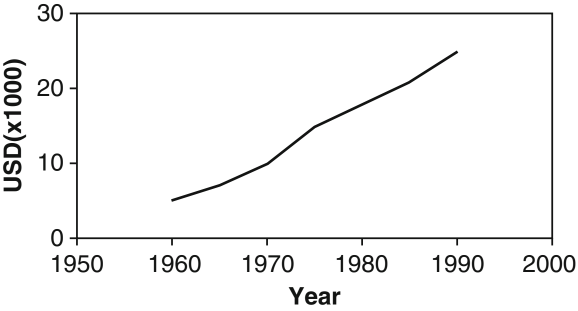


Fig. 2.5 Cost of centrifugal separators (6 m^3/h) in the period 1960–1990. Data from Kostaropoulos and Saravacos (1997)

low capacities (below 200 L), where a higher capacity factor (n) was found. The capacity factor for special mechanical equipment, like centrifuges and homogenizers, is nearly $n = 1$. There is an almost linear relationship between the weight and the power of the centrifugal pumps.

Nearly linear increases of the cost of centrifugal pumps and centrifuges during the period 1960–1990 were observed (Figs. 2.4 and 2.5), corresponding to average annual increases (inflation) of 6.5 and 7.5 %, respectively. These increases are significantly higher than the average annual increases of the M&S equipment index (4.5 %) over the same period (Fig. 1.2). The higher inflation rates of food processing equipment are due to the higher increases of prices of the alloying metals, i.e., Cr, Ni, and Mo, used in food-grade stainless steels (Hall et al. 1988).

2.3 Materials of Construction

The properties and cost of materials of construction are very important factors in the design, construction, operation, and maintenance of general processing equipment. Selection and application of these materials are based on the principles of metallurgy and materials science (Murray 1999; Cardarelli 2000).

The main materials being used for food processing equipment are metals, plastics, and glass–ceramics. Furthermore, wood and some natural fibers are used in some special applications. The materials used in the construction of food equipment must have the following properties: (1) mechanical strength, (2) easy to fabricate, (3) easy to repair, (4) resistance to corrosion, (5) hygienic properties, and (6) desirable thermal properties.

The mechanical strength is especially important in the construction of equipment used in processing of large quantities in a relatively short time, e.g., in seasonal processing. Furthermore, strength is usually more important in the first stages of processing, in which large amounts of raw material have to be processed. Mechanical strength is also important when material stress is involved, such as in loaded tanks and silos and in abrasion during cutting, milling, and pneumatic transport of grain. For protection against abrasion, hardening of the surface of the metal is necessary. In fabrication and repair of food processing equipment, the hardness and welding ability of the materials are also important.

The resistance against corrosion is especially important in (1) wet processing (e.g., canning industry) and (2) processing of foods or food ingredients of relatively low pH, which may attack the equipment materials and when corrosive chemicals are used, e.g., caustic solutions for peeling, SO_2 for preservation, and cleaning chemicals.

Factors that may enhance corrosion are (Perry and Green 1997) (1) increase of temperature, (2) pressure, (3) acidity (pH), (4) presence of impurities, (5) aeration, (6) relative velocity (material/product), and (7) temperature difference (ΔT) during heat transfer.

Corrosion of food processing equipment may be distinguished as: (1) uniform corrosion (e.g., oxidation due to humidity), (2) pitting (tiny holes on the surface of the metals, due to the attack of aqueous solutions containing chlorides), (3) stress corrosion (e.g., overloading of pumps and grinding machines), (4) intergranular corrosion (due to high temperature during welding), and (5) galvanic corrosion (due to the direct contact of dissimilar metals).

The materials that are used for food processing and preservation equipment may come directly in contact with the food or may be part of supporting elements of machines and structures without contacting food at all. Nevertheless, due to strict measures taken for protecting food from contamination, even materials not coming in direct contact with food should fulfill the hygienic conditions established by regulations for food protection. For materials of equipment that come directly in contact with food, the hygienic regulations are to a great extent the same as the regulations for food containers and packaging materials.

The hygienic (sanitary) materials do not exchange components with the food, i.e., they do not contaminate the food or absorb components of the processed product. They should have smooth or polished surfaces, not react with detergents, and they should be cleaned easily. Thermal properties are important when heat transfer to and from the processed products must take place (e.g., pasteurization of liquids in tubes, cooling down food in plate freezers). The main characteristics of materials employed in the construction of food processing equipment are given in Table 2.1.

2.3.1 Metals

Metals are the most important materials used in the construction of food processing equipment. They can be classified into two main categories: ferrous metals and their alloys and nonferrous metals. The nonferrous metals are either used in the construction of equipment and in equipment parts coming directly in contact with food or are included in alloys or in chemicals that are used for influencing the properties of other materials (e.g., paints, plastics).

Table 2.1 Properties of construction materials

Product	Tensile strength (MPa)	Thermal conductivity (W/m K)	Acetic acid	Nitric acid	HCl	H_2SO_4	NaOH	H_2O_2
Metals								
C steel	350–490	35–46	−	−	−	−	++	−
304/316 SS	565	18.8	++	+++	−	+−	++	++
Cu	20–40		−	−	++	−	+−	−
Cu alloys	400–450	375.8						
Al	50–60	208.8	+++	+−	−	−	−	+++
Al alloys	150–470							
Monel	480–600		+	−	−	+−	++	++
Plastics								
Polyester	55–72	0.170	++	+	+++	+++	−	++
PVC (soft)	20–60	0.160	+++	+++	+++	+++	+++	+++
Polyethylene	6–37	0.334	+++	+++	+++	++	+++	++
Rubber			−	−	++	+++	+++	++

Data from Loncin (1969), Schimpke (1959), and Perry and Green (1997)

+++: very good resistance

++: sufficient resistance, if used under normal conditions

+: sufficient resistance for no permanent contact

−: insufficient resistance

Recently, there have been efforts to develop metals containing antimicrobial compounds in their structure. Such metals are a special stainless steel coated with the antimicrobial compound, AgION, and a special titanium dioxide that can be used in cutting devices (Curiel 2001).

2.3.1.1 Steel

The ferrous metals used for food processing equipment are carbon steel, low-alloy steel, cast iron, stainless steel, and cast stainless steel. Stainless steel is the main material used in direct contact with food.

Carbon steel and low-alloy steel are used only in special cases in direct contact with food, e.g., in the edible oil industry (mills, presses, and oil tanks at temperatures below 150 °C; Loncin 1961), in preliminary processes of the canning industry (e.g., cleaning of raw potatoes), and in sorting of fruits and vegetables in packing houses.

Carbon is the main component (0.03–1.7 %) that influences the strength of steel. Increasing the carbon content causes an increase of the alloy tensile strength (e.g., the steel strength is tripled when 0.9 % carbon is added), a reduction of strain (down 14-fold when more than 1.6 % carbon is added), an increase of hardness (up to 3.5-

fold), and a reduction of welding ability (Schimpke 1959). The addition of elements such as Cr, Ni, Mn, Mo, Ni, or Ti leads to alloyed metals, which have enhanced properties.

The composition of the various carbon and low-alloy steels is given by the standards of the American Iron and Steel Institute (AISI). For example, AISI 1020 contains 0.2 % carbon, 0.3–1.65 % Mn, 0.1–0.3 % Si, $P < 0.04$ %, and $S < 0.05$ % (Peters and Timmerhaus 1990).

Carbon steel contains less than 4 % Cr, whereas the Cr content of low-alloy steel lies between 4 and 7 % (Sandler and Luckiewicz 1987). Low-alloy steel also contains small amounts of Mo (<0.5 %) to increase the high-temperature strength. Both metals must have a low content (<0.05 %) of S and P (Loncin 1961). Both are sensitive to oxidation and are often protected through coatings (paints, plastics). Carbon steel is resistant to water-free mineral acids (e.g., H_2SO_4) and relatively resistant to lye solutions, but it is attacked by organic acids and dilute mineral acids and it is very sensitive to moisture (Loncin 1961). Its corrosion rates are about 0.13–0.5 mm/year. Low-alloy steel is a little more resistant than carbon steel against humidity (Perry and Green 1997). Cast iron is used mainly for supporting purposes and casings and cast parts of food equipment that do not come directly in contact with food. The tensile strength of carbon steel and low-alloy steel is 345–485 and 220 MPa, respectively. The thermal conductivity of both metals is 36–46 W/m K (Perry and Green 1997).

2.3.1.2 Stainless Steels

High-grade stainless steel is the most important type of steel used in direct contact with food in constructing food processing equipment. Stainless steels are characterized, in general, by chromium content higher than 12 % and by their passivity, i.e., the ability to form an impervious surface coating, which inhibits corrosion. Austenitic stainless steel, containing nickel ($Ni > 3.5$ %), is mainly used, because this type is more corrosion resistant and more ductile. In most food equipment, two types of stainless steel are used: AISI 304 and AISI 316. The corresponding specification numbers in the British Standards for stainless steel (BS 1501) are 801B and 845B, respectively (Sinnott 1996). For the German Institute for Standardization (DIN), stainless steels have the specification DIN 17440 (X5CrNi18-8) (Grassuck et al. 1994). The carbon content of AISI 304 and AISI 316 is 0.08 %. Low carbon content improves welding, which may also be achieved by adding titanium (Ti) or niobium (Nb) (Ullmann 1973). The Cr and Ni content for both types is 18 and 8 %, respectively. Cr improves the hardness and abrasion resistance of the alloy. Ni increases the toughness and improves the properties at low temperatures. AISI 316 also contains 2–3 % Mo, which enhances the alloy properties at higher temperatures, important in welding (Perry and Green 1997), and increases the resistance to pitting due to chlorides. Besides these two types, variations 304L and 316L are also used. Both of them have further reduced carbon content (0.03 %), which enables welding of thicker stainless steel sheets (Sinnott 1996).

Both types of stainless steel are resistant to oxidation and acids. Their resistance against lye is similar to that of carbon steel. Therefore, HNO_3 and NaOH solutions may be used to an advantage in cleaning processes (CIP). Both materials are not very resistant against halogens (Cl), which cause pitting especially at high temperatures and low pH values. AISI 316 is about 25 % more corrosion resistant than AISI 304. The tensile strength of both types of stainless steel is 565 MPa. Their thermal conductivity (λ) is relatively low (18.8 W/m K). However, in heating or cooling fluids, the low λ of stainless steel does not influence heat transfer very much, since the thickness of the metal sheets in heat exchangers is small and the effect of other factors (viscosity and fluid velocity) is much more pronounced (Chap. 6).

2.3.1.3 Aluminum

Aluminum is the most widely used nonferrous metal for food processing equipment. It has the advantages of high strength-to-weight ratio, nonmagnetic properties, good thermal and electrical conductivity, and resistance to corrosive environments. Commercially pure (>99.5 % Al) wrought metal (DIN 1712, Sheet 3, American Aluminum Association, AA 1060) is used in tanks for storage and transportation of milk and beer, acetic acid, and alcohol (Ullmann 1973; Sandler and Luckiewicz 1987). Its alloys are used in supporting constructions. Since its strength remains stable at temperatures down to about −250 °C (Perry and Green 1997) and its thermal conductivity is high (208.8 W/m K, Loncin 1961), it is often used for food freezing equipment (e.g., plate food freezers). However, its strength is remarkably reduced at temperatures above 150 °C. The tensile strength of commercially pure aluminum is 69 MPa. Its strength increases through cold working (Perry and Green 1997). The strength of aluminum alloys (e.g., duralumin) is greater than that of the pure metal, but their resistance to corrosion is lower (Sinnott 1996). Therefore, in some cases, aluminum alloys are plated by pure aluminum metal to avoid direct contact with the food. The tensile strength of its alloy may approach that of low-alloy steel. It is very resistant against oxidation in humid air, but it is attacked by strong caustic solutions and acids (Table 2.1). Cleaning substances containing lye can be handled only if inhibitors (e.g., sodium metal silicate) are used.

2.3.1.4 Copper

Copper is characterized by its very good electrical and heat conduction properties ($\lambda = 375$ W/m K) and its low-temperature (−250 °C) strength (Schimpke 1959). It is used in some equipment that comes directly in contact with food, e.g., beer brewing ingredients that have a pH below 6 in the prefermentation and fermentation steps of beer brewing. Furthermore, it may also be used in processing of chocolate and confectionery, if the manufactured products do not contain acid substances.

It has been used in the past in the processing of jams and tomatoes, but, due to the oxidation of ascorbic acid, it has been replaced by stainless steel. Because of its relatively good corrosion resistance against nonoxidizing acids, copper is used in equipment employed in starch hydrolysis with dilute hydrochloric acid.

The tensile strength of copper is about 360 MPa (Perry and Green 1997). Copper alloys, such as brasses and bronzes (>60 % Cu), are stronger than pure copper. Brasses are virtually not used for food equipment, but bronzes (especially aluminum and silicon bronzes) are often used in valves, taps, and other cast parts of equipment (Loncin 1961; Perry and Green 1997). Bronze is used in some food equipment after plating with nonoxidized metals (e.g., Ni, Cr).

2.3.1.5 Other Metals

Tin is used as a constituent of copper alloys and in coating steel or copper so as to avoid their direct contact with food. Nickel and chromium are constituent metals in steel and copper alloys. The addition of Ni increases toughness and corrosion resistance of steel alloys. Chromium increases strength and hardness. Monel 400 is a nickel–copper alloy (67 % Ni) that has good strength and quite good corrosion resistance properties against alkalis, organic acids, and salt (brine solutions). It is more expensive than stainless steel, but it may be used in reducing conditions, in which stainless steel would be unsuitable (Schimpke 1959; Sinnott 1996; Perry and Green 1997).

2.3.2 Plastics–Rubber

Plastics are usually resistant to corrosion, but their mechanical strength is limited (Table 2.1). Furthermore, their strength depends strongly on the temperature of the material. The upper temperature application limit of most temperature-resistant plastics lies at 250 °C. Therefore, in food processing equipment, plastics are mainly used for coating and parts that are not under high and continuous stress (e.g., parts of ventilators and pumps, pipes, fittings, small tanks, covers of vessels, filters, gaskets). In all cases, plastics must fulfill the requirements concerning the interaction of materials with food. This is especially important for plasticizers, which are added to influence the properties of the plastics and which are generally undesirable in the food system.

Plastics, as construction materials, can be divided into two main categories: thermoplastic and thermosetting materials (Sinnott 1996). Examples of commonly used thermoplastics are poly(vinyl chloride) (PVC), polyethylene, and poly (tetrafluoroethylene) (PTFE; Teflon). Depending on the plasticizers added, plastics could become softer or harder. Polyethylene, for example, can be distinguished into low- and high-density material. The tensile strength of low-density polyethylene is 15 MPa, while that of the high-density material is about double. Low-density polyethylene can be used at temperatures up to 100 °C, while the high-density material can be applied at temperatures up to 130 °C. The thermal conductivity of both materials is 0.334 W/m K. PTFE has relatively low mechanical strength (7–25 MPa, Perry and Green 1997), but it is used when high temperatures prevail, as it withstands temperatures up to 250 °C (Loncin 1961). Examples of thermosetting materials are polyester and the epoxy resins. The tensile strength for polyester is 40–100 MPa and, for epoxy resins, it may reach 200 MPa (Perry and Green 1997). The thermal conductivity of polyester is 0.13–0.26 W/m K (Loncin 1961). Epoxy resins are also used as adhesive of plastic or even metal equipment parts. However, in this case, the application temperature should not exceed 100–180 °C (Ullmann 1973).

Rubber is used as part of equipment or machines coming directly in contact with food (e.g., gaskets, filters), as parts that must withstand friction (e.g., pumps), and in coating of metals. Rubber must be as pure as possible. Hard rubber has a tensile strength of 70–100 MPa and its thermal conductivity is about 0.4 W/m K (Loncin 1961). In conveyor belts, canvas may be more preferable than rubber.

2.3.3 Glass–Ceramics

Glass and ceramics are very resistant to acids and sufficiently resistant against lye. They are very hard and can withstand pressure of 100–400 MPa. However, they are very sensitive to bending (fragile). Their thermal conductivity is 0.62–1.45 W/m K. They are used in coating of other stable materials (e.g., in bins, vats) and in the construction of pipes and processing equipment for very sensitive products. Ceramics are also used in filtration (e.g., sand, porous silicate bodies), in ultrafiltration, and for insulation (glass wool). They can be used in enameling of metals to protect against corrosion (e.g., storage tanks) and for glass-fiber-reinforced plastics. Polyester resins, reinforced with glass fiber, have a relatively good strength up to 130 °C, are resistant to several chemicals, and can be easily formed. Therefore, they are often used for fittings and valves in connection with plastic pipes and vats. Ceramics can be also used in cutting blades, lasting longer than simple steel blades.

2.3.4 Wood

Wood was used in the past for the fabrication of various food processing equipment, but its use has been discontinued, due to hygienic (sanitary) and mechanical strength problems. At the present time, wood is used as an inexpensive material in some traditional food processes, such as fermentation tanks and storage containers for wine, pickles, and olives. The high acidity and the high salt (NaCl) content of brines in some of these products can cause severe corrosion problems even for expensive metallic construction materials, such as stainless steel.

2.4 Fabrication of Equipment

The requirements for construction of food processing equipment are to a great extent similar to those applied in building general processing equipment. However, due to the biological character of the processed food materials, certain limitations, influencing their quality and safety (e.g., temperature, moisture, pressure, contact with air), must be taken into consideration. The designer of food equipment must keep in mind the selection requirements of the final user in the food industry who will play a role in purchasing the constructed equipment, and a feedback of experience is indispensable (see Sect. 2.6 later in this chapter).

The following basic points must be taken into consideration for the proper design and construction of food equipment: strength, technological suitability, weak construction points, and fabrication and installation of equipment.

2.4.1 Strength of Construction

2.4.1.1 General Aspects

The basic types of forces applied in a material are tension, pressure, and shear. Furthermore, combinations of these forces, such as bending or perforation, are often applied. The stress applied to machine materials is due to forces caused by mechanical, thermal, chemical, or physical processes (e.g., phase change of a processed material). Food equipment stresses may be distinguished as "internal" and "external" stresses.

Mechanical stresses may be due to static forces, as in silos or tanks (weight of the equipment and weight of its contents). Other examples of mechanical stresses are the pressure experienced by materials of construction during mechanical processing, such as homogenization, pressing, filtration, extruding, and pumping.

Thermal stresses develop at high or low temperatures during processing (expansion/contraction). They are especially pronounced in positions in which two different construction materials are joined. Furthermore, elevated temperatures may cause mechanical weakening of the material.

Chemical reactions influence directly or indirectly the strength of the construction material. Chemical reactions may cause corrosion or produce substances that cause mechanical stress (e.g., gases).

Physical stress may cause indirectly mechanical stress. Phase changes of the product may cause mechanical stress, such as when water is vaporized (development of pressure).

Internal stresses are related directly to the equipment, including static forces of the equipment and its contents, and forces caused by changes during food processing. External stresses are usually caused by external forces such as wind and snow. These stresses occur when the equipment is located outside buildings, e.g., in silos, large tanks, and tall equipment, like barometric sterilizers, large evaporators, and distillation columns. However, external stresses may also be important in equipment located indoors, e.g., stresses due to seismic action or due to vibration of neighboring equipment.

Mechanical stresses can be controlled and minimized by proper selection of the construction materials, correct design of the equipment, and proper construction.

Recommended design stresses must be taken into consideration; e.g., the tensile strength of stainless steel 304 at 20–50 °C is greater than 500 N/mm^2, but typical design stress for such a material is only 155 N/mm^2 (Sinnott 1996; Perry and Green 1997).

Thermal stresses in pipelines should be controlled by flexible connections or Ω expansions.

Proper construction should apply sufficient tolerances against the risk of thermal expansions and contractions. Proper welding may reduce the risks of equipment corrosion or stresses, since welding is the weak point of several structures, due to the weakening effect of the local heat, produced during welding. Besides that, the electrolytic corrosion should be avoided by taking special constructive measures. In case, for example, of using steel bucket supports, in stainless steel equipment or tanks requiring free space beneath, welding should be done as indicated in Fig. 2.6.

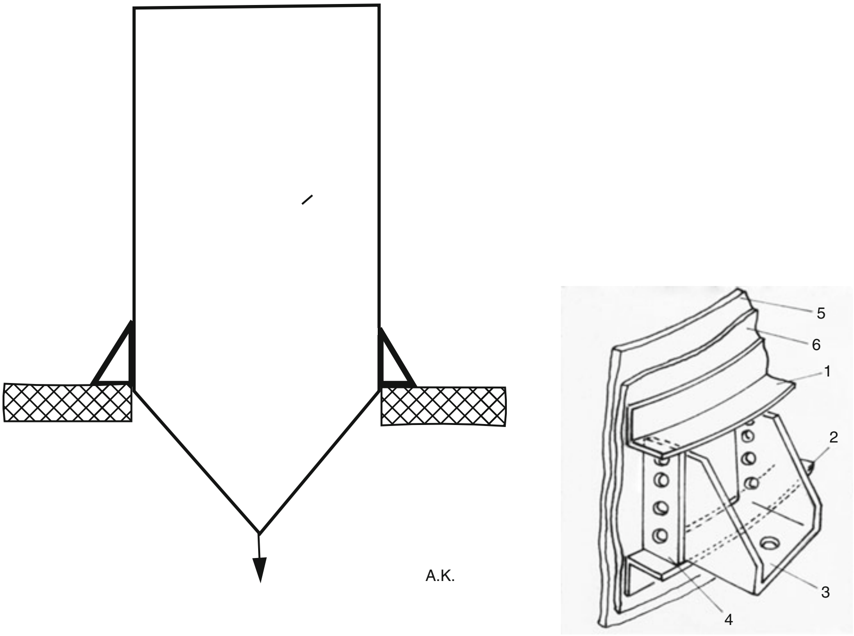


Fig. 2.6 Supporting equipment, tanks, and silos requiring free space beneath. A.K.: (1) upper ring-shaped steel, (2) lower ring-shaped steel; (3) bucket (U profile); (4) side-steel supporter; (5) apparatus stainless steel wall; (6) intermediate stainless steel plate

In storage silos (bins), material failure of the lower cone may be caused by uneven distribution and improper emptying of the particulate material. Silo failure is a potential explosion hazard for certain food powders. To prevent this problem, emptying of the particulate material should be facilitated by special devices and techniques. Metal support rings should be installed near the wider base of the metal cone, reinforcing the walls against excessive stresses.

2.4.1.2 Sensitive Construction Points

Sensitive and weak points in food processing equipment include (1) material joints and (2) parts for which a relative motion between equipment elements exists. Joints may be permanent (welded, riveted plates, parts connected with an adhesive) or flexible (screwed parts). Adhesives are frequently used in constructions, e.g., in pipelines (Ullmann 1973), but they do not withstand high temperatures, and the additives (plasticizers) they contain are not acceptable for direct food contact.

Welding, which is used extensively in joining various metal parts, should be polished in all surfaces coming into contact with food materials. Screws should be avoided in equipment parts contacting food. Screwed joints, used in external construction (supporting structures), should conform to sanitary requirements, e.g., wide-pitched screws and very short (hidden) nuts (Jowitt 1980). For the same reason, wide-pitched (thicker) coiled springs should be also preferred instead of thinner ones.

Bearings should be placed outside the food area, when a part of the equipment is stationary, while the other is rotating, e.g., shafts connecting an electric motor with agitators, extruder screws, scraped heat exchangers, or pumps. Food-grade gaskets should be used instead of full face ones, to avoid contamination.

2.4.1.3 Proper Engineering

In relating a given food processing technology to the construction of proper equipment, in addition to the sizing and economic factors, the interrelation of equipment with its environment (surroundings) must be taken into account.

The interrelation of equipment and its surroundings may or may not be desirable. For example, in heat exchangers, the transfer of heat between the product and the surrounding medium is desirable. On the other hand, undesirable interrelations include the leakage of equipment [loss of material (processed food), loss of heating medium (hot water or steam), inflow of air in vacuum] and contamination (inflow of microorganisms or undesirable fluids in food processing pipes).

2.4.2 Fabrication and Installation of Equipment

The principles and techniques used in the fabrication of process equipment for the chemical and other process industries are applicable to the food processing equipment. In addition, the food equipment must comply with strict hygienic (sanitary) standards and regulations, which will ensure the safety and quality of the food products.

2.4.2.1 General Process Equipment

Fabrication expenses account for a large part of the purchased cost of the process equipment. Mechanical details for the fabrication of general process equipment are given in various engineering codes, such as the American Society of Mechanical Engineers (ASME), the British Standards (BS), and the German Institute for Standardization (DIN).

The main steps in fabricating process equipment are cutting, forming, welding, annealing, and finishing (Peters and Timmerhaus 1990).

Cutting of the metal can be affected by shearing, burning, or sawing. Forming into the desired shape is accomplished by rolling, bending, pressing, pounding, or spinning on a die. Welding has replaced bolting in most metal constructions. Electric welding can be done by manual shielded arc or submerged arc. Stainless steel and nonferrous metals are welded by the Heliarc process (in inert He or Ar gas). The welded joints and main seams are tested by X-rays. Hydrostatic tests are required to detect any leaks.

Heat treatment (annealing) of the fabricated equipment is necessary to remove mechanical stresses, created during forming and welding, to restore corrosion resistance, and to prevent stress corrosion. The equipment is finished by sandblasting (abrasive) or mechanical polishing, and it may be painted. Final pressure tests at 1.5–2 times the operating pressure and other tests may be required by the codes or the inspector.

Metal cladding is sometimes used to reduce cost in corrosive environments: a thin sheet of an expensive corrosion-resistant material is used to clad (cover) a cheaper thick plate.

In the design of process vessels (tanks), empirical correlations are used to ensure the mechanical strength of the construction. Thus, the ratio of wall thickness to tank diameter (t/D) is taken as $t/D < 1/10$ for thin-walled vessels and $t/D > 1/10$ for thick-walled vessels (Sinnott 1996). Empirical correlations are also used for liquid storage tanks.

2.4.2.2 Food Processing Equipment

The fabrication of food processing equipment must follow some special requirements, related to the materials of construction, the design, and the characteristics of the various units. The requirements for hygienic design and operation are discussed in the next section of this chapter.

The materials used in food equipment and machines should not interact with food and should be noncorrosive and mechanically stable. For the majority of equipment used in direct contact with food, stainless steel (AISI 304) is employed. If the acidity of food products is high, AISI 316 is commonly employed.

If rubber and plastics are used in contact with foods, e.g., PVC, plasticizers that may migrate into the food should be contained. Tin, although nontoxic for normal dietary ingestion, should not be used in food equipment and machines if mechanical stresses occur, since its strength against stress is very low.

The cost of equipment/machines increases with (1) quality and quantity of stainless steel used, (2) total weight of the unit, (3) quantity of relatively expensive material used (e.g., insulation, special seals), (4) fabrication (e.g., smoothness of surfaces, type of welding), (5) antirust protection (e.g., double or electrolytic galvanization, special paints), and (6) quality of spare parts (e.g., bearings, electrical material).

In addition to the hygienic design (e.g., cleaning, sanitation), the following requirements are important in the construction of food processing equipment: (1) easy mechanical maintenance; (2) standardization of spare parts, important in seasonal processing, when the equipment is run continuously for a relatively short time; (3) durability and flexibility, important in seasonal processing and in switching from one product to another; and (4) high accuracy in some operations, like peeling, cutting, filling, packaging, and weighing.

The food contact surface of the equipment should be kept free of nonfood materials, like lubricants and greases, using gaskets, seals, and other insertions. Bearings and other mechanical parts should be isolated from the food.

2.4.2.3 Installation of Process Equipment

The process equipment is installed on various supporting structures, depending on the type and weight of the equipment and the nature of the processing operation.

Large and heavy equipment, e.g., barometric sterilizers and homogenizers, are installed directly on heavy ground foundations.

Large and tall equipment, requiring free space beneath it, like silos and storage tanks, are normally seated on bucket supports, welded on the surface of the equipment, near its center of gravity. Figure 2.6 indicates supporting of such equipment (see also Sect. 2.4.1 under Sect. 2.4.1.1). Between the stainless steel apparatus wall and the steel supporting its elements inserts a stainless steel plate welded on the apparatus wall. This eliminates apparatus damage due to electrolytic corrosion.

Supporting legs are used for short vessels and long structures, e.g., sorting tables and band dryers.

Equipment that has to be transported frequently within the plant from one area to another, e.g., silos containing semifinished products, can be installed on moving supports, hanging from the plant roof.

Equipment supports, made of carbon steel, like legs and bucket supports, should be welded to stainless steel patches, which are in turn welded on the processing equipment. This construction of equipment prevents electrochemical corrosion, caused by joining two dissimilar metals.

2.5 Hygienic Design of Food Processing Equipment

Hygienic or sanitary design of food processing equipment is based on proper selection of construction materials and fabrication techniques, which will facilitate food processing and thorough cleaning of the equipment.

Hygienic design of process equipment must be accompanied by a thorough hygienic design of the whole food process and processing plant (Jowitt 1980; Brennan et al. 1990; Gould 1994). Engineering implications of hygienic process design should be considered from the outset of the design process, especially for new, untested food processing systems (Chap. 1). The principles of food processing sanitation are detailed by Kutsuyama (1993). A guide to the sanitary design of food plants and food processing equipment was published by Imholte (1984). Hygienic aspects of food processing equipment are discussed by Schomick and Thor (1976), Kopp and Gerhold (1977), Kessler (1981), and Kessler and Lund (1989).

The European Union (EU) research and development program LINK includes a project on advanced and hygienic food manufacturing, consisting of hygienic processing and food process simulation and modeling.

Hygienic design and operational requirements of various food processing equipments, e.g., pumps, heat exchangers, freezers, and dryers, are discussed in individual chapters on specific equipment of this book.

2.5.1 Hygienic Standards and Regulations

The design and operation of food processes and processing equipment should ensure the microbiological safety of the final food products. Design engineers, equipment manufacturers, and food processors should follow strict hygienic standards and government regulations.

Government regulations of food processing equipment are essential for the manufacture of safe and wholesome foods and the protection of public health.

In the USA, the following government agencies and private organizations have published sanitary standards for food processing equipment (Troller 1993):

- USDA (US Department of Agriculture), Washington, DC: (1) Publication MPI-2 “Accepted Meat and Poultry Equipment”; (2) Agriculture Handbook No. 191 “US Inspected Meat Packing Plants. A Guide to Construction, Equipment, Layout”; and (3) “Poultry Processing Equipment”
- US Department of Interior, Washington, DC: Bureau of Commercial Fisheries “Fishery Products and Processing Equipment”
- US Public Health Service, Washington, DC: FDA (Food and Drug Administration). GMPs
- IAMFES (International Association of Milk, Food, and Environmental Sanitarians, Inc.), Ames, Iowa: Committee on Sanitary Procedures “3-A Sanitary Standards”
- ASME, New York: ANSI-ASME F2-1 “Food, Drug and Beverage Equipment”
- BISSC (Baking Industry Sanitation Standards Committee), New York: “BISSC Sanitation Standards”
- AFDOUS (Association of Food and Drug Officials of the United States), Littleton, Colorado: “AFDOUS Frozen Food Code”
- National Sanitation Foundation, Ann Arbor, Michigan: (1) “Food Service Equipment Standards” and (2) “Food Preparation and Service Equipment”

The 3-A sanitary standards were developed originally for the milk industry, but they have been extended to other food products in the USA and other countries. They resulted from the collaboration of equipment manufacturers; the users of food equipment; the IAMFES; the Dairy and Food Industries Suppliers Association (DFISA); the Poultry and Egg Institute of America; and representatives of the USPHS/FDA and USDA.

A list of the 3-A standards and 3-A accepted practices is presented by Rao (1992). The 3-A standards refer mainly to milk processing equipment, including storage tanks, heat exchangers, pasteurizers, freezers, evaporators, drying equipment, and various fittings. The 3-A accepted practices include HTST pasteurizers and culinary (potable) steam production. Special E-3-A standards apply to processing equipment for egg products (IAMFES 1988).

In addition to the 3-A standards, the following two rules/regulations should be considered in the USA: the Pasteurized Milk Ordinance and the good manufacturing practices (GMPs) of the FDA (Chap. 1).

Equipment used in USDA-inspected food plants must have been approved and listed in the “Compendium of USDA Approved Equipment.” Obtaining such approval is the responsibility of the equipment supplier. In addition to the US Federal Regulations, the Departments of Health of some states have specific requirements for dairy processing equipment (Clark 1997). Problems arise when equipment used in a less regulated industry is applied to highly regulated food industries, like meat and poultry.

In addition to the hygienic design of food contacting surfaces, process equipment should be designed to protect from external contamination (e.g., covers for processing equipment, proper drainage of the outside surfaces).

In the European Union, certain general rules apply to the hygienic design of food processing equipment, in addition to the regulations of the individual member countries. European Council Directive 89/109/EEC of 22 December 1988 specifies the materials and articles that may come into contact with foods.

A review of the European regulations for hygienic design in food processing, with emphasis on milk, was presented by Grasshoff (1992). The European Hygienic Equipment Design Group (EHEDG) is developing guidelines and test methods for food processing equipment. A series of related technical articles was published by EHEDG (1997).

The design of modern food processing equipment should be based on databases of hygienic requirements and regulatory standards. Special attention should be given to the sealing spots of moving parts, e.g., rotating and reciprocating shafts, where microbial contamination is possible (Hauser 1992). Developments in hygienic design of food processing equipment and food plants in Europe are presented in the annual meetings of EHEDG (2001).

The EU “Machinery Directives” (e.g., 89/392 and 91/368) specify that food processing machinery must be designed and constructed as to avoid any risk of infection and sickness. EU documents, such as CEN/TC 153 (CEN, European Standardization Committee; TC, Technical Committee), specify machinery, safety, and hygienic requirements for various food industries. The standard CEN 1672-2 concerns food machinery, safety, and hygienic requirements.

The specific requirements for the dairy industry are very strict, which are not practically feasible for some other industries, e.g., baking. The European food industry has, in general, adopted the US 3-A standards within the framework of the standards being developed by the EHEDG.

Other specifications used in the food industry are the DIN requirements for fittings, the bulletins of the International Dairy Foundation (IDF), and the British Standards BS 5750. “CE” (Conformite Europeenne/Provisional European Norm) is used as evidence of compliance (Table 2.2).

A number of guidelines have been published by EHEDG, which are voluntary and complementary to the corresponding national and international hygienic standards. The EHEDG guidelines include the following:

- Microbiologically safe continuous pasteurization of liquid foods
- A method for assessing the in-place cleanability of food processing equipment
- Microbiologically safe aseptic packing of food products
- A method for the assessment of in-line pasteurization of food processing equipment
- A method for the assessment of in-line steam sterilizability of food processing equipment
- The microbiologically safe continuous flow thermal sterilization of liquid foods

Table 2.2 Some European CEN specifications for food equipment

Document	Title: food processing machinery—safety and hygiene requirements
prEN 453	Dough mixers
prEN 1673	Rotary baking ovens
prEN 1674	Dough and pastry
prEN 1678	Vegetable cutting machines
prEN 12041	Molders
prEN 12331	Mincing machinery
prEN 12505	Centrifugals for processing edible oils and fats
prEN 12852	Food processors and blenders
prEN 13389	Mixers with horizontal shafts

prEN provisional European Norm

- The EC (European Community) Machinery Directive and food processing equipment
- A method for the assessment of bacterial tightness of food processing equipment
- Hygienic equipment design criteria
- Welding stainless steel to meet hygienic requirements
- Hygienic design of closed equipment for the processing of liquid food
- The continuous and semicontinuous flow thermal treatment of particulate foods
- Hygienic design of valves for food processing

The need for thorough hygienic design and operation of the entire food processing line is very important in food processing: A weak link in the processing line can nullify the whole hygienic operation.

2.5.2 Cleaning of Food Equipment

The principles of cleaning, rinsing, and sanitizing of food processing equipment are discussed by Loncin and Merson (1980), Schomick and Thor (1976), and Kessler (1981). Cleaning and sanitation should be considered an integral part of food process design and food processing operations (Plett 1992).

The food processing equipment should be designed to facilitate the removal and draining of all of the process effluents (steam condensate, waste solids, e.g., peels). All dead ends in tanks, containers, and piping should be eliminated.

Fouling is particularly important in heat exchangers and other installations involving fluid flow (e.g., tubes, filters, cyclones). Empirical models have been suggested to describe heat-induced fouling and its relationship to the overall heat transfer coefficient (U) and the pressure drop (ΔP) (Fryer 1997).

The food processing equipment must be cleaned easily either by quick dismantling and cleaning of the parts or by cleaning-in-place (CIP) techniques. The equipment of small food processing plants is usually cleaned by periodic

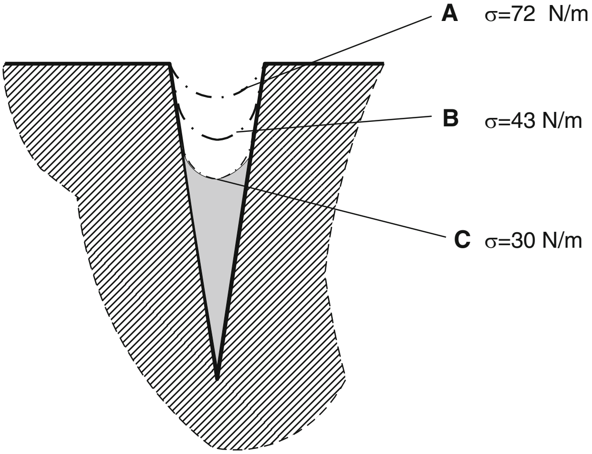


Fig. 2.7 Influence of surface-active substances in cleaning process (Thor and Schornik 1978). *A* water, *B* beer, *C* detergent with surface-active substances

dismantling of the principal units, such as pumps, plate heat exchangers, and filters. Quick dismantling and reassembling of process piping is facilitated by various hand-opening clumps.

The design and installation of CIP systems in large food processing plants requires specialized experience in pipe flow, sanitation, processing operations, and process control (Jowitt 1980; Seiberling 1997).

The CIP system involves the following sequential operations: (1) prerinsing with cold (soft) water, (2) alkali wash (supplemented with sodium hypochlorite), (3) intermediate water rinse, (4) acid rinse, (5) final water rinse, and (6) rinse with sanitizing solution (sodium hypochlorite) or flushing with hot (90 °C) water.

The CIP system is essentially a chemical cleaning operation, in which the chemical solution is brought into intimate contact with all soiled surfaces. Addition of surface-active substances, reducing substantially the surface tension of water, facilitates the penetration of water and aqueous cleaning solutions into crevices of the equipment. Figure 2.7 indicates the influence of the surface tension of cleaning fluids, with respect to their penetration in narrow gaps.

The required tanks, pumps, pipes, valves, and heaters (heat exchangers or steam injection devices) are used as either single-use or reuse (recirculation) systems. In large continuously operated units, double seat valves enable the cleaning of a part of the processing equipment, while other processing areas continue production. Air-operated piston or diaphragm-type pumps are used to feed the chemical solutions. For safety reasons, the pumps and the chemical supply containers are enclosed in a separate compartment of the processing plant.

Ball spray or rotating nozzles are commonly used to clean process and storage tanks. Detailed description about the type of nozzles and their capacity in relation to

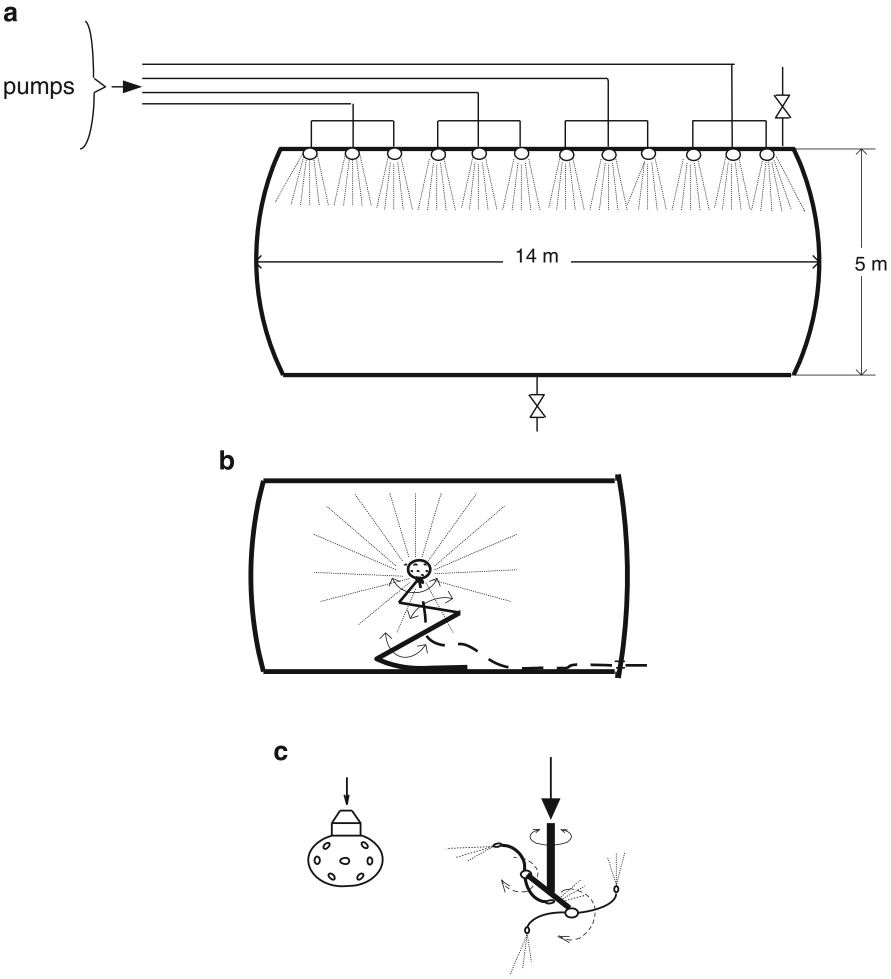


Fig. 2.8 CIP installation (**a**) Steady nozzles, (**b**) portable nozzle, (**c**) types of nozzles

cleaning processes is given by Kessler (1981) and Loncin (1961). Figure 2.8c indicates a ball nozzle and a device with rotating nozzles. Cylindrical and rectangular tanks are cleaned using liquid feed rates of 8–12 L/min m^2 internal surface, while vertical silos require liquid rates of 25–35 L/min m tank circumference. The fluid pressure in cleaning varies according to the dimensions of the tank/equipment, the surface it has to be cleaned, the product it was processed or stored, and the kind of processing before cleaning. Usually this is 3×10^5 to 5×10^5 P. Ball or other spray devices are common in CIP installations (Fig. 2.8a). The ball nozzles vary according to the type, number, and position of their holes. In larger installations, the nozzles are usually fixed ball spraying devices. In smaller tanks, portable spraying installations are applied (Fig. 2.8b). In larger continuously operating installations, double seat valves are used, which allow cleaning of a single part of the plant while other areas continue processing. The fluid pressure leaving the nozzles depends on the equipment that has to be cleaned. It is usually 3.5×10^5 P. Adequate inclination (slope) of piping and process vessels is essential for self-draining of process and cleaning liquids.

Special CIP systems are applied to dry food processing equipment, such as conveyors (belt, screw, pneumatic), dryers (e.g., spray, rotary), and dry food processing lines (e.g., cereals) (Seiberling 1997).

Usually, food equipment must be cleaned daily, after a processing period. However, when different products are processed in the same equipment, cleaning also depends on the frequency of product changes. If CIP is applied, the required valves and automation must also be reliable.

Cleaning and rinsing of equipment is difficult for very viscous fluid or semisolid foods, like cream, yogurt, and fruit pulps. A cleaning system, used in the oil and chemical industries (pigging), has been suggested for cleaning such difficult food pipes. A plug (pig) of food-grade flexible material containing a magnet is forced through the pipeline, removing the viscous material, before flushing with water and applying the CIP system.

Effective CIP requires automation of the whole system. Microprocessor controllers (PLC) are used in connection with on-line sensors for temperature, level, flow rate, pressure, and valve position (Grasshoff 1992). The concentration of cleaning agents and organic effluents can be measured with pH meters, redox potential meters, and optical density meters. The degree of surface contamination can be determined by pressure drop measurements in the pipeline.

2.6 Selection of Food Processing Equipment

2.6.1 Selection of Equipment

The selection of food processing equipment is based on the suitability for the intended application, the constructional and operational characteristics of the equipment, and the purchase and maintenance costs.

2.6.1.1 Construction Characteristics

In selecting food processing equipment, the following construction characteristics should be considered: dimensions/weight, cleanability, maintenance, standardization of spare parts, quality of materials, strength/durability, and automation.

Dimensions/Weight

In plant design, the space occupied by the processing equipment and its weight must be taken into consideration. These factors are especially important in multistory food plants, i.e., where equipment is installed on several floors. The dimensions of the equipment are also important in extension or replacement of existing food processing lines.

Cleaning Facility

Food equipment is usually cleaned daily after processing, but if the equipment is used in processing different products (e.g., a mixer), it must be cleaned before switching to a new processing program. In this case, easy and quick dismantling and assembling is essential, and joints and connections requiring minimum labor are necessary. If CIP is used, the valves and automation of the system should be reliable and resistant to the cleaning chemicals.

Maintenance

Special attention should be paid to the quality of equipment parts that are worn out quickly, e.g., brushes, screens, nozzles, bearings, seals, conveyor belts, knives, and equipment surfaces contacting flowing solids, e.g., grains. Equipment parts, requiring frequent maintenance, should have easy and quick access.

Standardization of Spare Parts

Equipment constructed of a relatively large number of standardized common parts, requiring periodic replacement of a small number of spare parts, is preferable. The use of the same standardized parts, even in different equipment, reduces the logistic cost of spare parts. Standardization facilitates maintenance and repairs, and less expertise is needed.

Quality of Materials

The appropriate quality of materials, used in equipment construction, is important for avoiding interaction with the food and for equipment stability. Quality factors for the materials are the total weight of equipment (heavier equipment is usually more robust), the quality of material workmanship (surface smoothness, type of welding), the quantity of relatively expensive materials used (e.g., stainless steel, Teflon, insulation), the antirust protection (e.g., double or electrolytic galvanization, special paints), and the quality of basic constructional elements, such as bearings and seals.

Firmness/Durability

Food machines and equipment must be stable and firm (robust), especially when they are strained due to frequent assembling and dismantling for cleaning and maintenance or due to moving, e.g., in flexible manufacturing. Robustness is especially required in seasonal processing, during which large amounts of raw materials are processed in a relatively short time and a significant part of the personnel is unskilled.

Automation

Automation is applied successfully when food processing is continuous, the output is high, the labor cost is significant, and the factory is located in regions where industrial infrastructure exists. However, automation increases the cost; the automated equipment is usually more sophisticated and, therefore, more delicate, requiring skilled personnel for adjustment and maintenance or repairs.

2.6.1.2 Operational Characteristics

The operational characteristics are features facilitating the operation of food processing equipment. In selecting processing equipment, the following requirements should be considered: reliability, convenience, safety, instrumentation, ergonomics, efficiency, effectiveness, accuracy, and environmental impact.

Reliability

Since food is perishable, storage time is relatively short. Fresh products, such as fish, milk, fruits, and vegetables, must be processed as soon as possible. This presumes high capacity and reliability of processing equipment, and downtime and breaking down during processing should be prevented. Equipment of plant utilities, participating indirectly in manufacturing of food, such as steam generation, process water, electricity, and refrigeration units, must also be reliable. Reliability is also important in food factories delivering on the basis of “just-in-time” agreements. However, since even for the best machines, there are limits in reliability, it is advisable to always have machines ready to replace the broken-down ones. Certainly, in the production of large volumes of products, such as tomato paste or frozen food, it is not possible to have spare evaporators or freezers for replacement. However, spare units to replace more delicate machines and instrumentation, which are part of such large units, should be available (e.g., pumps, fans, compressors, sensors for quality control).

Convenience

Convenience in operating equipment and machines is especially important in cases where the personnel are less skilled. As indicated by Kehoe (1989), the future growth of "middle management" in the factory may shrink due to restructuring, since much of the work formerly performed by supervisors and middle managers is now superfluous and the operation of machines is entrusted to less skilled individual workers.

Safety

Special care must be devoted to protect personnel working with machines that have bare moving parts, such as cutting machines, fans, and milling and forming machines. In all cases, machine guarding to protect the operator and other employees in the machine area must be foreseen. The guarding measures may include constructional measures (Fig. 2.9), barrier guards, two-hand tipping devices, and electronic safe devices (e.g., automated stopping of machine in any human limb passes a certain limit of a safeguarded area).

Conveying, transportations inside of processing units, insufficient cleaning of processing installations, and proceedings of reparations are, according to the HSE, (Health and Safety Executive) UK, the major causes of accidents in food factories. Analytically the major injuries are due to the following causation (Table 2.3).

As indicated in Table 2.3, the majority of accidents are connected with food factory planning and manufacturing organization matters. With respect to food equipment used, meat processing accidents are often in the following branches:

(a) Meat and fish processing (slicing, cutting/sawing, deboning, grinding, etc.)
(b) Forming and packaging (wrapping, deposing and molding, bottling, thermoforming, etc.)
(c) Moving machines including conveying (especially belt conveyors near personnel) and vehicles such as forklifts

Fig. 2.9 Design measures protecting personnel in grinding machine

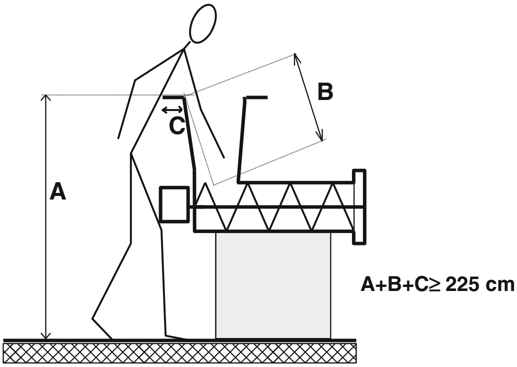


Table 2.3 Causation of injury in food and drink manufacturing (2008–2009)

Causation	% of total accidents	Remarks
Manual handling	32	Lifting of heavy objects, etc.
Trips and slips	25	Mostly slips in wet and greasy floor
Hit by moving or falling objects	8	Overhead transportation, etc.
Moving machinery	8	Conveyors, robots, packaging machines etc.
Hit by moving vehicles	2	Especially forklifts
Totally	75	

A significant percentage of injuries are caused during reparation or manual cleaning of machines. Furthermore, measures must be undertaken to eliminate accidents that are due to fire, electric shock (e.g., electric accidents in connection to defective cables in a nasty environment) and explosion of dust material. Explosions may take place in mills, silos, and conveying of granular and powder food. Food industries and facilities in which most fire hazards are found are mills, edible oil manufacturing units, and storage of dry products.

With respect to explosions, the mixture of dust with air over certain analogies can cause explosion, or oil can easily burn out, if, e.g., some electric spark due to e-motors or friction between metal parts takes place. The concentration of food dust or powder that may give rise to explosions is low. For corn, it is 73 g/m^3, for wheat 67 g/m^3, for wheat starch 30 g/m^3, for rice starch 60 g/m^3, and for sugar 30 g/m^3 (Hardex" Food Explosion in the Food Industry").

With respect to fire, besides measures against oily effluents, the autoignition temperature of corn or fine foods in silos is important. For sugar, this is 350 °C, for wheat 480 °C, and for flour 380 °C. Therefore, in cases such as in mills, silos, and conveying of granular and powder food, measures must be undertaken such as installing waterproof and not explosion-causing electric motors (V. van Amerom, Choose the right electric motors for hazardous locations, CEP, November 2011, www.aioche.org/cep).

Some prescriptions for eliminating hazards due to electric motors are regulations and standards worked out by organizations such as OSHA (Occupational Safety and Health Administration) of the US Department of Labor and HSE (Health and Safety Executive in the UK) and prescriptions of standardized organizations such as CEN (the European Standardization Committee). Furthermore, there are also standards of national organizations of standardization such as the German DIN 40050 and the British BSEN 61241, the BSEN 1449 for systems preventing dust explosions, and the BSEN 14373 for explosion suppression devices and systems.

Instrumentation

Food machines and equipment operate more efficiently when processing conditions are controlled continuously (Appendix C). This may require sophisticated instrumentation. The recent trend is, in addition to the usual indicating instruments, installed directly on the machines/equipment, to get all the process information on screens through computers. This also helps in developing CAD and CIM programs in food manufacturing. Optical weight instruments, for example, are very useful in combination with robots (see Sect. 12.6).

Equipment that can be fully automated through connection to computers may also be "telecontrolled" (operated from a distance), which is important in sophisticated continuous processing (e.g., edible oil manufacturing and milling) and in manufacturing of a number of special foods with the minimal possible contact of personnel with the products (e.g., baby foods).

Ergonomics

Ergonomics (human engineering) is important in operation and maintenance of food processing equipment and machinery. In ergonomics, the relation between the dimensions/capabilities of the machines and the human dimensions/capabilities is important. Generally speaking, operation and repair of machines should require the minimal possible human effort (force). Furthermore, it should be noted that women usually have only two-thirds of the force of men. Human force depends on age and training. Correct ergonomics is also important in jobs in which constant human concentration is required, such as in several quality control tasks (e.g., working in a sorting machine, control of final packaging).

Efficiency

A usual requirement of food processing equipment is that food processing should be accomplished in the shortest possible time. Long-time contact of the food with air, high temperature, humidity, and, in some cases, sun may reduce its quality (time-dependent microbial, enzymatic, and chemical changes of food). Processing may also reduce food quality. Thus, food quality increases the efficiency requirements of food processing equipment. Slight overdimensioning of processing units is useful.

Effectiveness

In food manufacturing, the process requirements must be achieved, as in sterilization, where the preset time–temperature values must be reached. The same is also true for the case of drying, in which certain temperature–drying time conditions must be applied, as well as the final product water activity. Chemical peeling of foods is another example of defined process conditions. Therefore, processing equipment must be operated effectively, especially in preservation processes.

Accuracy

Many food processing operations do not require high accuracy in industrial practice. However, in most packaging operations (e.g., bottling), in weighing, and in confectionery processing, high accuracy is required. High accuracy is also required when robots are involved in food processing.

Environmental Impact

"Environmentally friendly" machines and processing equipment are required mainly for legal reasons, but also for reducing the adverse effects on the health of people working in the food processing plant. Environmental burden includes equipment noise, odor, and effluents (water and air). Therefore, in selecting various machines and equipment for food plants, the requirements of equipment operation under environmental constrains must be met. The noise when personnel is working several hours per day near chutes, noise of equipment conveying and filling cans and bottles, as well as noise due to a large number of water jet cutting instruments (Chap. 4) are examples requiring hearing protection of the employees, as they may exceed 80 dB. Detailed protective measures against noise are described by HSE (series code L108, ISBN 978 0 7176 6164) (see also Sect. 2.6).

2.6.2 Testing of Equipment

Standard equipment is normally guaranteed by the manufacturers/suppliers and usually needs no testing of its performance before installation in the food processing plant. However, novel or complex equipment may need some form of testing, either in the pilot plant (small units) or in the processing plant. Testing procedures for various process equipment have been published by the American Institute of Chemical Engineers (AIChE 1960–1990). The following process equipment is covered: centrifugal pumps, rotary positive displacement pumps, centrifuges, evaporators, dryers, continuous direct heat dryers, heat exchangers, particle size classifiers, batch pressure filters, mixing equipment (impeller type), solids mixing equipment, paste and dough mixing equipment, and plate distillation columns.

As an example, the testing of a rotary positive displacement pump (Newtonian fluids) involves the following: definitions and description of terms (density, viscosity, Reynolds number, pressure drop, capacity, power, efficiency); instruments and methods of measurement; test procedure, test conditions, test data, and performance criteria; acceptance test; computation and interpretation of results; performance characteristics (power, capacity, efficiency versus total pressure drop).

2.6.3 Equipment Specifications

Lists of equipment suppliers are given in Appendix E of this book. “Off-the-shelf” standard equipment, such as pumps, tanks, heat exchangers, and centrifuges, can be supplied from the stocks of equipment manufactures. Specialized equipment may have to be fabricated by experienced manufacturers at a higher cost.

Equipment specification forms for various types of processing equipment are given by Walas (1988). Equipment forms, related to food processing equipment, include the following: pumps, fans, vacuum pumps, electric motors, heat exchangers, boilers, evaporators, packaged refrigeration systems, filter presses, centrifuges, screens, distillation columns, and process vessels.

The specification forms contain information on the type and properties of the product, the flow rate (capacity) and operating conditions (temperature, pressure), and other characteristic data. Several independent quotations of new equipment should be obtained from different manufacturers. Too strict specifications may significantly increase the cost of equipment. In some cases, secondhand equipment may be purchased, reducing the investment cost of the food plant.

Typical questionnaires of suppliers of processing equipment, given by Walas (1988), include information on dryers, mixers, distillation and extraction equipment, evaporators, and so on. For example, a dryer questionnaire should contain information on the type of product, capacity (kg/h), moisture content, particle size, bulk density, thermophysical properties, ambient air conditions, and materials of construction.

Example 2.1 Estimate the cost of the main equipment used in the orange processing plant of Example 1.1 and shown in Figs. 1.4 and 1.5. The plant processes 20 t/h of oranges, with the following products: (1) 1032 kg/h of aseptically packed frozen orange juice concentrate 65 °Brix, (2) 460 kg/h of canned frozen orange juice concentrate 42 °Brix, (3) 1800 kg/h of aseptically packaged orange juice 12 °Brix in cartons, (4) 1660 kg/h of dried orange peels/pulp, (5) 60 kg/h of peel oil, and (6) 40 kg/h of fruit essence.

Analytical Sizing of Equipment

The following major equipments of the orange processing plant were sized analytically in the numerical examples 3.1, 6.1, 7.1, and 8.1 of this book:

- Pump (Example 3.1): a centrifugal pump for transferring 9000 kg/h of orange juice 12 °Brix through the pasteurizer, pressure drop 2 bar, and power 1 kW.
- Plate heat exchanger (Example 6.1): for the regeneration and heating sections of the pasteurizer (90 °C for 15 s). Flow rate of juice 9000 kg/h, heat transfer area

8.04 and 2.8 m^2, and number of plates (1.60 m × 0.60 m) 10 and 4, for the regeneration and heating sections, respectively. In addition, the cooling section of the pasteurizer is estimated to require 2.8 m^2 heat transfer surface and 4 plates.

- Evaporator (Example 7.1): a three-effect falling film evaporator for concentrating 7000 kg/h of orange juice from 12 to 65 °Brix, using steam heating of the first effect at 110 °C. Evaporation rate, 5708 kg/h. Temperature of the first effect, 95 °C; the second, 81 °C; and the last, 50 °C. Heating surface of each effect, 60 m^2, and total surface, $3 \times 60 = 180$ m^2.
- Dryer (Example 8.1): a rotary air-dryer for the dehydration of 9940 kg/h of orange peels and pulp from 85 to 10 % moisture content, producing 1656 kg/h of dried animal feed. Water evaporated, 8284 kg/h. Dryer dimensions, 2.4 m diameter × 14 m length, with a volume of 86.2 m^3 and wall surface 123 m^2.

Approximate Sizing of Equipment

The following processing equipment of the orange processing plant were sized approximately on the basis of their capacity, using data from the material and energy balances of Example 1.1: (1) orange washer of 20 t/h capacity; (2) orange inspection belt, 20 t/h; (3) orange grader/sizer, 20 t/h; (4) FMC juice extractors of 4 t/h orange capacity each or Brown juice extractors of 10 t/h orange capacity each (Kimball 1999; Nagy et al. 1993); (5) juice finisher of 10 t/h capacity; (6) centrifuge decanter for the juice, 10 t/h; (7) high-speed centrifuge for the peel oil, 10 t/h liquid; (8) distillation column (essence recovery unit) for feed 1900 kg/h and distillate (essence) 40 kg/h, with essence concentration ratio 1/47.5; (9) ion exchange columns for debittering 2000 kg/h orange juice; (10) storage/surge juice tanks of 2 m^3 capacity; (11) centrifugal pumps of 10 t/h capacity, 2-bar pressure head, and 1 kW power (in addition to the pasteurizer pump) and positive displacement pumps of 2 t/h capacity, 2-bar pressure head, and 1 kW power; (12) scraped surface freezer for 1 t/h orange juice concentrate 65 °Brix; (13) freezing tunnel for freezing 500 kg/h of orange juice concentrate 42 °Brix in small aluminum cans; (14) aseptic packaging line for single-strength orange juice in 1-L cartons; (15) can closing machine for aluminum 1000 cans/h; and (16) aseptic packaging unit for frozen concentrate 65 °Brix in plastic-lined drums.

Cost of the Processing Equipment

The approximate cost of the main processing equipment of the orange processing plant is estimated using cost charts and indices found in the literature (Chilton 1960; Bartholomai 1987; Peters and Timmerhaus 1990; Kostaropoulos and Saravacos 1997) and cost quotations from equipment suppliers.

The cost data in Table 2.4 are expressed in USD (US dollars, $), converted to year 2000 values, using the M&S index (Fig. 1.2).

Fixed Capital

The total cost or the fixed capital (FC) of the processing plant can be estimated on the basis of the purchased cost of the main food processing equipment (CE). In general, the cost of food processing equipment, as a percentage of the fixed cost (FC), is higher than the cost of chemical processing equipment. FC includes the

Table 2.4 Cost analysis of orange processing plant

Processing equipment		Cost, USD
Orange washing machine, 20 t/h	1	75,000
Orange inspection belt, 20 t/h	1	15,000
Orange grader/sizer, 20 t/h	1	50,000
Juice extractors FMC, 5 t/h	5 × 5 000	25,000
Juice finisher	1	50,000
Juice filtering centrifuge decanter, 10 t/h	1	50,000
Pumps 10 t/h, 2 bar, 1 kW—centrifugal	3 × 5 000	15,000
Positive displacement	2 × 5 000	10,000
Juice plate pasteurizer, 10 t/h	1	50,000
Juice sterilizer, 1800 kg/h, 12 plates 1.00 × 0.30	1	40,000
Ion exchange debittering for 2 t/h OJ	1	150,000
Evaporator (3 effects), evap. capacity 6 t/h, 180 m^2	1	350,000
Distillation (essence) column, 1900 kg/h feed	1	150,000
Rotary dryer, 2.8 m × 14 m, 8.5 t/h evaporation	1	350,000
Scraped surface freezer, 1 t/h COJ 65 °Brix	1	80,000
Freezing tunnel, 400 kg/h canned COJ 42 °Brix	1	200,000
Aseptic packaging 2000 cartons/h (1 L) OJ 12 °Brix	1	200,000
Can closing machine, 1000 cans/min	1	100,000
Aseptic bulk packing, lined drums 2 t/h	1	60,000
Oil centrifugal separator, 10 t/h water emulsion	1	30,000
Total purchased cost of process equipment		(CE) = 2,050,000 USD

costs of equipment installation, piping, buildings and construction, electrical, instrumentation and control, engineering fees, and contingency (Table 1.2).

FC is related to CE by the empirical equation (1–2): FC $= f_L$ CE, where the Lang factor (f_L) can be taken as equal to 2.0 for food processing equipment (Chap. 1). A similar factor is suggested by Bartholomai (1987) (Chap. 1). Thus, the fixed capital of the orange processing plant will be

$$\mathrm{FC} = 2.0 \times 2{,}050{,}000 = 4{,}100{,}000\ \mathrm{USD}$$

Note: Solids waste treatment/disposal equipment may be required if the peel and pulp waste is not dehydrated and sold for animal feed. The pollution load of the wastewater is not heavy, and disposal to a local waste treatment plant may be preferable than building a medium-sized biological oxidation unit. No significant air pollution is expected from such a plant.

Operating Cost/Economic Analysis

The economic analysis of the orange processing plants requires some cost data and calculations, as outlined in Chap. 1. The required data include the depreciation of the fixed capital and the costs of the raw material, labor, and utilities. In this example, the cost of oranges is the most important cost component, amounting to about 70 % (Moresi 1984). This cost can vary widely, due to weather conditions (e.g., frosting) and agricultural policy/price support of the local government.

2.7 Directories of Equipment

Lists of manufacturers and suppliers of specific food processing equipment are given in Appendix E.

2.7.1 Directories of Food Equipment

ALRAD Equipment Corp. http://www.alrad-equipment.com Information on secondhand food machinery.

Bread Machinery Industry Association, http://www.breadmachine.org Information on bread machinery manufacturers and selection procedures.

CE. 1999. Chemical Engineering Equipment Buyers Guide. Chemical Engineering Magazine, McGraw–Hill, New York.

DECHEMA. Gesellschaft fuer Chem. Technik und Biotechnologie e.V. http://www.dechema.de

DFISA. 1995. Membership Directory of Products and Services. Dairy and Food Industry Supply Association, Inc., Rockville, MD. Worldwide list of companies manufacturing chemical industry machines, including food processing. List of companies participating in ACHEMA Exhibition.

FDA, U.S. Department of Health and Human Services. Public Health Service. http://vm.cfsan.fda.gov Information on food equipment, construction materials, and manufacturing lines. GMPs.

FP. 2000. Food Processors' Resource. Equipment and Supplies. Food Processing Magazine, Putman Publ., Chicago.

FPM&SA. 1996. Blue Book of Buyers Guide. Food Processing Machinery & Suppliers Association, Alexandria, VA.

GMV, Holland Manufacturers of Machinery for Food Processing Industry. http://www.fme.nl Information on Dutch manufacturers of food machinery.

IAFST, International Association of Food Industries Suppliers (IAFIS). http://www.iafis.org Information on food industry suppliers, standards, and regulations (safety, hygienic, environment).

IFT. 2001. Classified Services to Food Industry Services. Institute of Food Technologists, Chicago www.ift.org

IMT, Italian Machinery Technology, http://www.ime.it Information on Italian food machinery.

JFMMA. 1992. General Catalogue for Food Machinery in Japan. Japan Food Machinery Manufacturers Association, Tokyo.

National Food Processors Association (NFPA), http://wwww.fpi-food.org Information on food processing.

NSW Meat Industry Authority, http://www.meat.nsw.gov.au Standards for construction and hygienic operation of retail meat premises.

PPMA. Processing and Packaging Machinery Association, http://www.ppma.co.uk Information on processing machinery in the UK market. Classification of machines.

TAMI. 1995. Machinery for the Food and Beverage Industries. Taiwan Association of Machinery Industry, Taipei.

TEMA. Tubular Manufacturers Association Inc. http://www.tema.org Standards on tubular heat exchangers.

VDMA, German Machinery and Plant Manufacturers Association. http://www.vdma.org German machinery for food processing.

2.7.2 Exhibitions of Food Equipment

ACHEMA, Exhibition–Congress, Chemical Engineering, Environmental Protection, and Biotechnology, Frankfurt, Germany

Anuga FoodTec, FoodTec Exhibition, Cologne, Germany

Food and Dairy Expo, Chicago, Illinois, USA

Food Hygiene Europe, Exhibition and Conference, EMAP Business Communications, Maarssen, The Netherlands

GIA, SIAL, MATIC, Food Manufacturing Exhibition, Paris, France

IFT Annual Meetings, USA

Interpack, International Fair Packaging Machinery, Packaging Confectionery Machinery, Dusseldorf, Germany

Parma Food Fair, Food Processing Equipment Exhibition, Parma, Italy

References

AIChE (1960–1990) Equipment testing procedures. American Institute of Chemical Engineers, New York

Bartholomai A (1987) Food factories—process equipment costs. VCH, Weinheim

Brennan JC, Butters JR, Cowell NP, Lilly AEY (1990) Food engineering operations, 3rd edn. Applied Science, London

Cardarelli E (2000) Materials handbook: a concise desktop reference. Springer, Berlin

Chilton CH (1960) Cost engineering in the process industries. McGraw–Hill, New York

Clark JP (1997) Design of equipment for legal constraints. Paper presented at the annual IFT 97 meeting, Orlando, FL

Curiel GC (2001) Future requirements in the hygienic design of food factories. Paper presented at the symposium *Food Factories of the Future*, SIK–Swedish Institute of Food Preservation, Gothenburg, Sweden

EHEDG (1997) Guidelines and test methods. Trends Food Sci Technol

EHEDG (European Hygienic Equipment Design Group) Secretariat: Campden Food and Drink Research Association. Chipping Campden, Gloucestershire, GL55 6LD, England

EHEDG (2001) Food in Europe: building in safety. In: 11th EHEDG annual meeting, Valencia, Spain

Fryer PJ (1997) Thermal treatment of foods. In: Fryer PJ, Pyle RL, Rielly CD (eds) Chemical engineering for the food industry. Blackie Academic and Professional, New York, pp 331–382

Gould WA (1994) Current GMP's in food plant sanitation. CTI, Timonium

Grasshoff A (1992) Hygienic design. The basis for computer controlled automation. In: Food engineering in a computer climate. ICHEME, Taylor &Francis, London, pp 89–103

Grassuck J, Houben KW, Zollinger RM (1994) DIN-Normen in der Verfahreustechnik. B.G. Teubner, Stuttgart

Hall RS, Vatavuk WM, Mattey J (1988) Estimating process equipment costs. Chem Eng 66–75

Hauser G (1992) Hygienic design of moving parts of machines in the food industry. In: Food engineering in a computer climate, ICHEME, London, pp 1–12

HSE (Series Code L108, ISBN 978 0 7176 6164)

IAMFES (1988) International Association of Milk, Food, and Environmental Sanitarians, Ames

Imholte TJ (1984) Engineering for food safety and sanitation: a guide to the sanitary design of food plant and food plant equipment. Technical Institute for Food Safety, Crystal

Jowitt R (1980) Hygienic design and operation of food plant. Ellis Horwood, Chichester

Kehoe PJ (1989) Will today's workers be able to operate tomorrow's factories? Paper presented at the 4th international conference on designing and engineering new food plants, renovations and expansions. *Food Plants'89*. Food Plant Strategies Inc., West Chester

Kessler HG (1981) Food engineering and dairy technology. A. Kessler Verlag, Freising

Kessler HG, Lund DB (1989) Fouling and cleaning in food processing. Druckerei Walch, Augsburg

Kimball DA (1999) Citrus processing, 2nd edn. Aspen, Gaithersburg

Kopp R, Gerhold E (1977) Reininung und Disinfection in der Lebensmittelbetrieben. Z Lebensm Technol Verfahrenstechnik 5:157–163

Kostaropoulos AE, Saravacos GD (1995) Processing equipment and food quality. In: Charalambous G (ed) Food flavors: generation, analysis and process influence. Elsevier Science, London, pp 1043–1055

Kostaropoulos AE, Saravacos GD (1997) Cost estimation of food processing equipment. Paper presented at the annual IFT meeting, Orlando, FL

Kutsuyama AM (1993) Principles of food processing sanitation. Food Processors Institute, Washington, DC

Loncin M (1969) Principles of process technology in the food industry [in German]. Sauerlander, Aarau

Loncin M, Merson RL (1980) Food engineering. Academic, New York

Moresi M (1984) Economic study of concentrated citrus juice production. In: McKenna B (ed) Engineering and food, vol 2. Elsevier Applied Science, London, pp 975–991

Murray GT (1999) Handbook of materials selection for engineering applications. Marcel Dekker, New York

Nagy S, Chen CS, Shaw PE (1993) Fruit juice processing technology. Agscience Inc., Auburndale

Perry RH, Green DW (1997) Perry's chemical engineers, handbook, 7th edn. McGraw-Hill, New York

Peters MS, Timmerhaus KD (1990) Plant design and economics for chemical engineers, 4th edn. McGraw-Hill, New York

Plett E (1992) Cleaning and sanitation. In: Heldman DR, Lund DB (eds) Handbook of food engineering. Marcel Dekker, New York, pp 719–740

Rahman S (1995) Food properties handbook. CRC, New York

Rao MA (1992) Transport and storage of food products. In: Heldman DR, Lund DB (eds) Handbook of food engineering. Marcel Dekker, New York, pp 199–246

Rao MA, Rizvi SSH (eds) (1995) Engineering properties of foods. Marcel Dekker, New York

Sandler HJ, Luckiewicz ET (1987) Practical process engineering. McGraw-Hill, New York

Saravacos GD, Maroulis ZB (2001) Transport properties of foods. Marcel Dekker, New York

Schimpke P (1959) Technologie der Maschinebaustoffe, 15th edn. Verlag S. Hirzel, Stuttgart

Schomick G, Thor W (1976) Aspekte der Reininung und Disinfektion in der Lebensmittelindustrie. Z Lebensm Technol Verfahrenstechnik 8:225–228

Seiberling DA (1997) CIP sanitary process design. In: Valentas KJ, Rotsterin E, Singh RP (eds) Handbook of food engineering practice. CRC, New York, pp 559–666

Sinnott RK (1996) Chemical process design. In: Coulson JM, Richardson JF (eds) Chemical engineering, vol 6. Butterworths–Heinemann, London

Tannine AY, Law BA (2001) Mechanization and automation in dairy technology. CRC, Boca Raton

Thor W, Schornik G (1978) Reinigen, Desinfizieren, Nachspülen. In: Loncin M (ed) Hochschule Kurs: Ausgewählte Themen der Modernen Lebensmittel Verfahrenstechnik. Universität Karlsruhe, Karlsruhe

Troller JA (1993) Sanitation in food processing, 2nd edn. Academic, New York

Ullmann (1973) Enzyklopaedie der technische chemie, vol 3. Verlag Chemie, Weinheim

Walas SM (1988) Chemical process equipment. Butterworths, London