Chapter 4
Hygienic Design of Food-Processing Equipment

C.G.J. Baker

4.1 Introduction

Exemplary hygiene is an essential prerequisite for the manufacture of food that meets the high expectations of today's consumer in terms of safety, quality, and nutrition. The modern food factory must meet the stringent standards demanded both by national and local legislation and by retail customers. These focus principally on the following areas:

1. Any equipment used in food manufacture must be designed so as to permit efficient, safe, and hygienic operation, maintenance, and cleaning.
2. The equipment layout should also facilitate ease of operation, cleaning, and maintenance.
3. The equipment should be operated in a manner that is consistent with a high standard of hygiene.

This chapter is concerned primarily with the first two of these areas, namely, the hygienic design and layout of food-manufacturing equipment. This is a highly specialized subject and the author is indebted to Campden BRI in particular for permission to use and adapt relevant material contained in several of its technical reports.

It cannot be stressed too strongly that hygienic design is not an "optional extra"; it is fundamental to the safe and economic production of food. It should be an intrinsic feature of all equipment employed in food-manufacturing operations. Failure to appreciate this fact can result in food-poisoning and food-spoilage incidents, typical examples of which were quoted by ICMSF (1988) and are reproduced in Table 4.1. Subsequent attempts to correct basic design faults may not be fully successful and are invariably expensive. It therefore makes good commercial sense to ensure that any equipment purchased is fit for the purpose envisaged. Apart from the direct costs incurred in making any necessary modifications, indirect costs resulting from lost production and excessive downtime due to higher than necessary cleaning requirements may be even more daunting.

The findings of Campden's Hygienic Design Working Party were first published in 1982 and republished in 1992 (CCFRA 1992). In their report, the Working Party endorsed the seven basic principles for hygienic design (FDF/FMA 1967; Jowitt 1980) quoted below, which are equally valid today:

1. All surfaces in contact with food must be inert to the food under the conditions of use and must not migrate to, or be absorbed by, the food.

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Table 4.1 Examples of the consequences of poor hygienic design

Equipment	Problem	Consequences	Correction
Grain silo	Areas of high moisture	Moldy grain[a]	Proper ventilation and grain turnover
Can reformer	Holes in cans of salmon	Botulism	Proper maintenance of equipment
Gelatin injector	Welds difficult to clean	Salmonellosis from meat pies	Smooth weld
Wood smoke sticks	Bacteria surviving cleaning	Spoilage of sausage	Replace wood with metal
Heat exchanger (cooling side)	Cracked cooling unit permitting entrance of contaminated water	Salmonellosis from milk powder	Replace heat exchanger
Pump	Worn gasket	Spoilage of mayonnaise	Replace gaskets more frequently
Deaerator	Not properly cleaned or located in processing scheme	Contamination of pasteurized milk; enterotoxigenic cheese	Properly clean deaerator and move upstream of pasteurizer
Commercial oven	Poor heat distribution	Areas of undercooking, rapid spoilage, potential food-borne illness	Correct heat distribution in oven, monitor temperature to detect failure

[a] Molds can produce a range of aflatoxins

2. All surfaces in contact with food must be smooth and nonporous so that tiny particles of food, bacteria, or insect eggs are not normally caught in microscopic surface crevices and become difficult to dislodge, thus becoming a potential source of contamination.
3. All surfaces in contact with the food must be visible for inspection, or the equipment must be readily disassembled for inspection, or it must be demonstrated that routine cleaning procedures eliminate the possibility of contamination from bacteria or insects.
4. All surfaces in contact with food must be readily accessible for manual cleaning, or if clean-in-place techniques are used, it must be demonstrated that the results achieved without disassembly are the equivalent of those obtained with disassembly and manual cleaning.
5. All interior surfaces in contact with food must be so arranged that the equipment is self-emptying or self-draining.
6. Equipment must be so designed as to protect the contents from external contamination.
7. The exterior or nonproduct contact surfaces should be arranged to prevent harboring of soils, bacteria, or pests in or on the equipment itself as well as in its contact with other equipment, floors, walls, or hanging supports.

In addition, the Working Party indicated that the following additional principles should also be applied:

8. In design, construction, installation, and maintenance, it is important to avoid dead spaces or other conditions which trap food, prevent effective cleaning, and may allow microbial growth to take place.
9. The requirement of guarding machinery to ensure safety in operation may easily conflict with hygiene requirements unless considerable care is taken in design, construction, installation, and maintenance.
10. Noise suppression is important in providing acceptable working conditions. However, many noise-reducing materials can give rise to microbiological or infestation problems unless care is taken in their selection, installation, and maintenance.
11. It is important that the equipment itself is so designed, installed, and maintained that it does not cause product contamination. Examples of possible contamination are lagging, which may break up, or insufficiently secured nuts and bolts. Such hazards should be designed out of the system.

This chapter is divided into three parts. The first considers the materials of construction that are used in food-processing equipment. The second addresses the fundamentals of hygienic design and, finally, the third cites typical examples of good and unsatisfactory practice.

4.2 Materials of Construction

4.2.1 Selection

The first, and arguably the most important, step in formulating a hygienic design is the selection of appropriate materials of construction. The requirements have been summarized by Thorpe and Barker (1985):

> Good sanitary (hygienic) design of equipment used in the manufacture of foods and beverages requires that all surfaces in contact with the product must be nontoxic, inert under the conditions of use, must not have constituents which migrate or are absorbed by the product, and, in addition, must be resistant to (i.e., inert to) cleaning and disinfecting agents under normal (or expected) conditions of use.

Within the EU, all materials intended to come into contact with foods must conform with (EC) 1935/2004 (EC 2004).

Stainless steels are widely used in the construction of food-processing equipment and may be employed safely in contact with foods. The proper choice of stainless steel will ensure that it is resistant to corrosion and inert under the conditions to which it is subjected. The most commonly used stainless steels are austenitic in character; their properties are summarized in Table 4.2. Austenitic stainless steels are chromium–nickel alloys, which are non-hardenable by heat treatment. They have a very high corrosion resistance to most foods and cleaning agents and do not discolor products. The most commonly used types are 304 and 316. These are 18-8 steels, which contain around 18 % chromium and at least 8 % nickel. Type 304, containing 0.06 % carbon, is extensively

Table 4.2 Stainless steels commonly used in the construction of food-processing equipment

AISI grade	Composition (%)	Properties	Comments
304	Cr 18.0–20.0, Ni 8.0–12.0, C 0.08 (max)	Moderate corrosion resistance A general purpose steel	
304L	Cr 18.0–20.0, Ni 8.0–12.0, C 0.03 (max)	A low-carbon version of type 304 Used for applications involving welding, as no subsequent annealing is required	
316	Cr 16.0–18.0, Ni 10.0–14.0, C 0.08 (max), Mo 2.0–3.0	Good corrosion resistance Resistant to pitting	Mo improves general corrosion and pitting resistance and also high-temperature strength compared to basic general purpose steels (e.g., type 302)
316L	Cr 16.0–18.0, Ni 10.0–14.0, C 0.03 (max)	A low-carbon version of type 316 Used for applications involving welding, as no subsequent annealing is required	
321	Cr 17.0–19.0, 9.0–12.0, C 0.08 (max), Ti 5×C (min)	Used for large welded structures, which cannot be annealed after welding	Stabilized with titanium to permit use in the 420–870 °C range

Adapted from Peters et al. (2003)

used in the manufacture of pipelines, storage tanks, and a wide range of dairy-processing equipment. A low-carbon variety, 304L, has improved welding properties. Type 316 has an increased nickel content (~10 %) and contains 2–3 % molybdenum. The latter greatly enhances its corrosion resistance and makes it particularly suitable for use with highly corrosive products.

Process equipment constructed from stainless steel is considerably more expensive than that from carbon steel: typically by a factor of 2–4 depending on its type, design features, and size (Peters et al. 2003). The cost of type 316 is greater than that of type 304. Table 4.3 lists equivalent 304 and 316 stainless steel grades in several different countries.

A number of other materials are used in the construction of food-processing equipment. Some of the more common ones are listed in Table 4.4. The proposed application should always be considered in assessing their suitability. As well as the product in question, the process conditions, and any proposed cleaning and sanitizing agents, should all be taken into account. A summary of sources of information on a large number of materials of construction has been compiled by Shapton and Shapton (1998). The corrosion resistance of a variety of the more common materials of construction, including many of those listed in Tables 4.2 and 4.4, has been summarized in Chemical Engineers' Handbook (Green and Perry 2008). Table 4.5, adapted from Shapton and Shapton (1998), gives an overview of the effect of detergent materials on different surfaces. The authors point out, however, that it should be used with caution since, for example, stainless steels display a range of properties.

A number of common materials, and product containing them, should *not* be used in food manufacture. These include lead; cadmium; antimony; chromium and nickel platings; zinc or galvanized iron; plastics containing formaldehyde, free phenol, or plasticizers; enamel; and wood. If you are in any doubt as to the suitability of any particular piece of equipment or consumable item, always seek further information from the supplier.

Where equipment is constructed from two different metals, an electric potential may be set up between them if they are both in contact with a conducting liquid. Under these conditions, one of the metals will dissolve preferentially in the liquid and deposit on the other. This is known as galvanic action and can result in severe corrosion. Which metal dissolves is determined by its position in the electromotive series. A partial listing of metals arranged in decreasing order of their tendency to ionize and pass into solution is given in Table 4.6. Thus, zinc, for example, is higher in the electromotive series than iron and will therefore preferentially dissolve. This explains the improved corrosion resistance of iron when it is galvanized (i.e., coated with a thin layer of zinc). Note that the tendency for corrosion increases as the difference in electrode potentials between different metals increases.

4.2.2 Surface Finishes

The importance of surface finish in hygienic design has been discussed at length by Timperley and Timperley (1993) in Campden Technical Memorandum No. 679. They noted that:

> The Machinery Regulations (1992) state that all surfaces must be smooth and that all surfaces in contact with foodstuffs must be easily cleaned and disinfected. Surfaces should, therefore, be continuous and free from cracks, crevices and pits, which could harbor product residues and/or microorganisms and possibly be retained after cleaning. Ideally, materials should be such that the original surface finish is retained during the working life of the equipment; this should include expected abuse as well as normal wear resulting from production. It should be noted that plastic materials are more easily abraded than metals and this may affect their cleanability.

Surface roughness R_a can be defined as the arithmetic average value of the departure of the profile above and below the mean line throughout the specified sampling length. Lelieveld et al. (2003) cite the following recommendations of both 3-A Sanitary Standards, Inc., in the USA and the European

Table 4.3 Equivalent stainless steel specifications in selected countries

USA	France	Germany	Italy	Japan	Russia	Spain	Sweden	UK	EU
AISI	AFNOR	W.N. 17007	UNI	JIS	GOST	UNE	SIS	BSI	EuroNorm
304	Z 6 CN 18-09	1.4301 1.4303	X 5 CrNi 1810	SUS 304	08KH18N10 06KH18N11	X 6 CrNi 19-10	23 32	304S15 304S16	X 6 CR Ni 18 10
304N			X 5 CrNiN 1810	SUS 304N1					
304H			X 8 CrNi 1910	SUS F 304H		X 6 CrNi 19-10			
304L	Z 2 CN 18-10	1.4306	X 2 CrNi 1911	SUS 304L	03KH18N11	X 2 CrNi 19-10	23 52	304S11	X 3 CrNi 18 10
	Z 2 CN 18-10-AZ	1.4311	X 2 CrNiN 1811	SUS 304LN			23 71		
316	Z 6 CND 17-11	1.4401	X 5 CrNiMo 1712	SUS 316		X 6 CrNiMo 17-12-03	23 47	316S31	X 6 CrNiMo 17 12 2
316	Z 6 CND 17-12	1.4436	X 5 CrNiMo 1713	SUS 316		X 6 CrNiMo 17-12-03	23 47	316S33	X 6 CrNiMo 17 13 3
316F		1.4427							
316N				SUS 316N					
316H			X 8 CrNiMo 1712	SUS F 316H		X 5 CrNiMo 17-12			
316H			X 8 CrNiMo 1713		03KH17N14M2	X 6 CrNiMo 17-12-03			
316L	Z 2 CND 17-12	1.4404	X 2 CrNiMo 1712	SUS 316L		X 2 CrNiMo 17-12-03	23 48	316S11	X 3 CrNiMo 17 12 2
	Z 2 CND 17-12-Az	1.4406	X 2 CrNiMoN 1712	SUS 316LN	03KH16N15M3				
	Z 2 CND 17-13	1.4435	X 2 CrNiMo 1713			X 2 CrNiMo 17-12-03	23 53	316S13	X 3 CrNiMo 17 13 3
	Z 2 CND 17-13-Az	1.4429	X 2 CrNiMoN 1713		08KH17N13M2T 10KH17N13M2T		23 75		
	Z 6 CNDT 17-12	1.4571	X 6 CrNiMoTi 1712		08KH17N13M2T 10KH17N13M2T	X 6 CrNiMoTi 17-12-03	23 50	320S31	X 6 CrNiMoTi 17 12 2
		1.4573	X 6 CrNiMoTi 1713		08KH16N13M2B	X 6 CrNiMoTi 17-12-03		320S33	X 6 CrNiMoTi 17 13 3
	Z 6 CNDNb 17-12	1.4580	X 6 CrNiMoNb 1712		09KH16N15M3B				X 6 CrNiMoNb 17 12 2
		1.4583	X 6 CrNiMoNb 1713						X 6 CrNiMoNb 17 13 3

Source: The Engineering ToolBox: www.EngineeringToolBox.com/stainless-steel-standards-d_445.html (last accessed 26 September 2011)

Table 4.4 Other permitted materials of construction

Material	Comments
Ferrous metals	
Carbon steel	May be used for conveyors, runways, machined components, structures, some storage tanks (plated or coated as necessary)
Cast iron	Not suitable for applications involving contact with product
Black iron	Suitable for fats where moisture content is low. Unsuitable for water-based pastes, fat–water emulsions, or confectionery syrups
Nonferrous metals	
Aluminum—food grade	Unsuitable for applications involving contact with brine, alkaline solutions (e.g., sodium carbonate, bicarbonate, hydroxide), strong acids
Copper and its alloys (brass, bronze, phosphor bronze)	May catalyze rancidity in oils and fats and cause vegetable discoloration or loss of vitamin C. Incompatible with some products and cleaning materials
Admiralty gunmetal	Unsuitable for acidic products (e.g., fruit juices), particularly those containing sulfur dioxide; incompatible with sodium bicarbonate. See also copper alloys
Monel metal	Suitable for syrups
Tinned copper	Suitable where copper is unsatisfactory. As tinning eventually wears off, stainless steel and aluminum are preferred
Tinned iron	Suitable for low-moisture-content fats, etc.
Plastics	
LDPE, HDPE (low- and high-density polyethylenes)	Sundry applications
GRP (glass-reinforced polyester)	Highly resistant to acids and alkalis. Commonly used for tanks
Rigid PVC (polyvinyl chloride)	Pipelines
ABS (acrylonitrile butadiene styrene)	Pipelines
Other materials	
Glass	Vulnerable to breakage and chipping. Only used where effective means are taken to avoid possible product contamination
Carbon	Used in seals. May contain harmful additives. Check with supplier
Rubber (natural and synthetic)	Food-grade quality may be used. Check with supplier

Hygienic Engineering & Design Group (EHEDG). Large surface areas in contact with foodstuffs should normally have a finish better than $R_a = 0.8$ μm. However, a roughness exceeding 0.8 μm may be acceptable if test results have demonstrated that the required cleanability can be achieved through other design features. A similar recommendation (i.e., $R_a < 0.8$ μm) was made for closed equipment used for handling liquids and normally cleaned-in-place. Again, exceptions can be made provided that the surfaces can be shown to be cleanable.

The surface finish of stainless steels is usually defined in terms of the manufacturing process to which they are subjected rather than the topography, i.e., R_a value (BSSA 2010). Provided it is free from pits, folds, and crevices, unpolished cold rolled steel sheet with a standard 2B finish (BSI 2005) is suitable for the construction of food-processing equipment. This has a roughness of 0.1–0.5 μm, which therefore satisfies the requirement that R_a should be less than 0.8 μm.

As pointed out by Timperley and Timperley (1993), it is generally recognized that rougher surfaces provide a better mechanical "key" for product soil and hence for the growth of microorganisms. Moreover, the initial assessment of the cleanliness of open process equipment is visual, and it should be noted that residual soil is more readily observed on bright surfaces than on dull ones; this should be taken into consideration when selecting the finish. Electropolishing of stainless steel is a cost-effective method of obtaining a bright finish but, as only 10 μm of metal is removed from the surface, it will not remove deep scratches.

Table 4.5 Effect of detergents on common materials of construction and finishes

Surface	Caustic soda	Meta silicate	Synthetic detergents	Phosphoric acid	Nitric acid	Hydrochloric acid	Sulfamic acid	Solvents	Sodium hypochlorite
Stainless steel				TC	X	X	TC		
Mild steel				TC	X	X	TC		T
Copper				TC	X	X	TC		TC
Zinc	X			X	X	X	X		X
Aluminum	X				X	X	X		TC
PVC					TC	TC	TC	X	
Polypropylene					TC	TC	TC	X	
Oil paint	X	C	C	–			–	X	
Emulsion paint	X	C		–			–	X	

Adapted from Shapton and Shapton (1998)

Notes apply unless detergent is specifically inhibited against attack on surface

X not suitable, *T* may be used at recommended temperatures, and *C* may be used at recommended concentration

Table 4.6 Electromotive series of selected metals

Metal	Ion	Standard electrode potential at 25 °C (mV)
Aluminum	Al^{3+}	1.70
Zinc	Zn^{2+}	0.76
Chromium	Cr^{2+}	0.56
Iron	Fe^{2+}	0.44
Nickel	Ni^{2+}	0.23
Tin	Sn^{2+}	0.14
Lead	Pb^{2+}	0.12
Iron	Fe^{3+}	0.045
Copper	Cu^{2+}	−0.34
Copper	Cu^{+}	−0.47
Lead	Pb^{4+}	−0.8.

Adapted from Peters et al. (2003)

In Campden Technical Manual No. 17, Timperley (1997) noted that there is no evidence to support earlier ideas that the surface finish of stainless steels is a critical factor in efficient cleaning of food-contact surfaces by direct impingement from spray jets, provided R_a is less than 1 μm. As a result, the electroplating of surfaces or components, for example, heat exchanger plates, is now less frequently employed.

4.2.3 Examples of Do's and Don'ts

The Campden Hygienic Design Working Party (CCFRA 1992) set out a series of "Do's" and "Don'ts" relating to good practice in various aspects of hygienic design. Those relating to materials of construction may be summarized as follows. Note that the numbering of examples does not signify their order of importance.

Do

1. *Do* ensure that materials of construction are suitable to withstand both food and cleaning materials under the operating conditions.
2. *Do* ensure that all internal surfaces are inert and nonporous and have an appropriately smooth finish.
3. *Do* check that, where gaskets are fitted to flanged joints, the gasket material is of food quality, nonabsorbent, non-tainting, and trimmed flush both internally and externally.
4. *Do* take care to ensure that paint and other surface treatments adequately protect the joint areas between machine components to prevent corrosion and subsequent contamination.
5. *Do* remember that materials less expensive than stainless steel may be used for some applications, e.g., mild steel may be used for conveyors or runways, aluminum for dry ingredient bins or trays, galvanized steel for machine supports and platforms, epoxy-coated mild steel for some dry ingredient storage, fiberglass for tanks, and polypropylene and polyethylene for some pipelines. However, the cost of supporting plastic pipelines so that they do not sag may be as expensive as installing stainless steel lines.
6. *Do* check that any dissimilar materials will not corrode.
7. *Do* make sure of product and cleaning material compatibility if phosphor bronze or gunmetal is used.

8. *Do* ensure that conveyor belt materials are carefully chosen. Where applicable, a PVC top surface and polyester carcass are preferred for cleaning and minimal microbial contamination. Care should be taken to ensure effective sealing or bonding at cut edges.

Don't

1. *Don't* use wood in construction where it might splinter or otherwise contaminate the product. Wooden surfaces are very difficult to clean and disinfect thoroughly.
2. *Don't* use glass lining where it may become chipped during normal use or cleaning.
3. *Don't* use glass where it may be broken and contaminate the products—e.g., gage or sight glasses.

4.3 Fundamentals of Hygienic Design

The detailed mechanical design of food-processing equipment is a vital element in ensuring safe and efficient operation. An effective hygienic design should protect the product from microbial, chemical, and foreign-body contamination. It should also permit effective and efficient cleaning to be performed.

In this section, some of the more important aspects of hygienic equipment design are described. It is clearly not possible within the allocated space to cover all aspects in fine detail, nor is it necessary. Its primary purpose is to acquaint the reader with the more important principles involved, which will provide him (or her) with sufficient background to discriminate between good and inadequate designs. Perhaps most importantly, it should enable him to identify suitable equipment suppliers, who have the necessary expertise in hygienic design and construction and are familiar with the requirements of the industry.

Before entering into a description of the principal features that underlie the hygienic design of food-processing equipment, it is perhaps useful to consider some of the factors that affect bacterial growth on surfaces. To grow, bacteria require nutrients, a suitable temperature, and moisture. In many situations, these requirements are more than adequately met in plant and machinery used in food manufacture. The bacterial growth forms a film, which is attached to surfaces that are frequently in contact with the food being processed. Individual bacteria become detached from the surface, thereby contaminating the product. The film is often referred to as "soil." This term is not restricted to bacterial contamination; it may also be used to describe undesirable organic or inorganic material, including food that becomes attached to or covers a surface.

The bacterial soil can be removed and destroyed fairly easily on smooth exposed surfaces by the application of a suitable sanitation program. However, where surfaces are rough, porous, or corroded, it is more difficult, if not impossible, to clean and disinfect them effectively. Many bacterial cells are about 1 μm in diameter. Water and dissolved nutrients can penetrate a gap of this size at, for example, a joint or overlapping surfaces. Bacteria growing in the gap are very difficult to remove or destroy using normal cleaning techniques and provide a focus for reinfection of a cleaned surface. "Dead spots," in which product is able to accumulate for a length of time before eventually being swept back into the flow, also provide ideal sites for bacterial growth.

Table 4.7 (Timperley 1997) illustrates typical microbial counts after cleaning. Standards differ according to the product and the processing technology employed. The figures given in Table 4.7,

Table 4.7 Typical numbers of organisms on surfaces after cleaning

Grade	Per square decimeter	Per square foot
Satisfactory	0–540	0–5,000
Fairly satisfactory	540–2,700	5,000–25,000
Unsatisfactory	>2,700	>25,000

which are based on dairy standards for the cleanliness of product-contact surfaces, provide a guideline for general purposes. In some situations, however, they may not be sufficiently stringent.

Although microbiological concerns undoubtedly dominate the engineering design effort, chemical and foreign-body contamination should not be overlooked. For present purposes, chemicals include cleaning and sanitizing materials, and dust and other atmospheric contamination may be classed as foreign bodies. Hygienic design should also address the ease of dismantling the equipment for cleaning and maintenance. It should provide an appropriate balance between the need to provide for cleanliness and hygiene, on the one hand, and mechanical and electrical safety on the other.

See Brougham (2011) for a detailed description of cleaning and disinfection systems.

4.4 Design Principles

This section details some of the more important principles of hygienic design. The examples cited have been taken from Campden Technical Memorandum No. 679 (Timperley and Timperley 1993). Although the latter focuses on meat-slicing machines, the information presented is of general validity.

4.4.1 Permanent Joints

The Machinery Regulations (1992) state that "assemblies," i.e., the joining of two or more parts, should preferably be made by welding or continuous bonding so as to reduce projections, edges, and recesses to a minimum. They also state that "the joint must be smooth and must have neither ridges nor crevices which could harbor organic materials."

It is recognized that, in some cases, continuous welding may result in unacceptable distortion. In this case, intermittent welds may be employed. These create crevices and may retain product residues and harbor microorganisms, which cannot be removed or destroyed; these may subsequently grow out and contaminate the product. Permanent joints can be sealed effectively by other methods such as silver soldering but the solder must not contain cadmium. It may be necessary to employ both welding for strength and silver soldering for sealing. Welds must be ground and polished to a standard of finish equal to that of the surrounding material.

When two pieces of metal are to be joined together by welding, they should not be lapped because, as shown in Fig. 4.1a, b, a ridge is formed which makes cleaning more difficult. An uncleanable crevice is created at (A) if the joint is intermittently welded (Fig. 4.1a). While a continuous weld, as shown in Fig. 4.1b, would eliminate the crevice, there would still be a ridge even if the filled weld were to be ground and polished. Wherever possible, the two pieces should be butt welded, as shown in Fig. 4.1c, and the surface on the product side ground and polished to the same finish as that of the adjacent surfaces.

4.4.2 Semipermanent Joints

From a manufacturing viewpoint, many components have to be made individually and fixed together by means of fasteners, such as bolts and screws. Many of these joints are of a semipermanent nature and are not routinely broken, e.g., on a daily or even weekly basis, for cleaning. Such joints may

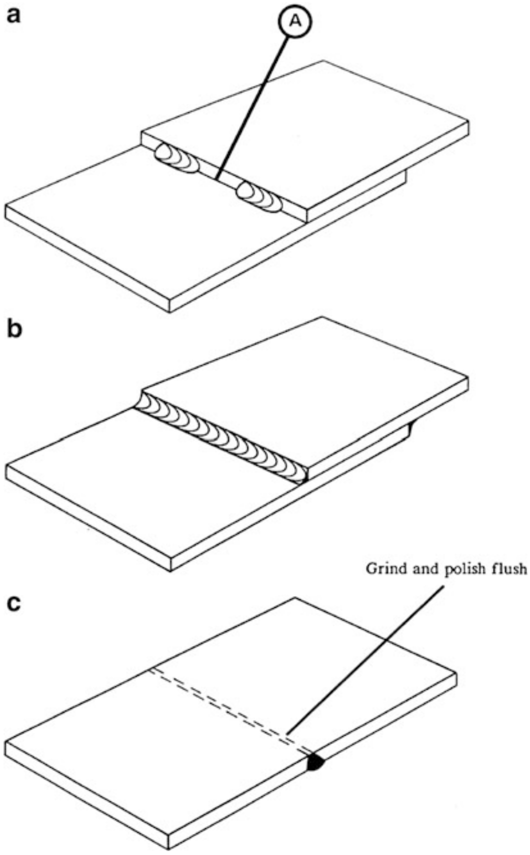


Fig. 4.1 Examples of hygienic and unhygienic welded joints

harbor product residue and high microbial counts. Hence, all such joints must be sealed against the ingress of product, liquids (from cleaning), and microorganisms by means of a gasket. It is recommended that, where possible, a gasket material such as the FDA-approved GYLON is used; controlled compression of gaskets is, of course, essential. In certain cases, the mating surfaces are coated with a silicone rubber sealant prior to assembly. However, it has not yet been proven how effective and lasting this technique is.

The semipermanent joints shown in Fig. 4.2 are used as a means of construction and are not intended for frequent disassembly. Uncleanable crevices are denoted by (A). In both (a) and (b), unhygienic fastening arrangements are employed; see Sect. 4.4.3.

Figure 4.3 shows what is claimed by Timperley and Timperley (1993) to be potentially the most hazardous part of a meat-slicing machine from the microbiological view. It is referred to as the shear edge and is a strip of material attached by screws to the end of the log feed bed. It is usually constructed from plastic because the blade passes over its end face, and any other harder material could cause damage to the blade if contact was made. There is a crevice in the joint at (A), Fig. 4.3a, between the plastic and metal. In all instances where the shear edge is not removed for cleaning on a daily basis, this crevice has been found to contain residual product and is a potential site for the growth of pathogenic microorganisms.

The example shown in Fig. 4.3a is also secured in an unhygienic manner by means of recessed head socket screws. A more hygienic arrangement is shown in Fig. 4.3b in which thread inserts have been used in the plastic and hexagonal-headed screws inserted from the nonproduct side.

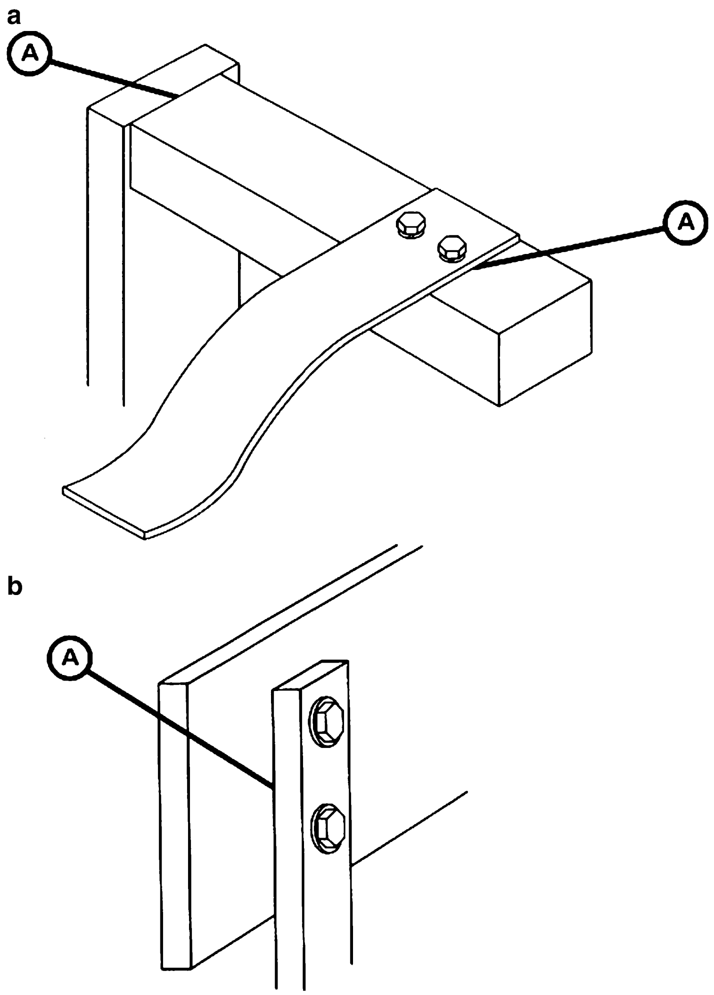


Fig. 4.2 Examples of unhygienic semipermanent joints

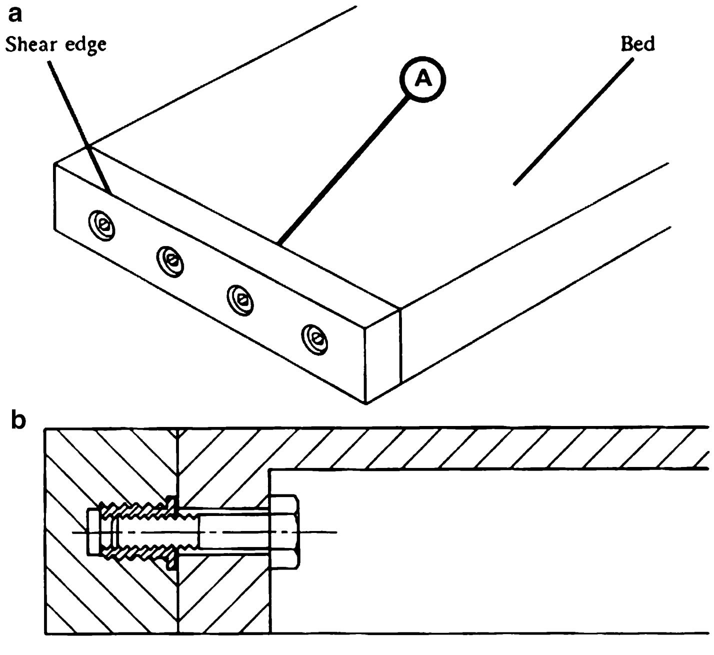


Fig. 4.3 Shear edge of a meat-slicing machine

4.4.3 Fasteners

It is stated in the Machinery Regulations (1992) that screws, screwheads, and rivets may not be used except where technically unavoidable. Due to the complexity of many food-processing machines, particularly those containing rotating parts, many components have to be assembled by means of screws and bolts. Many of these present a potential hygiene hazard because the slots or sockets in the heads can retain product, which may be difficult to remove. The metal–metal joint between the head and the surface can permit the ingress of microorganisms, which may subsequently multiply.

Where fasteners are removed on a daily basis, to remove components or assemblies for cleaning purposes, for example, they are unlikely to give rise to hazardous conditions. However, fasteners that are cleaned infrequently may give rise to hygiene problems.

In some situations it is necessary to prevent nuts and screws from coming loose. This is usually achieved by the use of spring washers; these present a further potential problem because of the gap between the ends. It is suggested that thread locking compound be used instead.

Figure 4.4 shows typical examples of unhygienic fasteners. The illustrations depict hexagon socket head cap screws (a and b), countersunk head screws (c and d), a hexagon socket round head screw (e), and, finally, a recessed hexagon head screw (f). In each case, the sockets (in a, b, d, and e) and the screwdriver slot (in c) may retain product residues. In every case, there is also an unsealed metal–metal joint, denoted by (B). Finally, in (f), there is a large annular space (C), which may also retain product residues.

Figure 4.5, in contrast, illustrates examples of hygienic fastenings. In (a) and (b), the fastenings are on the nonproduct side. If, as shown in (a), the metal on the product side is thin, then a stud can be welded to the nonproduct side to secure the component. However, if the metal on the product side is thicker, a blind hole can be tapped so that the component may be secured by a screw inserted from the nonproduct side, as shown in (b). The effective sealing of metal/metal joints under hexagon heads is illustrated in (c) and (d). Here, a metal-backed rubber washer is used to prevent the ingress of microorganisms. This consists of a metal ring around which a wedge-shaped rubber ring is bonded. The head of the hexagon screw is shown just making contact with the outer edge of the rubber in (e). The screw is shown fully tightened in (f); the inner metal ring prevents over-compression of the rubber and allows the required tightening torque to be applied.

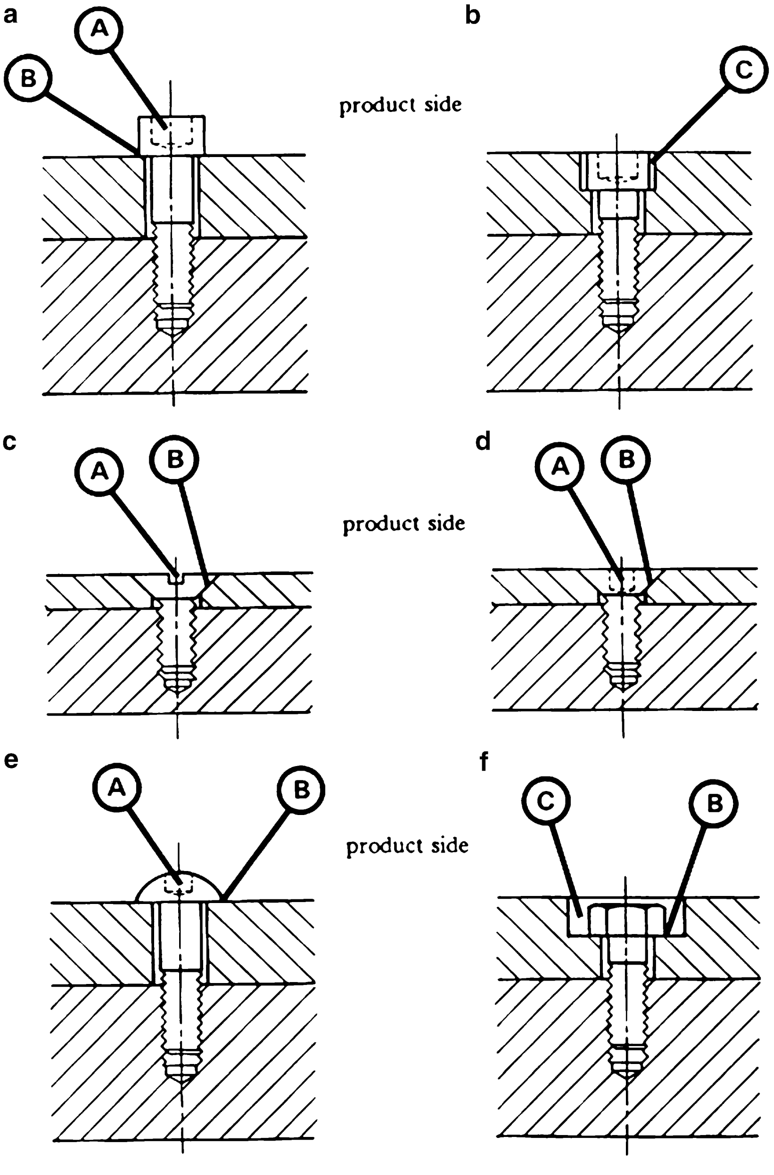
4.4.4 Drainage

The Machinery Regulations require that liquid deriving from foodstuffs should be capable of being discharged from the machine without impediment. The same is true of cleaning, disinfecting, and rinsing fluids. Examples of properly engineered equipment are given in Sect. 4.5.

4.4.5 Internal Angles and Corners

The Machinery Regulations require that inside surfaces have curves of a radius sufficient to allow thorough cleaning. Although no value can be given, especially as a radius may not be technically achievable, it should be as large as possible. A radius can be obtained when metal is bent or machined but, when components are bolted or screwed together, a sharp corner is usually

Fig. 4.4 Examples of unhygienic fasteners



unavoidable. Such arrangements in product areas should be avoided in the design or kept to a minimum unless the components are routinely removed for cleaning.

Figure 4.6 shows examples of different internal corners. In (a), the weld is on the product side and is both difficult to clean and difficult to grind and polish. As a result, it should be avoided. In (b), the weld is on the nonproduct side. This results in a crevice (A) that is difficult to clean; this method of fabrication should therefore also be avoided. Where possible, the metal should be bent to form a smooth, easy to clean radius, as shown in (c). If, as in (d), a joint is necessarily close to an internal angle, then the metal should be bent and a butt-welded joint made away from the corner. This can be more easily ground and polished flush to the same finish as that of the adjacent surfaces.

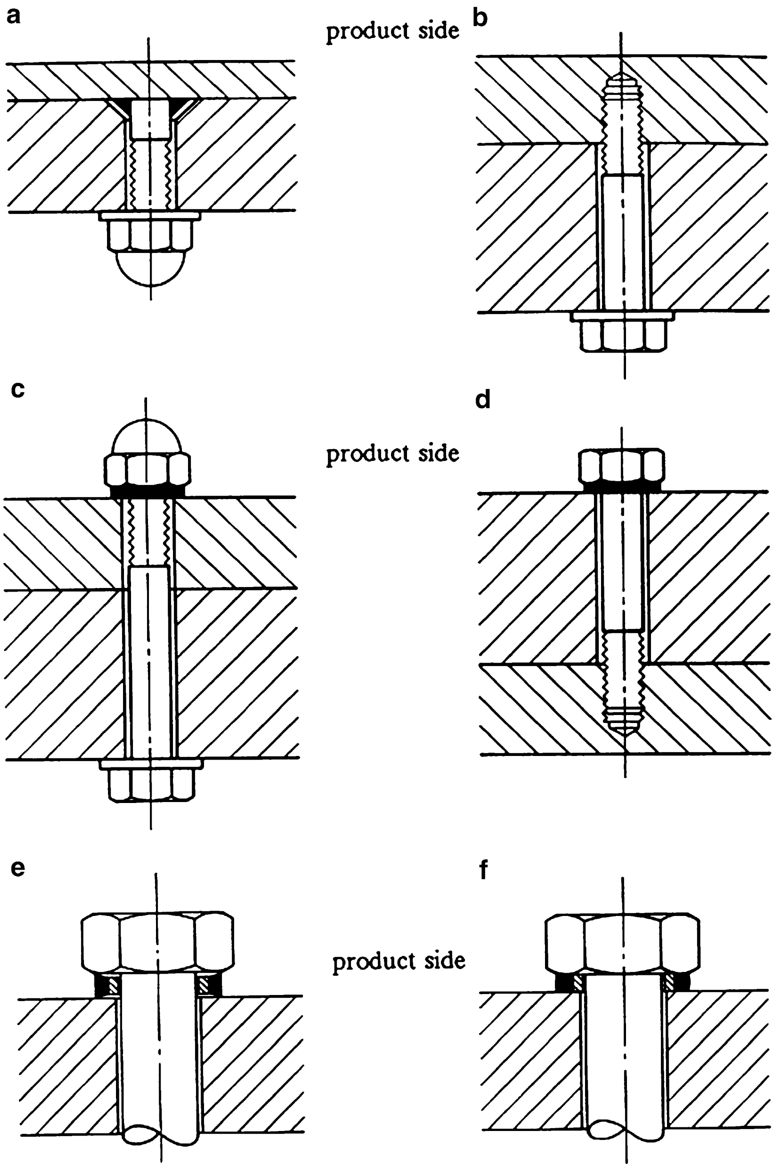
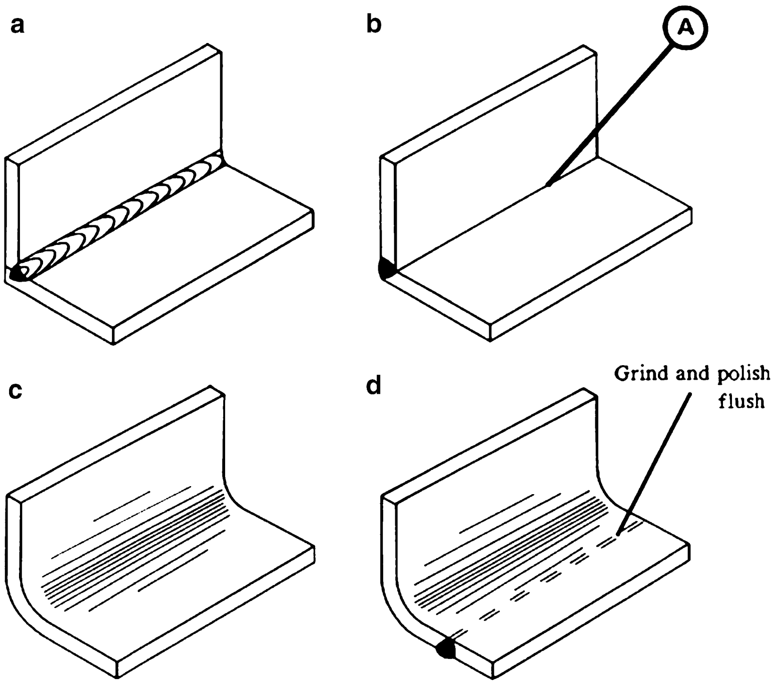


Fig. 4.5 Examples of hygienic fasteners

4.4.6 *Dead Spaces*

Dead spaces are those parts of the equipment in which product residues or cleaning fluids can be retained and subsequently contaminate the product. The Machinery Regulations state that equipment must be designed and constructed so as to prevent the ingress of liquids and living creatures (e.g., insects) into any areas that cannot be cleaned. In addition, organic matter must not be permitted to accumulate in such areas. In practice, this means that any space within a machine must be effectively sealed by means of a suitable gasket or be designed for regular dismantling to permit the space to be cleaned and disinfected. The gasket material must, of course, be approved for food-contact applications if it is in the product zone, and its condition should be checked periodically because some materials such as rubber eventually harden and crack in service.

Fig. 4.6 Examples of good and bad internal angles and corners



4.4.7 Bearings and Shaft Seals

The Machinery Regulations require that machinery must be designed and constructed so as to prevent ancillary substances (e.g., lubricants) coming into contact with foodstuffs. In addition, provision must be made to ensure that, where necessary, continuing compliance with this requirement can be checked. Bearings should be either of the "sealed-for-life" or "double-sealed" variety and should be located external to the equipment in order to minimize contact with product. Bearing covers should be fitted where possible. Note, however, that seals ultimately wear and leak. Their condition must therefore be monitored regularly and they must be replaced periodically as part of planned maintenance programs.

It is essential that noncompatible lubricants should not come into contact with the product. Therefore, where possible, edible greases such as acetylated monoglycerides should be employed. It is advisable to avoid steam cleaning of lubricated bearings. If this is essential, they should be allowed to dry out before they are relubricated. Any excess lubricant should be removed.

In order to prevent damage to the seals, they should also be designed so as to minimize the ingress of product particles. In many cases, however, the total exclusion of particles is not economically possible. Under these circumstances, the seals should be subject to frequent cleaning.

4.4.8 Controls

The operator who operates the controls often handles product. As a result, contamination from residual product on controls can be transferred to fresh product immaterial of whether the operator wears gloves or not. Controls must therefore be of hygienic design so that they can be maintained in a

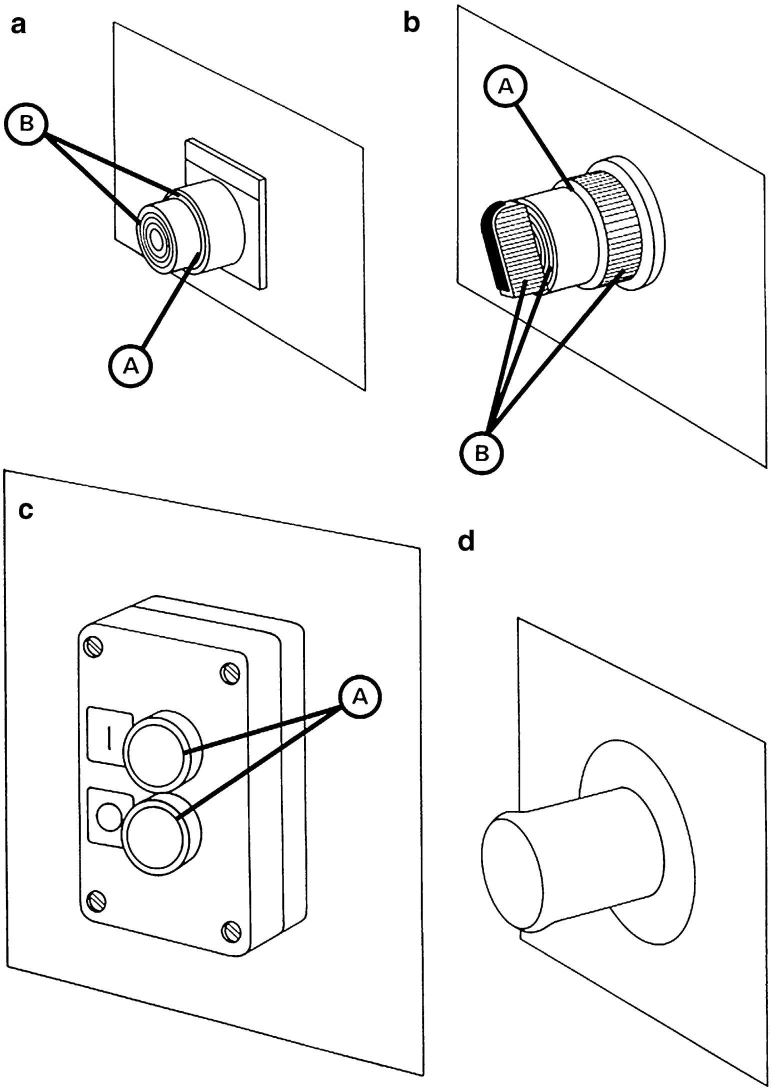


Fig. 4.7 Examples of hygienic and unhygienic controls

clean condition. It goes without saying that they must be capable of withstanding whatever cleaning regime is used on the entire machine; this may involve high-pressure water jetting.

Most push buttons and rotary selector switches have many uncleanable crevices. Although protective caps can be fitted to push buttons, which does give some improvement, the ends often become split by fingernails. Wherever possible, touch panels having a membrane covering should be used, as these can be easily kept clean throughout production periods by the regular use of disinfectant-impregnated disposable wipes.

Some examples of good and bad controls are shown in Fig. 4.7. The type of push button switch shown in (a) has an uncleanable annular crevice (A) and grooves that are difficult to clean (B). The fitting of a protective rubber cap would be an improvement, but its condition would have to be checked regularly. The rotary selector switch (b) suffers from similar deficiencies: an uncleanable annular crevice (A) and difficult-to-clean grooves (B). A protective rubber sleeve fitted at the base of the switch would provide only partial improvement. Although a protective rubber cap would cover the uncleanable annular crevices (A) in (c), the cap in this instance is very prone to damage from fingernails because the end of the push button is flush with the fixed outer sleeve. In addition, the recessed screws would be difficult to clean.

The construction of the emergency stop button shown in (d) is such that it is totally enclosed and meets the requirements of the Machinery Regulations in that it has to be pulled out to reset it. It is protected against the ingress of water and its smooth profile makes it easy to clean.

4.4.9 Equipment Location and Installation

The discussion to date has concentrated on individual items of equipment. In practice, hygiene is also affected by their location and installation and these aspects also require detailed consideration. A number of important points that should be taken into consideration have been listed in Campden Technical Manual No. 17 (Timperley 1997). These were elaborated by Shapton and Shapton (1998).

1. There should be sufficient height to allow adequate access for inspection, cleaning, and maintenance of the equipment and cleaning of the floors.

   In practice, small items of equipment, including motors and gearboxes, should be mounted at least 200 mm off the floor (Foresythe and Hayes 2000). Larger items require a greater clearance. Shapton and Shapton (1998) concur with the recommendation of Ridgeway and Coulthard (1980) that this should be sufficient to allow a brush, held at 30° to the horizontal, to reach the center line of the machine. This permits the floor underneath the equipment to be fully cleaned from both sides without the cleaner having to stoop.
2. All parts of the equipment should be installed at a sufficient distance from walls, ceilings, and adjacent equipment to allow easy access for inspection, cleaning, and maintenance, especially if lifting is involved.

   In practice, there should be a minimum clearance of 1 m between the equipment and the nearest wall, ceiling, and adjacent plant item.
3. Ancillary equipment, control systems, and services connected to the process equipment should be located so as to allow access for maintenance and cleaning.

   Shapton and Shapton (1998) cite ICMSF (1988):

   > It is worth repeating an earlier observation about the need properly to encase and waterproof all electrical and other service or control facilities/connections; leakage from conduits can be a potent source of contamination. Similarly it is important to install liquid flow connections, such as vacuum breakers, that do not permit back-siphonage of liquids, as this can lead to microbiological contamination of processed product by unprocessed product or even by waste water.

   Note that mounted switchgear should be either sealed to the wall (the preferred option) or mounted with a minimum clearance of at least 500 mm from it. All electrical equipment should be sealed to a minimum of IP65 in wet areas and IP5 elsewhere.
4. Supporting framework, wall mountings, and legs should be kept to a minimum. They should be constructed from tubular or box-section material, which should be sealed to prevent ingress of water or soil. Angle- or channel-section material should not be used.

   To prevent the collection of soil on flat surfaces, horizontal square tubing should be rotated through 45°.
5. Base plates used to support and fix equipment should have smooth, continuous, and sloping surfaces to aid drainage. They should be coved at the floor junction. Alternatively, ball feet should be fitted.
6. Pipework and valves should be supported independently of other equipment to reduce the chance of strain and damage to the equipment, pipework, and joints.
7. Avoid draining equipment directly onto the floor.

8. Avoid, as far as possible, installation practices that introduce, for example, ledges and soil traps, recess corners, spot, or tack welds, which result in incompletely sealed seams and projecting bolt threads.

Katsuyama and Strachan (1980) advise the following: tubular support braces should be welded to structural members; open tubes should be capped; drilling into tubes should be avoided.

Campden Technical Memorandum 17 notes that in situations where soil trapping occurs because of inadequate attention to hygienic design or installation, there is a real likelihood that:

1. Cleaning operations will involve more time and increased costs.
2. Clean-in-place (CIP) procedures may not remove all soil deposits.
3. Failure to remove soil may result in microbial growth and contamination of products.
4. The risk of a corrosion attack associated with retained soil will be increased.

4.4.10 Examples of Do's and Don'ts

The Campden Hygienic Design Working Party (CCFRA 1983) set out the following "Do's" and "Don'ts" relating to good practice in hygienic design, cleaning, and sanitation.

Do

1. *Do* ensure that all surfaces in contact with food are completely self-draining and can be easily and quickly reached to ensure adequate cleaning.
2. *Do* ensure that all pumps and valves in contact with food are of sound mechanical and hygienic design, that the surface finish meets the required specifications, and that the installation is hygienic and will allow complete drainage.
3. *Do* ensure that tank inlets and outlets are flush with interior surfaces and are self-draining.
4. *Do* ensure that there are no internal filth traps around any stirrer, probe, or level-control fittings inside tanks.
5. *Do* seal the ends of all hollow-section frames wherever used.
6. *Do* position framework members and brackets so as to avoid horizontal flat surfaces wherever possible.
7. *Do* keep machine design as open as possible and avoid dark, difficult-to-reach corners.
8. *Do* ensure that any oil drip trays that are provided under motors and gearboxes can be drained and cleaned.
9. *Do* make product catch trays large enough, slope them to drain at the lowest point, provide them with a big enough drain to avoid blockage, and make it accessible for visual inspection, especially after cleaning.
10. *Do* ensure that proper provision is made at the design stage for waste and effluent removal.
11. *Do* design conveyors so that the belt can be readily slackened, thereby allowing it to be raised clear of the bed for cleaning.
12. *Do* design the cleaning programs as part of the installation right from the start.
13. *Do* ensure adequate access for hose cleaning when ensuring that guarding complies with health and safety requirements.
14. *Do* leave adequate clearances under and around machinery to allow for effective cleaning and ensure that floor-bearing surfaces are either sealed or can be cleaned.
15. *Do* ensure that movable joints and hinges can be easily cleaned.
16. *Do* plan to clean in place if possible—including conveyors and elevators in addition to tanks, pipework, and other equipment.

17. *Do* remember that some items of equipment and installations such as ball valves and horizontal pipelines are particularly difficult to clean.
18. *Do* design for the hygienic installation of control equipment and cables.

Don't

1. *Don't* use a socket head or other screws where these might constitute a product trap point.
2. *Don't* drill into hollow sections where product contamination could occur.
3. *Don't* allow soil-trapping ledges over the product path.
4. *Don't* create "dead spots" where product may be retained for a time and subsequently dislodged back into the system.
5. *Don't* allow any surfaces to harbor any form of dirt, oil, or grease.
6. *Don't* place vulnerable electrical equipment where damage may arise during washing or cleaning operations.

4.5 Examples of Hygienic Design

This section describes several examples of the proper application of the design principles described above. Taken mainly from Campden reports, they focus on pumps, pipework, and fittings (Timperley 1997), post-process can handling (Thorpe and Barker 1985) and product transfer in fruit and vegetable processing lines (CCFRA 1983). Only a brief overview of these topics is possible here because of space limitations. The reader is therefore referred to the original documents for full details.

4.5.1 Pumps

Many types of pump are used in the food industry for applications such as filling, emptying, transferring, and dosing. The choice of pump for any given application depends primarily on the characteristics of the material to be pumped; of particular importance are its rheological properties and its sensitivity to shear. There are, broadly speaking, two classes of pump, which are widely employed in the food industry. Rotodynamic (centrifugal) pumps are used for transferring low-viscosity liquids at relatively high flow rates but at comparatively low heads. Positive displacement pumps, of which there are many types (e.g., lobe, gear, vane impeller, and progressive cavity), are capable of handling high-viscosity and shear-sensitive liquids; several are capable of pumping liquids containing suspended solids with minimal damage.

The choice of a particular pump naturally depends primarily on the type of product being handled and the required process duty. However, in food-industry applications, due attention must also be paid to its hygienic design to ensure that the surface finish is adequate, that there are no crevices or dead spots in which product can be retained, and that the pump casing can be properly drained.

In the food industry, the materials of construction most commonly used for product-contact surfaces in pumps are 304 and 316 stainless steels. In some cases, elastomers and plastics are also used. These should, of course, be compatible with the products to be handled, including detergents and disinfectants, and comply with all relevant legislation relating to materials in contact with food. They should also be capable of withstanding the maximum envisaged process temperature; this will exceed 100 °C if steam sterilization is employed. There are no specific standards for the internal surface finish of pumps. In practice, a roughness similar to that recommended for the internal surfaces of pipes (less than 1 μm R_a) is commonly employed.

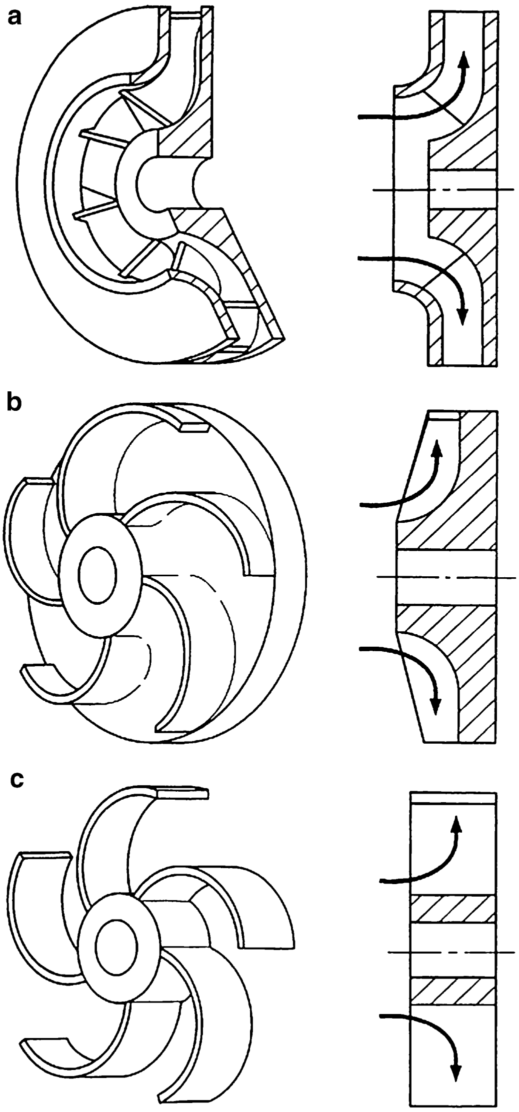


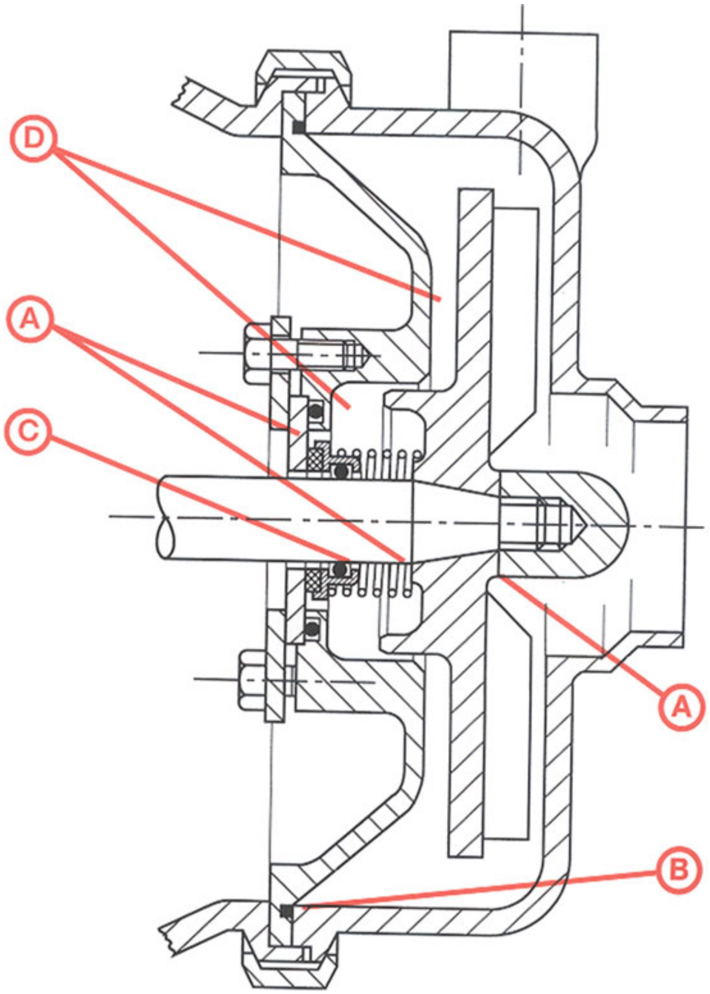
Fig. 4.8 Types of centrifugal pump impeller

By way of example, we will now consider the application of hygienic design principles in relation to centrifugal pumps. The reader is referred to Timperley (1997) for similar details relating to several types of positive displacement pump.

Centrifugal pumps are widely used in the food industry. They are of simple design and relatively inexpensive. Liquid is directed into the eye of an impeller rotating at around 3,000 rpm, which elevates both its pressure and velocity. On leaving the impeller, it is directed into a volute-shaped casing from which it is discharged tangentially. Mechanical seals are widely used to seal the shaft. A single seal is adequate for hygienic design purposes but a double seal is required for aseptic duties. In this case, the space between the two seals is continuously flushed with either steam or antimicrobial fluid.

The typical types of impeller and shroud shown in Fig. 4.8 illustrate well the compromises that have to be made to ensure a hygienic design. The fully shrouded impeller (a) is the most efficient from a mechanical viewpoint, but the channels cannot be polished economically. The unshrouded impeller (c) is the least efficient but is the easiest to polish. The partially shrouded design shown in (b) represents an acceptable compromise between (a) and (c). An alternative design features a fully

Fig. 4.9 Centrifugal pump—unhygienic design features



shrouded impeller with a detachable front shroud in an attempt to achieve the best of both worlds. However, it features metal–metal joints between the impeller body and the front shroud and must therefore be regarded as questionable from a hygienic point of view because these are very difficult to clean in place satisfactorily.

Figure 4.9 illustrates a number of design features that could create hygiene problems in a centrifugal pump; suggested improvements are shown in Fig. 4.10. The two designs are compared in Table 4.8.

As noted above, complete draining of pumps is an essential hygienic design feature. In order to achieve this, correct orientation of the pump is necessary. While it is often convenient to mount the pump with its outlet port pointing vertically upwards, this will result in liquid being retained in its casing. The casing will drain if the outlet is oriented horizontally at the bottom of the pump.

4.5.2 *Pipelines and Fittings*

In large liquid processing plants, the pipework can amount to a considerable proportion of the surface in contact with the product. The correct selection and installation of such pipework and its associated fittings is therefore of prime importance in maintaining plant hygiene.

Fig. 4.10 Centrifugal pump—suggested design improvements

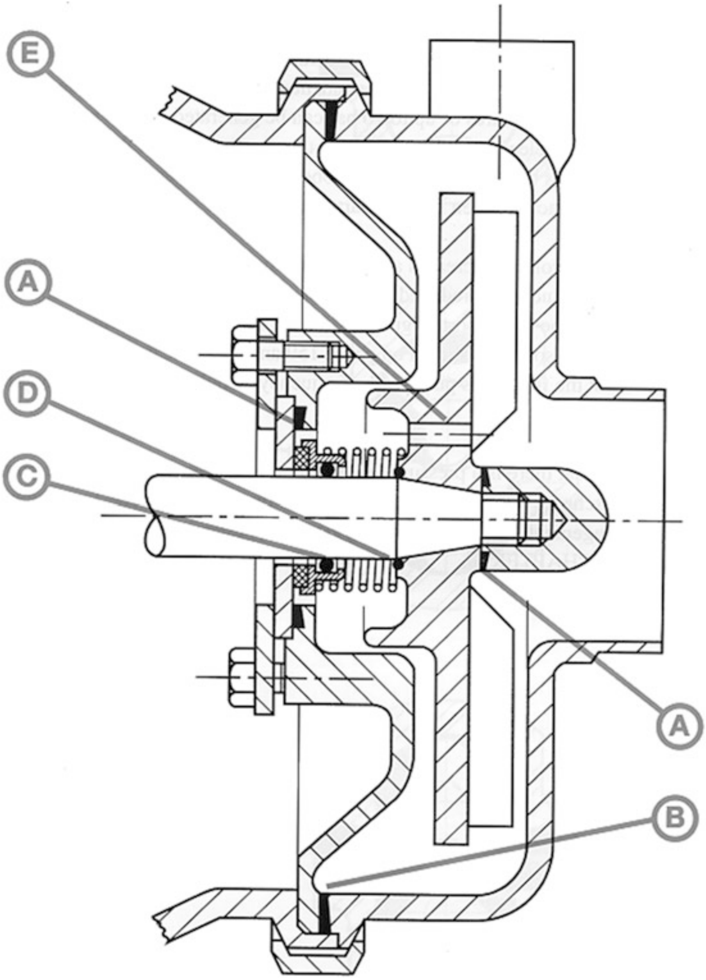


Table 4.8 Comparison of centrifugal pump designs

Unsatisfactory design, Fig. 4.9		Satisfactory design, Fig. 4.10	
Symbol	Description of feature	Symbol	Description of feature
(A)	These metal–metal joints may permit the ingress and retention of product and microorganisms	(A)	This metal–metal joint has been eliminated by means of a controlled-compression gasket
		(D)	This metal–metal joint has been eliminated by fitting a hygienic o-ring seal
(B)	Product residues may be retained in this crevice if cleaning-in-place is employed	(B)	Cleanability is improved by radiusing the corner and moving the gasket away from the corner
(C)	Product residues may be retained in this annular space after cleaning	(C)	The radial gap is increased to improve cleanability of the annular space
(D)	These areas experience low flow and the surrounding surfaces may not be properly cleaned if clean-in-place techniques are employed	(E)	The flow of liquid behind the impeller is increased to improve cleanability of the surfaces by placing holes in the shroud

4.5.2.1 Steel Pipe

Most pipelines are constructed of stainless steels; types 304 and 316 are the most widely used materials. As specified in ISO 2037: 1992 (E) and BS 4825: Part 1: 1991, the internal surface finish should be less than 1.0 μm R_a. This can be achieved with descaled or bright-annealed finishes without the need for mechanical polishing. Tube is manufactured in either seamless or welded form. While the former is highly regarded for its high quality, the latter is now widely used as it is satisfactory for most applications and less expensive than seamless tube. It is essential, however, that there should be full penetration of the weld, which should be smooth and flush with the interior of the pipe.

Stainless steel tubing is available with outside diameters ranging from 25.0 to 51.0 mm with a wall thickness of either 1.6 or 1.2 mm. It is most important that the internal diameters of pipe and fittings, including welded-type couplings, flanges, and gaskets, are properly matched as any abrupt changes in the bore can give rise to cleaning problems

4.5.2.2 Plastic Pipe

In certain applications, particularly those involving highly acidic products containing chlorides, plastic pipe is superior to steel pipe in terms of corrosion resistance. Plastic pipelines are also used for potable and ultrapure cold water. All plastics that come into contact with product must be approved for such use in the country concerned. Where there are no national standards, the plastic should comply with the internationally recognized standards such as the American Food and Drug Administration (USFDA) or the German Bundesgesundheitsamt (BGA). The material should naturally be compatible with any cleaning fluids used.

The plastics most commonly used in food-industry applications are polyvinyl chloride (PVC), acrylonitrile butadiene styrene (ABS), and polypropylene (PP). The operating temperature ranges for these materials are PVC (5–60 °C), ABS (−40 to 80 °C), and PP (−20 to 90 °C). The maximum operating pressure depends on the temperature and the wall thickness. Plastic pipes are lighter and cheaper than their steel counterparts and their surface finish is superior. However, plastic pipework requires more frequent support to prevent sagging, which may offset any possible cost advantages.

Flexible tubing for food-industry use is available in PVC, ethylene vinyl acetate (EVA), low-density polyethylene (LDPE), and polytetrafluoroethylene (PTFE), among other materials. Most have a maximum operating temperature of between 60 and 70 °C, but PTFE is suitable for continuous use at temperatures in excess of 200 °C. Flexible tubing is available in reinforced or unreinforced forms with smooth or convoluted bores. The latter are more flexible but may experience cleaning problems.

Rubber (natural as well as synthetic) hoses are used in the dairy and brewing industries to fill or empty road tankers. The rubber must be approved for food-industry use and be compatible with the chemicals employed for cleaning and disinfection. Regular inspection of hoses is necessary as rubber deteriorates more rapidly than many materials.

4.5.2.3 Connections

There are two basic methods of joining lengths of pipework. Orbital welding is frequently used in large semipermanent installations. The process is automatic and, if properly executed, is capable of producing consistent, high-quality welds that do not require polishing.

Couplings are used when welding is impractical as, for example, when frequent dismantling and reassembly are required. A large number of different types of coupling are available, which are made to international and national standards as well as to equipment manufacturers' proprietary designs. Most types are available in versions that can be butt welded to the end of the pipe or attached by means of an expanded-type fitting. When using a welded coupling, care should be taken to ensure that the inside diameter of the fitting is the same as that of the tube and that the welded parts are constructed from the same grade of steel.

Table 4.9 summarizes the principal types of stainless steel coupling employed in the food industry, together with their main features. Several of these are illustrated in Fig. 4.11. The following features are required of a hygienic coupling. First is an absence of metal–metal joints, which can permit the ingress of microorganisms. Secondly, where gaskets are employed, care should be taken to ensure that they do not protrude into the bore of the tube as this will result in cleaning problems. This is best avoided by the use of customized gaskets and controlled compression. Finally, designs that feature internal crevices, which may harbor food residue and microorganisms, are also unsuitable.

Timperley (1997) also describes a variety of couplings for rigid plastic pipework. These are frequently of plastic construction, which are "welded" to the pipes. Solvent welding is normally used for ABS and PVC pipe and fusion welding for PP pipe. Flanged couplings are also employed; these normally feature galvanized steel backing plates to effect rigidity. The principal problem associated with both types of connection is the presence of internal crevices. However, these can normally be eliminated by good design. A typical example is illustrated in Fig. 4.12, where (A) is a customized gasket, which, when properly installed, is flush with the pipe bore.

Connections between flexible plastic hoses and stainless steel pipes were also discussed by Timperley (1997). These are of particular importance as flexible hoses often have to be used on filling machines and may therefore be a critical point. Such connections are often made by pushing the hose over the pipe stub and securing it with a single worm-drive hose clip. This is unsatisfactory as it results in a potential product trap. This problem is overcome using the arrangement shown in Fig. 4.13.

Flexible plastic hoses may be supplied with hygienic end fittings. With some designs, there may be abrupt changes in the internal diameter, which could result in cleaning problems with viscous products. If convoluted hose is employed, product may be retained after cleaning.

4.5.2.4 Installation of Pipelines

Pipelines should be installed in such a manner as to ensure self-draining. To achieve this, the following guidelines should be followed:

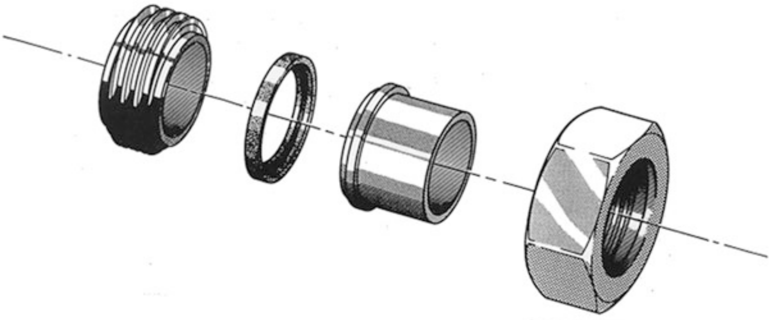
1. Pipelines must be adequately supported to prevent sagging and the resulting retention of residual liquid after draining. In practice, straight runs of stainless steel piping require supports at approximately 3 m intervals. Supports should also be installed either side of valves and at each change in direction. Pipelines should not be rigidly clamped, as this would prevent thermal expansion, thereby causing distortion.

   Plastic pipe is much less rigid than stainless steel pipe and therefore requires supporting at more frequent intervals. The coefficient of thermal expansion of most plastics is significantly higher than that of stainless steel. As a result, special attention must be given to the design and layout of plastic pipelines, with due provision being made for expansion loops. Pipes may be supported from the wall, the ceiling, or the floor. Supports should be of good hygienic design to minimize dirt and dust traps (see, e.g., Moerman 2011).
2. Pipelines should be installed so as to give a fall of about 1 in 100 if possible, to drain at the lowest point of the system. Where there is a restriction in a horizontal pipeline due, for example, to a flowmeter, the pipework on both sides of the restriction should fall to drain.

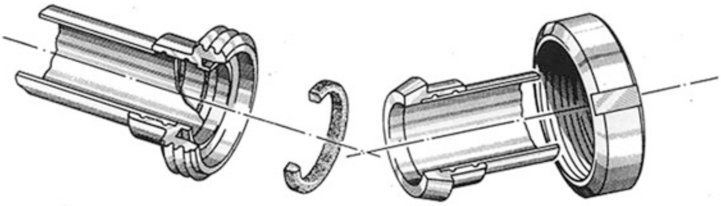
Table 4.9 Features of stainless steel pipework connections

Coupling type	Relevant standards	Comments
IDF-type coupling—welded	ISO 2852: 1993 BS 4825: Part 4: 1991 IDF Standard 14, 1960	Intended primarily for applications involving in-place cleaning. Overtightening can result of the protrusion of the gasket into the bore. The trapezoidal thread makes these couplings unsuitable for applications involving frequent dismantling
IDF-type coupling—expanded	ISO 2852: 1993 BS 4825: Part 4: 1991 IDF Standard 14, 1960	Protrusion of the gasket may result in the retention of food residues after cleaning
Clamp-type coupling	ISO 2852: 1993 BS 4825: Part 4: 1991 IDF Standard, 1960	Suitable for applications involving in-place cleaning where frequent dismantling is necessary. Welded and expanded versions are available. The welded version is preferable for handling viscous products
SMS coupling	SMS 1145, 1957	The standard describes four screwed-type expanded couplings. All feature rounded screw threads, which make them suitable for frequent dismantling. Only one version is considered suitable for handling viscous products and for in-place cleaning. The others have an internal annular crevice
DS coupling	DS 722, 1955	Similar to one version of the SMS coupling. An annular crevice between the ends of the tubes and the bore of the gasket may retain product. Suitable for frequent dismantling
DIN coupling	DIN 11851, 1989	Expanded-type screwed coupling. Undesirable features include an internal annular crevice and metal–metal joints resulting in possible retention of product and microorganisms. An alternative design eliminates these problems. Suitable for frequent dismantling as threads are rounded
RJT (ring joint type) coupling	BS 4825: Part 5: 1991	Both welded and expanding versions are available. Easily dismantled. An internal annular crevice makes it unsuitable for in-place cleaning
3-A coupling—ground seat type	US 3-A Sanitary Standard 08-17 Rev, 1976	Expanded-type coupling. A conical metal-to-metal seat often requires a high wrench torque to effect a seal. The seat, together with an internal annular crevice, makes it unsuitable for in-place cleaning. A similar fitting, described in BS 3581:1963, has now been withdrawn
3-A coupling—gasket seat type	US 3-A Sanitary Standard 08-17 Rev, 1976	Gasket seat screwed coupling. When correctly assembled, a smooth crevice-free internal surface is obtained. Suitable for handling most products and for in-place cleaning
Flanged joints	–	Joints without gaskets are unhygienic (metal–metal joints); discontinuities in bore due to misalignment. An improved design features a gasket and spigot–recess arrangement to ensure alignment and controlled gasket compression. Suitable for in-place cleaning

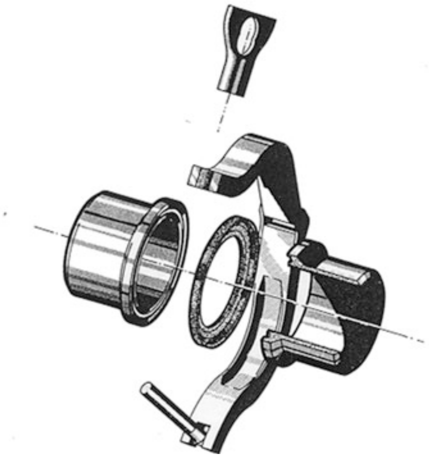
Fig. 4.11 Examples of pipe couplings



IDF Coupling



DIN Coupling



Clamp-type Coupling

3. Changes in pipe diameter should be made as smoothly as possible as abrupt changes may give rise to cleaning and drainage problems. The blanking piece shown in Fig. 4.14a, for example, is unsatisfactory, for two reasons. Firstly, residual liquid will be retained in (A) when the flow to drain is in the direction shown. Secondly, product can be retained at (B). The concentric reducer shown in (b) cannot be drained either; liquid is again retained at (A). Eccentric reducers, Fig. 4.14c, are satisfactory in this respect and should be used.
4. Blanked-off tees and other dead-legs should be avoided wherever possible, as they constitute a potential hazard. This is discussed further below.
5. Undrainable sections can result when a level change of horizontal pipe is necessary to avoid obstructions—see Fig. 4.15a. A drainable arrangement is shown in Fig. 4.15b.

Fig. 4.12 Hygienic plastic pipe coupling

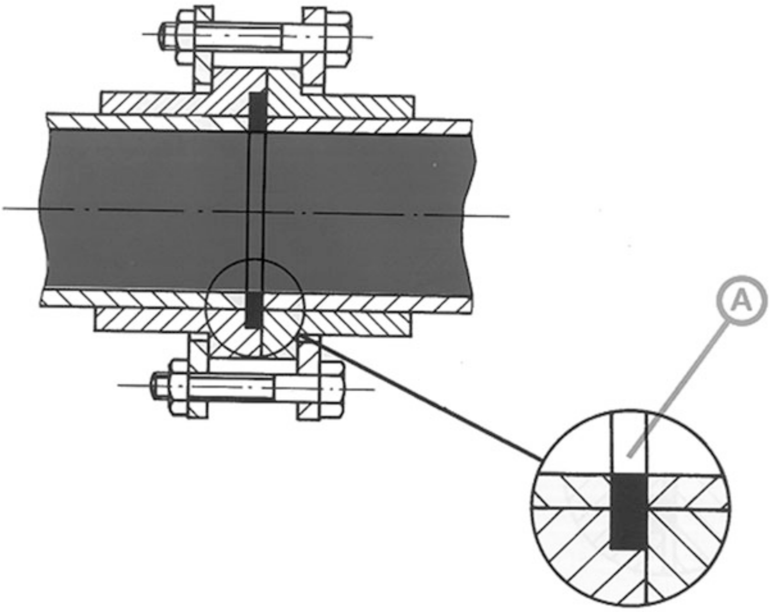


Fig. 4.13 Hygienic hose connection

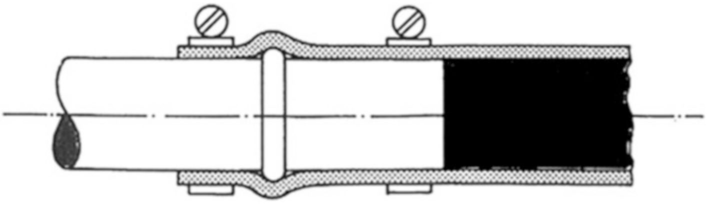
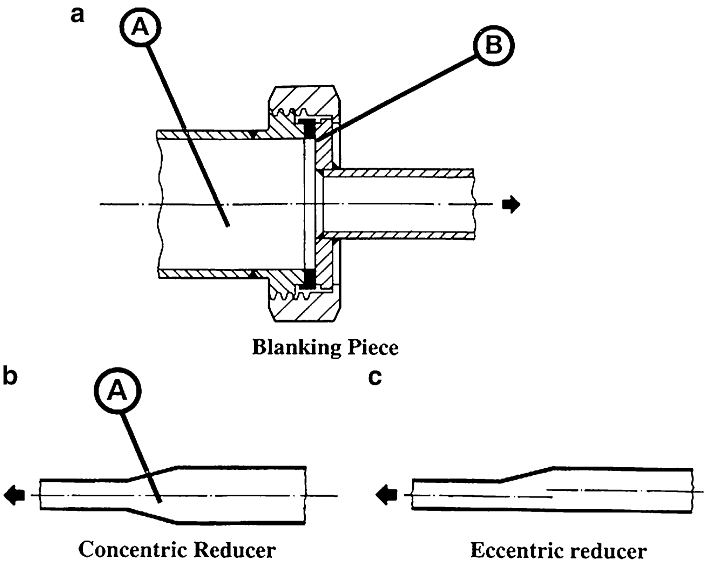


Fig. 4.14 Examples of satisfactory and unsatisfactory reducer



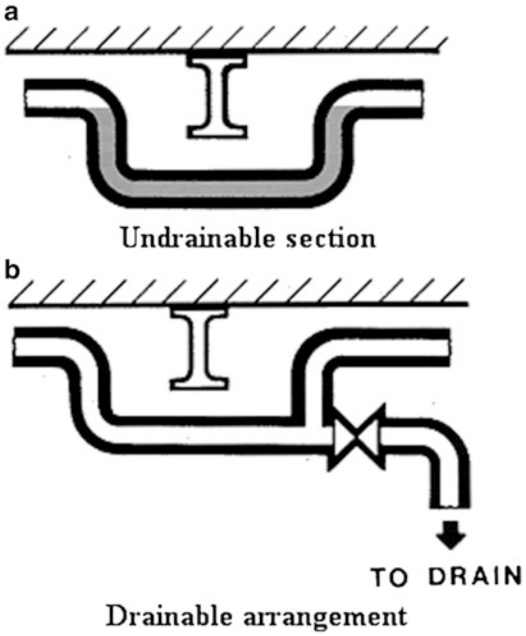


Fig. 4.15 Satisfactory and unsatisfactory pipe drainage arrangements

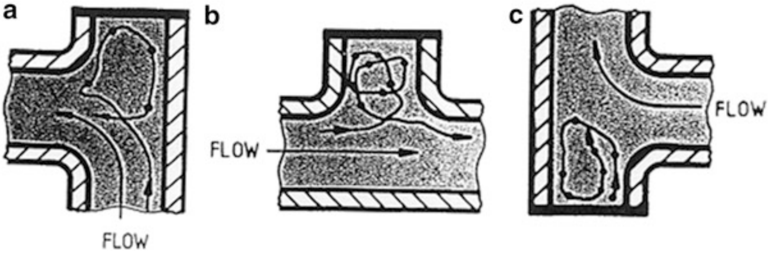


Fig. 4.16 Flow visualization within "dead-legs"

4.5.2.5 Dead-Legs

As noted above, dead-legs should be avoided whenever possible. Where their use is absolutely necessary, as, for example, to mount sensors, they should be designed to be self-draining and to facilitate effective cleaning. Typical examples of tees, each of which has the same dimensions, are shown in Fig. 4.16. That shown in (a) is satisfactory. The branch is self-draining and, as the fluid is directed into the branch at a relatively high velocity, cleaning is satisfactory. In (b), the flow is across the dead-leg. This results in lower flows and hence less satisfactory cleaning. Flow away from the dead-leg, as in (c), results in even poorer cleaning.

Another cause of dead-legs is faulty design or installation of plant. Consider, for example, the two feed vessels shown in Fig. 4.17a. These share a common discharge line and are in continuous use for lengthy periods of time. A typical production cycle could be as follows:

1. Vessel 2 acts as the feed tank while vessel 1 is being filled.
2. Vessel 1 then acts as the feed tank while vessel 2 is being filled, and so on.

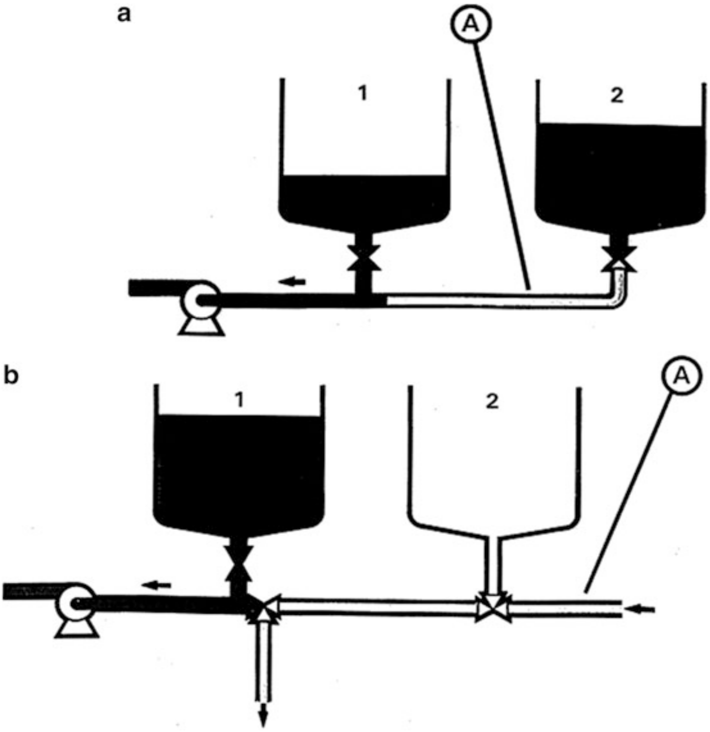


Fig. 4.17 Satisfactory and unsatisfactory tank outlet arrangements

Stagnant product remains in line (A) between the vessels while vessel 2 is being refilled. Depending on the product, its temperature, and the time, this arrangement may give rise to microbiological and perhaps cleaning problems. A better arrangement is shown in Fig. 4.17b. This permits the line between the vessels to be given an intermediate rinse of potable water at (A). This arrangement also prevents the line from being backfilled should the feed be taken from vessel 1 first. Special precautions are, however, required to prevent contamination if detergent rather than potable water is used as the intermediate rinse.

4.5.2.6 Air Pockets

Care should be taken to avoid air pockets in pipework, as these will create cleaning problems. Examples of where they may occur include the branch of a blanked-off tee pointing vertically upwards and in the raised section of a horizontal run of pipe routed vertically upwards and then downwards to avoid beams, doorways, and other obstructions.

4.5.2.7 Pipework Insulation

Insulation used in food-production areas must be nontoxic, resistant to moisture when applied to cold pipes, and must not support mold growth. If necessary, the bare pipework should be coated with a protective paint to prevent stress corrosion. The insulation should be sealed with a nontoxic, mildew-resistant coating, which should provide a vapor barrier in areas of high humidity. A suitable cladding (aluminum, stainless steel, or glass-reinforced plastic) should be used to protect pipework liable to mechanical damage.

4.5.3 Valves

Valves are widely used in the food and drinks industry to control liquid flow. They fulfill a variety of roles: shut off, diversion, pressure and flow regulation, pressure relief, and non-return. As with many other plant items employed in the food industry, types 304 and 316 stainless steels are widely used as construction materials. While there are no standards for the surface finish of valve components that come into direct contact with product, this is normally specified as being less than 1 µm R_a.

Table 4.10 summarizes the principal types of on/off and diversion valves commonly used in the food industry. The selection of an appropriate valve for a given duty depends on several factors. For example:

1. Is the envisaged application aseptic or hygienic?
2. Is diversion as well as on/off capability required?
3. Is automated or remote operation required?
4. What are the physical and chemical characteristics of the product? Does it contain solids?
5. Cost implications?
6. Are frequent inspection and/or maintenance likely to be a problem?

Figure 4.18 illustrates several of the types of valve listed in the table.

Where cleaning-in-place is planned, a single valve seat must never be relied upon to protect the product from the cleaning fluid even if the product is to be maintained at a higher pressure. In such circumstances, two valves with the space between them open to the atmosphere may be used. However, this arrangement has largely been superseded by the introduction of double-seat, mix-proof, or block-and-bleed-type valves. Figure 4.19 illustrates, by way of example, a mix-proof linear plug and stem valve in the closed (top) and open (bottom) positions. The valve has a space (A) between the two seats so that, if either fails, the fluid will leak to drain through the bore of the lower valve stem (B). Each valve head is held independently on its seat by spring pressure. On opening, the lower valve head is raised off its seat first and moves upwards a short distance before contacting the upper valve head. Both then move together into the open position, as shown.

As noted above, valves also perform other functions in food-manufacturing plants. The flow-control valve, for instance, as its name implies, regulates the flow rate of product through the pipeline. It is similar in construction to an on/off linear plug and stem valve but has a tapered valve head. The valve may be controlled manually but, more frequently, this is done automatically and remotely with the aid of a pneumatic actuator. As is the case with the on/off and diversion types, its suitability for hygienic or aseptic applications is determined by the design of the valve stem seal.

In certain process operations, such as the continuous mixing of aerated products, it is necessary to maintain a constant back pressure. This is achieved by means of a back pressure valve, which may be of the membrane or diaphragm type. The former is suitable for hygienic and aseptic applications.

Pressure relief valves are fitted in food-processing systems to ensure that unforeseen increases in pressure do not create a safety hazard or damage equipment. Most are variants of the on/off linear plug and stem valve fitted with a spring having a much lower rating, which can be varied to suit the requirements. Care should be taken when mounting this type of valve to avoid hygiene problems. A 4-port version of this valve is commonly used to protect equipment on the downstream side of a positive displacement pump from overpressure.

Finally, non-return valves are used to ensure that liquid flows in one direction only. When the flow is in the desired direction, the drag causes the valve head to move away from its seat. When the flow stops, a lightly loaded spring returns the valve head to the seat, thereby preventing flow in the reverse direction. Such valves are unsuitable for use with viscous liquids and, because of the nature of their design, there could be cleaning problems.

Table 4.10 Characteristics of on/off and diversion valves

Valve type	Description	Hygienic characteristics
Plug cock valve	Plug cock consists of a conical plug having either a straight-through port (on/off) or ports arranged in a tee configuration (three-way), which is rotated in the tapered bore of the body	Valve cannot be cleaned in place as product is trapped between plug and bore
Ball valve	Similar to the plug cock valve but the plug is replaced by a sphere (ball). On/off operation only. Not easily dismantled for cleaning. Steam-purged version available	Valve cannot be cleaned in place if it is left fully open after use due to product entrapment. It may be cleanable in place if left in the half-open position—this should be carefully checked, however
Butterfly valve	Comprises a disc, which is rotated through 90° within the valve body. A rubber seal clamped between the halves of the body provides a seat for the disc to close on and a disc spindle seal. On/off operation only	Incorporates most of the features required for hygienic applications. Can be cleaned in place. Buildup of product on the edge of the disc may occur and cause a cleaning problem
Linear plug and stem valve	Based on the globe valve. The flow is controlled by a valve head fitted with either a rubber or PTFE seal. Various types of stem seal, including a lip, an "o" ring, a diaphragm, a bellows, and a steam barrier. Manual or automated operation. Designs are available for on/off and diversion applications	The following stem seal arrangements are suitable for hygienic operation only: lip seal and "o" ring. Diaphragm seals and bellow seals are suitable for aseptic applications. The steam barrier is not widely used because of its high cost
Diaphragm valve	The diaphragm is clamped between the valve bonnet and body and is pressed against the weir by an external mechanism. The diaphragm is subject to wear and must be replaced regularly. A flow-diversion variant is available	This valve is of simple design and glandless, which makes it suitable for both hygienic and aseptic applications
Membrane valve	A rubber hyperboloid membrane clamped between the linear valve plug, the valve head, and body to provide crevice-free and bacteria-tight joints. The diaphragm is subject to wear and should be replaced at regular intervals. Two on/off valves can be combined to form a diversion valve	The valve is suitable for both hygienic and aseptic applications
Rising stem tank outlet valve	This is a modified version of the on/off linear plug and stem valve. It is usually fitted with a flange incorporating the valve seat, which is welded into the base of the tank. In the open position, the valve head projects into the vessel	This type of valve is widely employed for hygienic and, where necessary, aseptic applications
Falling stem tank outlet valve	Similar to rising stem valve. However, in this design, the valve head drops down from its seat. It may be used where the agitator blades are in close proximity to the bottom of the tank	Versions are available for both hygienic and aseptic applications

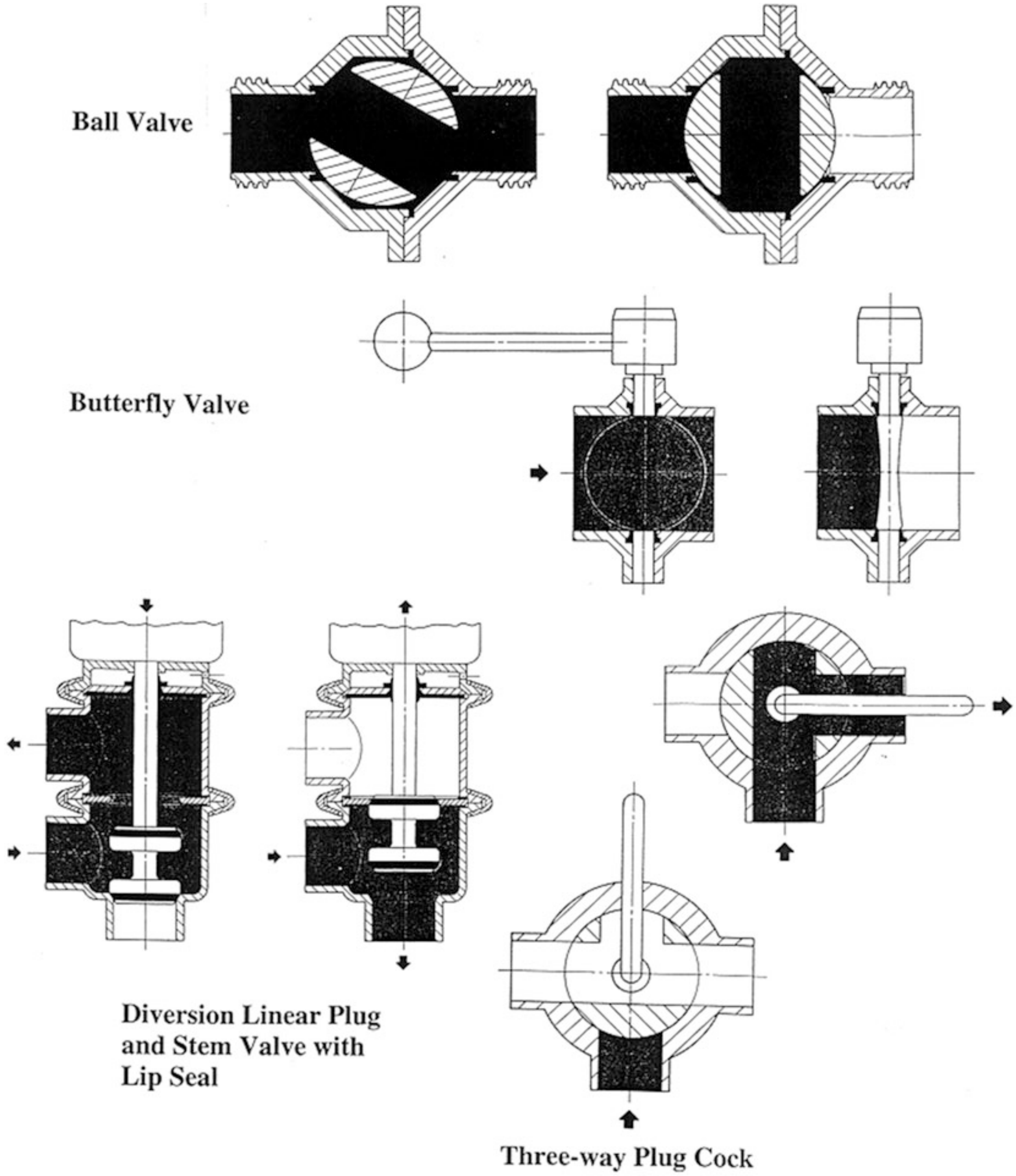


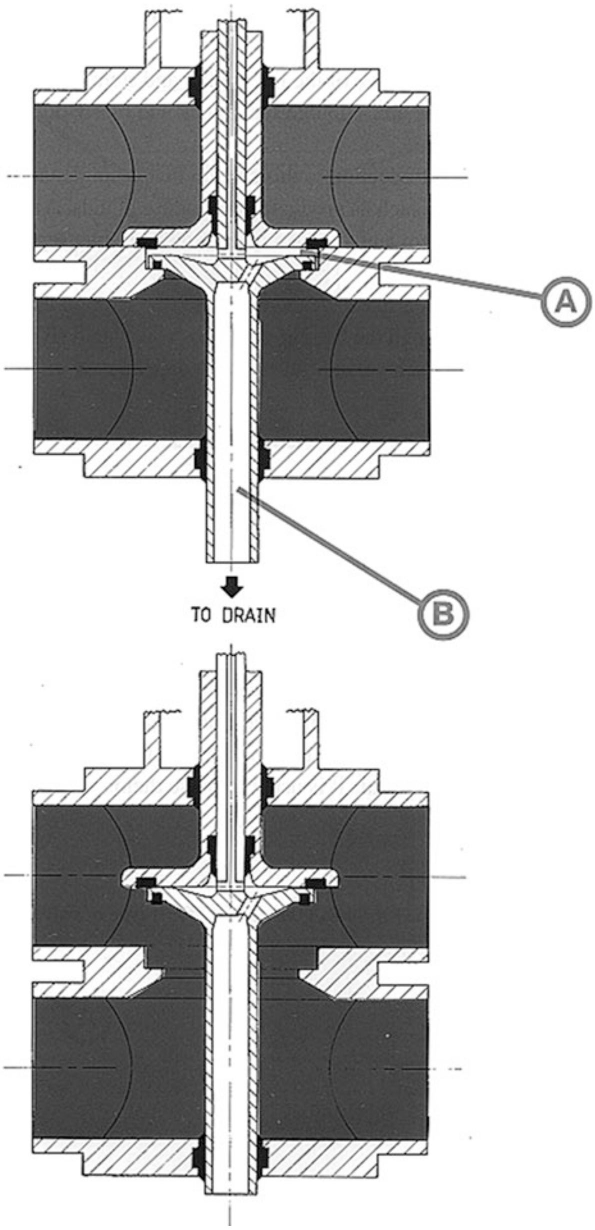
Fig. 4.18 Examples of on/off and diversion valves

4.5.4 *Post-process Can Handling*

Hygiene problems are not restricted to liquid food products; solid foods are equally vulnerable. Some of these potential problems are described in this and the following section.

Thorpe and Barker (1985) describe how good hygienic design can significantly reduce the occurrence of infection of canned food resulting from temporary leakage through damaged can seams. They made the following points relating to leaker infection:

Fig. 4.19 Mix-proof linear plug and stem valve



1. Leaker infection is the commonest form of spoilage encountered in the canning industry.
2. Leaker infection has been associated with a number of serious food-poisoning incidents.
3. Manual unloading of wet processed cans greatly increases the risk of infection by food-poisoning organisms.
4. Abuse of can seams on conveying equipment can result in temporary leaks through the seams.
5. Wet cans may become infected while being conveyed over contaminated can-handling equipment surfaces.
6. The risk of infection through temporary leaks disappears once cans and their seam regions are dry.
7. Carry-over of chlorinated cooling water onto runway surfaces does not prevent the growth of bacteria.

8. Can drying reduces the time cans are vulnerable to leaker infection and the surface area of can-handling equipment that becomes wet during production.
9. Badly designed, constructed, and maintained equipment is much more difficult to clean efficiently, and this, in turn, reduces the effectiveness of subsequent disinfection treatments.

In short, the lessons to be learnt from the above are (a) avoid manual handling of wet cans (batch retorts should always be unloaded mechanically), (b) avoid rough handling of the cans, (c) minimize contact between the seams and standing water on equipment surfaces, and (d) use a can dryer. There are two basic causes of can damage. Impact abuse occurs when cans roll or slide down runways and knock into each other or protruding sections of the conveyor. It can occur when cans are slowed down or caused to change direction. Pressure abuse normally occurs when cans on cable conveyors stop moving forward but the cable itself continues to run. As a result, cans ride up on each other so that the seam of one can presses into the body of the next can.

Water deposited on can-handling systems from the cans themselves not only makes it possible for bacteria to multiply on equipment surfaces but also provides the primary means of transferring bacteria onto cans. The chances of contamination greatly increase if the equipment surfaces have not been adequately cleaned and disinfected and if the can-handling systems have been badly designed, constructed, installed, or maintained. By way of example, Fig. 4.20 illustrates some of the problems that can occur with a push bar elevator:

(A) Can seams run on a solid backplate. Both seams are in contact with the plate and risk contamination. An improved design in which the plate is replaced by rails is shown in Fig. 4.21.
(B) There is double-seam contact with the push bars. An improved design is also shown in Fig. 4.21.
(C) The covering material on the retarding mechanism is usually soft and often porous. When it becomes heavily contaminated, bacteria are transferred onto the wet can bodies.
(D) Can transfer timing device. Unless there is a smooth transition from the turning wheel to the "pockets" between bars, the cans will be subjected to severe abuse.
(E) The buildup of cans approaching the elevator may cause impact abuse. This can be minimized by running the elevator at a slightly faster speed than the can line.
(F) The distance between the bottom of the side guards and the floor restricts access for general housekeeping. The minimum clearance should be 200 mm.

In view of the hygiene and can abuse problems with this type of elevator, Thorpe and Barker recommended that alternatives (e.g., magnetic elevators or alpines) be used.

Can seams may also be contaminated indirectly. In this process, bacteria are transferred from the surfaces of can-handling equipment onto the bodies of the cans. These are carried into the seam area in water droplets running down the cans. Thorpe and Barker (1985) cited a large number of cases where hygienic design is critical. These include, for example, the method of attaching rails to support framework; the method of joining side guides to those of straight conveyor sections, hinge links on slatted conveyors, can dryers, particularly those sited within hydrostatic sterilizers; and the loading and unloading of hydrostatic sterilizers. These and other relevant topics are treated in great detail and the reader is referred to this report for further guidance.

4.5.5 Product Transfer Systems

Campden Technical Manual No. 7 (CCFRA 1983) addresses the hygienic design of fruit and vegetable preparation lines and, in particular, problems associated with the product transfer systems. In this report, the Working Party noted that, whereas large or expensive plant items were subjected to considerable scrutiny, the hygienic design of product transfer systems (hoppers, conveyors,

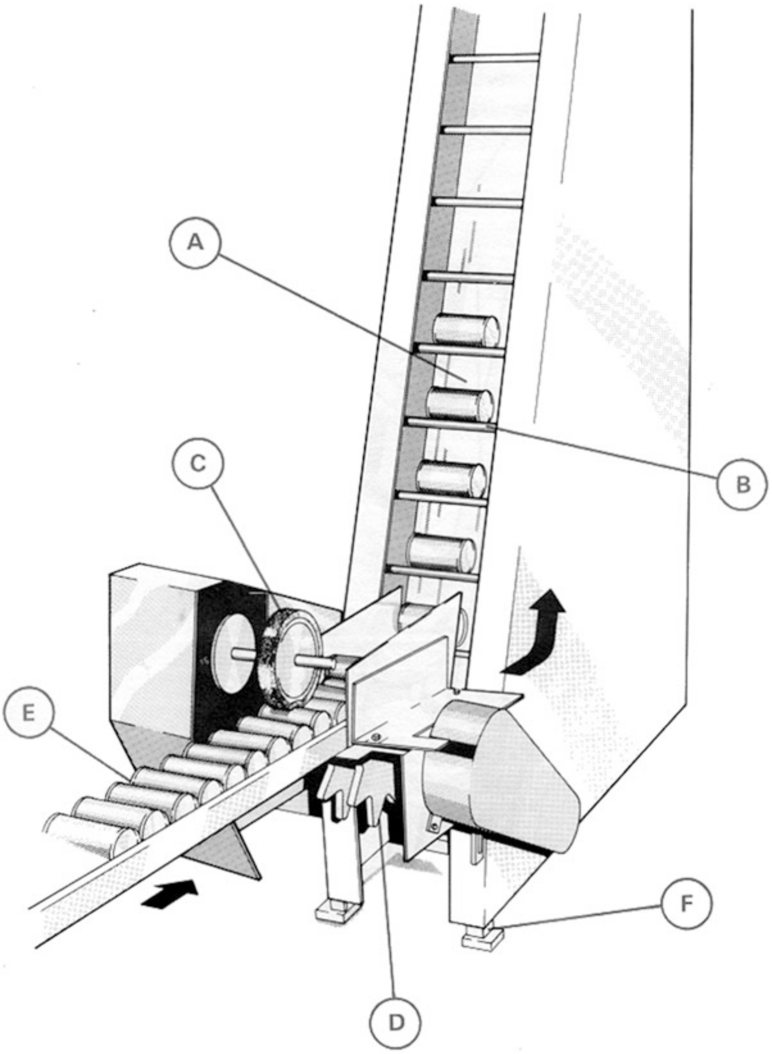
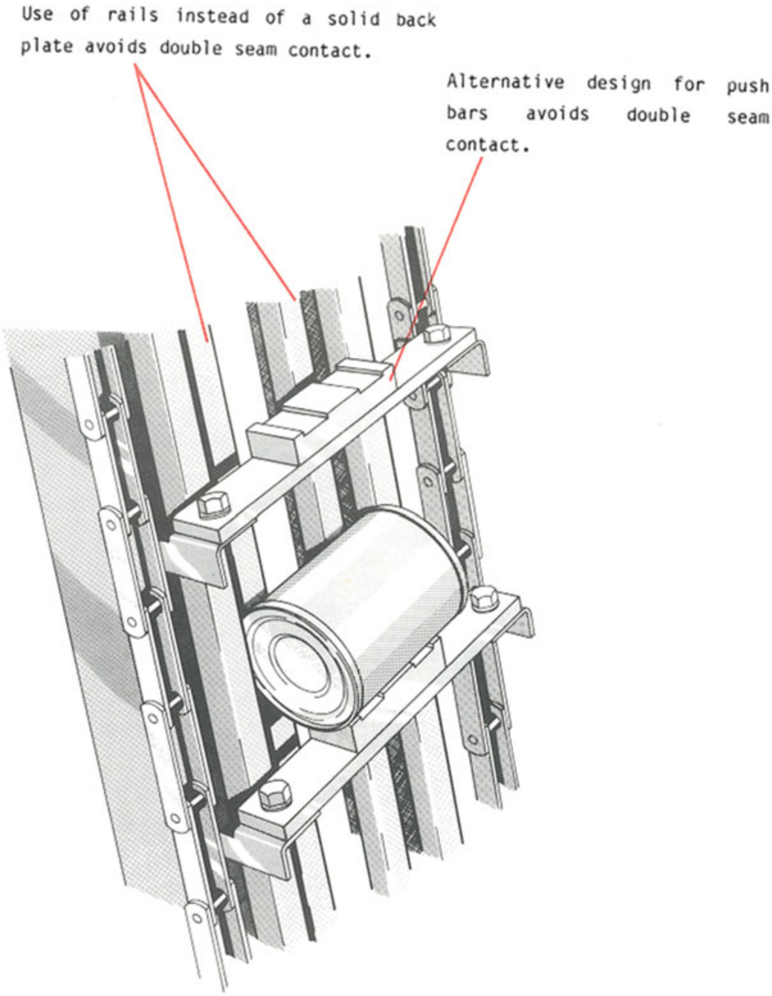


Fig. 4.20 Hygiene problems associated with a push bar elevator

elevators, etc.) often received little attention. They attributed this to a number of factors including the pressure of tight deadlines, the fact that the equipment is often used to meet the particular and frequently short-term needs of different production lines, and local design and construction by nonspecialist suppliers. As a result, a number of recurrent faults, which tended to be repeated at different points on the line, were observed. These were:

1. Incorrect location of adjoining equipment, which results in inefficient discharge of product from one unit to the next. For example, the end of a conveyor belt should be positioned directly over a reception hopper to ensure that the product transfer is effected smoothly and without spillage. The use of a deflector plate as an alternative to correct design and location is a poor example of hygienic design.
2. Design faults that permit product to become trapped in a "backwater" can result in loss of product quality, microbial growth, and product contamination. In addition, they increase the time and cost of cleaning programs. There are numerous examples. The use of deflector plates, behind which product can accumulate, is one common example. The inadequate design of hoppers that results in product retention within them is another. A third is the poor design of conveyor rollers, which allows debris to lodge in their ends.

Fig. 4.21 Suggested improvements to push bar elevator



3. The use of unsuitable fasteners, which may work loose and cause damage to other equipment and give rise to consumer complaints. As discussed in Sect. 4.4.3, they may also cause hygiene problems.

The authors cite a large number of examples of poor hygienic design and propose solutions to alleviate the resulting problems. Two examples are reproduced here. Figure 4.22 illustrates an unsatisfactory design for the transfer of product from a conveyor to an inspection belt. The backstrip (A) serves no useful purpose. Moreover, debris from the belt collects on the back of the strip and provides a source of nutrients for the growth of microbial slime on surfaces. The height of the conveyor (B) is inadequate and prevents its correct location with respect to the inspection belt. This creates a number of problems. As the full width of the inspection belt is not utilized, the depth of product is too great to permit adequate inspection. Moreover, debris builds up on the inspection belt frame beneath the conveyor and behind the product guide and spills onto the floor (C). Product tends to flow in surges from the conveyor, thereby causing "waves" to pass down the inspection belt. This, in turn, results in product being pushed high up the side of the guide, which tends to become trapped until subsequent surges sweep it back into the main flow. Another design fault is that the flat horizontal frame members provide a surface on which debris can lodge. These sections should be replaced by tubular-section material or square-section members turned through 45° to provide sloping surfaces. The authors conclude that these problems could be overcome by replacing the existing conveyor belt with a suitable vibrator conveyor.

Fig. 4.22 Unsatisfactory product transfer

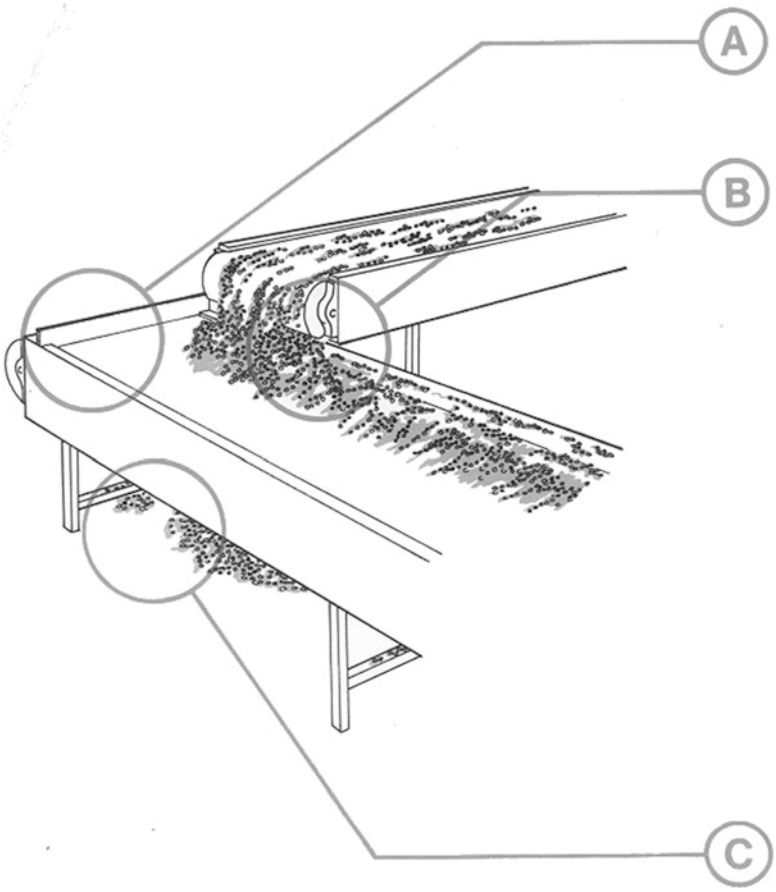


Figure 4.23 illustrates several design faults associated with a raised walkway. The principal hygiene problem here is that dirt may be transferred from clothing or footwear onto the product line beneath the catwalk (A). The problem is compounded by the use of expanded metal or mesh flooring (B) through which extraneous matter can pass. Finally, open risers above the level of the product (C) can result in dirt being kicked into it. An improved design is shown in Fig. 4.24. Here, the decking (A) is constructed from solid plate. Checker plate is particularly suitable for this purpose as it features a raised anti-slip surface. Fitting a kickplate (B) minimizes the chance of dirt being transferred from footwear. Where possible, the decking and kickplates should be of one-piece construction. Finally, the risers are constructed of the same anti-slip plate as the decking. Those above the level of the product flow are encased (C) to prevent it from being contaminated by dirt.

4.6 Closure

This chapter has presented an overview of the hygienic design of food-processing equipment. The subject is complex and multifaceted. It involves interactions between process factors, materials of construction, and the detailed mechanical design. It is clearly impossible to cover all aspects hygienic design in the depth they deserve; the reader should therefore refer to the references cited for more detailed guidance.

Fig. 4.23 Unsatisfactory walkway

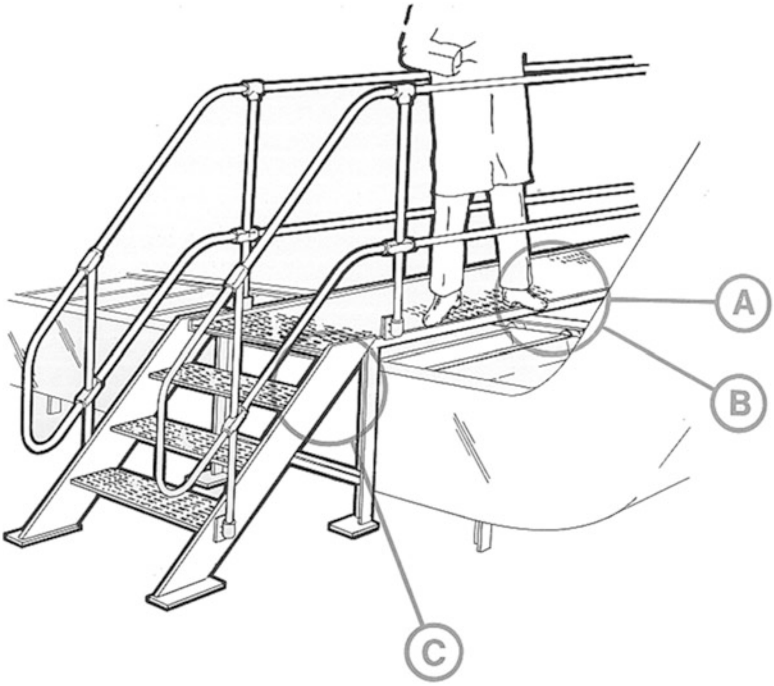
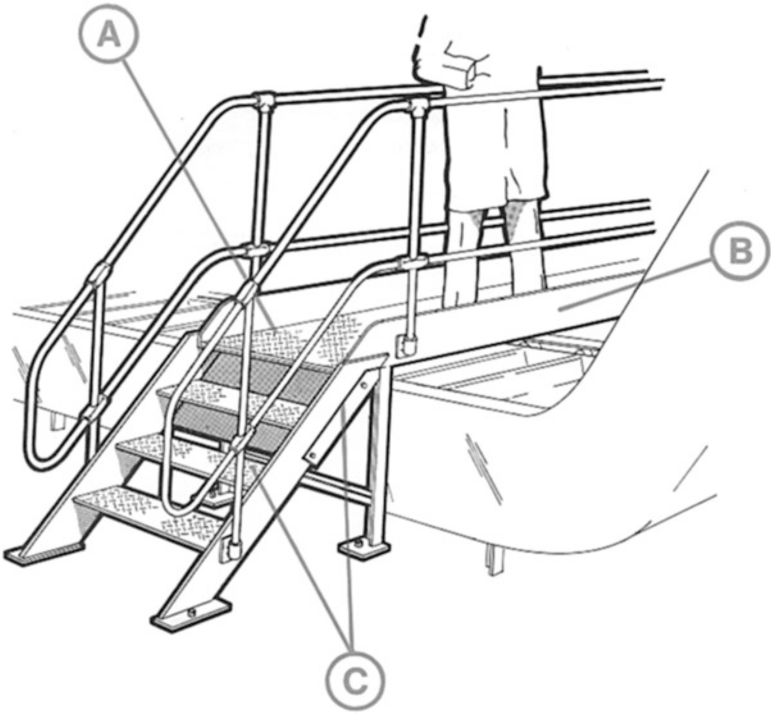


Fig. 4.24 Satisfactory walkway



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