Chapter 7

Hygienic Design of Closed Equipment for the Processing of Liquid Food

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7.1 INTRODUCTION

There is a global trend in the food industry toward minimal food processing and preservation. But the general tendency to apply mild processing and preservation techniques often shortens the shelf life of food, may put foods at risk and may compromise consumer health. It forces food manufacturers to pay more attention to hygiene during the manufacturing of food. Poorly designed or maintained closed equipment for the processing of liquid foods may compromise the product's hygienic condition. Cross-contamination may occur even after applying rigorous cleaning and disinfection practices. Typical contaminants are spoilage microorganisms and pathogens, as well as allergens. Additionally, broken equipment parts may find their way in as foreign body contaminants, while poor installation and lubrication practices may result in food contaminated with lubricants.

Closed equipment used for the processing of liquid food falls into two categories: (1) process equipment that can be cleaned in-place and can be freed from relevant microorganisms without dismantling and (2) process equipment that in addition is sterilizable and impermeable to microorganisms so as to maintain its aseptic status. Examples of closed process equipment (components) are closed vessels (reactors) often provided with insulation and cladding, piping and pipe joints, pumps, valves, measurement devices, etc. Good hygienic design of this equipment is essential to ensure that the required level of food safety is maintained, in compliance with compelling national and international food safety legislation, as well as food safety management systems built on the well-known concepts of Good Manufacturing Practices (GMPs), Hazard Analysis and Critical Control Point (HACCP) and prerequisite food safety and quality programs. On request of their customers, many

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food manufacturers also need to certify their food processing operations against the SQFI (Safe Quality Food Institute), BRC (British Retail Consortium), FSSC 22000 (Food Safety System Certification 22000) or GFSI (Global Food Safety Initiative) standards and/or certification schemes. Interest in correct equipment design has also grown in the light of rising production costs, one reason being that hygienically designed process equipment is much more sustainable and cost-effective from a long-term perspective. Although sometimes initially more expensive, hygienic design may (1) reduce the risk of costly product recalls, (2) reduce labor costs by minimizing the effort and time needed to clean and disinfect, and (3) allow cost savings in the consumption of water, cleaning agents/disinfectants, as well as the energy required to heat the cleaning/disinfection solutions.

Therefore, this chapter aims to familiarize users of closed equipment for the processing of liquid food with food safety hazards related to the design, construction and application of these systems. Furthermore, process equipment manufacturers are made more aware of state-of-the-art engineering solutions to improve the hygiene friendliness of their process equipment. In Section 7.2, an overview is given of the current legislation and standards dealing with the hygienic design of food processing equipment. Section 7.3 lists the basic hygienic design requirements that food processing equipment must meet to produce microbiologically safe food products. Section 7.4 describes the hygienic and food grade materials that can be used in the manufacturing of food processing equipment, followed by a section that outlines the requirements for the food contact surface finish (Section 7.5). In the next sections, we discuss the hygienic design of closed equipment (components) for the processing of liquid food such as closed vessels and reactors, including agitators (Section 7.6), processing and utility piping, including hoses (Section 7.7), pumps (Section 7.8), valves (Section 7.9), pressure measurement devices (Section 7.10), and temperature measurement devices (Section 7.11).

7.2 LEGISLATION, STANDARDS AND GUIDELINES COVERING HYGIENIC DESIGN

7.2.1 Legislation

Food processing equipment intended to be sold in European countries and designing operations in food factories must comply with the European Machinery Legislation, consisting of the Machine Directives 2006/42/EC and 98/37/EC, and an endorsing guidance document published by the Industry and Enterprise Department of the European Commission with the title: “Guide to application of the Machine Directive 2006/42/EC” (European Commission, 2010). Annex I of the Machine Directive 98/37/EC (formerly 89/392/EEC and its amendments 91/368/EEC and 93/44/EEC), and Annex V of Council

Directive 93/43/EEC on the Hygiene of Foodstuffs require that all equipment used to handle food should be hygienically designed.

7.2.2 European Standards and Guidelines for Liquid Food Processing Equipment

7.2.2.1 EN Standards

The Comitée Européen de Normalization technical committee CEN/TC 153 has developed two Harmonized European standards with respect to food machinery: prEN1672-1 and EN1672-2. With respect to hygienic design, the most important is EN 1672-2, which sets design principles for both safety and hygiene objectives.

7.2.2.2 EHEDG Guidelines

In Europe, the European Hygienic Engineering & Design Group (EHEDG) is the most experienced organization in the field of hygienic design. EHEDG is a European-based nongovernmental organization, more specifically a consortium of process equipment manufacturers, food industries, universities, research institutes and public health authorities, founded in 1989, with the aim to promote hygiene during the processing and packing of food products. It has developed 45 guidelines. In Table 7.1, an overview is given of those EHEDG guidelines, dealing with the hygienic design of closed equipment for the manufacturing of liquid food.

7.2.2.3 Other European Standards

Other specifications used in the food industry are the requirements of the International Standardization Organization (ISO) and the German Standardization Authority (DIN) (more specifically for fittings), the bulletins of the International Dairy Foundation (IDF) and the British Standards BS 5750. Note that many food and equipment manufacturers have developed their own hygiene standards for internal use.

7.2.3 US Standards and Guidelines

7.2.3.1 3-A Sanitary Standards

The International Association of Milk, Food, and Environmental Sanitarians, Inc. (IAMFES) and the committee on sanitary procedures 3-A (an independent organization of equipment manufacturers, food processors and regulatory agencies) introduced the first industry hygienic standards for equipment, which relate to the cleanability of dairy equipment. 3-A Sanitary Standards provide material specifications, design criteria and other necessary information for several types of equipment. It also provides a third-party evaluation for some food producing equipment. With respect to US sanitary standards,

TABLE 7.1 Available EHEDG Guidelines for the "Hygienic Design of Closed Equipment for the Manufacturing of Liquid Foods"

Doc. No.	Title
2	A method for assessing the in-place cleanability of food processing equipment
8	Hygienic equipment design criteria
9	Welding stainless steel to meet hygienic requirements
10	Hygienic design of closed equipment for the processing of liquid food
14	Hygienic design of valves for food processing
15	A method for the assessment of in-place cleanability of moderately sized food processing equipment
16	Hygienic pipe couplings
17	Hygienic design of pumps, homogenizers and dampening devices
18	Chemical treatment of stainless steel surfaces
20	Hygienic design and safe use of double-seat mixproof valves
25	Design of mechanical seals for hygienic and aseptic applications
32	Materials of construction for equipment in contact with food
35	Hygienic welding of stainless steel tubing in the food processing industry
37	Hygienic design and application of sensors
42	Disc stack centrifuges—design and cleanability
45	General principles of cleaning validation in the food industry

both NSF and 3-A cooperate with EHEDG, so as to achieve global harmonization of guidelines and standards.

7.2.3.2 Other US Sanitary Standards

In the United States, the following government agencies and private organizations also have published sanitary standards for food processing equipment:

- US Public Health Service: Food and Drug Administration (FDA) and GMPs
- American Society of Mechanical Engineers (ASME): ANSI-ASME F2-1: "Food, Drug and Beverage Equipment"

- American Society of Mechanical Engineers (ASME): Bioprocessing Equipment guideline, ASME BPE-2014
- Baking Industry Sanitation Standards Committee: BISSC Sanitation Standards
- Association of Food and Drug Officials of the United States: "AFDOUS Frozen Food Code"

7.3 BASIC HYGIENIC DESIGN REQUIREMENTS

In all stages of design, construction, installation and maintenance of food processing equipment, hygienic design aims to reduce the buildup of food material or microorganisms in individual items of equipment and the complete line, and to ensure that all detectable soil is removed after cleaning and disinfection. According to European Standard EN1672-2, soil is "any matter, including product residues, microorganisms, residual detergents or disinfecting agents." Food processing equipment should at least meet the following basic hygienic requirements (Moerman & Kastelein, 2014):

- Piping and components should be constructed from the same materials, so as to prevent contact corrosion (bimetallic corrosion) between dissimilar metals (Fig. 7.1). However, this is not always possible. The tendency for corrosion increases as the difference in electrode potentials between different metals increases. The user has to check whether any dissimilar materials will or will not corrode.
- Smooth product contact surfaces must minimize the adhesion and colonization of microorganisms, so as to prevent the formation of biofilms.

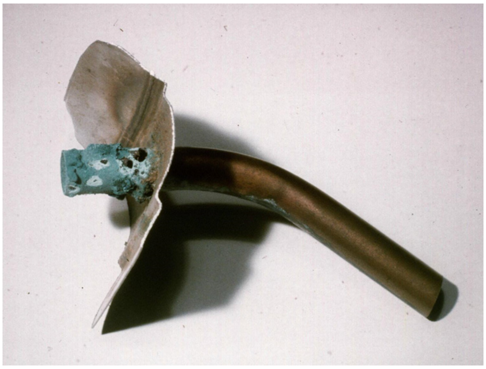


FIGURE 7.1 A badly corroded copper pipe is entering a large stainless steel hot water tank. Stainless steel is cathodic to copper in fresh water. Where the area ratio of stainless steel to copper is large, severe galvanic corrosion can occur.

- Food processing equipment design and construction may not allow bacterial ingress, survival, growth and reproduction on both product and non-product contact surfaces. Effective and efficient cleaning over the whole lifetime of the equipment must be guaranteed.
- The Machine Directives 2006/42/EC & 98/37/EC states that assemblies, e.g., joining of two or more parts, preferably should be made by welding or continuous bonding so as to reduce projections, edges and recesses, as well as fastenings, to a minimum. The joint (e.g., welds) must be smooth and have neither ridges nor crevices, pits or cracks that could harbor organic materials. Welds must be ground and polished to a standard of finish equal to that of the surrounding material.
- Overlapping sheets of metal must be avoided. Wherever possible, the two pieces should be butt welded. If the weld is also exposed to the product, the weld must be ground and polished to the same finish as that of the adjacent surfaces.
- In some cases, continuous welding may result in unacceptable distortion. In this case, although not recommended from a hygienic point of view, exceptionally intermittent welds may be employed (Fig. 7.2).
- Where components are fixed together by means of fasteners, these joints are often of a semipermanent nature. It means that they are not routinely broken, e.g., on a daily or even weekly basis, for cleaning. All such joints must be sealed by means of a gasket. The gasket material must be of food quality, nonabsorbent, nontainting and trimmed flush both internally and externally. Their physical and mechanical properties must be suitable to prevent the ingress of product, liquids (from cleaning) and microorganisms. The condition of gaskets should be checked periodically because some materials such as rubber eventually harden and crack in service.

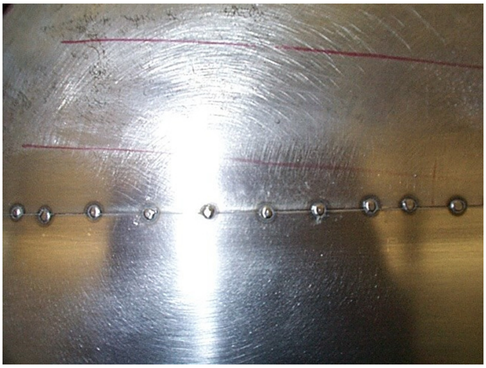


FIGURE 7.2 Spot welds create crevices and may retain product residues, as well as harbor microorganisms.

- 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.
- Avoid exposed screw threads, nuts, bolts and rivets whenever possible, certainly in product contact areas. The slots and sockets in screw or bolt heads can retain product. Preference should be given to domed hexagonal-headed screws or bolts. Sometimes, nuts and screws also come loose, a problem that is often solved by using spring washers, which create a gap between the ends where dirt may accumulate and microorganisms may find a niche to grow. A thread locking compound or component (e.g., washer with a compressible rubber insert) may form a bacteria-tight seal.
- Niches such as pits, cracks, crevices, open seams, gaps, lap seams, inside threads, holes that may accumulate dirt and hamper the cleanability of the food processing equipment are not allowed.
- All inaccessible horizontal flat areas, ledges, projections, protrusions, recesses, edges, etc., where product residues can accumulate, should be eliminated.
- The Machine Directives 2006/42/EC and 98/37/EC 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 (Fig. 7.3). Retained product residues or cleaning fluids may subsequently contaminate the product on rejoining the product stream.

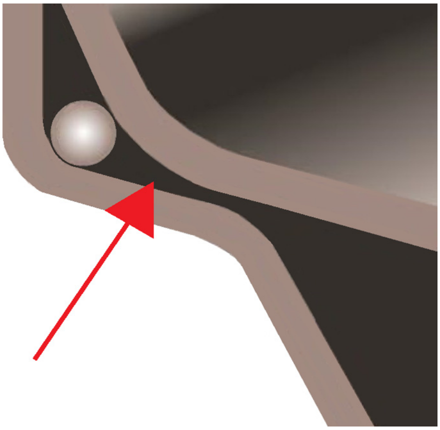


FIGURE 7.3 Hard-to-clean pocket between two metal parts and the O-ring. This crevice/dead zone forms a dead leg with an L/D measurement of an astonishing 50–100. It is impossible to achieve the velocity required to clean the bottom of the crevice. Food debris can be retained in these pockets for many hours and even days, after which it may rejoin the product stream causing food spoilage problems. *Courtesy of Alfa Laval.*

There is also significantly reduced transfer of energy to the food residues (soil) in dead areas in process equipment that is placed outside of the main flow of cleaning liquids than there is to the soil in the main flow. Such areas are difficult to clean and therefore should be avoided or sealed. If unavoidable, their presence should be taken into account when devising the cleaning procedures. Where possible, any space must be designed for regular dismantling to permit the space to be cleaned and disinfected. Typical shadow zones, for example, can be found in the legs of T-pieces in pipelines (Fig. 7.4). In many food factories T-pieces are used to mount sensors such as pressure gauges.

- External surfaces that are not in contact with foods should be corrosion resistant, smooth, easily cleanable and free of protruding parts and crevices where debris may accumulate.
- The exterior of nonproduct contact surfaces should be so arranged that harboring of contamination in and on the equipment itself, as well as in its contact with other equipment, floors, walls or hanging supports, is prevented.
- All parts of the equipment shall be readily accessible for inspection, so as to facilitate the detection of all potential contaminants on representative surfaces throughout the product contact zone. So, all surfaces in the product zone must be immediately visible for inspection, or the design of the equipment shall allow dismantling readily without use of any tools.
- Disassembly and reassembly must be as simple as possible, so that the surfaces and parts exposed to bacterial contamination can be cleaned within 15 min. For that purpose, the number of working parts must be minimal, while their weight and dimensions may not be too large. Ideally components that require frequent cleaning should be easily manageable by one person, and suitable racks should be provided to hold dismantled components off the floor. Heavier components may be more suitably removed by some form of a hoist. Quick release devices, e.g., captive bolts with coarse threads or

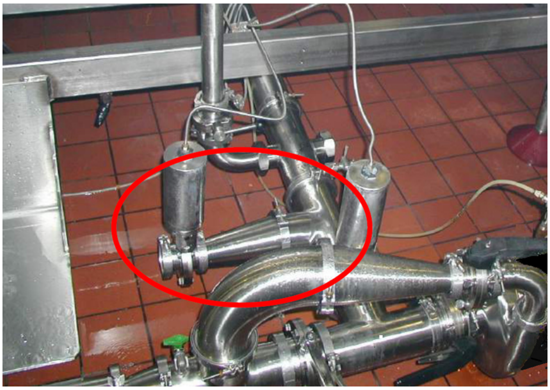


FIGURE 7.4 The too-long T-piece functions as a dead leg, where fluid movement is reduced. *Courtesy of Mondelēz International, ©2016.*

clamped joints, allow fast and easily dismantling and have the advantage of overcoming the microbiological hazards associated with screw threads as mentioned earlier. Whatever quick release devices are used, it is important to ensure that only the simplest tools are required in the dismantling and reassembly of the equipment. Equipment designed for simple and speedy dismantling and cleaning is going to be cleaned more enthusiastically and efficiently than equipment that proves tedious and difficult to handle.

- Equipment surfaces must be readily accessible for manual cleaning and disinfection, unless it can be demonstrated that the result of in-place cleaning and disinfection procedures without dismantling is equivalent to the result of dismantled and manual cleaning procedures. All potential obstructions to cleaning, disinfection and maintenance should be avoided or minimized.
- For the same reason and to facilitate cleaning, sharp corners in the product area should be avoided. A radius can be obtained when metal is bent or machined. When components are bolted or screwed together, a sharp corner is usually unavoidable. Constructions where the sharp corners are continually swept, such as in lobe pumps, are acceptable.
- Where a joint is necessarily close to an internal angle, a butt-welded joint should be made away from the corner on the flat surfaces, and must be smooth. Preferably the weld should be made at the non-product side.
- Microbes can flourish in stagnant pools of water, especially when nutrients are trapped in the internal pockets. Hence, accumulated and pooling cleaning and disinfection solutions may contaminate food products. Moreover, when liquid food, cleaning and disinfection solutions, and rinsing water are retained during idle periods, corrosion may occur. Therefore all equipment surfaces in the product zone and piping must be so arranged that they are self-draining, which means that they should be sloped toward drain points. There should be no ridges that may hamper draining. Where it is not possible to build equipment in such a way that proper draining is possible, procedures must be developed to ensure that residues of cleaning and disinfection liquids can be removed in another way.
- Equipment design, therefore, should not permit the formation of condensate that may enter the food zone and contaminate product or product-contact surfaces.
- 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. When bearings are mounted outside the product area, contamination of food products by lubricants is avoided, as well as the ingress of bacteria. There is also less chance that the bearing gets damaged due to ingress of product. Where possible the bearings should be self-lubricating. 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 repaired periodically as part of planned maintenance programs.

- When the bearing is within the product area (e.g., slide bearings, such as bottom bearings of top-driven stirrers or bearings in scraped-surface heat exchangers), it should be self- or product-lubricated. In the case of a foot bearing for an agitator shaft, the design of the shaft and bush should allow the passage of cleaning fluid to all surfaces. Grooves must be provided in the shaft through the whole length of the bush.
- It is advisable to avoid steam cleaning of lubricated bearings. After contact with fluids or steam (where essential), bearings should be allowed to dry out before they are relubricated.
- Food grade lubricant should be used, and leaking of lubricant onto food product must be excluded. To protect the product zone a drip pan should be used, or motors driving equipment components such as belt drives, etc. should be placed outside the product area. If they are within the splash area, they should be protected by a removable cover. Where possible, food grade grease such as acetylated monoglycerides should be employed. Any excess of lubricant should be removed.
- Equipment design must ensure hygienic compatibility with other equipment and systems, such as hydraulics and electrical, steam, air and water systems.
- Shaft passages and seals may leak product to the outside. Microorganisms may then multiply in the product and grow back to the product side. In the case of dynamic seals, such as those for shafts of valves, pumps and mixers, the movements of the shaft will assist the transfer of product to the outside and the transfer of microorganisms to the product side. This applies to reciprocating shafts, and to a lesser extent to rotating shafts. However, rotating shafts also display some axial movement. Reciprocating shafts can be sealed by means of flexible diaphragms or bellows. To prevent the ingress of microorganisms in rotating shafts, double seals with microbicidal barrier liquids should be used. If not replaced in a timely manner, however, such barriers may become a growth medium for microorganisms. In order to prevent damage to the seals, they should be designed to minimize the ingress of product particles. In some cases, however, the total exclusion of particles is not economically possible. Under these circumstances, the seals should be subject to frequent cleaning.

7.4 SELECTION OF THE CORRECT MATERIALS OF CONSTRUCTION

Food contact materials must meet specific requirements. They must be inert to the product under all in-use conditions, such as temperature and pressure, as well as to any chemicals used, such as detergents or biocides. They may also need to be resistant to pressurized hot water or steam sterilization. They must be corrosion resistant, nontainting, mechanically stable, smooth, and nonporous. Materials of construction that are used for surfaces in contact with food should allow the original finish to be maintained and no porosity should develop. In addition, materials should be resistant to deformation, denting, chipping, flaking, and delamination. Materials that may release unacceptable concentrations of harmful components to the food may not be used in contact with food. Particular care must be taken when elastomers, plastics, adhesives, and signal transfer liquids are used, as these may contain toxic components that could be leached out into product. The suppliers of such components must provide clear evidence that the materials meet all legislative requirements. With the above requirements in mind, it is not surprising that the range of construction materials available is rather limited.

7.5 SURFACE FINISH

Product contact surfaces must be finished to a degree of surface roughness that is smooth enough to enable them to be easily cleaned and disinfected. The surface finish must have a roughness area R_a as low as practicable and without cracks, pits or cavities where water or soil might remain. 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. A surface finish of roughness $R_a \leq 0.8$ μm is considered as acceptable for closed equipment used for handling liquid food and normally cleaned in-place. A roughness R_a exceeding 0.8 μm may be acceptable if test results have demonstrated that the required cleanability can be achieved through other design features or more intensive cleaning methods.

7.6 HYGIENIC DESIGN OF CLOSED VESSELS

A wide range of tanks is used in the food industry, which can be classified either as storage tanks or process vessels. The function of storage tanks is purely storage of raw materials and intermediate or final products at different stages of the production process. Process vessels can include mixing, blending, heating, cooling, separation, and fermentation operations. Process vessels are more complex in design than plain storage tanks because of the presence of various internal components. However, the design criteria are the same for all types of tank.

7.6.1 Interior and Exterior Design of Closed Vessels

Vessel and appurtenances must be designed to facilitate the tank cleaning process (ASME BPE committee, 2014):

- Vessels need to be designed with smooth, straight walls and curved corners that can be cleaned easily by liquid spray produced by stationary (e.g., static spray balls) or rotary cleaning devices. Corners shall be well-rounded, with a radius equal to or larger than 3 mm (Fig. 7.5).

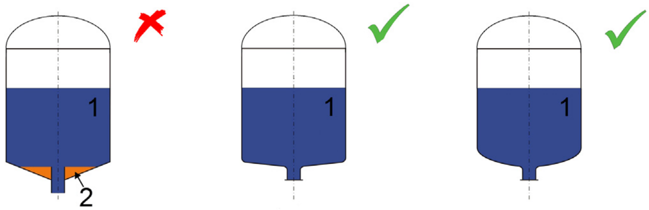


FIGURE 7.5 Full drainage of products and cleaning solutions is required. If discharge outlets are above the lowest level of the closed vessel, self-draining will be hampered, and residual products and cleaning solutions (2) will be left in the vessel. Closed vessels must be self-draining with discharge outlets at the lowest level. Bottoms must be sloped and all corners should be well-rounded (Hauser et al., 2004b).

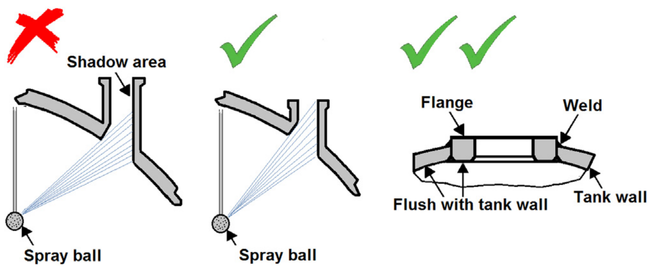


FIGURE 7.6 The tank-cleaning process by means of tank-cleaning devices can be facilitated by applying short-neck nozzles, which means tank head ports with reduced L/D ratios, short in length and large in diameter. During the cleaning action of the tank-cleaning devices, internal shadows in the top nozzles can be reduced to a certain extent if the lower part of these top nozzles is sloped toward the center of the vessel.

- Junctions between vessel and piping must be smooth, flush and without crevices.
- Closed vessels with bottom outlets must have their discharge outlet at the lowest level and their bottom shall be sloped (Fig. 7.5). Tank outlets should be flush with interior surfaces and self-draining.
- Flat top surfaces should pitch 4% from center to sidewalls to encourage the continuous flow of cleaning solutions sprayed on these surfaces toward the side walls.
- Death corners in the top of the vessel or tank should be eliminated. Difficult to clean areas are the annular space between the neck of the top nozzles in the tank head and agitator shafts, as well as down pipes, installed in the tank by means of an exterior tank connection. The ratio of nozzle neck length to annular space gap width should be $\leq$2:1.
- Short-neck ports must be used, which means tank head ports with reduced L/D ratios. To avoid a dead leg, the maximum recommended length to tank head port diameter ratio shall be two-to-one. Top nozzles should preferably be flush with the tank wall (Fig. 7.6).

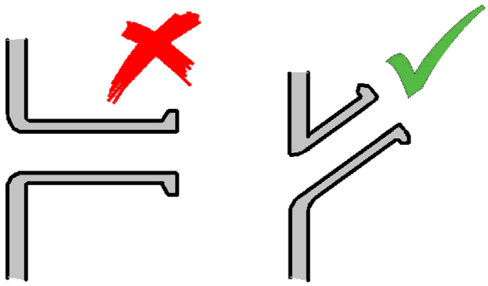


FIGURE 7.7 Use sloped side ports, rather than ports perpendicular to the vessel wall.

- The depth of manways must be reduced to avoid interior shadows, especially because they are harder to clean and a source of possible contamination.
- Sloping the lower part of the top nozzles toward the center of the vessel may eliminate shadows and provide the tank cleaning devices good "sight" angles into the top nozzles (Fig. 7.6).
- For maximum cleanability, side-wall sensor ports must be provided with a slope (5-degree angle) (Fig. 7.7), rather than ports perpendicular to the vessel wall.
- Eliminate dead corners in lower tank parts.
- To provide a reasonable flow across the tank bottom surfaces for moving suspended solids, the bottom of flat vessels should pitch no less than 2% from rear to front outlet, and 4% from side to center outlet for round bottom vessels.
- A probe (e.g., pH sensor) in the reactor wall shall be inserted in a sloped side port, with an O-ring seal to prevent the ingress of soil into the sensor port and the probe. An elastomeric O-ring seal should be placed as close as possible to the vessel wall so that only a short crevice is formed. When this seal is placed at the entrance of the port (end opposite to the tank wall), then a long and uncleanable large crevice is formed. Where cleaning relies on a free falling film, protrusion of stationary parts like sensor probes in a vessel wall should be avoided. They may form a shadow area during cleaning (Fig. 7.8).
- Baffles only partially fastened onto the side wall of the tank should be used instead of full-length fastened baffles. The internal support members to fasten the baffles to the tank wall must be made from solid round bar stock having a downward slope of 5 degrees (Fig. 7.9). When gaps are left between the baffle and tank wall, the flow allows the baffles and the tank wall to be cleaned more easily. Recommended gaps between the baffles and the vessel wall are equal to 1/72 of the internal vessel diameter, and 1/4 to 1 full baffle width between the bottom of the baffles and the vessel base. Instead of full-length baffles, the use of baffles can be limited to the lower part of the tank or the tank may be provided with intermittent

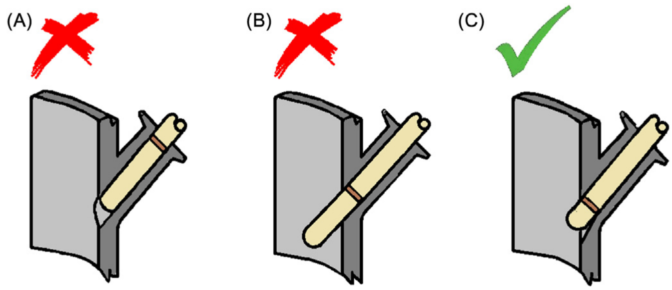


FIGURE 7.8 Probes shall be inserted in sloped, welded-in side ports, the weld being polished to obtain a surface finish comparable to that of the original finished metal. (A) An elastomeric seal at the entrance of the port (end opposite to the tank wall) gives rise to an uncleanable long and large crevice between the interior surface of the sensor port and the outside probe surface. (B) Protrusion of probes in a vessel wall should be avoided, as they may form a shadow area during cleaning. (C) When the elastomeric O-ring seal is placed close to the vessel wall, only a short crevice is formed.

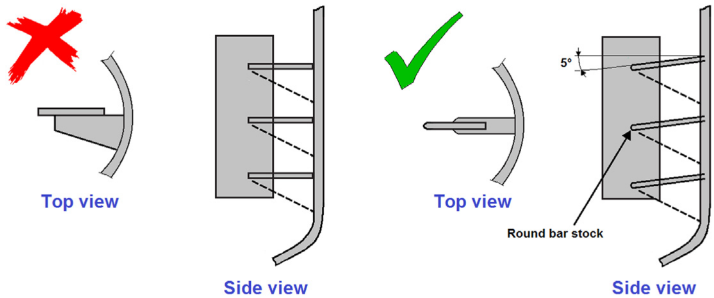


FIGURE 7.9 The internal support members to fasten the baffles to the tank wall must be made from solid round bar stock having a downward slope of 5 degrees. When gaps are left between baffle and tank wall, the flow allows the baffles and the tank wall to be cleaned more easily (ASME BPE committee, © 2014).

baffles (underbroken baffle, resulting in two shorter baffles, one below the other), without loss in agitation efficiency. Baffles can be omitted in small tanks (<500 L), and in designs where the agitator is mounted off-center and angled at the same time. Where material can hang up or becomes trapped in stagnant regions around the baffles during drainage, profiled baffles instead of flat-plate baffles are recommended (Myers et al., 2002; ASME BPE committee, 2014).

- Suitable covers or lids must be provided and should be made of the same material as the vessel. Covers on smaller vessels should be close fitting and easily removable for cleaning. Covers on such vessels should preferably be unhinged since the hinge, especially piano hinges (Fig. 7.10), can collect dust and food debris which might fall into the product when the cover is opened. Where hinges are used they should pivot sufficiently

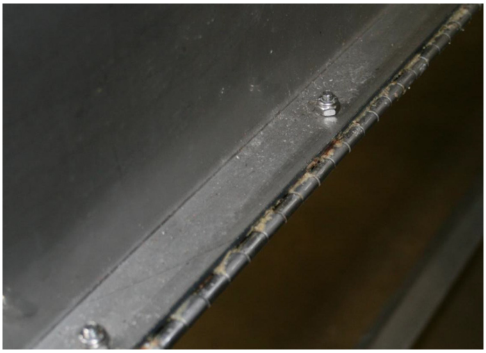


FIGURE 7.10 The piano hinge prohibits removal of the cover, and allows food residues to accumulate in the hinge. In the piano, microorganisms may find a niche to grow (Don Graham, Graham Sanitary Design Consulting LCC, ©2010).

outwards to avoid product contamination (Fig. 7.11). For maximum cleanability, hinges should be removable and, where possible, consist of a simple hook-on type without bolts. Larger vessels are usually fitted with manholes, either in the top or side, which preferably should be ca. 90 cm in diameter for easy access. Mandoor covers intended to protect the food products may accumulate dirt or liquids on top of the lid while in a closed/horizontal position. If these mandoor covers are not correctly designed and mounted, these liquids and dirt may slide into the vessel opening and, respectively, spill and fall into the product when the lid is opened. Policy should specify that no tank is opened during production unless absolutely necessary. Correct design and mounting of covers must prevent soil and/or liquids from dripping/falling into the product during the opening of the cover. In Fig. 7.11A, the cover protecting the vessel opening is at the back side provided with a sloped edge, draining any dirt or liquids away from the vessel opening. In Fig. 7.11B, drip of soil and liquids into the food product is prevented by the curved edges at the left and right side of the bolted flat cover plate. Seals must be of a removable type (Fig. 7.12) to allow for inspection, cleaning, and replacement.

- Instead of a weld-on top surface, vessels, bins, etc. also can be closed with a (detachable) lid. Flat lids provide a horizontal surface (Fig. 7.13A) where dirt may accumulate. Hence, where nonremovable lids are used, preference should be given to domed lids with sloped tops that collect less dirt and allow for proper drainage of liquids (Fig. 7.13B). When the vessel is permanently covered by a lid, no sharp top corner (junction vessel wall—lid), which may hamper the cleanability, should be created.
- Conventionally designed right-angled grooves containing O-rings invariably create gaps and crevices that are impossible to clean in-place and/or to sterilize in-line (Fig. 7.14). One cause is that the elastomer material of the O-ring has a significantly higher thermal expansion coefficient than

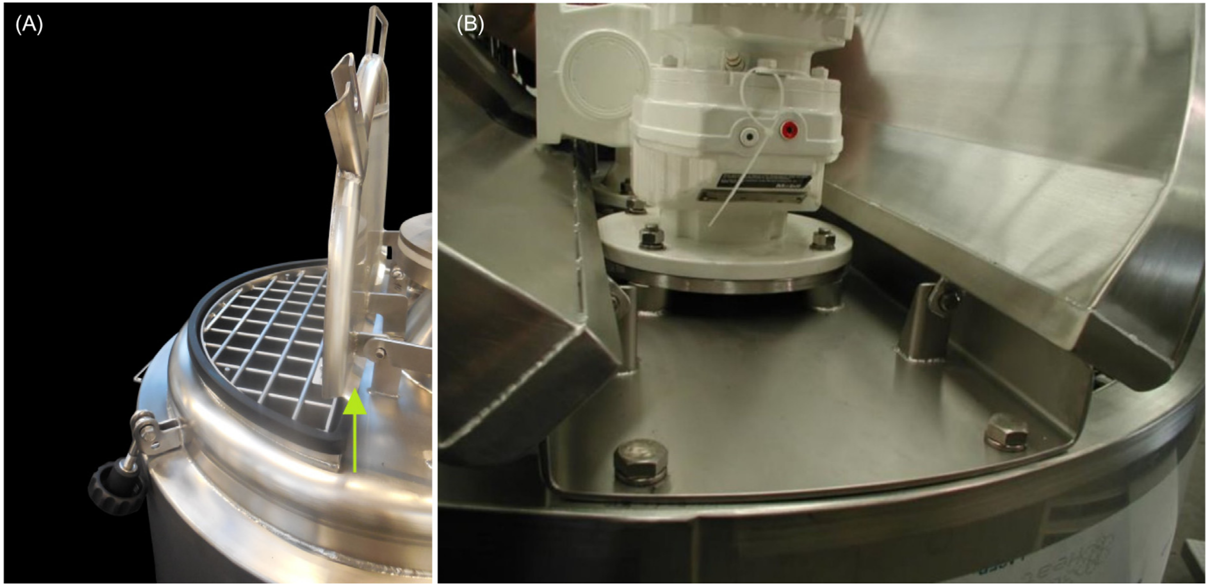


FIGURE 7.11 Correct design and mounting of covers must prevent any soil and/or liquids from accumulating on the cover while in a horizontal position, as they may fall into the product during the opening of the cover. (A) The cover is at the back side provided with a sloped edge (*arrow*), draining any dirt or liquids away from the vessel opening (Frank Moerman, © 2016). The pin hinges are less sensitive to the accumulation of debris. (B) In this example, drip of soil and liquids into the food product is prevented by the curved edges at the left and right side of the bolted flat cover plate. Pin hinges prevent the buildup of dirt. *Courtesy of Fineweld Stainless Steel Pty Ltd.*

FIGURE 7.12 Seals for mandoor covers must be of a removable type to allow for inspection, cleaning and replacement. Food debris may accumulate under the seal, providing nutrients for microorganisms. *Courtesy of Burggraaf & Partners B.V.*

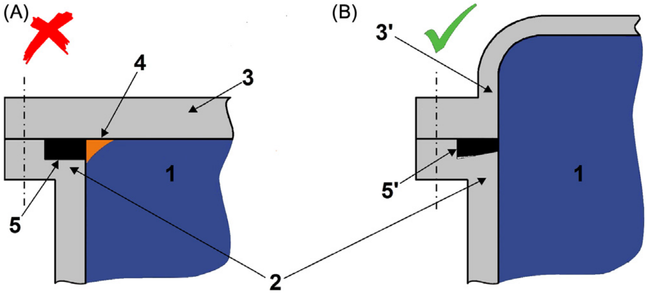


FIGURE 7.13 (A) Covers are used (e.g., for process vessels, tanks, bins, etc.) to avoid contamination of food product (1) from the environment during processing or storage. When the vessel (2) is covered with a flat lid (3), a horizontal surface is provided where dirt may accumulate. Moreover, a sharp corner (4) is created at the top near the seal. This seal (5) is not very appropriate because overcompression may lead to protrusion of the seal in the product area, thereby impeding cleaning, while undercompression may lead to both indentations and crevices and failure to provide a reliable seal. Even when it is not visibly leaking, the seal may permit the ingress of microorganisms. (B) Preference should be given to domed lids (3′) with a sloped top that collect less dirt and allow for proper drainage of liquids. The present sloped gasket groove allows for controlled compression of the gasket (5′) at the product side while providing space for expansion at the nonproduct side (Lelieveld et al., 2003; Hauser et al., 2007).

steel. During heating the seal will expand to cover an increasingly larger surface of steel, protecting microorganisms trapped between the O-ring and the steel surface against contact with hot water, chemical solution or steam. Although the seal contact surface will usually reach the correct temperature during treatment with hot water or steam, the water activity in the grooves will be too low for the destruction of many microorganisms at the temperature and time applied. After cooling down and shrinkage of the seal, the surviving microorganisms may be released and will multiply and

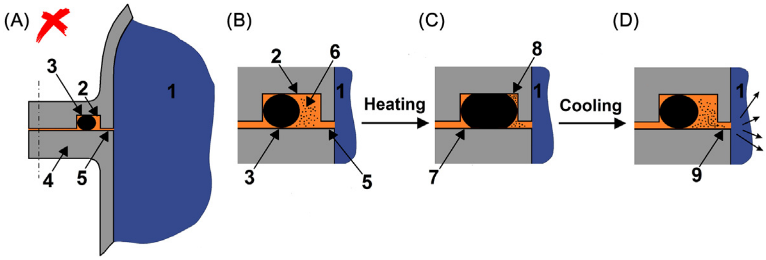


FIGURE 7.14 (A) A conventionally designed right-angled groove (2) contains an O-ring (3) that is compressed between the sealing faces of two stainless steel surfaces (4) to separate the product area (1) from the outside. (B) Such a rectangular groove–O-ring design invariably create gaps and crevices (5) that are impossible to clean in-place and/or to sterilize in-place. The groove provides sufficient space for microorganisms (6) to enter via the crevice. (C) During heating, due to the difference in thermal expansion between metals and elastomers, the O-ring will expand (7) to cover an increasingly larger surface of steel, protecting microorganisms (8) trapped between the O-ring and the steel surface against contact with hot water, chemical solution or steam. (D) After cooling down and shrinkage of the seal, the surviving microorganisms may be released (9) and will multiply and contaminate the product (Lelieveld et al., 2003; Hauser et al., 2007).

contaminate the product. Additionally, repeated thermal expansion of the seal into the product flow may result in damage which will not only contaminate the product but may also progressively reduce its ability to seal again upon recooling.

7.6.2 Hygienic Design and Installation of Agitators in Closed Vessels

The traditional arrangement of agitators is a driveshaft with an overhead drive unit and impeller blades mounted on the shaft. A wide variety of blade designs are used and typically the blades cover about two-thirds of the diameter of the vessel.

7.6.2.1 Hygienic Design of Permanently Installed Agitators

Top entering agitators with shaft seals are typically mounted to a vessel using a flanged or hygienic clamp connection, with hygienic O-rings or gaskets to seal between the mating surfaces. Agitators and agitator shaft assemblies passing through the seals shall be designed and constructed to be smooth, with all surfaces meeting all the hygienic design criteria applicable to a product contact area. Agitator ends shall have surfaces of minimum area immediately adjacent to the recipient ends and no longer than necessary to ensure proper incorporation of ingredients into a mix. The design of agitator product contact parts should minimize the occurrence of crevices and sharp corners, and be free of pockets, screw threads, void spaces, and dead spaces in grooves (Fig. 7.15).

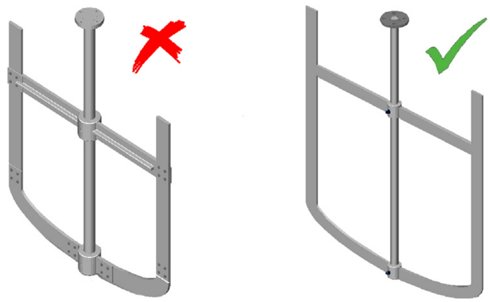


FIGURE 7.15 Install hygienically designed agitators, free of pockets, sharp corners, crevices, screw threads, etc. *Courtesy of Post Mixing Optimizations and Solutions, LLC.*

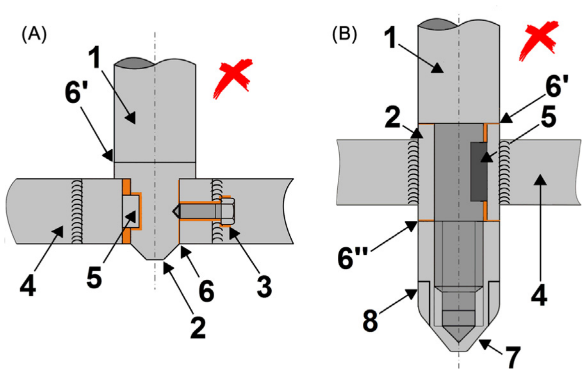


FIGURE 7.16 (A) The hub (2) is secured to the shaft (1) by means of a screw (3), which is exposed to product that may collect in and around the screw head. The hub-to-shaft connection gives rise to a metal-to-metal joint (6′) that may permit the ingress of product and bacteria. Agitator blades (4) should be welded to the hub, although screw connections are sometimes observed. These exposed screw heads (even bolts with dome head nuts and washers of suitable food grade material) again will create a food safety hazard, and the blade-to-hub connection gives rise to a new metal-to-metal joint (6). To avoid the latter problem, the joint between the blade and the lug on the hub can be sealed by a thin gasket. Keyways (5) exposed to product are not recommended, because product and microorganisms may be retained in the keyway. Keyways may require additional design and/or cleaning practice to ensure drainage and cleanability, e.g., spray ball and wand additions, increased CIP flow and adjusted spray coverage. (B) Once the hub (2) is secured to the shaft (1), an end cap (impeller nut, 7) is screwed on the interior male thread end of the shaft. The nonwelded impeller hub-to-shaft and hub-to-end cap connections give rise to crevices and metal-to-metal joints (respectively 6′ and 6″) that may allow the ingress of product and bacteria. In that way, the keyway (5) may retain product and microorganisms. The sharp corners of the spanner flats (8) on the end cap may be difficult to clean (Hauser et al., 2004b; Moerman and Kastelein, 2014).

Less suitable, not recommended designs are those in which hub, impeller blades and end nut are assembled together by screw joints (bolting) (Figs. 7.16A and 7.17A). Debris may collect on exposed screw threads, even if bolts with dome head nuts and washers of suitable food grade material are

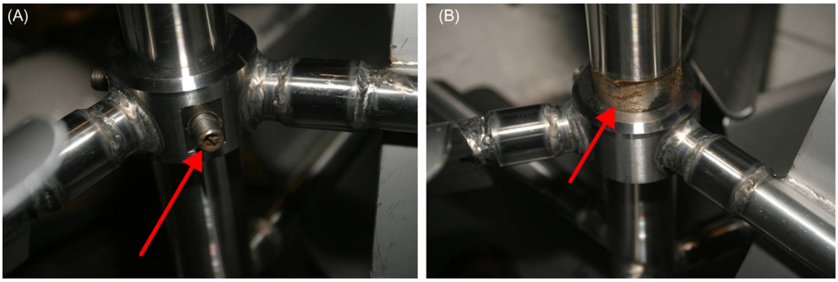


FIGURE 7.17 (A) The hub is secured to the shaft by means of bolts with dome head nuts. However, product may collect in and around the screw head (*red arrow*). (B) This nonwelded hub-to-shaft joint also lacks a food grade gasket that could seal the dead spaces in the groove and avoid crevices at points of metal-to-metal contact. Ingress and accumulation of product and/or microorganisms at the inside (*red arrow*) are shown. Welds also have a high degree of roughness. *Courtesy of Burggraaf & Partners B.V.*

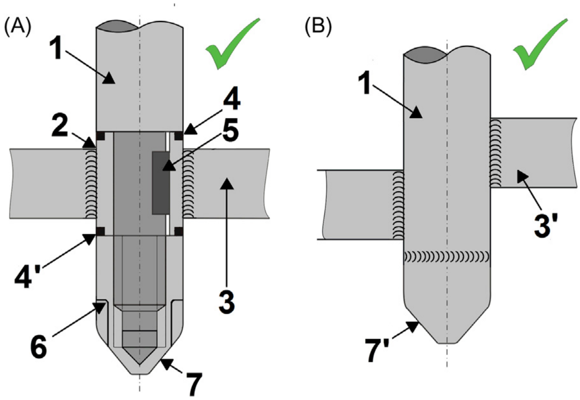


FIGURE 7.18 The hub (2) with blades (3) is secured to the shaft (1). All voids should be closed by either fabrication (welding) or approved sealing techniques (O-rings, seals, etc.) to give surfaces ground flush and free of crevices at points of metal-to-metal contact. (A) Food quality gaskets under controlled compression respectively may seal the propeller hub to the shaft (4) and end cap (4′). Keyways (5), where employed due to mechanical design considerations, shall have edge radii not less than 3 mm. The corners of the spanner flats (6) on the end cap have been radiused. (B) An all-welded impeller assembly (e.g., hub, blades, end cap) is still preferred. Impeller hubs welded to the shaft are preferred over removable hubs. Although the designer may omit the hub, and immediately can attach the blades to the shaft by welding (3′). Finally, also the end cap (7′) can be welded to the shaft (Hauser et al., 2004b; Moerman and Kastelein, 2014).

used. Metal-to-metal joints (e.g., keyways, hub-to-shaft joints, hub-to-end cap joints, etc.) may allow ingress and accumulation of product and/or microorganisms (Figs. 7.16B and 7.17B). Food quality gaskets under controlled compression may seal the propeller hub to the shaft and to the impeller nut (end cap) that secures the end of the agitator shaft (Fig. 7.18A). Alternatively, the hub should be welded to the shaft and the end cap (Fig. 7.18B), with the blades of appendages (stirrers, homogenizers, mixers, etc.) welded to the hub. As an alternative to impeller blade-to-hub attachment, blades can be immediately attached to shafts by welding (without hub) (Fig. 7.19). In this all-welded one-piece design, all welds must be ground flush and polished.

Permanently joined metal surfaces with a total included internal angle less than 135 degrees on agitators (e.g., at hubs and nuts) shall have a radius of not less than 3 mm tangential to both adjacent surfaces. Corners (e.g., at hubs, nuts, spanner flats, etc.) must be radiused to facilitate cleaning, and horizontal areas must be sloped to prevent debris from becoming lodged on the surfaces and to allow for maximum drainabilty. Machined transitions such as shaft steps, coupling surfaces, spanner flats, etc. should have 15- to 45-degree sloped surfaces. Impellers with flat, horizontal surfaces (e.g., flat-blade disc turbines, concave-blade disc turbines) may require additional design and/or cleaning practice to ensure drainage and cleanability, e.g., drain holes, spray ball and/or wand additions, increased CIP flow, adjusted spray coverage and faster impeller rotation. Where permanently installed agitators are equipped with an outer frame to which rubber, plastic or other similar scraping edges (Fig. 7.20) are attached, these scrapers shall be readily removable from the agitator. They should be regularly checked for integrity. Cases are known where plastic scrapers were broken and pieces lost in the product as a foreign-body contaminant.

Welded in-tank shaft connections are preferred, although in-tank shaft couplings (Figs. 7.21A–C and 7.22A–B) and in-tank threaded shaft connections (Fig. 7.22C) are allowed if they are of acceptable hygienic design. Threaded shaft connections are preferred over in-tank shaft couplings, although shaft rotation of the first is limited to a single direction to avoid the shaft

FIGURE 7.19 All-welded impeller assembly (e.g., hubs, blades, end cap). The agitator paddle blades being attached to the shaft by welding must have their welds ground and polished. *Photo right, courtesy of Intechwell/Alfa Laval AB.*

FIGURE 7.20 This agitator may cause hygiene problems because of the bolts and plastic scrapers. Cases are known where plastic scrappers were broken and pieces lost in the product as a foreign body contaminant.

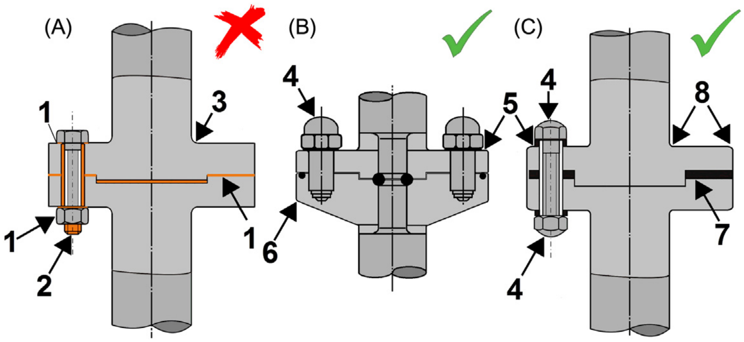


FIGURE 7.21 (A) Bolted agitator couplings with flat hexagon head screws without elastomer gasket under the bolt head and the nut give rise to metal-to-metal crevices (1) that may allow the ingress of food product and bacteria. Moreover, debris may lodge in and around the bolt thread (2). The absence of a circumferential O-ring or flat gasket gives rise to another metal-to-metal crevice, and product and microorganisms may be retained in the cavity (3). (B, C) Agitator couplings made by means of domed hexagon bolt heads and nuts (4) provided with an elastomer gasket (5) under the bolt head and the nut allow for a crevice free joint without metal-to-metal contact. Due to the presence of a circumferential O-ring (6) or flat gasket (7), no product and microorganisms can enter inside the agitator coupling. Corners are radiused (8). However, there is still a horizontal flat surface at the upper side of the agitator coupling where debris may lodge (Hauser et al., 2004b; ASME BPE committee, 2014; Moerman and Kastelein, 2014).

sections separating. The designer must ensure that the use of a threaded shaft connection is appropriate for the selected shaft diameter and design loads. To avoid exposure of the threads to the product, O-rings or flat gaskets (preference for the first mentioned) should be used to seal mating surfaces (Fig. 7.22C). Hygienic bolted coupling construction may be used where appropriate for the

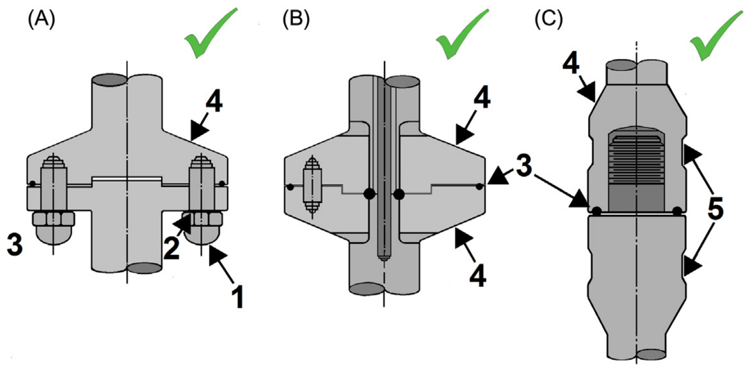


FIGURE 7.22 (A, B) Aseptic applications require the fastening of hardware at the bottom side of the agitator coupling. Agitator couplings made by means of domed hexagon bolt heads and nuts (1) provided with an elastomer gasket (2) under the bolt head and the nut allow for a crevice-free joint without metal-to-metal contact. Due to the presence of a circumferential O-ring (3), no product and microorganisms can enter the inside of the agitator coupling. The upper parts of the coupling should be sloped to a minimum 15–45 degrees (4) to prevent debris from collecting at these places and to allow for maximum drainability. (c) The optimal agitator coupling in an aseptic environment is a threaded shaft connection with O-rings or flat gasket (preference for the first mentioned) (3) to seal the mating surfaces to avoid exposure of the interior thread. The corners of the spanner flats on the end cap have been radiused (5) (ASME BPE committee, 2014; Moerman and Kastelein, 2014).

particular application. The preferred location for fastening hardware is on the underside of couplings, and the fasteners typically used should be hex-head cap screws, acorn-head cap screws and threaded studs with acorn nuts (Fig. 7.22A). These fastener heads shall be free of raised or engraved markings that might inhibit cleanability. Again, O-rings or flat gaskets (preference for the first mentioned) should be used to seal coupling mating surfaces. Elastomer seal washers (Figs. 7.21B–C and 7.22A) must avoid metal-to-metal contact.

7.6.2.2 Top Mounted Installation of Agitators

Agitators permanently mounted are not required to be removable if they are readily accessible to be effectively cleaned via spray, directed flow, immersion or cleaning-in-place (CIP) and if they do not interfere with drainage from the tank. Top entering agitators with shaft seals are typically mounted to a vessel using a flanged or hygienic clamp connection, with hygienic O-rings or gaskets to seal between the mating surfaces. The selected mounting arrangement must support the agitator mounting design loads while achieving an appropriate seal. The upstand for the top mounting of the agitator should have limited length L because of the difficulty of cleaning of the annular space in-place. The annular space between the agitator shaft and agitator nozzle shall, for cleaning purposes, have the target maximum L/A ratio of 2:1. At least a 25 mm gap is required to

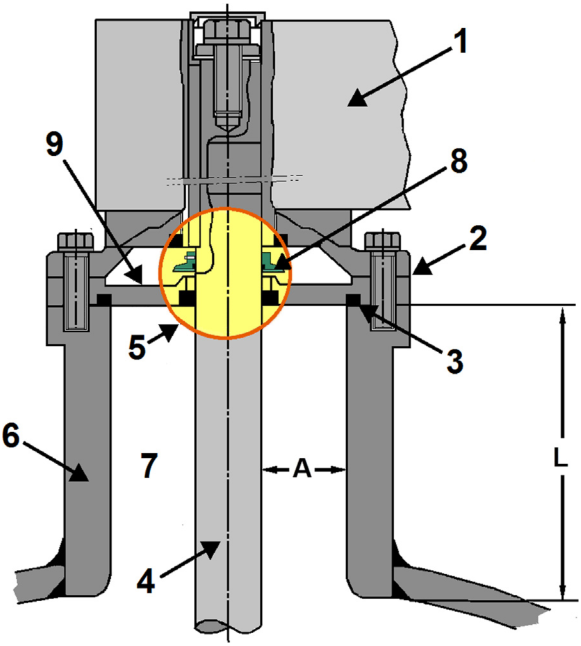


FIGURE 7.23 The top entering agitator with motor (1) is mounted to a vessel using a flanged or hygienic clamp connection (2), with hygienic O-rings or gaskets (3) to seal between the mating surfaces. A retained gasket having limited compression is more hygienic than an O-ring in the face for sealing the joint. The agitator shaft (4) passes through the mounting flange via a seal (5). The upstand (6) for the top mounting of the agitator should have limited length L because of the difficulty of cleaning the annular space (7) in-place. The annular space between the agitator shaft (4) and agitator nozzle (6) shall, for cleaning purposes, have the target maximum L/A ratio of 2:1. Agitator motors (1) should be equipped with permanently lubricated bearings. Where lubrication is required, the design and construction shall be such that lubrication cannot leak, drip, or be forced into the product zone. Self-lubricating agitator shaft (packing) seals (8) shall be provided with convenient means for adjustment to prevent leakage and to allow for complete drainage to the exterior. In that way, accumulations of foreign material in the event that leakage does occur can be avoided. Further, a drip protection plate (9) can be provided to prevent lubricant from entering the product zone (Moerman and Kastelein, 2014).

facilitate CIP spray coverage (Fig. 7.23) (CFCRA, 1997; BISSC, 2003; ASME BPE committee, 2014).

Agitator motors should be equipped with permanently lubricated bearings. Where lubrication is required, the design and construction shall be such that lubrication cannot leak, drip, or be forced into the product zone. Self-lubricating agitator shaft (packing) seals shall be provided with convenient means for adjustment to prevent leakage and to allow for complete drainage to the exterior (Fig. 7.23). In that way, accumulations of foreign material in the event that leakage does occur can be avoided. Further, drip protection is commonly provided to prevent lubrication from entering the product zone.

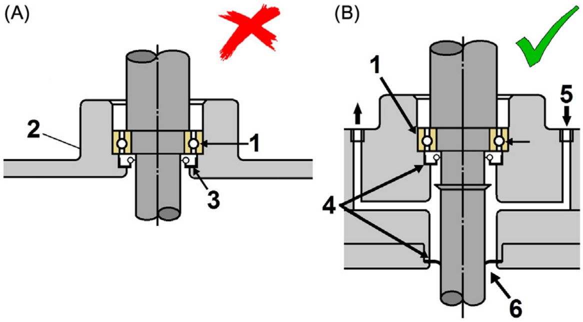


FIGURE 7.24 Rotary shafts running at a high number of revolutions are held in-place in an adaptor sleeve with a radial roller bearing (1). (A) Single dynamic seals (2) are lubricated by a lubricant (top-mounted agitator) or the product (bottom-mounted agitator) which may be transported past the seal and back again, contaminating the product further. They may be easy to clean if properly designed but they will not prevent the passage of microorganisms, and hence they are not suitable in aseptic process equipment. There is also a narrow annular space (3) at the product side in the proximity of the seal, which makes cleaning very difficult. (B) A double seal arrangement (4) allows the use of a barrier medium (5), such as steam, hot water, condensate, or a disinfectant solution that makes it well-suited from a microbiological standpoint. The volume of the annular gap around the shaft is increased (6), improving the cleanability of the seal and its proximity (Holah, 2000).

All surfaces of shaft seal ring assemblies passing through a bowl or cover shall be accessible, removable or retractable to permit cleaning of all product zone surfaces.

Rotary shafts running at a high number of revolutions are held in-place in an adaptor sleeve with a radial roller bearing. Single dynamic seals (Fig. 7.24A) will not prevent the passage of microorganisms. If properly designed, they may be easy to clean but not bacteria tight because rotating shafts always exhibit some axial mobility. This makes single dynamic seals unsuitable for aseptic equipment. A narrow annular space at the product side in the proximity of the seal, such as that shown in Fig. 7.24A, must be avoided because it is difficult to clean. The space around the seal should be as wide as possible. Rotary shafts with double seal arrangement allow the use of a barrier medium, and have been shown to be well-suited from a microbiological standpoint. In Fig. 7.24B, one seal is seated rigidly in the housing (longitudinal shading), while the other moves with the shaft. The sealing surface between the two seals must be lubricated. If the shaft opening has product flowing through it, which could be the case with agitators having a shaft entry from the bottom of vessels, the product itself can be directly used as lubricant. The product flowing through can be carried away by the barrier medium, which could be steam, hot water, condensate or a disinfectant solution (e.g., alcohol). The sterile fluid may scavenge the microorganisms that enter the space between the seals, maintaining sterile conditions. Which flushing fluid should be used will depend on the product and the process but both the barrier medium and lubricant chosen must be product-compatible. To avoid transfer of microorganisms from the outside of the equipment to the inside the distance between the two seals must always be sufficiently large (Lelieveld et al., 2003; Hauser et al., 2007).

Bearings in the product area should be avoided but an application may mandate the use of foot bearings. In the example given, if the shaft of a top entry agitator is very long, a foot bearing may be required at the bottom of the vessel to steady it. It shall be of a packless bearing type. The foot bearing must be mounted well clear of the base so as not to impede free draining of product and to allow easy cleaning of their supports. Design features and/or procedures required to ensure cleanability are: drain holes, spray ball, and/or wand additions, increased CIP flow, operating the steady bearing immersed in CIP fluid. The arrangement of wear surfaces (bushing, shaft, or shaft sleeve) shall facilitate drainage. A longitudinal or helical groove may be cut in either the bush or the shaft. It should be deep enough to allow access into the bearing of either the product as a lubricant or the detergent for cleaning (Fig. 7.25). Sealed bearings should not be used in the product area because they can cause hygiene risks at their seals. If, however, their use is unavoidable, their lubricants should be specified as being allowed in contact with food.

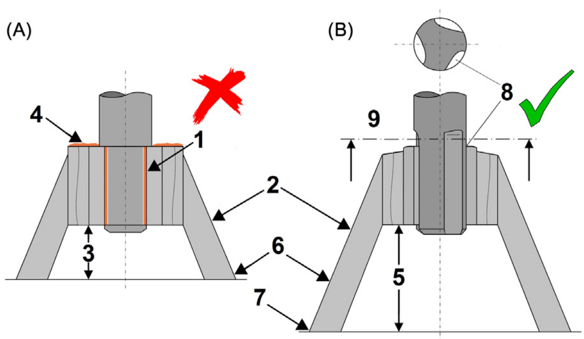


FIGURE 7.25 (A) Cleaning may be impeded due to too-tight clearance (1) in the foot bearing itself (2), and due to too little clearance between it and the base (3). Horizontal ledges (4) where product may accumulate or where liquids are not allowed to drain must be avoided. (B) The foot bearing is now mounted clear of the bottom of the vessel (5), allowing free flow of product and cleaning solution around it. Bearing pedestal support members (6) should preferably be made of solid construction. Hollow constructions are not recommended, but if used, they shall be of sealed (welded) construction and inspected for integrity. Round legs are preferred over flat members, even if the latter are radiused. The legs should be flush welded in-place to the tank bottom (7). All welds must be ground and polished to blend smoothly with the adjacent surfaces. The agitator shaft is provided with grooves (8) in the bearing area to facilitate both lubrication by fluid products and cleaning. Sloped and radiused surfaces (9) reduce the probability of debris getting lodged on the top of the foot bearing and allow for proper drainage of liquids (e.g., cleaning solution) (CFCRA, 1997; Lelieveld et al., 2003; Hauser et al., 2004b; ASME BPE committee, 2014). *Courtesy of Campden BRI.*

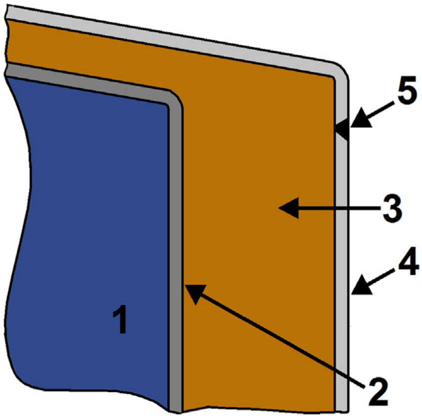


FIGURE 7.26 The inner tank wall (2) is provided all around with thermal insulation to keep food products (1) at the correct temperature. Rockwool (3) doesn't give rise to unhygienic conditions provided it is kept vapor tight by installing aluminum or stainless steel cladding (4) of appropriate thickness. Joints facing downwards must be continuously welded (5) to avoid any ingress of dust, liquor, air, and moisture.

7.6.3 Good Insulation Practices

Non-chloride-releasing insulation material should be used. For thermal insulation of vessels, appropriate qualities of rock wool are acceptable. It is highly recommended to install fully welded, vapor-tight, aluminum, or stainless steel cladding of appropriate thickness that resists tear and abrasion (Fig. 7.26). The exterior of the insulation protection should be smooth, properly sealed to avoid ingress of dust, liquor, air and moisture, and should be installed in a correct way with joints facing downwards. Such ingress could promote corrosion between the walls, assisted by possible microbial growth.

7.7 HYGIENIC DESIGN OF PROCESS AND UTILITY PIPING

7.7.1 Drainable Process and Utility Lines Without Dead Ends

Pipes must ensure minimum resistance to flow, and therefore there should be no sudden changes in cross-sectional area or obstructions that are likely to hinder the flow. However, valves and flowmeters may restrict the flow. Pipes also must be hygienically designed and meet standards that are required nationally and internationally. Consideration of CIP should be integrated into the mechanical and process design at an early stage, rather then being incorporated into an already fully specified plant. Hence, pipework must be so designed that as far as possible a minimum velocity of 1.5 m/s is achieved over the whole trajection of pipes, unless data for the specific soil indicate otherwise. As a consequence, substantial flowrates for larger-diameter pipework are required. Failure to achieve 1.5 m/s does not necessarily mean that effective cleaning cannot be achieved, but the process is likely to be nonoptimal.

To avoid the formation of standing "pools" of liquid that can support the growth of microorganisms, process and utility piping runs should be sloped to at least 3% in the direction of flow and should be properly supported to prevent sagging (Fig. 7.27). Nondrainable pipe sections are not allowed (Fig. 7.28). Where valves are fitted, additional support must be given. Where plastic piping is installed, special care should be taken to avoid sagging by increasing the frequency of support. Pipelines and valves should be supported independently of other equipment to reduce the chance of strain and damage to the equipment, pipework, and joints.

A properly designed food processing line must not have dead legs, as blanked-off tees constitute a hazard. A dead space, being an area outside the product flow where liquid or gas can become stagnant and where water is not exchanged during flushing, is formed. An air pocket may be present if the branch of a blanked-off tee is pointing vertically upwards (Fig. 7.29A). Hence it will prevent liquids (cleaning solutions, disinfectant solutions, or hot water) from reaching all surfaces to be treated, with the result that CIP and

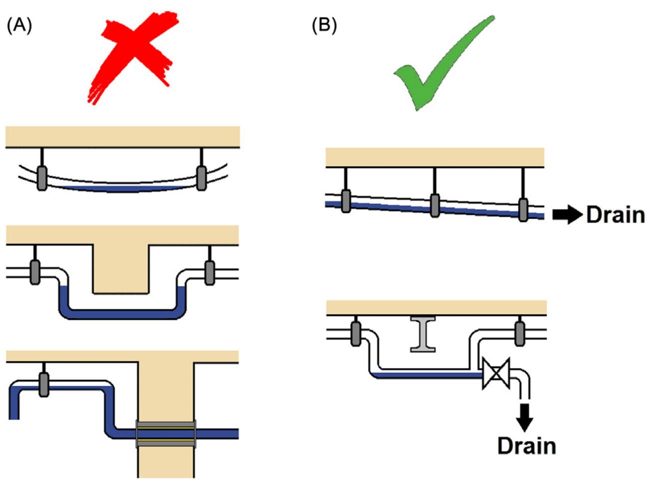


FIGURE 7.27 Pipes must be completely self-draining. (A) Sagging of piping must be avoided because standing "pools" of liquid can support the growth of microorganisms. Changes in the level of horizontal runs of pipelines should be avoided; otherwise, there will be an undrainable section. Horizontal runs of pipe which are routed vertically up and then down to bypass beams, doorways or other obstructions will allow air to collect in the raised section. (B) Process and utility piping runs should be pitched at least 3% in the direction of flow. Piping must be installed in a way that air doesn't collect in the raised section. While automatic air release valves can be installed (on top of elevated horizontal pipe sections) to remove trapped air, the resulting dead leg may cause contamination and/or cleaning problems. Where liquid collects in a lower horizontal pipe section, fitting a valve in a shortened tee allows liquid to be drained (CFCRA, 1997). *Courtesy of Campden BRI.*

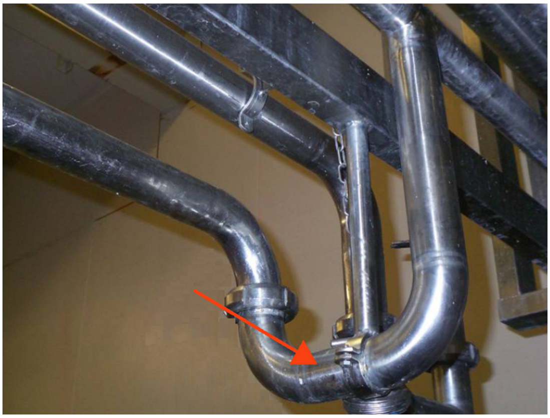


FIGURE 7.28 Nondrainable pipe section. *Courtesy of Mondelēz International, © 2016.*

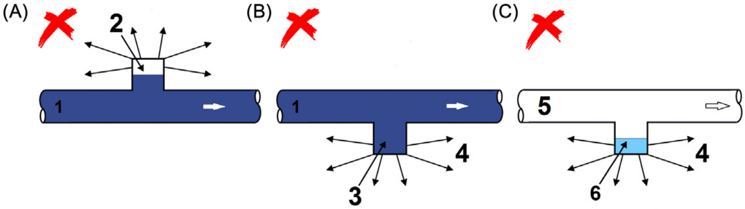


FIGURE 7.29 (A) When cleaning and disinfection solutions (1) flow through the piping, an air pocket (2) will be formed if the branch of a blanked-off tee is pointing vertically upwards. This will prevent the solutions from wetting the surface in the dead leg. (B) Drain points pointing downwards (3) again act as a dead leg, providing an area of entrapment that may not be reached by cleaning or sterilizing procedures, and hence they may lead to contamination of the product. Moreover, during a hot water treatment, the hot water also will stagnate in the downwards pointing pocket, so that the temperature of the surfaces in the dead area may be lower than required as the consequence of heat loss (4). (C) A downwards pointing dead area also will collect condensate (6) due to heat loss (4) during steam sterilization (5), with the result that again the temperature of the surfaces in the dead area may be lower than required. Blanked-off tees should be positioned such that they are a few degrees above the horizontal (Lelieveld et al., 2003; Hauser et al., 2007).

decontamination processes will be unsatisfactory. Drain points pointing downwards act as a dead leg (Figs. 7.29B and 7.30) and are not acceptable because they provide an area of entrapment that may not be reached by cleaning or sterilization procedures. During a hot water treatment, the hot water also will stagnate in the downwards pointing pocket, so that the temperature of the surfaces in the dead area as a consequence of heat loss may be lower than required. A downwards pointing dead area also will collect condensate during steam sterilization (Fig. 7.29C), with the result that again the temperature of the surfaces in the dead area may be lower than required. As a consequence, the thermal disinfection or sterilization of the dead space is compromised.

FIGURE 7.30 This drain point pointing downwards acts as a dead leg (organization Sanitary Design Workshop, © 2016).

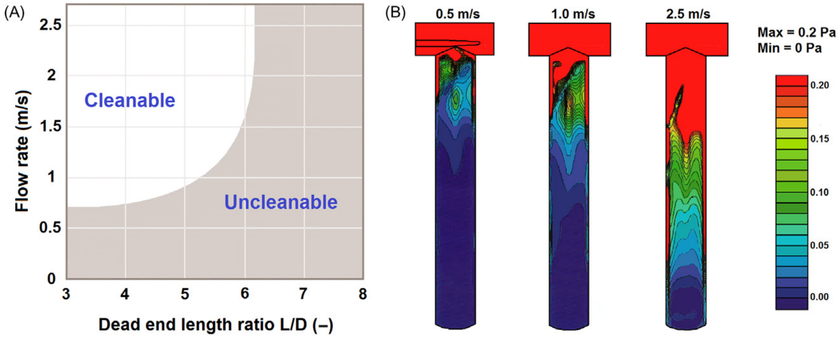


FIGURE 7.31 (A) Impact of the flow velocity and leg geometry on the cleanability of the dead zone. For an L/D of 6, it is possible to remove food residues adequately even when the main-pipe velocity is higher than 1.5 m/s. When the main pipe velocity is lower than 0.7 m/s, then it is impossible to remove food residues in a T-section with L/D of 3. (b) Moreover, thermal disinfection processes may be compromised due to a failure to reach the required minimum temperature conditions. (B) Dead end inner pipe surface shear stress (Haga et al., 1997).

Even with turbulent flow within the horizontal pipeline, the shear rate and temperature within the dead leg will fall rapidly with distance from the junction between the horizontal and vertical sections (Fig. 7.31).

The direction of the flow of food product has a significant influence on the residence time in the dead leg. When the food product flows in the direction as indicated in Fig. 7.32A, B and C, part of the product will stand still in the dead leg, especially if the length or depth of the T-section is too long. If the length of the T-section is equivalent to the diameter of the main pipe, a flow velocity of 2 m/s in the main pipe will already result in a reduced velocity of

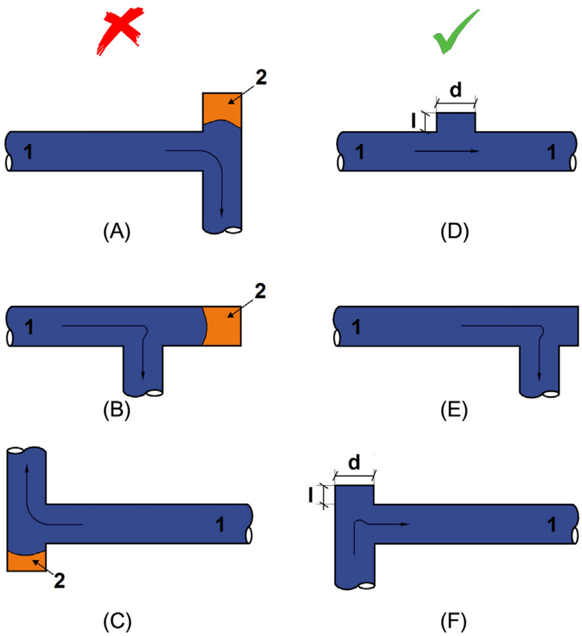


FIGURE 7.32 When the food product flows in the direction as indicated in (A, B, and C), part of the product will stand still in the dead leg, especially if the length or depth of the T-section is too long. Long T-sections outside of the main flow of cleaning solutions are also very difficult to clean. For most liquids, the dead leg should be positioned as shown in (D, E, and F). In particular, the configuration in (F) is quite acceptable if $l \leq d$, because the flow directed into the short dead leg provides sufficiently high velocities for proper cleaning. If the dead leg is very short ($l \leq d$), configuration (D) is acceptable, although flow across a dead leg results in much lower velocities within it and thus only provides moderate cleaning. Configuration (E) may not be suitable, if products contain any particulate matter that may accumulate in the dead leg (CFCRA, 1997; Lelieveld et al., 2003; Hauser et al., 2007).

0.3 m/s in the T-section. This decrease in flow velocity provides a relatively stable pocket or dead leg in which product residues can accumulate and microorganisms begin to multiply. Long T-sections outside of the main flow of cleaning solutions are also very difficult to clean. During cleaning there is much less transfer of thermal (heat), chemical (detergent and disinfectant chemicals) and mechanical energy (action of turbulent flow) to the food residues in the T-sections (outside the main flow of cleaning liquids) than to the soil in the main flow. Notice that flow away from the dead leg such as in Fig. 7.32A and C further gives rise to more contamination problems and worse cleaning, as velocities in these dead legs are even much lower.

For most liquids, the dead leg should be positioned as shown in Fig. 7.32D, E and F. If the dead leg is very short, configuration Fig. 7.32D is acceptable, although flow across a dead leg results in much lower velocities within it and thus prolongs the time for cleaning. Configuration Fig. 7.32E may not be suitable, if products contain any particulate matter, which may accumulate in the dead leg. The configuration in Fig. 7.32F is the most acceptable, because the flow directed into the short dead leg provides sufficiently high velocities for proper cleaning

For pipe diameters of 25 mm or larger, T-sections should have a depth/length of preferably under 28 mm, while for smaller pipe diameters this length should be smaller than the diameter. Blanked-off tees should be positioned such that they are a few degrees above the horizontal. The dead leg will then be drainable but not necessarily cleanable even if made as short as possible. If a sensor must be installed in a process line, it should be installed in a bend on a shortened tee in a position that the flow of cleaning fluid should be directed into the tee (Fig. 7.32E and F). Where an angle valve is installed in the process piping circuit, this valve also must be mounted in a shortened tee so that no or a minimum of annular space above the side branch is formed. Again, the flow of cleaning solution must be directed into the tee. In all cases, the cleaning procedure must take the presence of the dead leg into account.

Flow diversion should not be done in a way that would cause part of the product to stand still in a dead leg. The two-valve system for flow diversion (Fig. 7.33A) creates a dead leg toward the closed valve. The correct type of valve is shown in Fig. 7.33B.

For horizontal piping, eccentric reducers should be used instead of concentric reducers, because the latter provide a dead spot where condensate and dirt may collect (Fig. 7.34).

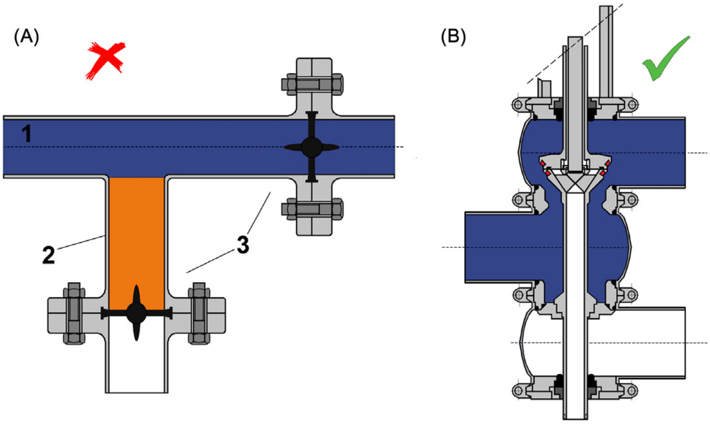


FIGURE 7.33 (A) Flow diversion should not cause part of the product (1) to stagnate in a dead area (2). The system of two butterfly valves (3) for flow diversion creates a dead area (2) toward the closed valve. (B) The correct type of valve is shown on the right (Lelieveld et al., 2003; Hauser et al., 2007).

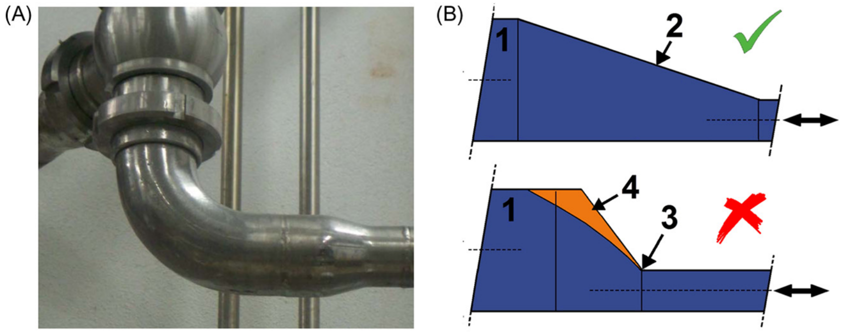


FIGURE 7.34 Changes in pipe diameter should be made by the use of reducers to ensure a smooth transition of the product flow. (A) In vertical piping, a concentric reducer is fully acceptable for food product to flow. However, this is not the case for horizontal piping, where the concentric reducer prevents full drainage if product flow is in the wrong direction. A dead spot is created where condensate and dirt may collect. (B) For horizontal piping, eccentric reducers are preferred. The reducers should be long enough (2) to avoid shadow zones during product flow (1). If a short eccentric reducer (3) is applied, a potential shadow zone (4) will be created (Lelieveld et al., 2003; Hauser et al., 2007).

7.7.2 Pipe Joints

Pipe work may be designed either for rapid regular dismantling to permit cleaning (sterilization takes place after reassembly), or for CIP without dismantling the plant. In the first case, couplings can be used, while in the second case preference is given to welding. It is strongly recommended to minimize the number of joints, whether welded or detachable. Cold bending of pipes is highly preferable to the use of prefabricated bends that have to be installed using couplings. Pipes may be joined together either by welding or by couplings, which again should meet the highest standards, both technically and hygienically. It is important to avoid crevices and gaps where product residues can accumulate and potentially begin to decompose. Although more hygienic, welded joints may be the weaker places in a process system, depending on the quality of the weld.

7.7.2.1 Permanent Pipe Joints (Welded Joints)

Welding is the preferred method of joining, provided that it is done correctly. Stainless steel hygienic tubing joints should be made by automatic orbital welding (Fig. 7.35) where possible and hand welding in those places that are difficult to access. However, those welds that are difficult to access should, wherever possible, be completed in the workshop prior to installation on the plant. The applied materials should be easily weldable, and higher alloyed filler metal in comparison to the welded material should be used to improve the corrosion resistance. Piping with the correct interior diameters should be applied because any mismatch in diameters or thickness may result in misalignment,

FIGURE 7.35 Stainless steel hygienic tubing joints should be made by automatic orbital welding where possible. Orbital welding provides smooth and crevice-free junctions (Kopitzke et al., 2006).

introducing a step in the wall or bore. If the diameters of the pipes to be joined are not the same, then the smaller pipe should be expanded to match the larger one. Misalignment also can be due to incorrect fitting up (missed coincidence between the axes of the two coupled components) prior to welding. Alignment and clamping tools are available to ensure accurate alignment. Misalignment tolerance must be limited to less than 20% of the wall thickness.

For proper welding, the parts to be welded should be adequately prepared. Cutting should be done with a mechanical mill or saw to ensure that the cut face is exactly at right angles to the longitudinal axis of the pipe. Any burrs must be removed with either a file or emery paper. Care must be taken not to remove the corner edges of the pipe, as this can give rise to problems with fusion of the root of the weld. The pipe surface 25 mm either side of the weld should be roughened up with a stainless steel wire brush, or emery paper. Then both pipe ends and the roughened surface area should be degreased with a solvent and cleaned from contaminants, because any organic substances remaining on the metal surface are vaporized during the welding process and form bubbles (porosity) in the weld metal. Pores in welds may trap product residues.

After two deburred pipe ends are aligned and butted together to a gap of less than 0.25 mm between both pipe faces, a butt weld joint is made by fusing together the two stainless steel edges with the aid of filler material. If the gap during the joint preparation is too wide, a crack running along the weld metal itself may be the result (center line cracking). Full penetration welds should be used whenever possible to avoid pockets where volumes of gas or contaminants can be trapped. Single pass welds should be utilized instead of multipass welds to avoid trapped volumes. The weld metal should exactly fill the joint and remain flush with the surface. Underpenetration leaves a crevice at the joint, while excessive overpenetration can give rise to hold up of product in pipework once taken into service. The weld metal in the joint must be fully fused to the parent metal; otherwise a crevice will form at the interface between weld and plate. Weld zones should be continuous, smooth, and flush with this parent metal. The welding process always should occur with sufficient weld seam protection, because insufficient inert gas shielding or no internal purge will result in roughened welds of lower corrosion resistance, which are prone to increased adhesion of soiling and are difficult to clean. Typically, where inert gas shielding was inadequate, significant discoloration or carbonization in the heat-affected zone is observed.

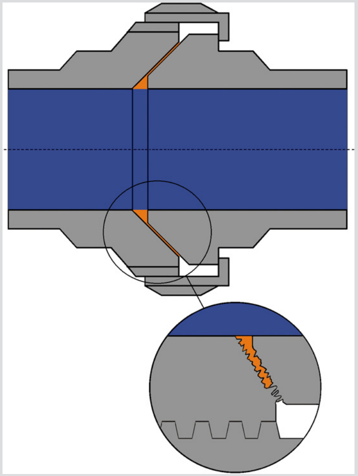
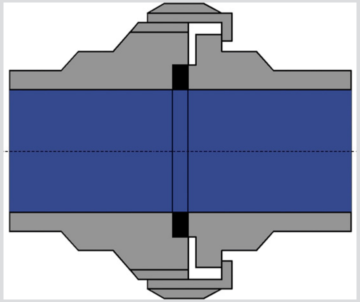
Weld slag and debris generated within the pipe must be removed from the inside and outside of the weld by proper maintenance and cleaning practice with an alkaline detergent solution prior to the start of the production process. This is followed by rinsing with water of good microbiological quality, usually chlorinated water to 2 ppm available chlorine maximum. After draining, the access points should be covered and sealed. In some circumstances there is an additional requirement to passivate the weld area on the product contact side. The welds may be mechanically polished (outside) or electro-polished (inside and outside), but air leakage should be monitored after the polishing procedure.

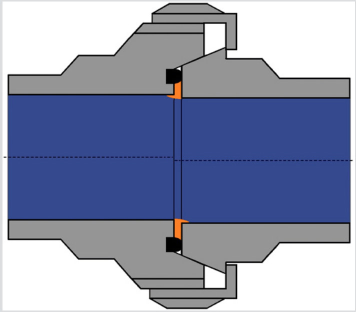
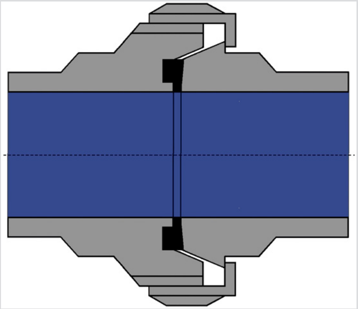
Weld seams finally should be visually inspected for any discoloration and surface breaking defects, usually by endoscopy and aided by dye penetrant tests that highlight these defects. Inspection personnel should be trained and act with caution to avoid internal surface damage while handling endoscopic tools (Hauser et al., 1993; Kopitzke et al., 2006).

7.7.2.2 Dismountable Pipe Joints

From a hygienic point of view, the use of threaded piping is not recommended, because it provides crevices and areas where bacteria can adhere and proliferate. Couplings must be crevice-free and only external threads are allowed. Several well-established pipe couplings and seal arrangements (Table 7.2) have been assessed for applications in the food industry.

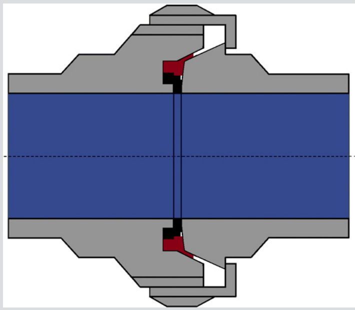
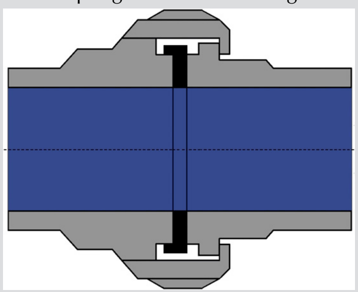
TABLE 7.2 Overview of Market Available Pipe Couplings and Seal Arrangements (CFCRA, 1997; Lelieveld et al., 2003; Hauser, 2008b)

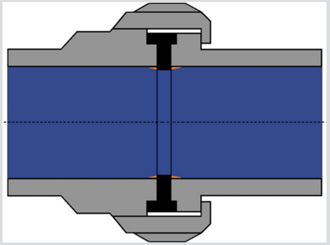
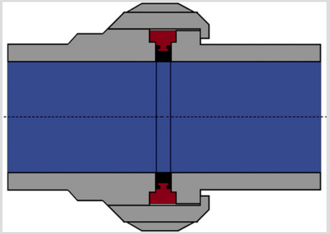
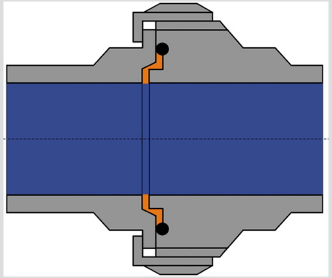
Type	Hygiene Characteristics	Application
3-A coupling—ground seat 	When these surfaces become permanently damaged, it becomes more difficult to obtain a tight seal after every disconnection. The metal-to-metal seat does not prevent the partial penetration of low viscosity liquids nor the ingress of microorganisms. Even if the joints are not visibly leaking, the ingress of microorganisms is possible. Furthermore, the seal obtained is very unlikely to be continuous at the interface with the product. More likely, the actual seal follows an irregular line between the inside and outside. The resulting annular crevice will trap product.	Not recommended for use in hygienic plant pipelines and CIP installations, because the internal annular crevice may retain product during production and/or after CIP. It is widely used in situations where a gasket is unacceptable.
3-A coupling—gasket seat 	When correctly fitted and assembled a smooth, crevice-free internal surface is obtained.	Suitable for handling most products and for CIP.

Dairy coupling DIN 11851—standard gasket 	There is an internal annular crevice between the ends of the coupling parts and the bore of the gasket. Product may be retained during production and/or after CIP. An additional potential problem with this design of fitting is that it has a clearance on the cone fitting, with the consequence being that the two pipes are not automatically aligned. This could give rise to a potential step in the pipe joint. The coupling does not comply with 3-A or EHEDG hygienic design criteria.	Often found in the food industry (pipes and tanks) due to the fact that it is reasonably priced. Not considered as suitable for CIP, which means that the fitting should only be used where the pipework is manually cleaned.
Dairy coupling DIN 11851—nonstandard collared gasket 	It provides a smooth, crevice-free internal surface when correctly fitted and assembled. However, because of the mobility of this type of coupling and the alternate expansion and contraction of the gasket, this gasket may be damaged by shear. Does not comply with 3-A or EHEDG hygienic design criteria.	Not recommended for use in hygienic plant process lines and CIP installations. Expensive and does not fulfill standard hygienic design criteria.

(*Continued*)

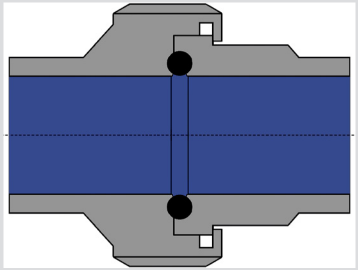
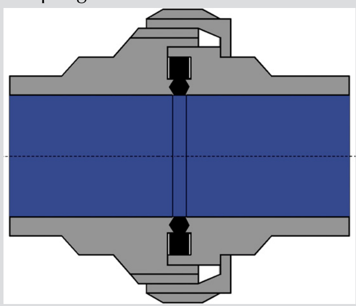
TABLE 7.2 (Continued)

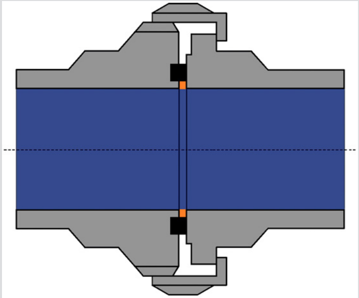
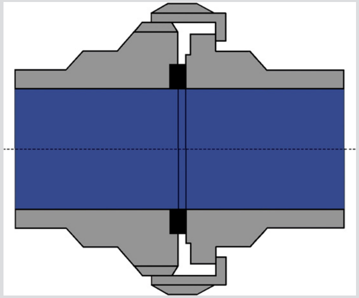
Type	Hygiene Characteristics	Application
Dairy coupling DIN 11851—alternative gasket with SKS ring 	With support of the steel ring the gasket remains flush with the surface. The special designed gasket fills all dead areas in the coupling and will expand to the outside in cases of high temperature. At elevated temperatures, expansion of the seal to the inside is limited. This solution takes all critical points of a DIN 11851 coupling away. Complies with 3-A or EHEDG hygienic design criteria.	A stainless steel center ring and gasket are an easy solution to upgrade a DIN 11851 coupling to a hygienic status. The smooth surface gives excellent cleanability.
IDF coupling ISO 2853 with L-gasket 	When the coupling is correctly fitted and assembled, a smooth continuous bore and internal surface without crevice is obtained, so that cleaning may be performed without any problems.	This coupling is recommended for applications where CIP is normally applied. Widely used for pasteurized circuits where dismantling is infrequent.

IDF coupling ISO 2853 with nonstandard T-shaped gasket 	When properly made up, the joint is crevice-free and has a smooth bore, flush with the pipe walls. If overtightened, the gasket may expand into the bore of the pipe, which creates a step where product can become trapped. Unless the nut is tightened correctly, the coupling will not be bacteria-tight.	Most suitable for permanent or semipermanent installations that are going to be cleaned in-place. If the seal material is suitable, then it can be sterilized.
IDF coupling ISO 2853 with metal-backed T-shaped gasket 	By supporting the seal with a stainless steel ring, both axial stop and centering can be achieved, allowing the connection to meet the requirements of hygienic design. The rubber is specifically shaped to give a flush interior joint when the union is tightened.	Most suitable for permanent or semipermanent installations that are going to be cleaned in-place. If the seal material is suitable, then it can be sterilized.
Recessed ring joint type (RJT) screwed coupling 	There is an internal annular crevice between the liner and the male part and the bore of the joint ring. Hence, product may be trapped and retained between the two metal components during production and could cause problems if certain products are handled. Does not comply with 3-A or EHEDG hygienic design criteria.	This type of coupling is recommended for use where piping systems are frequently dismantled, but is not suitable for CIP. It is used in the brewing and dairy industry in applications where pipework is manually cleaned. Excellent for flow-plates, owing to the wide dimensional tolerance on mating bends.

(*Continued*)

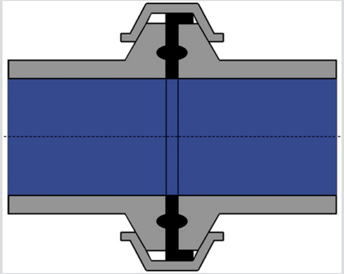
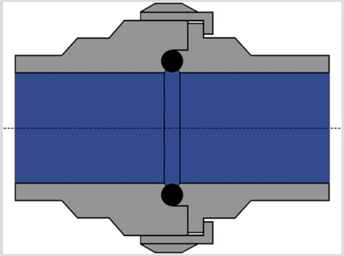
TABLE 7.2 (Continued)

Type	Hygiene Characteristics	Application
Coupling DIN 11864 form A 	A smooth interface within the pipe work while simultaneously achieving a metal-to-metal seat behind the joint. A sufficient gap is created between the seal and the product space to facilitate rinsing in cleaning processes. This gap also serves as an expansion space that can accommodate volume expansions in the material as a result of heat or the influence of media without forces that can result in shearing. The groove is designed to minimize protrusion of the O-ring into the pipe bore. Complies with EHEDG and 3-A design criteria.	Optimal for aseptic operations because they are successfully tested for CIP-ability, steam sterilizability and bacteria tightness.
Coupling DIN 11864 form B 	The volume of the functional part of the gasket (diamond section) is minimal to limit the effects of thermal expansion. A small area of the gasket is exposed to the product. The width of the exposed part of the gasket is only 1 mm. The block of elastomer behind the seal will accommodate the thermal expansion, relieve stress buildup on the sealing faces and limit expansion into the product stream to a minimum. The small functional part of the gasket may expand into two directions. To prevent air from being trapped between the gasket shoulder and the male part groove, small slits are provided on the outside, acting as vents.	Optimal for aseptic operations because they are successfully tested for CIP-ability, steam sterilizability and bacteria tightness.

Standard SMS 1145 coupling  (DS coupling is similar to this coupling)	Standard SMS couplings are not hygienic because an internal annular crevice is formed in which product may be retained during production and/or after CIP. The bore of the gasket may retain product. L-profile gaskets are available but do not provide self-centering. A later version, when correctly fitted and assembled, provides a smooth, crevice-free internal surface. Does not comply with 3-A or EHEDG hygienic design criteria.	Only the latter version is suitable for handling viscous products and for in-place cleaning.
SMS 1145 coupling—Alternative gasket 	When correctly fitted and assembled, provides a smooth, crevice-free internal surface.	Suitable for handling viscous products and for in-place cleaning.

(*Continued*)

TABLE 7.2 (Continued)

Type	Hygiene Characteristics	Application
Clamp coupling ISO 2852 	The seal is considered to form a smooth, crevice-free joint between the liners, which makes clamp type couplings suitable for CIP duties. Some users have indicated a preference for clamp fittings rather than screw-type couplings because in the event of a spill, screw threads cannot be decontaminated effectively. Clamp-type couplings are perceived to have the advantage that in the event of a product spillage at the fitting there is no thread to become filled with product that may be difficult to clean.	Often found in the food and pharmaceutical industry, in pipes and tanks. Not considered suitable for CIP.
VARIVENT flange coupling 	VARIVENT flange coupling ensures a smooth transition, free of dead space. It complies with EHEDG and 3-A design criteria.	Successfully tested for CIP-ability. Suitable for aseptic processes.
NEUMO BioConnect 	The seal is almost completely encapsulated. The highest press-on power is found at the transitions to wetted areas, preventing dirt and germs from penetrating into the sealing space behind the sealing element. Dead volume is minimized. Complies with EHEDG and 3-A design criteria. Successfully tested for CIP-ability.	Optimal for aseptic operations because they are successfully tested for CIP-ability, steam sterilizability and bacteria-tightness.

They are often covered by national, international, or internal company standards. Many of these couplings have been in use for some considerable time and are not considered to be compatible with current requirements in some areas of the food and drink industry. In most examples, a joint ring, usually made of rubber, is clamped between two stainless steel ferrules drawn together by a nut or split clamp. The ferrules must be of a similar grade to that of the tube and securely fitted to the pipe by welding. The inside diameter of the ferrules and tubes must be the same.

To make detachable joints, the use of conventional O-ring grooves is not recommended, because these groove designs leave a considerable free space in the groove. With O-rings, product and bacteria can accumulate in the crevice on the product side, up to the O-ring. If O-rings are to be used, they must be fitted as close to the product area as possible to minimize the depth of the crevice formed. So properly located gaskets are preferred, but then the seal material must be compatible with both the system product and the cleaning fluids, which may be at a much higher temperature.

When making bolted flange fittings, a lot of care should be taken to avoid offsets, gaps, penetrations, and voids. Careful tightening is necessary since, if overstressed, the seal ring may become extruded. Therefore, an axial stop for controlled compression of the seal is essential. However, if too little torque is applied, bacteria can gain access from the outside into the product area even though no leakage of product occurs from the inside to the outside. The seal also must be retained in the correct position at all times, flush with the internal bore of the pipe. Depressions and steps of more than 0.2 mm in the pipe work may prohibit cleaning fluids from thoroughly washing the surface and proper drainability of the piping will be hampered. Therefore, coaxial alignment of the two mating bores is of utmost importance, and there must be room for thermal expansion of the seal. Also avoid sharp edges so that seals are not damaged.

Table 7.2 Overview of market available pipe couplings and seal arrangements.

7.7.3 Piping Insulation

To insulate piping, styrofoam (maximum continuous service temperature is 60−65°C), foam glass or another rigid foam (e.g., foamed nitrile butadiene rubber) are preferred over fibrous materials. The problem with fiberglass batting is that this material has already proven to be an excellent harborage of dust, insects and rodents, and can be a clean-up and maintenance nightmare if not properly installed and maintained. Therefore, it is highly recommended to install vapor-tight aluminum or stainless steel cladding of appropriate thickness, which resists tear and abrasion (Fig. 7.36). The exterior of the insulation protection should be fully welded and smooth, with joints facing downwards. Proper sealing of the insulation cladding prevents the ingress of dust, insects, liquor, air, and moisture that could promote corrosion between the walls,

FIGURE 7.36 Fiberglass batting has been proven to be an excellent harborage of dust, insects and rodents (Moerman & Wouters, 2015).

FIGURE 7.37 The cladding which surrounded the insulation of the refrigerant supply and removal piping was probably lost during high-pressure cleaning operations. Now, worn off particles of insulation may be entrained by the airflow into the product (Moerman & Fikiin, 2016).

which could be assisted by possible microbial growth. Damaged or wet insulation should be repaired or immediately replaced (Fig. 7.37). Insulated lines should be kept away from food products, while pipes frequently soiled by food products or requiring periodic disassembly must be left uninsulated (Moerman and Kastelein, 2014).

7.7.4 Application of Hoses

The use of hoses is less recommended, because (1) failure of hoses can occur due to overstretching, kinking, rough handling, mechanical impact, aging, fatigue, abrasion, corrosive atmospheres, etc. and (2) the chance of leakage of

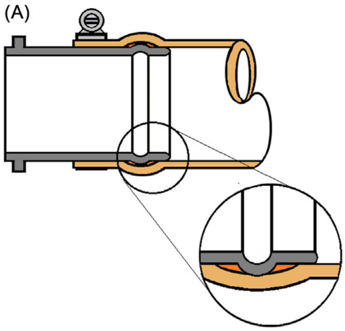


FIGURE 7.38 (A) Incorrect installation of hoses. (B) Correct installation of hoses on fixed pipes. Attached to stainless steel pipes, they should be clamped at the very end of the pipe. In this manner, the amount of dead space between the clamped portion and the end of the pipe is minimized. *Courtesy of Huub Lelieveld, personal communication.*

liquid occurring is much higher than when fixed piping is used. Attached to stainless steel pipes, they should be clamped at the very end of the pipe to minimize the amount of dead space between the clamped portion and the end of the pipe (Fig. 7.38). Braided (woven wire or fabric) covers on hoses should not be used.

Hoses need regular inspection for damage, deterioration and cleanliness, and should be cleaned and maintained in good condition. For ease of inspection, cleaning and maintenance, hoses should not exceed 3 m in length. Hoses out of service shall be pendant without touching the floor, and may never hang over open process equipment. When not in use, the ends of the hoses should be covered or capped to maintain proper hygienic conditions.

7.7.5 Hygienic Integration of Process and Utility Piping in Food Factories

Adequate pipework support must take into account provisions for thermal expansion during CIP operations. Welding of attachments on food processing support piping is not recommended, as they can cause stress on the pipe and the part of the supporting anchoring structure. All hangers and supports have to be designed in such a way that they either move together with the pipe (roll or slide) or that they can swing without exposing any stress either on the pipe or on the part of the supporting anchoring structure. Furthermore, process and utility piping should be grouped together in pipe trains whenever possible. All of this process and utility piping should preferably be positioned in such a way that all exterior surfaces are readily accessible, to allow cleaning from all sides (Fig. 7.39). The points of use should also be grouped, in an attempt to minimize individual ceiling drops. Vertical entrance of piping into the equipment is more hygienic than horizontal piping runs. Running of process and utility

FIGURE 7.39 For suitable cleaning, process equipment and piping must be installed at sufficient distance off the wall, ceiling, and floor. *Courtesy of CSI Central States Industrial, www.csi-designs.com.*

piping over open equipment in food preparation areas cannot be accepted, and nesting of ductwork should be avoided. Process equipment should be sited at a distance of ca. 4–10 cm from the nearest ceiling, wall and adjacent equipment so as to allow access for cleaning. Eventually greater gaps may be required. The distance depends on the diameter of the pipe. In addition, the equipment should be raised at least 20 cm off the ground to facilitate inspection, cleaning and maintenance.

7.8 HYGIENIC DESIGN OF PUMPS

7.8.1 Centrifugal Pumps Versus Positive Displacement Pumps

Many types of pump are used in the food industry for applications such as filling, emptying, transferring, and dosing. They are also often an integral part of a CIP system. The choice of pump for any given application depends primarily on the characteristics of the product and liquids to be pumped. Of particular importance are its rheological properties and its sensitivity to shear. Broadly speaking, there are two classes of pumps widely employed in the food industry:

- Centrifugal pumps used for transferring low viscosity liquids at relatively high flow rates but at comparatively low pressure heads. Liquid is directed into the eye of an impeller rotating at around 3000 rpm, which elevates both fluid pressure and velocity. On leaving the impeller, it is directed into a volute-shaped casing from which it is discharged tangentially.
- Positive displacement pumps (e.g., lobe pumps, gear pumps, vane impeller pumps, and progressive cavity pumps) capable of handling

high-viscosity and shear-sensitive liquids. Several positive displacement pumps can pump liquids containing suspended solids with minimal damage.

Design for cleanability is an important criterion in pump selection, but in many cases the functional requirements of the pump, such as delivery pressure and flowrate, determine the type of pump used, even if they are not the most hygienic option available. Positive-type pumps are usually considered to be less easily cleaned than the other due to the nature of their design.

7.8.2 Basic Hygienic Design Requirements

Pumps must meet the basic hygienic requirements:

- Materials of construction commonly used for product-contact surfaces should be stainless steels AISI 304L or 316L, as well as food grade plastics and elastomers. Materials of construction must comply with relevant legislation relating to materials in contact with food. Besides being compatible with the foods to be handled, they must withstand the corrosive effect of detergents and disinfectants. Materials of construction also must withstand the maximum envisaged process temperature, which may exceed 100°C if steam sterilization is employed.
- The internal surface finish of pumps does not have to meet specific standards, although a roughness similar to that recommended for pipes (less than 1 μm R_a) is commonly employed.
- Passage shapes must be smooth; sharp changes in cross-section should be avoided.
- Dead spots in which product can be retained or liquids held-up are not allowed. Even hygienically designed pumps can contain pockets if incorrectly reassembled after cleaning.
- Corners and edges must be rounded.
- Screw threads in contact with food are not allowed.
- Fastenings for pump bodies, clamp rings or bayonet couplings of smooth "clean" shape are preferred over bolts. No embossing and socket head screws should be used.
- Moving components should be fixed by flats rather than by keyways or splines.
- Bearings (sealed) must be located outside the product zone, although self-lubricating bearings are allowed in the product area for applications other than pumps.
- The pump casing must be drainable, either self-draining or capable of being operated so as to be self-emptying.
- Where pumps are cleaned by means of CIP, all parts must be intensively in contact with cleaning and disinfectant solutions.

- Where manual cleaning is used, pumps must be designed for quick dismantling with a minimum of tools and skills. There should be good access to all product contact surfaces to facilitate cleaning.
- Parts requiring periodic replacement should be easily replaceable and designed so that they cannot be wrongly assembled.
- Joints and seals should be so designed that a leakproof assembly is obtained. This is easiest to achieve with the correct components and without recourse to sealing compounds. Connections and seal areas must be crevice free.
- Wherever possible, shaft seals should be of the mechanical type and accessible for inspection, adjustment, and maintenance.
- Any leakage from the pump body must be easily visible.
- All external pump parts should be easily cleanable and capable of withstanding frequent hosing or similar cleaning-down procedures, as commonly used in the intended location.

7.8.3 Hygienic Design of Centrifugal Pumps

Typical types of impeller and shroud (Fig. 7.40) are: (1) unshrouded impellers (least efficient from a mechanical viewpoint), (2) partially shrouded impellers, (3) fully shrouded impellers (most efficient from a mechanical viewpoint), and (4) fully shrouded impellers with a detachable front shroud. The unshrouded impellers is easy to polish, whereas the shrouded impeller with its channel design cannot be polished economically. The shrouded impeller with detachable front shroud features metal-to-metal joints between the impeller body and front shroud, which are very difficult to clean in-place.

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 seals is continuously flushed with either steam or antimicrobial fluid. Antimicrobial fluids should not be used where products are produced by means of fermentation processes. Shafts

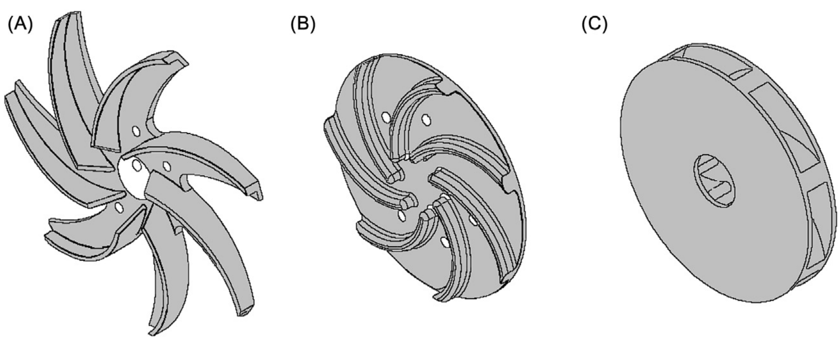


FIGURE 7.40 Types of impeller: (A) unshrouded, (B) partially shrouded, and (C) fully shrouded impeller (ASME BPE committee, © 2014).

must be so protected that food material cannot leak into the bearings or motor. Protection can be afforded by thrower rings and housing on the shaft between the motor and pump casing. However, if the shaft is enclosed at this point, inspection must be facilitated.

While it is often convenient for the arrangement of pipework to orientate the casing of a centrifugal pump so that the outlet port is pointing vertically up, this will result in the pump casing retaining liquid up to the level of the inlet port. The pump casing is drainable through the outlet port if the pump's outlet is arranged to point horizontally at the bottom (Fig. 7.41A), or the pump casing can be made drainable through its suction port if installed in vertical execution (Fig. 7.41B). Alternatively, a casing with a drain valve at the lowest point of the centrifugal chamber can be used (Fig. 7.42). The drain pipe section of the drain valve must be as short as possible, because the drain valve otherwise becomes a dead leg on its own.

Fig. 7.43A illustrates a number of design features that could create hygiene problems in a centrifugal pump, while suggested improvements are shown in Fig. 7.43B.

7.8.4 Hygienic Design of Rotary Lobe Pumps

Rotary lobe pumps having unhygienic design features (Fig. 7.44A) can only be cleaned effectively after dismantling. To avoid any introduction of contaminants into food products and to allow for CIP without dismantling, rotary lobe pumps should be hygienically designed (Fig. 7.44B and C). Metal-to-metal joints should be eliminated by hygienic O-ring assemblies. The O-ring groove design should be improved and O-rings should be positioned more appropriately. Alternatively, gaskets having controlled compression should be used. Sharp corners must be rounded to a minimum radius of 3 mm.

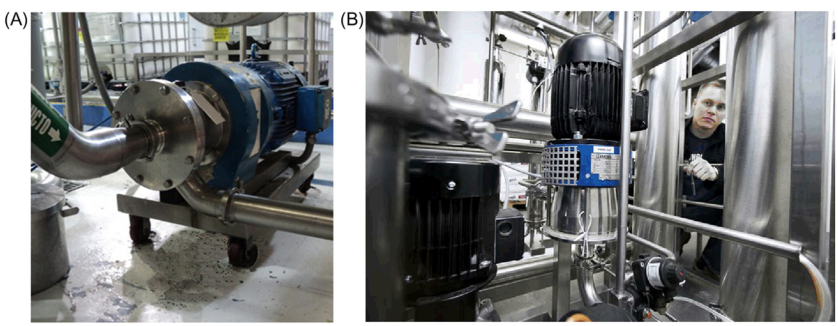


FIGURE 7.41 (A) The pump casing is drainable through the outlet port if the pump's outlet is arranged to point horizontally at the bottom. However, one must keep in mind that with this manner of installation, air may become trapped in the upper part of the casing (courtesy of Unilever). (B) Now, the centrifugal pump is installed in a vertical position and is fully drainable through its suction port. *Courtesy of GEA Hilge.*

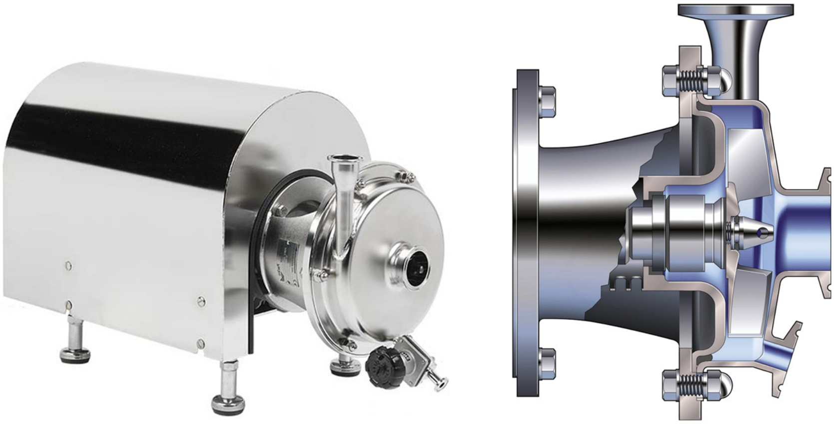


FIGURE 7.42 A casing with drain valve at the lowest point of the centrifugal chamber can be used. This solution where the pump's outlet is pointing vertically upwards while being self-draining prohibits the accumulation of air in the upper part of the casing. The drain pipe section of the drain valve must be as short as possible, because otherwise the drain valve becomes a dead leg on its own. The front cover can be removed to allow cleaning of the impeller area. *Courtesy of Packo.*

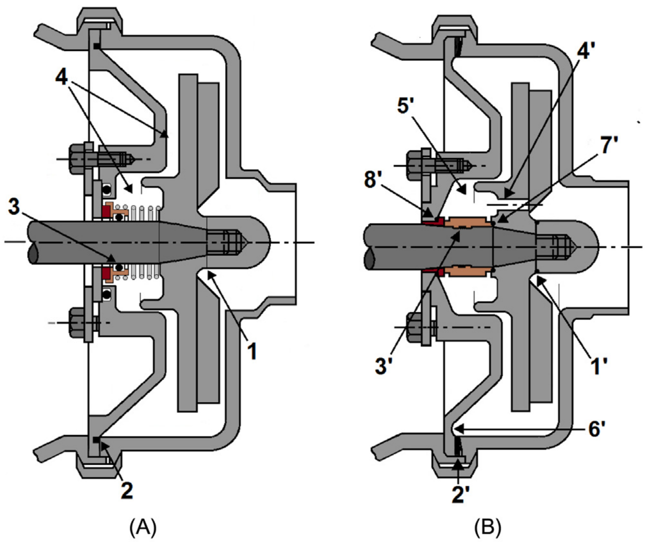


FIGURE 7.43 (A) Hygienically unsatisfactory centrifugal pump design with the following shortcomings: (1) metal-to-metal joints allowing the ingress and retention of product and microorganisms, (2) retention of product residues in the crevices of the seal zone, even if CIP is employed, (3) retention of product residues in the annular space after cleaning, (4) dead volume unswept by fluid volume, resulting in a too-low turbulence to properly clean the surrounding surfaces in-place; (B) satisfactory hygienic centrifugal pump design: (1′) cap nut O-ring closing the metal-to-metal joint, (2′) translocation of the gasket away from the corner, (3′) slide ring (mechanical seal) encapsulates the spring, (4′) holes in the shroud increasing the flow of liquid behind the impeller, hence improving the cleanability of the surface, (5′) area behind the impeller containing fewer low-turbulent zones, (6′) radiusing of the corner, (7′) shaft O-ring and (8′) O-ring between the pump housing and the counter ring acting as slide ring holder. *Courtesy of Campden BRI.*

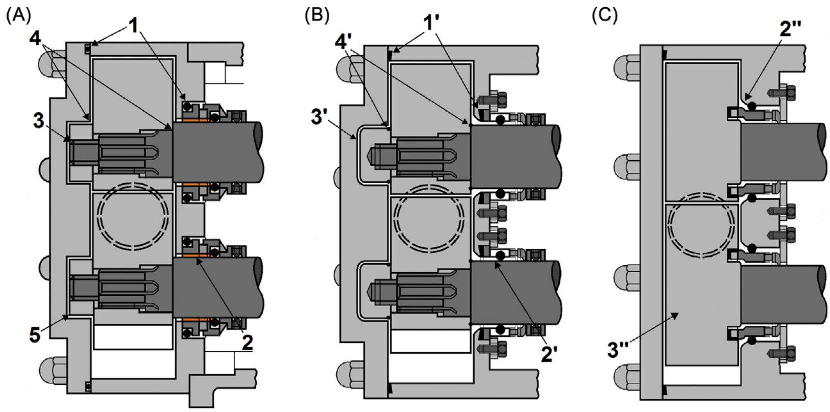


FIGURE 7.44 (A) Hygienically unsatisfactory lobe pump design with the following shortcomings: (1) metal-to-metal joints allowing ingress and retention of product residues and/or microorganisms, (2) long annular space within the mechanical seals which may retain food products and provide microorganisms a niche to grow, (3) retention of product residues in the threads of the rotor retaining nuts, (4) metal-to-metal joints and crevices accumulating dirt and microorganisms, (5) retention of product residues in the space around the rotor nuts within the end cover. (B) Improved hygienic lobe pump design: (1′) metal-to-metal joints in these areas have been eliminated by means of gaskets having controlled compression, (2′) the length of the annular space is reduced by changing the design of the mechanical seal, (3′) the exposed screw threads of the shaft are enclosed by the use of special nuts, (4′) metal-to-metal joints eliminated by the hygienic application of O-rings. (C) Further improvements to the hygienic design of lobe pumps: (2″) further reduction in the length of the annular space by reversing the elements of the mechanical seal and increasing the radial distance to give improved in-place cleanability; (3″) rotor retaining nuts and associated metal-to-metal joints are eliminated if the rotors and shafts are of integral construction (CFCRA, 1997). *Courtesy of Campden BRI.*

The length of the annular space within the mechanical seals should be reduced by changing the design of these mechanical seals (e.g., the elements of the mechanical seal should be reversed and the radial distance increased). Any exposed threads (e.g., threads of the rotor shafts, Fig. 7.45A) should be covered by crevice-free domed retainer nuts and have O-rings eliminating metal-to-metal joints. As a further improvement, the rotors and shafts should be designed as an integral construction so that rotor retaining nuts and associated metal-to-metal joints can be eliminated. As such, the inside of the front cover can be made completely flat and free of space holes for rotor retainers.

Some types of rotary lobe pumps are traditionally positioned in such a way that draining is impossible without dismantling. The inlet and outlet ports of these rotary lobe pumps are arranged in the horizontal position, as this has again been convenient for connecting the pipework. This results in the retention of liquid in the casing up to the level of the inlet and outlet ports. However, nowadays, there are hygienically well-designed rotary lobe pumps available with the ports arranged in the vertical plane (Figs. 7.45B and 7.46) so that it is possible to drain the casing.

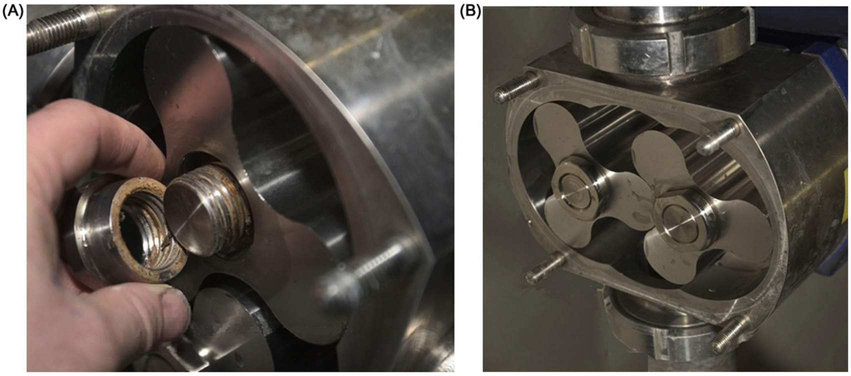


FIGURE 7.45 (A) Ingress and retention of product residues and/or microorganisms in the threads of the rotor retaining nuts should be avoided by making use of crevice-free domed retainer nuts and by application of O-rings. (B) In a more improved version, the rotors and shaft should be designed as an integral construction. With the ports arranged in the vertical plane, it is possible to drain the lobe pump casing (Burggraaf and Partners B.V.).

FIGURE 7.46 Nowadays there are hygienically well-designed rotary lobe pumps available with the ports arranged in the vertical plane. Slots in the rotor retaining nuts create turbulences in the flow passing the narrow gap between end cover and lobes. They provide enhanced cleanabilty of the end cover and the front surfaces of the lobes. *Courtesy of Alfa Laval AB.*

7.9 HYGIENIC DESIGN OF VALVES

Valves are used to shut-off (isolate) processes or services, to prevent backflow (nonreturn), to change the direction of the flow of product or cleaning solutions (flow diversion in function of the product/cleaning routing selected), to regulate the flow and pressure, or to protect a process or service system against overpressure. Valves must be selected for the function of the chemical and physical characteristics of the product (does the product contain solids?), the envisaged application (aseptic or hygienic?) and the manner of operation (automated or remote?). Valves can be actuated manually, electromagnetically, pneumatically or with electric motors, and may have visual and/or electrical position indicators (limit switches). Any power-actuated valve is subject to the EU Machinery Directive 2006/42/EC & 98/37/EC and CE marking. However, some actuators (e.g., pneumatic actuators) are not compact, which could be a problem in confined spaces or where small valves are required. Compact nonpneumatic actuators are available which may possibly be employed in these confined spaces. Cost implications, the frequency of inspection and/or maintenance, as well as the ease of access are other decisive factors in the valve selection process.

The cleanabilty of a valve is largely determined by its internal geometry, the way in which the inlet and outlet connections are made, and the seal between the fluid and the external environment. The seals may be under a static or dynamic load with linear or rotary motion. Valves must meet the following hygienic requirements (Cocker, 2004; Moerman and Partington, 2014):

- Materials for valve bodies and seal materials must be selected as a function of the exact conditions of use, such as temperature and chemical exposure. Valve bodies are usually made of stainless steel AISI 316L (or AISI 304L where applicable), while other valve components could be designed in plastic (e.g., discs, balls, plugs, etc.) or elastomer (e.g., seals). Users must take into account that where high temperatures and/or halides are present, drying out can lead to very corrosive conditions even though normal operational conditions are much less severe. The cost of using higher-grade materials may have to be balanced against the cost of failure during production.
- Surface finish of valve components in direct contact with the product must be less than 1 μm R_a, not only to facilitate cleaning but also to impose minimal friction on the fluids passing the valve.
- Selection of a strong, stiff valve-body construction is a key defense against torsion, compression and pipe stress, for example from thermal expansion and contraction or from poor installation practices. Instances are known where the valves were distorted and there was an intermittent failure to close fully.
- Operating conditions must be taken into account, as excessive temperatures, pressures, and hydraulic shocks are common causes of hygienic failure.
- Marked changes in piping cross-section must be avoided, with the bore of the valve being similar to that of the adjacent pipes. With plug, stem, or diversion type valves, there must be sufficient turbulence to ensure adequate cleaning.

- Valves must have a minimum of dead volumes, and be free of pockets and crevices.
- Keep in mind that valves may give rise to dead ends (Fig. 7.47).
- Without dismantling, the valve body must be fully drainable in at least one installation position. Pooling liquid (Fig. 7.48) not only may give rise to microbial growth, the collection of condensate during steam sterilization will also result in cold spots, and hence an increased risk of microbial survival.
- Where valves are cleaned in-place, all parts must be intensively in contact with cleaning and disinfectant solutions.
- Where manual cleaning is used, valves must be designed for quick dismantling with a minimum of tools and skills. There should be good access to all product contact surfaces to facilitate cleaning.

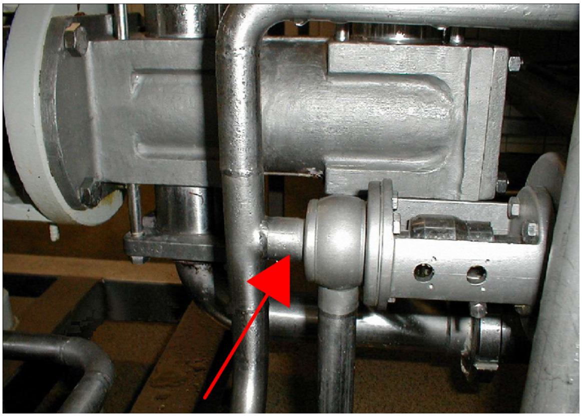


FIGURE 7.47 Valves may give rise to dead legs (www.ourfood.com; Karl Heinz Wilm, © 2016).

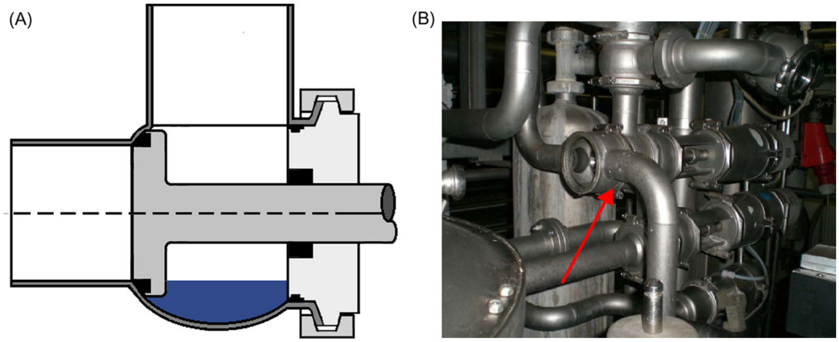


FIGURE 7.48 Nondrainable valve body (Matthias Schäfer, GEA group AG, © 2016).

- Valve seats should ensure an effective seal where full shut-off is required. Usually valve seats are sprung closed and opened by powered actuators, so that in the event of power failure the valve fails in the closed position.
- Don't use metal-to-metal seat seals for hygienic application, as they are not bacteria-tight. Although weak in hygienic design, they can be used where the product is resistant to spoilage.
- Valves also should be designed to resist wear. Failing valves may lead to loss of production (food out of specification), loss in production time, as well as maintenance costs. However, regular maintenance will always be needed since wear and distortion are inevitable with time, affecting the cleanability and hygiene. It is important in an installation with many valves that each valve can be overhauled reliably and quickly to avoid expensive downtime. Useful enhancements here are the provision of single-armature multiseat valve modules (you can replace several seat seals at once), single-fastener body clamps and fail-safe aids such as fixed compression stops on all seals.
- Minimize the number of seals, positively retained to avoid distortion and flush with adjacent surfaces.
- Seals must be regularly inspected as they may get distorted or even ruptured. Selected materials for seals must withstand temperatures and pressures likely to be met during processing and cleaning.
- In aseptic processing, dynamic seals on valve shafts must maintain aseptic conditions, requiring an absolute barrier between the product and the environment to prevent microbial recontamination. This can be achieved by using a bellows-type (Fig. 7.57C) or diaphragm-type seal (Fig. 7.57D) or a double seal arrangement (Fig. 7.57E).
- Allow rapid detection of internal leakage. Continuous leak detection for the seat seal is normally required for assurance of safe operation and should be an integral part of the design. As a minimum, this takes the form of an atmospheric leakage port, though some automatic detection and feedback systems are in evidence, especially for aseptic barrier modules, where the barrier zone has to be pressurized.
- The valve mechanism must be isolated from the product. There must be no possibility of external contamination of the product through the valve mechanism.
- Where unavoidable, springs in contact with product should have minimum surface contact area.

7.9.1 Diaphragm Valves

Diaphragm valves are suitable for aseptic operations. They use a flexible diaphragm clamped between the valve bonnet and valve body. The diaphragm may be of a variety of polymeric materials to suit the product and operating temperature. For closing the valve, the diaphragm is pressed by means of an external closure element (also called compressor) against the weir (Fig. 7.49A) located between the inlet and outlet port. Diaphragm valves without weir (Fig. 7.50) are also available from some manufacturers, but then the distortion of the diaphragm is much greater than for the weir type. Due to the short diaphragm movement, the lifetime of the diaphragm in a weir-type diaphragm valve is longer than in a weirless diaphragm valve. Because the diaphragm may rupture after a period of service in either type, diaphragm valves need visual detection of leakage (usually there are leakage holes in the valve bonnet). Damage to the diaphragm can result in product leaking through into the nonproduct side, which may give rise to contamination and also makes cleaning and disinfection nearly impossible. To avoid premature rupture, the diaphragm should be replaced at regular intervals depending upon the operating conditions. Maintenance, however, can be performed very quickly. Weir-type diaphragm valves with the actuating spindle vertical upwards in the horizontal position are not self-draining.

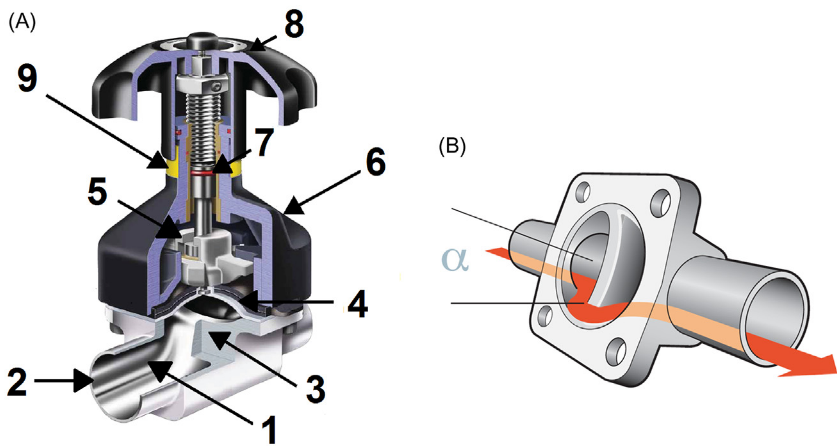


FIGURE 7.49 (A) Weir-type diaphragm valve with the following characteristics: (1) stainless steel 316 L valve body without cavities where soil could become entrapped, (2) butt well ends having sufficient turnback for orbital weld installation, (3) weir, (4) food grade rubber-backed PTFE diaphragm, (5) compressor supporting the diaphragm in both the open and closed positions for extended life, (6) bonnet made of temperature and chemical resistant plastic (e.g., polyethersulfone) covering the body fasteners to provide a clean exterior profile with minimum sensitivity to contamination, (7) O-ring seal preventing ingress of water and dirt from the outside environment into the bonnet, (8) contoured handwheel for optimal external washdown and cleanability, (9) valve position indicator. (B) In vertical piping, this type of valve is normally free draining, but when the pipe axis is approximately horizontal, the valve stem has to be inclined from the vertical to allow for drainage past the weir. An angle (α) less than 20 degrees above the horizontal is required, The angle may differ according to the valve size. *Courtesy of Crane Process Flow Technologies Ltd.*

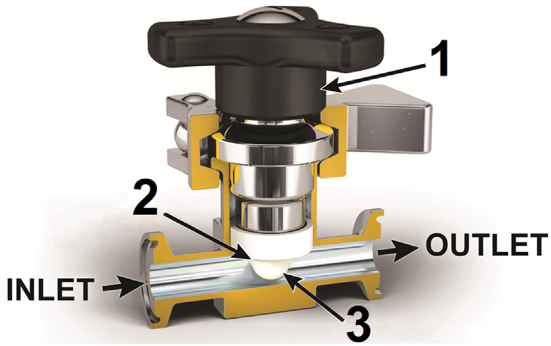


FIGURE 7.50 Weirless straight-through diaphragm valve: (1) manual actuator, (2) shoulder seal (static seal), and (3) shut-off seal (dynamic seal). *Courtesy of ASEPCO Corporation.*

For satisfactory drainability, the horizontally positioned diaphragm valve must be rotated about the port axes so that the actuating spindle is no more than 20 degrees above the horizontal (usually the drain angle is about 2−3 degrees) (Fig. 7.49B). Full self-drainability is always guaranteed with diaphragm valves installed in a vertical position. In addition to the diaphragm valve for on/off applications, there is also a flow-diversion variant. The design of this diversion diaphragm valve minimizes any dead spaces (advantageous if the valve is used for sampling) and ensures good drainability. However also for this diversion diaphragm valve, replacement of the diaphragm at regular intervals is required. Diaphragm valves are suitable for both hygienic and aseptic applications (CFCRA, 1997; Schonrock, 2005; Moerman & Kastelein, 2014).

7.9.2 Back-pressure Valves

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 (CFCRA, 1997):

- A diaphragm type back-pressure valve (Fig. 7.51) comprises a diaphragm separating the product from the preset air pressure. The diaphragm actuates the valve controlling the product flow (Fig. 7.52). As the product pressure increases to a level greater than the preset air pressure, the diaphragm lifts the valve allowing for increased product flow. This reduces the product pressure, so as to maintain it at a constant level upstream of the inlet port to the valve. Conversely, the valve closes if there is a reduction in product flow to maintain a constant pressure upstream. The outer parts of the conical area are difficult to clean, particularly if viscous products are handled.

FIGURE 7.51 Diaphragm type back-pressure valve. *Courtesy of Alfa Laval AB.*

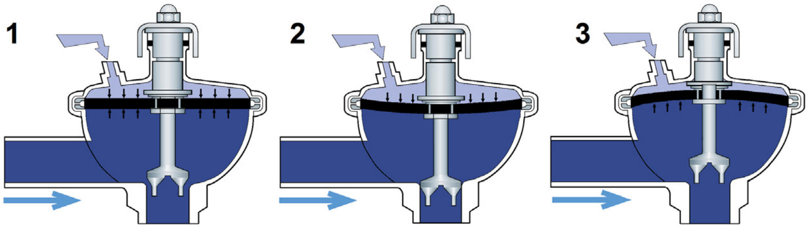


FIGURE 7.52 Diaphragm back-pressure valve in different situations: (1) product and air are in equilibrium; (2) the product pressure drops, the valve closes and the product pressure increases to the preset value; (3) the product pressure increases, the valve opens, and the product pressure drops to the preset value. *Courtesy of Tetra Pak Processing Systems AB; From Bylund, G., 2015. "Building-blocks of dairy processing", Ch. 6, section 6.8 – Piping, valves and fittings, Ch. 21. In: Teknotext, A.B. (Ed.), Dairy processing handbook. Tetra Pak Processing Systems A/B, Lund, Sweden.*

- Membrane type back-pressure valves (also called pinch valves) (Fig. 7.53) have a reinforced flexible elastomeric tube through which the product flows, further surrounded by an air chamber. Externally supplied compressed air may compress the tubular membrane to close it off. If the air pressure is constant, maintained by a preset regulator, the back pressure on the product upstream of the valve remains constant. Pinch valves are intrinsically hermetic and therefore suitable for both hygienic and aseptic applications. They can give full-bore flow and have the widest range of orientations for self-draining. They are not found in multiseat versions, and for hygienic applications currently are only available in small sizes.

7.9.3 Butterfly Valves

Butterfly valves (Fig. 7.54) comprise a plastic or stainless steel disc rotating through 90 degrees within the valve body, and further a rubber seal clamped

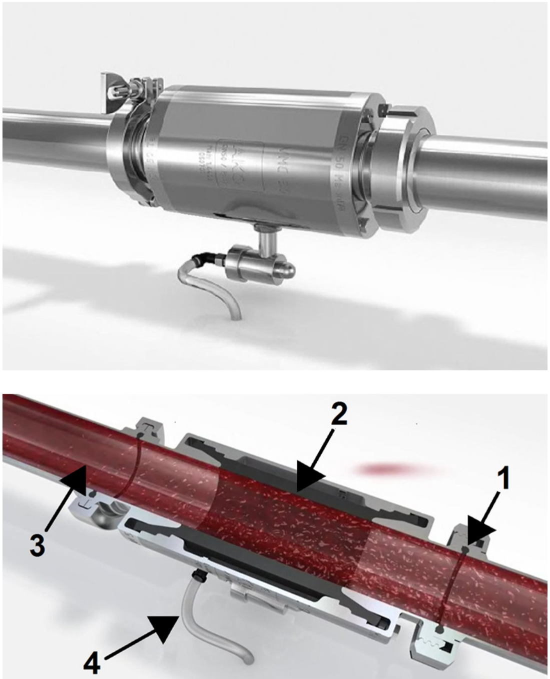


FIGURE 7.53 Membrane type back-pressure valves (also called pinch valves) can be installed in piping by means of flange, tri-clamp or weld-in connections, as well as couplings (1). The elastomeric tube (2) through which the product (3) flows is compressed by means of air at constant pressure (4) so as to keep the back pressure on the product upstream of the valve constant. *Courtesy of AKO Armaturen & Separationstechnik GmbH.*

between the halves of the body providing both a seat for the disc to close on and a seal for the disc spindles. Butterfly valves are suitable for on/off operation only, although they also may serve as throttle valves in vacuum systems. If properly designed, they are hygienic low-cost valves, with as main properties: low resistance to flow, appropriateness for automation and being cleaned in-place, as well as their very short length of pipe-run. Butterfly valves with a streamlined disk free of external ribs are hygienic. However, product containing fibrous material may build up on the leading edge of the disc and cause a cleaning problem. Moreover, the circular rubber seal can wear (Fig. 7.55) and break down after a period of time due to the frequent opening and closing of the butterfly valve, as well as cleaning and disinfection solutions. With time, uncleanable cavities will appear. Another weak point is the rotating shaft which passes in the valve body. Due to product pressures in the system, product can migrate along the shafts. Therefore, butterfly valves should preferably be disassembled for manual cleaning.

FIGURE 7.54 Butterfly valve having a highly polished stainless steel disc with a surface roughness $R_a \leq 0.8$ μm. The bearing bushes are clipped onto the disc stems, avoiding any metal-to-metal abrasion and ensuring smoother disc movement. The rubber seal clamped between the halves of the body provides both a seat for the disc to close on and a seal for the disc spindles. However, as they are not hermetically sealed, they are not suitable for aseptic duties. *Courtesy of Alfa Laval AB.*

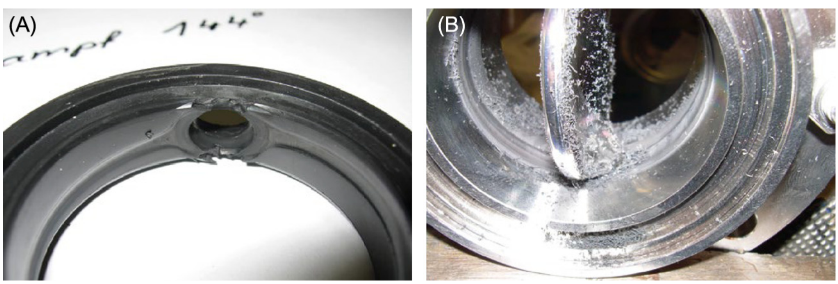


FIGURE 7.55 (A) Swelling of the seal, with tear, in conjunction with imprecise closing of the butterfly valve. (B) Seal abrasion at the disk (Wiedenmann, 2013). *Courtesy of Krones AG.*

If butterfly valves are in use, appropriate cleaning and maintenance schedules must be implemented (CFCRA, 1997; Schonrock, 2005; Moerman and Kastelein, 2014).

7.9.4 Ball Valves

Ball valves provide smooth, uninterrupted flow passage with minimal turbulences and pressure drop, which can be an advantage if the liquids contain large or delicate particulate material. However, they are not appropriate to control flow or pressure, and are suitable for on/off operation only. Traditional ball valves are considered to be unsuitable for process installations that are cleaned in-place. Due to the presence of inner-body cavities and crevices, the area between the ball, housing, and seal face is uncleanable. Food product is transferred into the annular dead space when the valve is operated from its open to its closed position. When the ball valve is then rotated back from its closed to its open position to allow CIP, the food product trapped in the annular space between the sphere and the housing will not be removed by CIP. As a result, the debris trapped in the inner-body cavity may start to ferment (putrefaction), cause damage to the seating surface and even block the valve operation. Finally, ordinary ball valves may also retain condensate in their internal cavities.

Often ball valves have special seat design incorporating cavity fillers (usually polytetrafluoroethylene) (Fig. 7.56) or encapsulating seals to prevent product flow around the exterior of the ball. However, product still may find its way under the seat surface and become an area for bacterial growth. Ball valves in existing installations must be disassembled completely for manual cleaning. But their design and construction do not always allow easily dismantling for cleaning. Certain ball valves with improved design allow for CIP, especially in a half-open position. However, this must be carefully checked. For some applications, steam-purged versions are available. Having connections to the housing, the annular space may be continuously purged with steam throughout production (CFCRA, 1997; Schonrock, 2005; Moerman and Kastelein, 2014).

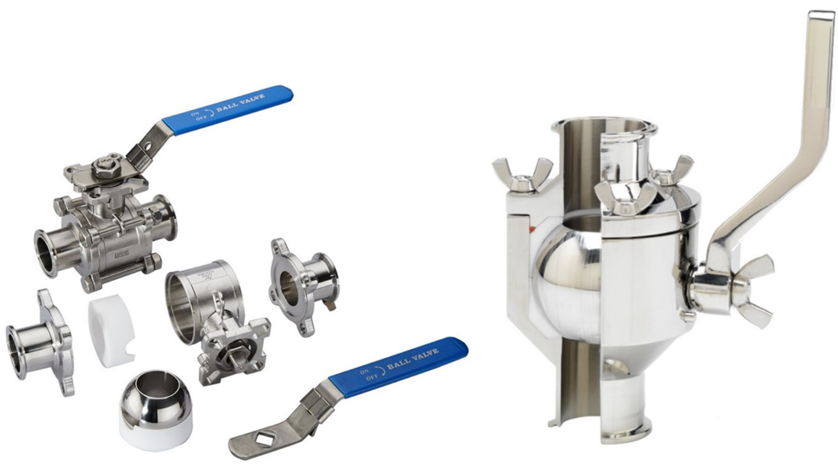


FIGURE 7.56 Cavity filled ball valves have special seat design that fills the gap (dead space) around the ball. Surfaces of the ball and valve body in contact with the product have a smooth finish with $R_a < 0.8\ \mu m$. The ball valves are easy to dismantle allowing for inspection, cleaning, and maintenance. *Photo left, courtesy of Kaysuns Industry Ltd.; photo right, courtesy of Lee industries Inc.*

7.9.5 Linear Plug and Stem Valves

Linear plug and stem valves are actuated either manually or automatically, with typical applications being on/off and flow diversion operations. Linear plug and stem valves look quite similar to globe valves with a reciprocating shaft moving the valve head in open or closed position. This valve head is fitted with either a rubber or polytetrafluoroethylene (PTFE) seal. Various types of stem seals are available: lip, O-ring, diaphragm, bellows, and a double seal arrangement with steam barrier. Lip seal and O-ring arrangements are suitable for hygienic operation only. For aseptic processing applications where ingress of microorganisms must be prevented, the shaft must be sealed by means of a diaphragm and bellows (CFCRA, 1997; Schonrock, 2005; Moerman and Kastelein, 2014).

Characteristics of linear plug and stem valves:

- Linear plug and stem valves may incorporate a lip seal (Fig. 7.57A) to limit microbial contamination via the reciprocating shaft. However, although easily cleanable, the lip seal will not prevent the ingress of microorganisms because the stem passes from the atmosphere to the product side. Moreover, when the lip seal wear becomes excessive, product leakage will occur. A hole is required to detect product leakage.
- Arrangements incorporating an O-ring seal (Fig. 7.57B) are less hygienic because product can enter the clearance around the stem and become trapped in the O-ring groove. This debris cannot be removed by in-place cleaning.
- In the design of the bellows sealed linear plug and stem valve, stainless steel or PTFE bellows (Fig. 7.57C) are sealed to the collar of the valve body and the valve shaft. The bellows isolate the process interior from the outside mechanical part of the valve (mechanical activation elements located outside the process area can be lubricated without contamination of the process) and provide a bacteria-tight seal for aseptic processing applications. However, if the product contains large fibrous (e.g., rhubarb) or chunky products (e.g., nuts), these foodstuffs can become lodged in the creases. This particulate material trapped in the convolutions of the bellow is difficult to remove during cleaning operations, leading to long cleaning times. The waves of the bellows may not have an omega shape to avoid the formation of ring chambers, which are difficult to access for cleaning or sterilization. The circumferential grooves also may hamper the self-draining capability, especially when such a bellows is positioned vertically. Furthermore, the bellows are sensitive to pressure peaks, and dimples on the bellows edges due to inferior inflow from the side may lead to malfunction of the bellows. Finally, the bellows may rupture after a period of service (especially where cycle rates are high) (Fig. 7.58), requiring costly replacement at regular intervals (Ladenburger, 2015).

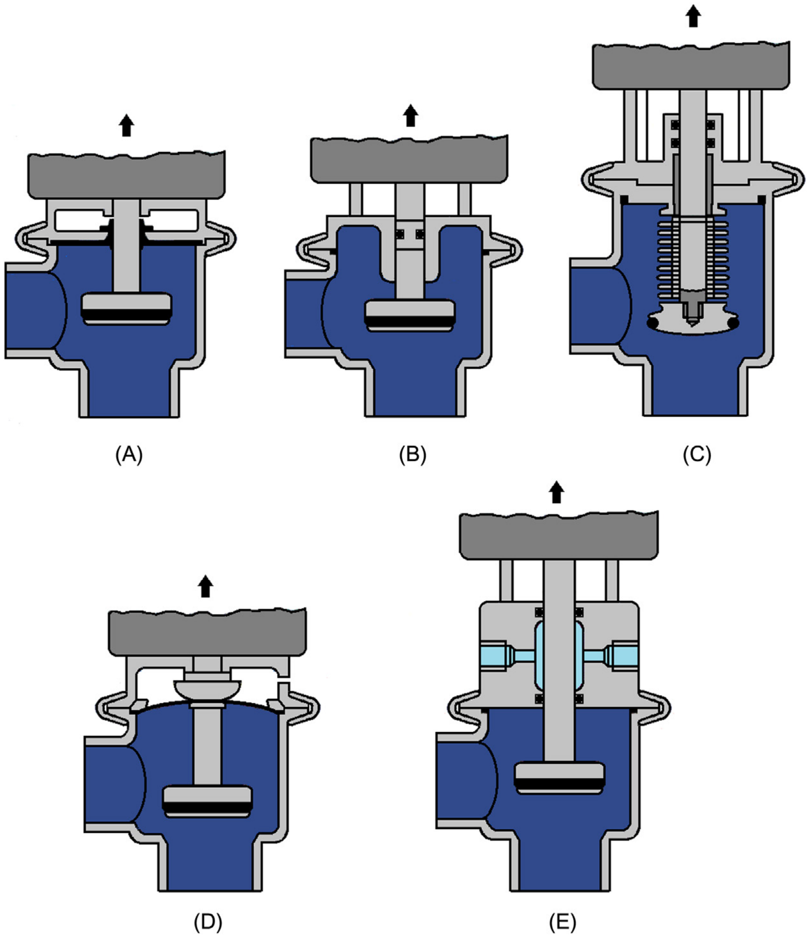


FIGURE 7.57 Linear plug and stem valves may incorporate: (A) lip seal, (B) O-ring seal, (C) stainless steel or PTFE bellows, (D) diaphragm, and (E) double seal arrangement, in between flushed with pressurized steam (CFCRA, 1997). *Courtesy of Campden BRI.*

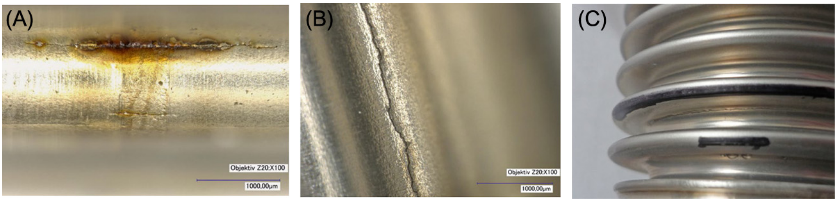


FIGURE 7.58 Metal bellows prone to (A) crack formation on the product-facing side (outside area) without complete breakage and recognition of a leak from the metal bellows. (B) and (C) Prematurely broken metal bellows (Ladenburger, 2015). *Courtesy of Pentair Südmo GmbH.*

FIGURE 7.59 Diaphragm made from uniform and flexible PTFE with improved cold flow performance, and suitable for a high number of load changes. The risk of pocket or crack formation, typical for multicomponent systems, is absent (Ladenburger, 2015). *Courtesy of Pentair Südmo GmbH.*

- A diaphragm, usually of PTFE or PTFE-faced rubber (Fig. 7.57D), is clamped to the stem and in the housing to provide a bacteria-tight seal. A leakage hole must be provided to indicate failure of the diaphragm. The diaphragm must be replaced at regular intervals. For years efforts have been made to replace the bellows (described just above) with a diaphragm. These attempts, however, have failed due to the lack of an appropriate material. Nowadays, plastic materials with superior mechanical characteristics (Fig. 7.59) are available, allowing development of linear plug and stem valves with a diaphragm that provides hermetic protection of the spindle travel during aseptic applications (Fig. 7.60) (Ladenburger, 2015).
- Where the stroke of the shaft is too great to enable such a seal to be used, it is necessary to use a double seal arrangement (Fig. 7.57E). Such a seal has the following requirements: (1) the distance between the two seals must be greater than the distance moved by the shaft, in order to prevent microorganisms being brought into the aseptic zone during operation; (2) the space between the seals must be capable of being sterilized prior to production and to maintain asepsis during production. Hence, the space between the seals is usually flushed with pressurized steam, with the steam jacket having a length greater than the stroke of the valve. By using a steam barrier between the atmospheric and product sides of the valve stem, ingress of microorganisms is not allowed. However, the steam barrier is not widely used because of its high cost.

7.9.6 Mixproof Valve Systems

Mixproof valve systems (Fig. 7.61) are an essential part of automated processing. Double-seated mixproof valve systems have two independently operating shut-off valves, allowing separation of incompatible media such as liquid food product and cleaning/disinfectant solutions at flow path intersections

FIGURE 7.60 Linear plug and stem valves where a PTFE diaphragm with superior mechanical characteristics provides hermetic protection of the spindle travel during aseptic applications. Contrary to bellow sealed linear plug and stem valves, this valve is suitable for process operations handling liquid food with abrasive particles or products that crystallize in the atmosphere, such as lactose or instant coffee. *Courtesy of Pentair Südmo GmbH.*

within the pipe system. The operation principle of a mixproof valve is explained in Fig. 7.62. In the closed position of the mixproof valve system (nonactuated position), two seals are always located between the pipes, hence avoiding product contamination from cleaning fluids during CIP. Note that a single valve seat must never be relied upon to protect the product from the cleaning fluid, even if the product is maintained at a higher pressure (Moerman et al., 2014).

The valve heads of these two valves, held on their seat by spring pressure, are separated by a self-draining opening to the atmosphere. If one of these seals fails, leakage may drain via the thus-provided leakage outlet to the atmosphere (usually the drain pipe in the bottom shaft of the lower closure device) without intermixing with the product being in the second pipe. The vent space also must avoid a pressure buildup in case of a leak from a seal. The outlet from the vent line must be visible to detect any leakage.

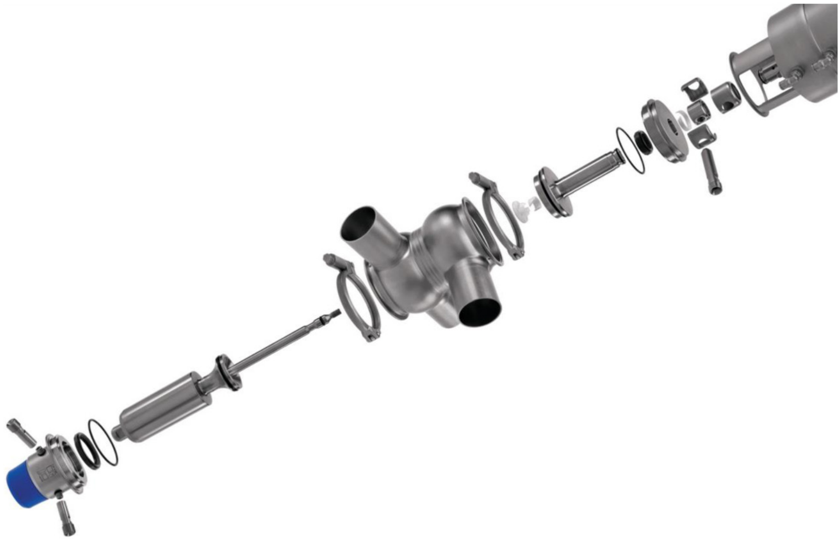


FIGURE 7.61 Mixproof valve system. *Courtesy of Alfa Laval AB.*

A steam or sterile barrier may also be applied in the atmospheric opening (vent) to prevent ingress of microorganisms (Moerman et al., 2014).

Also, double-seat mixproof valves need cleaning: both the upper and lower chamber of the valve housing soiled by the product being conducted through the pipeline, the seat area between the two chambers soiled when the valve is in the open position, and the cavity with the drain pipe in the bottom shaft due to operational leakage and leakage as the consequence of worn seat seals. The housing chambers can be cleaned in-place independently from each other, limited by the shaft seal on the one side and the seat seal on the other side. The seat seal and leakage chamber can be cleaned by seat lifting, that may occur periodically during each cleaning phase. The duration of the lifting pulses and intervals between them depend on the level of soiling, and are generally between 10 and 60 s in duration, with 3–5 min between the pulses. As an alternative to cleaning by means of seat lifting, cavity spray cleaning via an external CIP line connected to the leakage chamber can be done (Moerman et al., 2014).

7.9.7 Plug Cock Valves

A plug cock (Fig. 7.63) is a manual valve that has a conical plug rotated in the tapered bore of a valve body. The conical plug has either a straight-through port (on/off) or ports arranged in a tee configuration (three-way ports). Three-way plug cock valves allow 90-degree changes in flow direction of both food product and cleaning solutions. Although they have good internal flow design, they are relatively expensive and have the disadvantage that

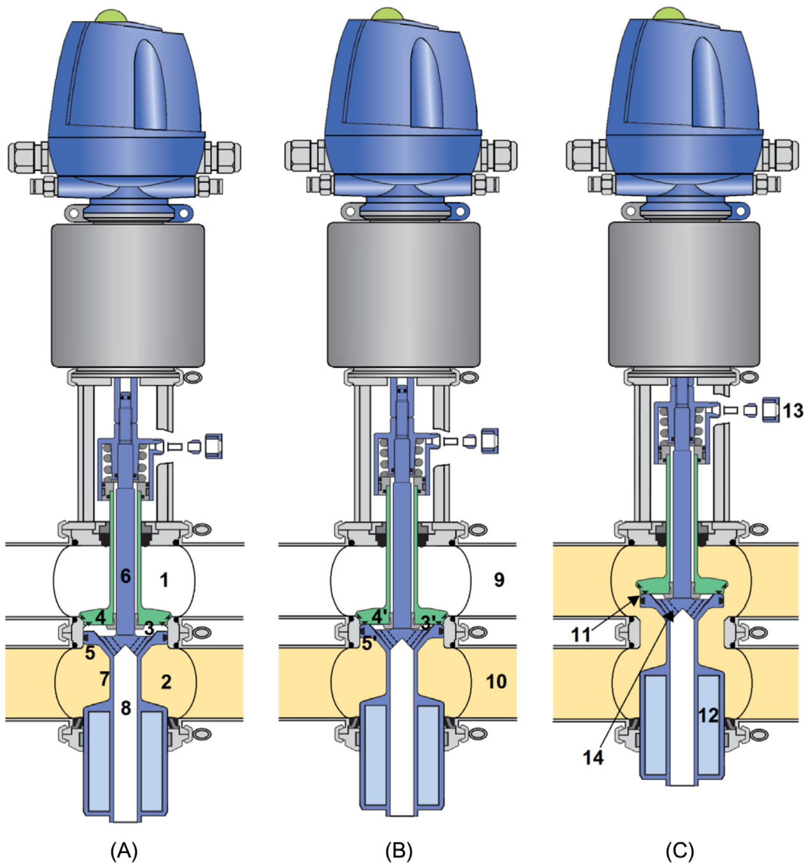


FIGURE 7.62 (A) A typical design of a double-seated mixproof valve consists of a valve housing with an upper valve chamber (1) and lower valve chamber (2). Between the two chambers the valve seat area is arranged with two seats, usually one on top of the other with a separation cavity (3) (vent space) in between. The seats consist of an upper closure device (4) and a lower closure device (5), typically a disc, which are connected independently to the upper shaft (6) and lower shaft (7) for opening, closing and individual seat lifting. The cavity acts as a leakage chamber (3) and is open to the atmosphere via a drain pipe in the bottom shaft (8) for leak detection (outlet of the vent pipe must be visible for leakage!!). In the closed position, the upper valve chamber (1) and the lower valve chamber (2) are each sealed by the two valve disks, held independently on their seat by spring pressure. (B) To open the connection between the upper pipeline (9) and lower pipeline (10), the actuated lower valve disk (5′) is raised off its seat first and then moves upwards a short distance before contacting the upper valve head (4′). As a consequence, the drainage chamber (3′) between the upper and lower body is gradually decreased. (C) Both valve disks then move further together into the open position. Meanwhile, in the more modern double-seated mixproof valves, the remaining cavity between the upper and lower valve disks remains sealed against the product area (11). It is important that the lower plug is hydraulically balanced (12, balancer) to prevent pressure shocks from opening the valve, hence allowing products to mix. When the valve closes, first the upper plug seals and then the lower plug seals. Both opening and closing of double-seated mixproof valves may show very small product losses getting into the cavity between the two valve discs during operation. However, this cavity can be flushed clean with cleaning fluid via a hose connection (13). The cleaning fluid will drain to the outside via the bores (14) and drain pipe (8) of the lower closure device. In aseptic applications, steam or a sterile barrier may be applied in the atmospheric opening (vent) to prevent ingress of microorganisms. *Courtesy of GEA group AG.*

FIGURE 7.63 Plug cock valves are unsuitable to be cleaned in-place, because product can get caught around the clearance between the plug and the valve body during rotation of the plug in the turned-off position. But, as they are easy to dismantle, they can be cleaned manually. *Courtesy of Sanitary Solutions, Inc.*

FIGURE 7.64 With respect to plug cock valves, product can get caught as a thin stagnant film around the clearance between the plug and the valve body during rotation of the plug, and finally may leak to the outside. *Courtesy of Mondelēz International, © 2016.*

they neither can be automated nor cleaned in-place. They are unsuitable for CIP, because product can get caught as a thin stagnant film around the clearance between the plug and the valve body during rotation of the plug in the turned-off position (Fig. 7.64). Bacteria can also gain access via this route. However, due to their simple design, plug valves are easily to dismantle for manual cleaning. They are also self-draining (CFCRA, 1997; Schonrock, 2005; Moerman and Kastelein, 2014).

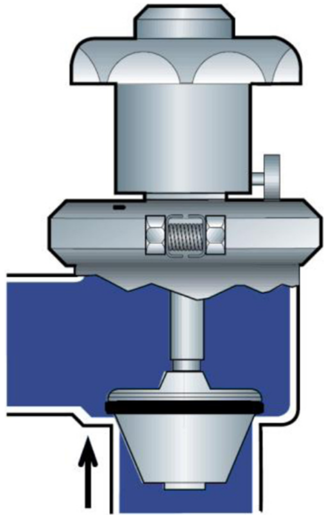


FIGURE 7.65 Manual control valve with variable-flow plug. *Courtesy of Tetra Pak Processing Systems AB; From Bylund, G., 2015. "Building-blocks of dairy processing", Ch. 6, section 6.8 – Piping, valves and fittings, Ch. 21. In: Teknotext, A.B. (Ed.), Dairy processing handbook. Tetra Pak Processing Systems A/B, Lund, Sweden.*

7.9.8 Flow Control Valves

Control valves with variable-flow plug (Fig. 7.65) are either operated manually or automatically and remotely with the aid of a pneumatic actuator. When the regulating handle is turned, the plug moves up or down, varying the passage and thereby the flow rate or the pressure. A scale on the valve indicates the setting. The plug-and-seat arrangement is similar in construction to an on/off linear plug and stem valve but has a tapered valve head. Its suitability for hygienic or aseptic applications is determined by the design of the valve stem seal (Bylund, 2015; CFCRA, 1997).

7.9.9 Nonreturn Valves

Nonreturn valves (also called check 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 (disc), ball or shutter to move away from its seat. When the flow stops, the valve head or ball returns to the seat, thereby preventing flow in the reverse direction. Nonreturn valves must be installed in a position that allows full drainage (CFCRA, 1997; Schonrock, 2005; Moerman and Kastelein, 2014). Available types are:

- Nonreturn valves with a spring (Fig. 7.66) work on the principle that a light spring loading closes the valve head onto its seat once the flow stops. In this manner, flow in the reverse direction is prevented. As the

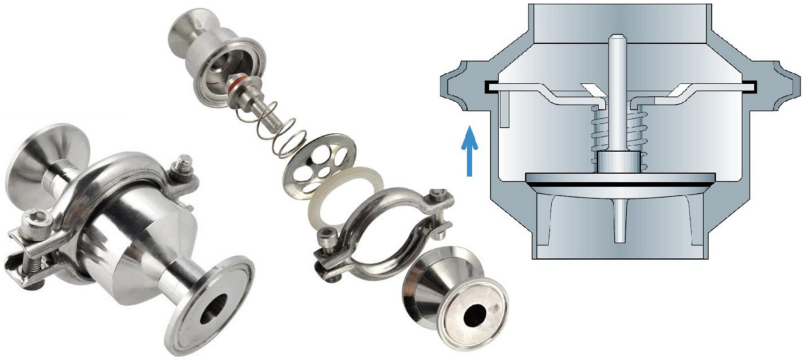


FIGURE 7.66 Stainless steel nonreturn valve with spring (tri-clamp type). *Figure right: Courtesy of Tetra Pak Processing Systems AB; From Bylund, G., 2015. "Building-blocks of dairy processing", Ch. 6, section 6.8 – Piping, valves and fittings, Ch. 21. In: Teknotext, A.B. (Ed.), Dairy processing handbook. Tetra Pak Processing Systems A/B, Lund, Sweden.*

disc is forced against the flow by the spring, resistance to the inflowing fluid and pressure drop is high. Such valves are unsuitable for use with viscous liquids and may be a cleaning nightmare. There is also no indication as to whether the nonreturn valve is working. When spring-loaded nonreturn valves are used, the coil spring(s) having product contact surfaces shall have at least 2 mm openings between coils, including the ends when the spring is in a free position. Spring-loaded nonreturn valves must be fully disassembled for manual cleaning (CFCRA, 1997).

- Nonreturn valves of the swing type (Fig. 7.67) use a hinged disc which swings open when the flow travels in the right direction. The disc closes toward the seat when the flow goes in the reverse and wrong direction. The spring-assisted closure tension holds the disc in-place. As the flappers, hinges and springs quickly become contaminated and could give rise to cleaning problems, nonreturn valves with hinged flapper should be avoided. In most cases, on a few exceptions, they are only applicable in horizontal pipe sections.
- Springless floating ball nonreturn valves are more preferable. When the fluid enters the inlet of the Y-type ball check valve (Fig. 7.68), an elastomeric ball is pushed upward into the "Y" branch of the valve. When the flow stops, the pressure within the valve equalizes, and the ball will return from the "Y" branch of the valve, and rest itself against the smaller diameter of the valve near its inlet. The opposing pressure of the reverse flow will seat the ball firmly against the inlet of the valve. Springless in-line floating ball check valves are mounted vertically, with simply the weight of the ball or poppet holding it against its seat. This ball-type check valve is hydraulically highly efficient, with flow passing straight

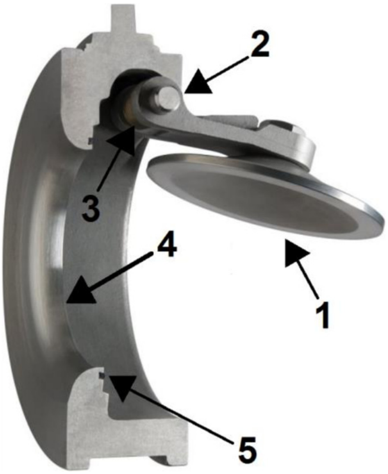


FIGURE 7.67 This nonreturn valve of the swing type consists of a disc (1) which opens in the right direction of flow by means of a hinge (2). When the flow goes in the reverse and wrong direction, the spring (3) forces the disc toward the seat (4). As an O-ring is contained in the groove of the body's seat, a uniform zero leakage seal is obtained. This design contains plenty of dead areas, and the hinge and spring are sensitive to contamination. Also the valve's drainability can be questioned.

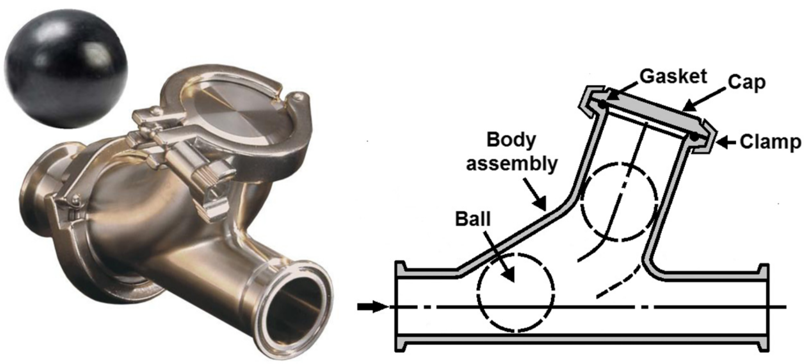


FIGURE 7.68 Y-type ball check valve. *Photo left, Dixon Valve & Coupling, © 2016.*

through vertically. Its streamlined internal design reduces the potential for material to clog or hang up.

- A magnetic nonreturn valves with floating ball (Fig. 7.69A) or shutter (Fig. 7.69B) are also available. Magnets built in the valve body keep the floating ball or shutter in a closed position. The nonreturn valve opens when the inflow pressure exceeds that of the combined pressure of the outflow and the magnetic field. As the ball or shutter moves away from the magnet, it is less attracted to the seat and therefore starts to provide lower resistance to flow. The valve closes when the difference in pressure

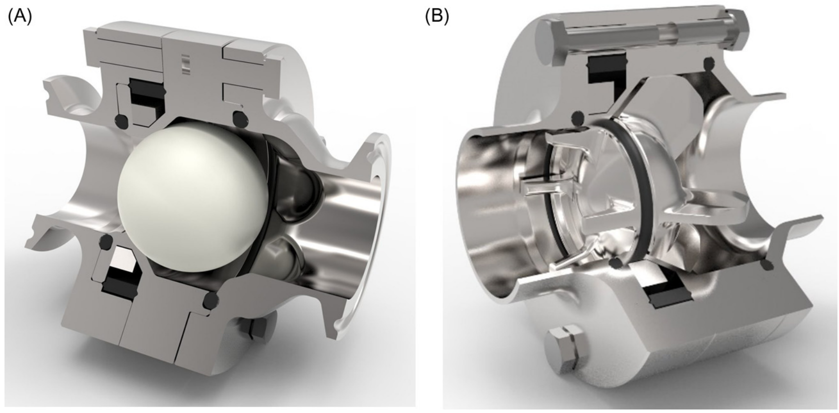


FIGURE 7.69 Springless magnetic nonreturn valves with butt-welded end or clamp connections, suitable for liquids, steam, and food gases. The risk of contamination is minimal due to the springless design and the lack of flow obstructing components. The check-valve can be installed horizontally and vertically (up and down), although full drainage of the valve in horizontal position may be compromised. The minimum opening pressure is ≤ 0.1 bar. (A) floating ball-type, (B) shutter type. *Courtesy of Carollo SRL, division Ygros valves.*

ceases or in cases of back pressure. The magnet will attract the ball or shutter back to its seat, to finally push it against the seat. Due to the design of the valve without flow-obstructing components, resistance to flow and pressure drop are low, as there are no springs, hinges, discs, or other components and there are no contamination or stagnation points. These check valves can be installed in horizontal as well as in vertical up-and-down positions.

7.9.10 Tank Outlet Valves

Tank outlet valves should be installed as close as possible to the product vessel to reduce the dead leg formed by the stub pipe that connects the bottom valve with the vessel. They may be manually or mechanically operated, and cleaned depending upon their design features. Two types of tank outlet valves are available (CFCRA, 1997; Schonrock, 2005; Moerman and Kastelein, 2014):

- Rising stem tank outlet valve (Fig. 7.70) 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 (Fig. 7.71) is similar to rising stem valves. However, in this design, the valve head drops down from its

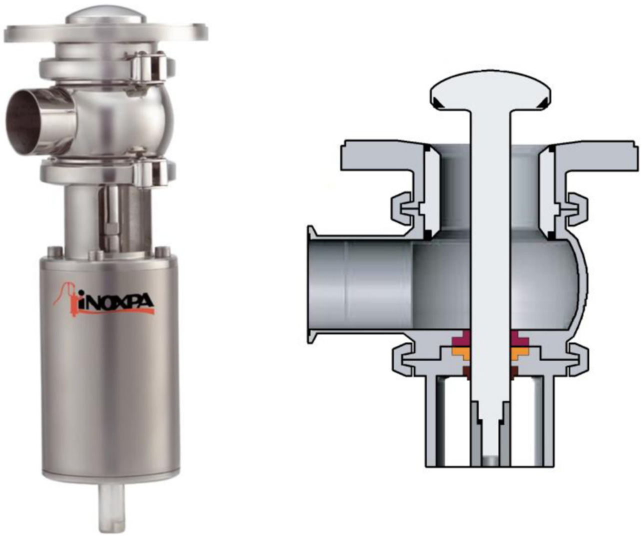


FIGURE 7.70 Rising stem tank outlet valve: the valve disk opens into the tank. This design avoids accidental openings in case of excessive pressure in the tank. *Courtesy of INOXPA S.A.*

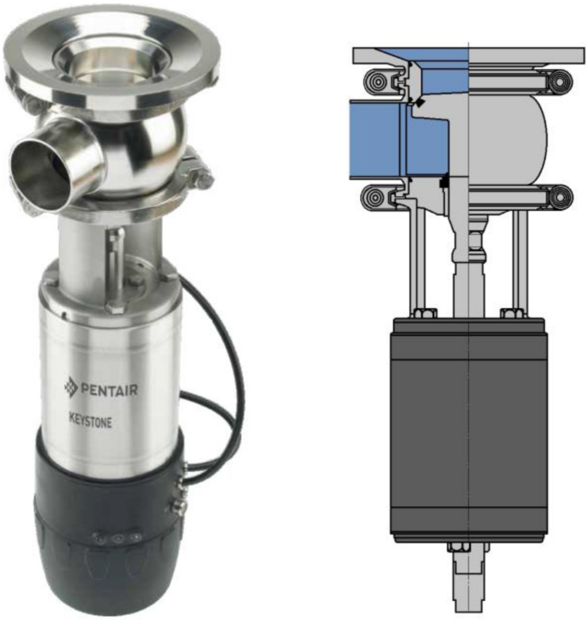


FIGURE 7.71 Falling stem tank outlet valve: the valve head drops down from its seat. *Courtesy of Pentair Südmo GmbH, division Keystone.*

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.

At present, bottom outlet valves can be purchased with side ports to allow flushing of the body cavity. But according to the Pasteurized Milk Ordinance (FDA, 2007) the bottom outlet valve cavity is not allowed to be pressurized during cleaning when there is product in the tank. Experimental cleaning trials have shown that cleaning of the bottom outlet valve cavity, even with stationary spray devices, is very difficult. In a sophisticated and automated form, a retractable or permanently mounted cleaning device can be used. It allows cleaning of the inside cavity, stem, and plug of the bottom outlet valve without pressurizing the cavity. However, due to the shadowing effect caused by internals in the bottom valve cavity (e.g., valve stem), even that option is not completely successful. A patented solution with a spray device rotating around and fed by cleaning solution via a hollow stem (Fig. 7.72) can efficiently clean the bottom valve cavity without shadowing effects (Jensen et al., 2011).

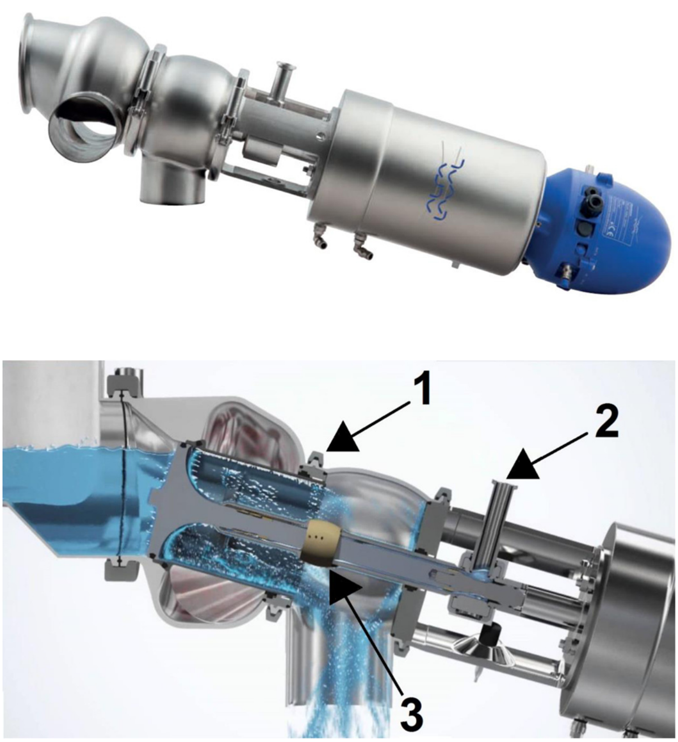


FIGURE 7.72 PMO mixproof valve for horizontal tank outlets: (1) sealing element, (2) liquid supply line for cleaning and disinfectant solutions, (3) cleaning nozzle (Jensen et al., 2011; Moerman and Kastelein, 2014). *Courtesy of Alfa Laval Tank Equipment A/S.*

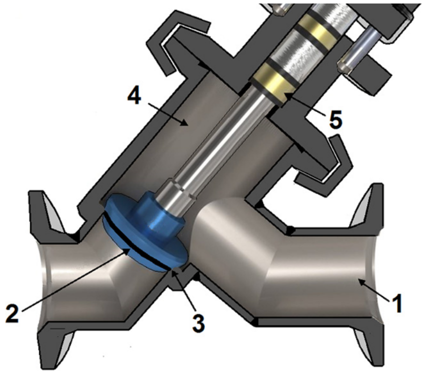


FIGURE 7.73 Y-type globe valve: (1) valve body, (2) profiled valve disc with plug seal, (3) seat designed for minimum pressure drop and dead zone, (4) valve disc retracts completely in the body, and (5) packed glands.

7.9.11 Globe Valves

Globe valves (Fig. 7.73) should not be used unless particular attention has been paid to hygienic design. They incorporate packed glands making cleaning extremely difficult and, furthermore, their flow characteristics are often unsatisfactory.

7.9.12 Membrane Sampling Valves

Sampling valves are used to take small samples of the fluid inside a tank or pipe. The sampling valve as shown in Fig. 7.74 is designed to be cleaned and sterilized during production, once the sample has been taken. The V-shaped valve has an outlet port for the sampled fluid and an inlet port for chemical cleaning (CIP) and/or steam cleaning (SIP). After flushing the fast draining valve chamber with cleaning solution, it can be rinsed and subsequently disinfected or steam sterilized if required. Via the outlet port, cleaning/disinfectant solutions and condensate are allowed to drain from the valve body.

In some occasions, the plunger is spring-loaded. On release of the plunger, the spring pressure then moves the plunger against the valve seat, hence closing the sample valve opening in front of the plunger.

7.9.13 Pressure Relief Valves

Pressure relief valves (Fig. 7.75) are fitted in food processing systems to ensure that unforeseen increases in pressure do not create a safety hazard or damage equipment. The valve head of the pressure relief valve is lifted off its seat when the product pressure exceeds that at which the valve has been set. Pressure relief valves are often variants of the on/off linear plug and stem valve fitted with a spring having a much lower rating, and which can be varied to suit the requirements. When the valve opens to relief

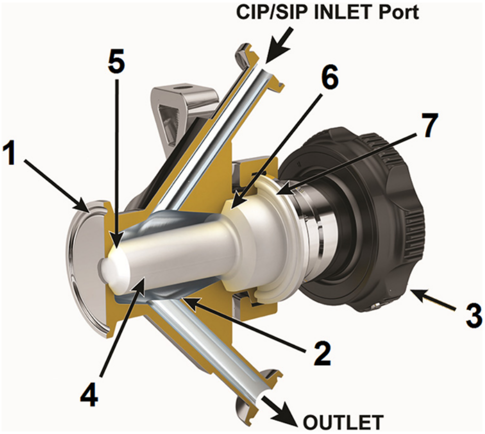


FIGURE 7.74 The sample valve is provided with (1) a ferrule for mounting to the outside of a tank or pipe by means of a hygienic clamp connection, although welding onto a short upstand is also possible. It is important that no dead leg is formed during mounting. The valve chamber (2) allows fast draining. Samples are taken by turning the handwheel (3) counterclockwise, allowing the plunger (4) enclosed by a rubber sleeve (diaphragm) (5) to be withdrawn from its seat. Once the sample is taken, the plunger can be moved forward on turning the handwheel clockwise, to finally make a seal with the valve body. In this closed position, the diaphragm sits flush against the inner tank wall or piping. *Courtesy of ASEPCO Corporation.*

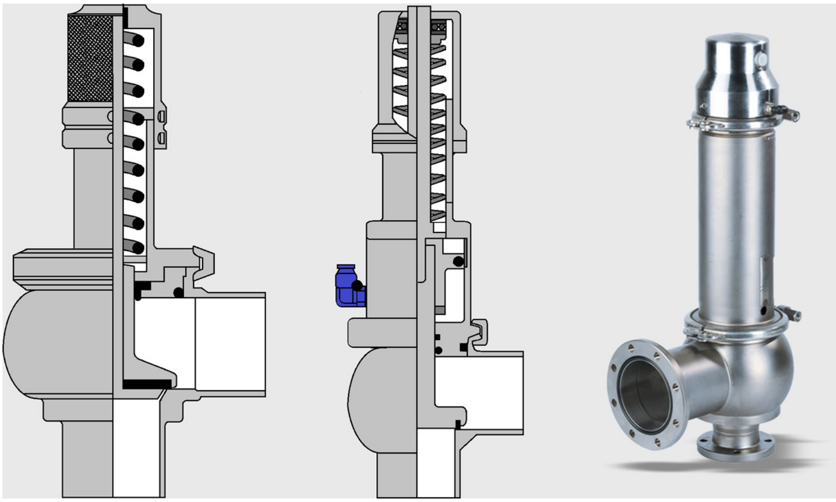


FIGURE 7.75 Hygienic pressure relief valve. *Photo right, courtesy of GEA group AG.*

pressure, product may be discharged to drain through the discharge port. To flush the inside of the valve body and the discharge port during CIP, it must be possible to lift the valve seat. Furthermore, the valve body must be installed in a position so that it is fully drainable to the outlet side, and should be mounted on a short tee to avoid a large dead leg in which product can be retained throughout the production. For tank applications, it is necessary to ensure that spray devices are so installed that cleaning fluid can access the valve (CFCRA, 1997; Schonrock, 2005; Moerman and Kastelein, 2014).

7.10 PRESSURE MEASUREMENT DEVICES

7.10.1 Selection of the Appropriate Pressure Gauge for Accurate Pressure Measurement

Pressure measurement devices serve to measure the pressure in the food factory's process and utility infrastructure, allowing detection of system malfunctioning, unsafe conditions and leaks.

7.10.1.1 Liquid-Filled Pressure Gauges

Open manometers measure pressure relative to the local barometric pressure, and therefore are not very accurate. On the other hand, the closed manometer is a simple and exact, low-cost gauge for measuring pressure independent of the atmospheric pressure. Unfortunately, its use in food plants is limited because of its size and being prone to breakage. If the gauge fluid is mercury (usually), it may contaminate the process, but the use of food grade oils instead of mercury may reduce that contamination risk. These oils also may increase the sensitivity of a closed manometer. When liquid-filled vacuum pressure gauges are used for pressure measurement in vacuum systems, low vapor pressure oils must be used. High vapor pressure oils may contaminate vacuum processes because the working liquid may evaporate if its vapor pressure exceeds the pressure within the vacuum system (Moerman, 2013a).

7.10.1.2 Mechanical Gauges

Mechanical pressure gauges measure the pressure directly by recording the force that liquids, air, or steam exert on the gauge surface in contact with these media (Moerman, 2013a).

- The Bourdon gauge is the oldest type of mechanical gauge. Its pressure reading depends on the external pressure and is only moderately accurate ($\pm 2\%$ of span). There are also Bourdon gauges that give their readings in absolute pressure. When the whole gauge is subject to mechanical vibration, the entire case (containing the pointer and indicator card) can be filled with an oil or glycerin to dampen the vibration of the pointer. Furthermore, it leaves no room for humid ambient air to enter. As a result, water cannot condense and accumulate within the gauge.

Bourdon gauges are less likely to contaminate the system than liquid-filled gauges.

- Capsule diaphragm pressure gauges use a hermetically sealed beryllium-copper capsule as basic component. This capsule, manufactured by fusion-welding of two diaphragms together at their peripheries, is evacuated to a pressure several orders of magnitude below the lower limit of the gauge pressure range. A capsule diaphragm pressure gauge indicates the pressure of a gas on a linear scale, independent of the external atmospheric pressure. Because capsule gauges are sensitive, they should not be used for pressure measurements in liquids.
- Differential diaphragm gauges use a flexible disc as diaphragm, which is made from a sheet of special steel or metal, either flat or with concentric corrugations. The diaphragm separates the interior of the differential diaphragm gauge - in which the lever system of the gauge head is located - from the process. The diaphragm deflection is again transmitted to a pointer. Due to its capacity to measure over a larger range of pressures, a differential diaphragm gauge is more suitable than a capsule diaphragm gauge, although the differential diaphragm gauge is more sensitive to vibration. When food residues accumulate in the mechanical diaphragm gauges—both the capsule and differential type—their accuracy may be compromised, while backflow of the food debris may cause the food to be at risk.

7.10.1.3 Electronic Gauges

In electronic gauges, the pressure signal is converted into an electrical signal that can be transmitted, recorded, or displayed. The most commonly used electronic gauges to monitor pressures in process and utility systems in the food industry are the (oil-filled) capacitance manometers (Moerman, 2013a).

- This is a pressure gauge in which the diaphragm makes up a part of a capacitor. A change in pressure leads to the flexure of the diaphragm, which results in a change in capacitance. Capacitance diaphragm gauges are rugged measuring devices, immune to contamination, because the gauge electronics never come in contact with the process. The only part in direct contact with the process is the diaphragm, which separates the reference cavity from the process or service system. The sensor body is usually fabricated from stainless steel or Inconel. The diaphragm that is exposed to the process pressure on one side and to the reference pressure on the other side is made from stainless steel, high-nickel steel alloys (e.g., Inconel and Hastelloy, for corrosive service), tantalum (for highly corrosive and high-temperature applications) or ceramic material with a vacuum-metalized coating. The use of ceramic diaphragm material can minimize the influence of temperature. Variable-capacitance sensing increases the accuracy, repeatability, and sensitivity of diaphragm gauges by several orders of magnitude, but changes in ambient temperature or process temperatures require either electronic compensation of the known temperature drift or sensor heaters to maintain the sensor at elevated temperature (typically 40−80°C).

- Liquid-filled capacitive transmitters make use of a diaphragm seal. That diaphragm seal protects the sensing element of the capacitance manometer by placing an isolating diaphragm between the gauge sensor and the process media that it is measuring. The cavity between the gauge-sensing diaphragm and isolating diaphragm is filled with a liquid. One side of the sensing diaphragm is evacuated and sealed to provide a reference for measuring absolute pressure. As the measured pressure changes, the outside isolating diaphragm (also called process diaphragm) deflects slightly, shifting the position of the fill fluid. The fill fluid transmits the deflection of the process diaphragm to the sensing diaphragm which causes a change in capacitance, which is translated to a stable dc voltage or current signal.

7.10.2 Hygienic Design of Pressure Gauges

The casing of pressure gauges (Fig. 7.76) should preferably be made of stainless steel AISI 304, 316(L) or food grade plastic, and should be watertight to protect the gauge against cleaning and disinfectant solutions. The outside, nonproduct contact area of the casing may have a roughness $R_a \geq 0.8\ \mu m$ if test results have shown that the required cleanability is achieved. Weep holes (Fig. 7.76) can be provided in the bottom of the case to ensure proper drainage of condensate, cleaning solutions, etc. The type of glass used as gauge window or gauge tube should be carefully evaluated with regard to crack risk and sensitivity to corrosion, as hydrolysis, especially at higher temperatures and pH values, may occur. Polycarbonate (PC), poly(methyl

FIGURE 7.76 Weep holes can be provided in the bottom of the vacuum gauge case to ensure proper drainage of condensate, cleaning solutions, etc.

methacrylate) (PMMA) and polysulfone (PES) are the most commonly used materials for gauge windows (Höhler et al., 2007; Cole-Parmer, 2009).

To avoid buildup of food pathogens and spoilage microorganisms and/or to prohibit the formation of biofilms, product contact surfaces (e.g., metallic diaphragm) should be free of microscopic faults and electropolished to a surface finish of 0.8 μm R_a or better. When in contact with process media, they need to be passive and free of pits and crevices, to reduce the likelihood of unwanted particles adhering to these surfaces. When a ceramic diaphragm separated from the metallic sensor body via an elastomer seal is used, there is an increased risk of pores. Therefore, this design must be considered carefully. Finally, all wetted surfaces should be fully drainable (Hauser et al., 2004a).

The housings of electronic pressure instrumentation (Fig. 7.77) (transducers, transmitters, switches, etc.) are made from stainless steel or plastic (either fully or partially). This plastic should be stress-crack resistant, resistant to cleaning agents and disinfectants, and possess high hydrolytic stability in the presence of hot water and steam. External housing and wiring may not collect dust or soil, and must be easily cleanable and self-drainable. The recommended ingress protection rating for electronic pressure instrumentation in the food industry should be IP65 or better. However, when exposed to CIP or SIP an ingress protection rating of IP67 or better is required (Höhler et al., 2007; Cole-Parmer, 2009).

7.10.3 Proper Installation of a Gauge

7.10.3.1 Installation for Visibility

When possible, pressure instrumentation should be installed in visible, readily accessible locations. Readouts should be located at eye elevation. Headroom should be provided for instrument removal, as well as any space for tools and test equipment that might be needed (Moerman, 2013b).

7.10.3.2 Measures to Eliminate Temperature Effects

Ambient temperatures above or under the specific acceptable temperature operating range of the gauge (due respectively to the vicinity of a source of heat or cold) must be avoided. The external housing must be checked for sufficient temperature decoupling from the process or utility system, as gauges may be affected by the temperature of the fluids flowing within the process or utility system. If the process/utility system or lines become too warm, the effects of changes in process fluid temperatures can be minimized by means of a cooling element (Fig. 7.78), a diaphragm seal with capillary tubing for remote mounting, a siphon, a loop seal or by purging. Loop seals and siphons are less hygienic solutions. Alternatively, the gauge housing can be

FIGURE 7.77 Hygienically designed electronic pressure measurement devices with stainless steel or plastic housing. The external housing and wiring may not collect dust or soil, requiring a design with smooth transitions and free from pockets. To be self-draining the instrument housing can be made with a sloped top surface, although it is possible to install pressure measurement devices with angles of more than 30 degrees from the vertical. *Courtesy of Endress + Hauser AG.*

cooled electrically (Peltier effect) or by means of water. If the process/utility system or lines have become too cold, sensor heaters may keep the sensor at elevated temperature (typically 40−80°C). If there is downward temperature drift due to the process/utility system being frozen, freeze protection may occur by means of steam tracing or resistance heating (electronic compensation) in combination with thermal insulation. If a diaphragm seal is used, the oil filling in the diaphragm seal housing not only may prevent humid ambient air to enter the gauge but it also may prevent a cold process/utility fluid from freezing any condensate within the gauge (Moerman, 2013b).

FIGURE 7.78 Changes in ambient temperature around the measurement system due to high process/utility temperatures can be minimized by means of a cooling element mounted between the gauge and the hot process/utility system. *Courtesy of Endress + Hauser AG.*

7.10.3.3 Measures to Eliminate Pressure Misreadings Due to Dirt

Pressure measurements may become falsified, especially for all types of gauges in which high-sensitivity and high-accuracy measurement systems are particularly susceptible to soiling. Besides incorrect pressure readings, unhygienic conditions may be created in the food contact area. It is nearly impossible to prevent the measurement system in a gauge from becoming soiled. Also, considerable quantities of continuously or intermittently liberated process gases or vapors may pass into the pressure measurement system. In this manner they may damage and destroy the pressure sensing mechanisms due to condensation, corrosion or deposition of contaminants. Especially in mechanical gauges, delicate links, pivots, and pinions are sensitive to condensation of water vapor. That water condensate, in colder climates, may even freeze and damage the gauge housing. Therefore, measures should be taken to ensure that the influence of contamination on pressure measurement remains as small as possible. Where possible, the gauge should be installed in such a way that product cannot come in contact with the gauge, especially because positioning a gauge at the same height as the process equipment may result in its contamination (Moerman, 2013b).

Sensors should only be installed inclined upwards (Fig. 7.79) with the flange at its bottom to keep condensate, debris, suspended solid particles, flakes, etc. from clogging the sensor port or from falling into the sensor and the measurement system. The user of the gauge can attempt to protect the measurement systems against contamination by providing suitable shielding but this solution—although clean—often leads to pressure readings deviating considerably from the pressure actually prevailing in the system. Cleaning the

FIGURE 7.79 An instrument branch facing downward instead of inclined upwards creates a difficult-to-clean dead area where condensate, debris, suspended solid particles, flakes, etc. may accumulate. Fluid velocities in the dead leg are much lower, and thus the area of entrapment may not be reached by cleaning or sterilizing procedures, hence leading to contamination of the product. *Courtesy of Joe Stout, Commercial Food Sanitation LLC - Intralox, © 2016.*

measurement system is another solution but certain gauges (e.g., liquid-filled gauges, mechanical gauges, etc.) are too fragile to be cleaned (Moerman, 2013b).

7.10.3.4 Measures to Eliminate Vibratory Effects

Install gauges at those points in the process/utility system that will remain free of vibration during operation, because liquid-filled and mechanical gauges are prone to failure by vibration. Glass tubes of the liquid-filled gauges may break, and the delicate links, pivots, and pinions of the mechanical gauges may become damaged. Pulsation dampeners can help to absorb pressure shocks and average out pressure fluctuations. To dampen pointer vibration and gauge lifetime, the pointer gauge housing is usually filled with a viscous oil (Section 7.10.1.2 on mechanical gauges) (Moerman, 2013b).

7.10.3.5 Measures to Eliminate the Effect of Magnetic Fields and Electrical Potentials

Measurement cables that are too long (connector cables between the sensor and the pressure gauge control unit) should be avoided because strong interfering magnetic leakage fields or electrical potentials can falsify pressure measurements. Wireless transfer of data between pressure measurement instrumentation and control equipment is highly recommended (Moerman, 2013b).

7.10.3.6 Installation for Hygiene

Most pressure instruments (gauge, switch, transducer, or transmitter) are designed without hygienic process connections. However, the connector threads of standard sensors provide a space where bacteria could grow. Installation of pressure gauges on piping and equipment processing sensitive food should occur in agreement with EHEDG guideline documents Nos. 10, 16 and 37. Typical hygienic connections free of crevices, threads, metal-to-metal contact, etc. are DIN 11864A & B, ISO 2852, NEUMO BioConnect, and VARIVENT. Flush-welded versions are also available (Cole-Parmer, 2009).

Incorrect mounting of sensors in process lines will result in large dead areas in the instrument branches, which are unacceptable (Figs. 7.80 and 7.81). So, instrument branches must be installed inclined upwards, especially to avoid air pockets. Moreover, the length of the dead area must be as short as possible and its cleanability must be demonstrated. For all pipe diameters the length of the up-stand should be smaller than its diameter ($l \leq d$). Furthermore, it is possible to avoid such dead areas by mounting, e.g., the pressure transmitter on a swept tee (Fig. 7.82), but the dimension l must be as short as possible relative to dimension d: maximum $l = d$. However, as swept tees in a horizontal pipeline could hamper the drainability, the swept tees preferentially should be mounted in a vertical pipeline. Alternatively, pressure transmitters with tubular membranes, with the same inner diameter as the adjacent pipelines, can be installed by means of clamp fittings in spherical valve bodies welded into the piping. The stainless steel diaphragms are sealed by O-rings fitted into grooves such that there is no metal-to-metal joint on the product side (Fig. 7.83). This way of mounting of pressure transmitters provides a dead space−free, flush transition from the process line to the pressure transmitters (Moerman, 2013b). In a similar manner, pressure transmitters with tubular membranes can be directly installed in the wall of a tank, again providing a dead space−free, flush transition, more specifically from the tank wall to the pressure transmitters (Fig. 7.84).

7.10.4 Retractable Measurement Instruments

Automatic retractable assemblies (Figs. 7.85−7.87) permit removal and installation of the sensor while protecting both the process and operating

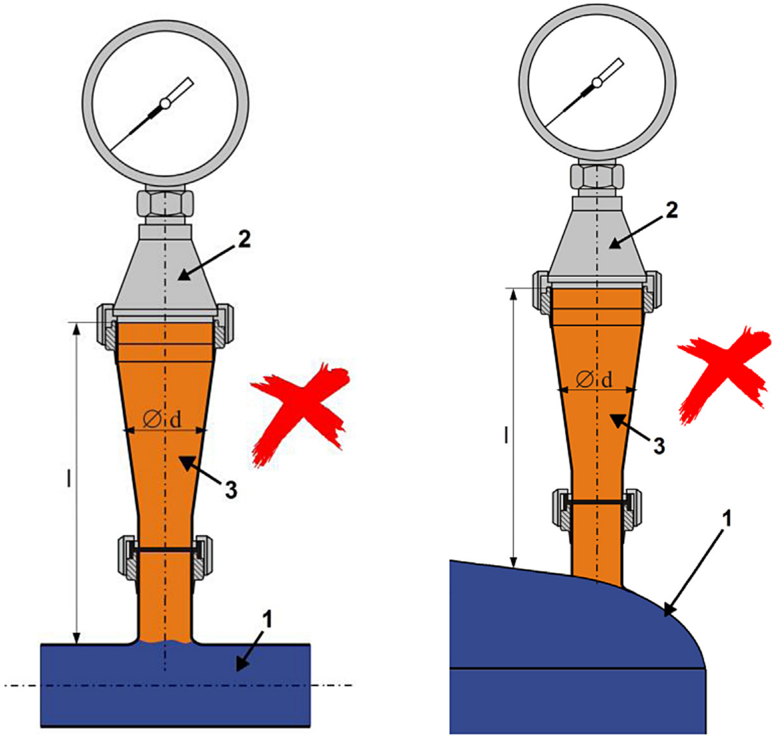


FIGURE 7.80 Product (1) is present in a pipe (left) or tank (right) with a pressure gauge (2) mounted on a too-long tee branch. An unacceptably large dead area (3) is created. The length of the up-stand should be smaller than its diameter ($l \leq d$) (Hauser et al., 2007).

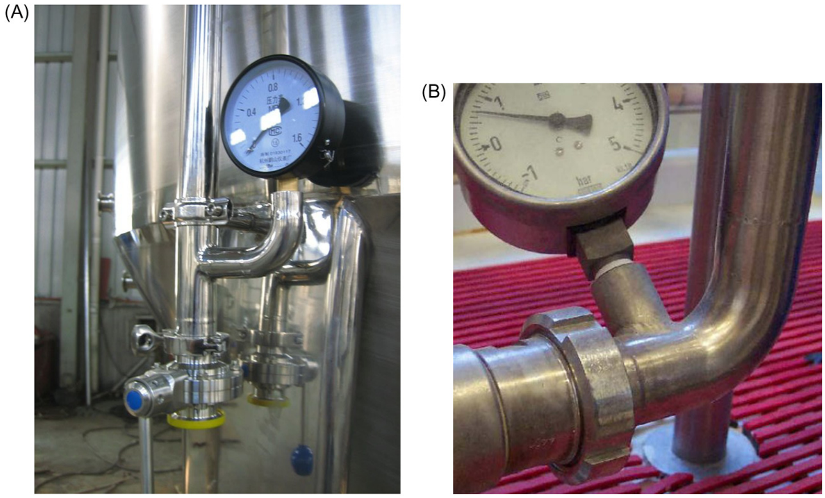


FIGURE 7.81 Pressure measurement devices installed on a too-long instrument branch.

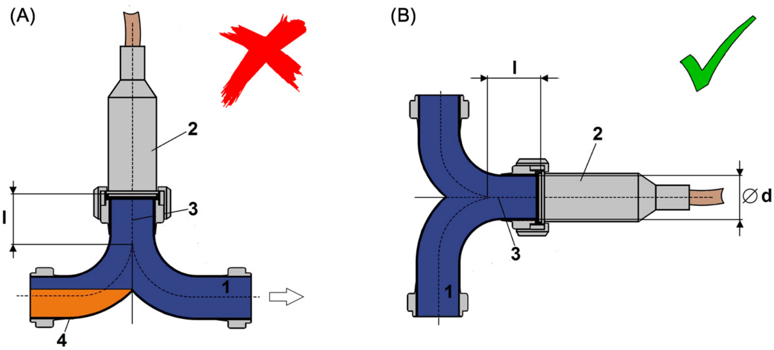


FIGURE 7.82 Incorrect mounting of sensors (2) in process lines (1) may give rise to tees with closed ends (3), which may create large dead areas if too long. (A) But a swept tee if mounted in a horizontal pipeline may impede adequate drainage (4). (B) Swept tees should be mounted in a vertical pipeline. Dimension "l" must be as short as possible relative to dimension "d," maximum l = d (Lelieveld et al., 2003; Hauser et al., 2007).

FIGURE 7.83 A pressure transmitter with tubular membranes, having the same inner diameter as the adjacent pipeline, can be easily integrated into the process line. Installation usually occurs by means of a clamp fitting, in a standard spherical valve body welded into the piping. The stainless steel diaphragm is sealed by O-rings fitted into grooves so that there is no metal-to-metal joint on the product side. This way of mounting of pressure transmitters provides a dead space−free, flush transition from the process line to the pressure transmitter. At the bottom side a temperature measurement device is installed, again by means of a clamp fitting. *Courtesy of WIKA Alexander Wiegand SE & Co. KG.*

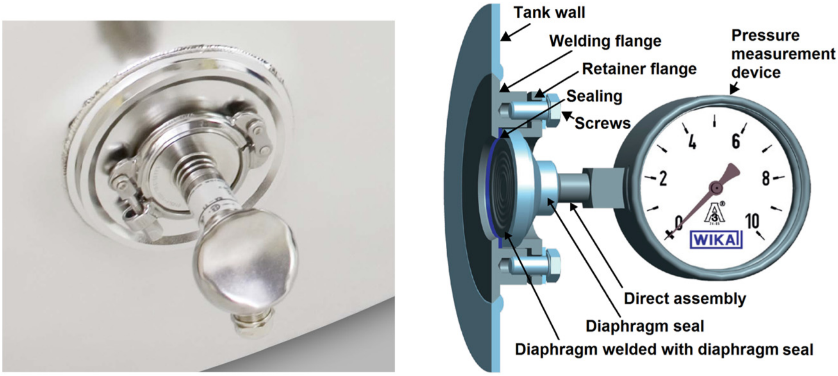


FIGURE 7.84 Pressure measuring instrument directly installed in the wall of a tank by means of a clamp fitting allows a flush transition from tank wall to diaphragm of the pressure measurement instrument. *Courtesy of WIKA Alexander Wiegand SE & Co. KG.*

FIGURE 7.85 A retractable assembly permits removal and installation of a sensor while protecting both the process and operating personnel. *Courtesy of Endress + Hauser AG.*

personnel. Moreover, when moving the sensor from the measuring position to a service position, retractable assemblies allow the sensor to be cleaned, calibrated, or replaced without interrupting the process. Fig. 7.86 shows a retractable assembly with only one chamber (service chamber) separated from the pressure cylinder by means of two fixed seals. Fig. 7.87 shows the other option with two chambers (front and service chamber) where the

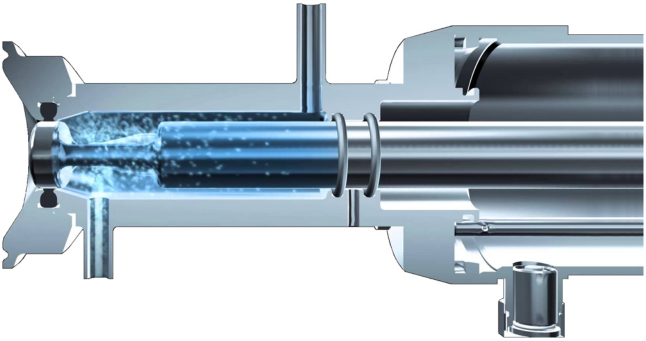


FIGURE 7.86 Retractable sensor assembly with two fixed seals separating the service chamber from the pressure cylinder. By moving the sensor from the measuring position to a service position, the retractable assembly allows the sensor to be cleaned, calibrated, or replaced without interrupting the process. It is also possible to clean and sterilize the seals' contact surfaces, which ensures that the sensor remains free from contamination when it is reinserted into the process. *Courtesy of Endress + Hauser AG.*

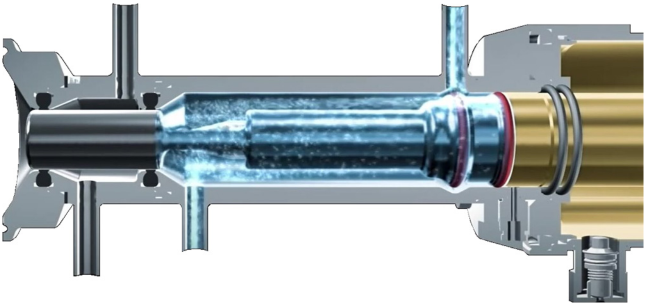


FIGURE 7.87 This assembly consists of a dual chamber system, with a front chamber being used as an extra protective barrier to the process. The front chamber is located between two fixed seals and can be cleaned and sterilized. The service chamber is now separated from the pressure cylinder by means of two dynamic seals. The front dynamic seal is cleaned and sterilized together with the service chamber. During the cleaning of the service chamber, it is possible to continuously flush the front chamber (near the surface) with sterile water, and therefore excluding any potential entry of cleaning solution from the service chamber into the process, even when the seal between the front and service chamber is damaged. The front chamber can also be used to isolate the service chamber temperature from the process. After cleaning and sterilization, the sensor guide as well as the two dynamic seals move toward the front chamber. During this action, the sterile front space and the medium remain untouched by unsterilized parts, ruling out the possibility of cross-contamination. *Courtesy of Endress + Hauser AG.*

service chamber is separated from the pressure cylinder with two dynamic seals. The later, more advanced retractable sensor assembly can better maintain aseptic conditions, which is optimal for situations where very sensitive food is manufactured.

In both versions, the retractable immersion tube, process connection, and service chamber (as well as front chamber in the advanced version) could be made of stainless steel or other alloys, while the seals can be ethylene propylene diene terpolymer (EPDM), fluoro-elastomers (FKM) or perfluoro-elastomers (FFKM). The materials selected depend on the application. The service chamber (as well as front chamber in the advanced version), process connections and couplings must be designed for minimal dirt buildup and maximum cleanability, as well as sterilizability where required. The alignment of the inlet and outlet of the service chamber (and front chamber in the advanced version), as well as the flow configuration, facilitates the loosening and removal of built-up solid deposits in the chamber(s) and from the sealing surfaces during the cleaning process. The chamber(s) also must allow liquid media to drain freely and completely.

7.10.5 Diaphragm Seals

7.10.5.1 Single Diaphragm Seal

Without a diaphragm seal, process fluids accumulated in the port or dead-ended sensor cavity of pressure gauges may compromise the physical and microbiological integrity of the process fluid. As an example, milk getting into the pressure port of a pressure gauge may spoil and contaminate the milk in a vacuum pan during its *in vacuo* evaporation and concentration. Furthermore, certain metals in electronic pressure sensors may contaminate the fluid with lead, zinc, copper, cadmium, etc. Therefore, to protect the process, the use of a diaphragm seal is recommended. In addition, the isolating diaphragm between the gauge sensor and process media prevents the pressure gauge port from plugging up with debris and liquid condensate, as well as protects the sensing element of the gauge by prohibiting corrosive, abrasive and noxious process materials from reaching the dead-ended sensor cavity (Fig. 7.88) (Moerman, 2013b).

A single diaphragm seal is composed of three main parts (Moerman, 2013b):

- The housing containing the fill fluid and process and sensor connections for the diaphragm seal.
- The isolating diaphragm, a flexible membrane that separates the fill fluid and mechanical or electrical sensing element from the process fluid or process aid. Pressure effects are allowed to cross the isolating diaphragm from the process/utility system and are hydraulically transmitted by the fill fluid to the sensor's measuring element. Isolating diaphragms have a thickness of approximately 3 mm, and are made of food process compatible materials such as plastics, rubbers, or metal plate. Metal diaphragms of stainless steel (several grades), Hastelloy, Monel, Inconel, tantalum, titanium, and other metals should be welded flush to the housing.

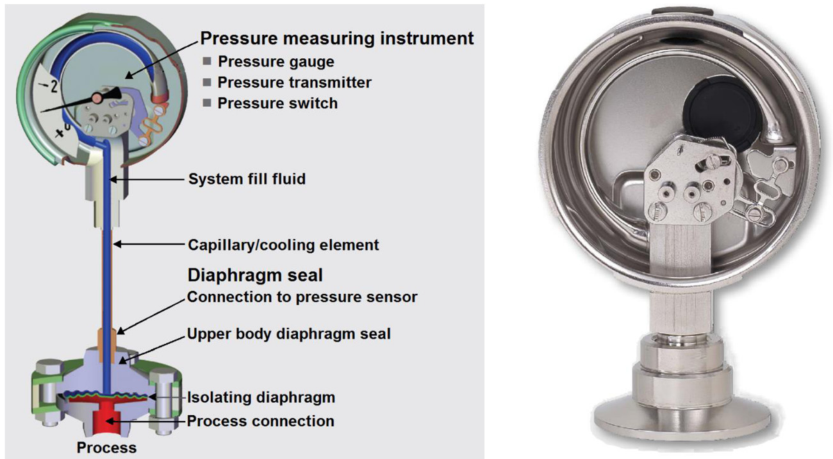


FIGURE 7.88 Mechanical gauges in particular, such as the bourdon gauge, require a diaphragm seal. Diaphragm seal gauges can cope with a greater range of process temperatures and aggressive products. *Courtesy of WIKA Alexander Wiegand SE & Co. KG.*

Capacitive sensors consist of a ceramic diaphragm of Al_2O_3, separated from the metallic sensor body via an elastomer seal. This design must be considered carefully as there is a risk of pores.

- A fill fluid (in the cavity between the gauge sensing diaphragm and the isolating diaphragm) is application specific, which means that it varies for food, beverage, or industrial applications. In food applications, a stable, food grade, noncorrosive, low thermal expansion, and viscosity fluid should be used (Table 7.3). For high-temperature applications, a sodium-potassium eutectic is commonly used, while a mixture of glycerine and water is recommended for ambient temperatures. Ethyl alcohol or silicon oil are applied for low temperatures. Water-based glycerine is not an appropriate fill fluid in vacuum and high-temperature applications due to its risk of vaporization, which can destroy the diaphragm seal, while at low temperatures it becomes too thick to produce accurate readings due to the extremely slow response time.

With regard to diaphragm seals, besides the common pressure gauge mounting to existing fittings such as T-pieces or welding sockets, there are also pressure measurement device installations using flow-through diaphragm seals (Fig. 7.89). These diaphragm seals consist of a body with an internal cylindrical thin diaphragm, which can be made of a variety of plastics. The diaphragm in-line seals can be installed directly in the pipeline between two flanges. A variety of nominal pipe diameters enables adaptation to the cross-section of the particular pipeline. These diaphragm in-line seals are ideal for use with flowing process media. With the seal being completely

TABLE 7.3 Fill Fluid in Pressure Gauges (Cole-Parmer, 2009)

Fill Fluid	Suitable Temperature Range		Kinematic Viscosity at Temperature	
	P_{abs} <1 bar (°C)	P_{abs} >1 bar (°C)	(10^{-6} m^2/s)	(°C)
Glycerine	N/A	+15 to +240	1110	+20
Glycerine/water	N/A	−10 to +120	88	+20
NEOBEE M-20	−28 to +160	−25 to +205	9.8	+25
Food grade silicone oil	N/A	−15 to +300	350	+25
Mineral oil	−20 to +170	−20 to +250	56	+20
Vegetable oil	−10 to +120	−10 to +200		
Propylene glycol/water		−18 to +93		

N/A = not applicable.

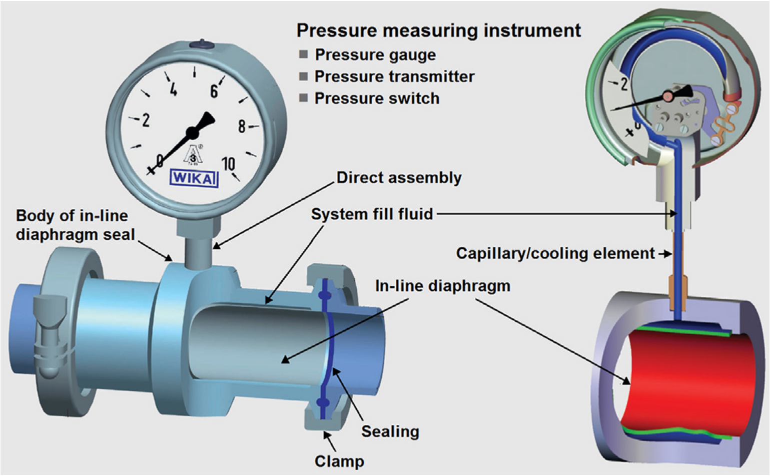


FIGURE 7.89 Diaphragm in-line seals. *Courtesy of WIKA Alexander Wiegand SE & Co. KG.*

integrated in the process line, measurements are not affected by any turbulence, corners, sharp edges, dead-ended cavities (where solids could accumulate), or other obstructions in the flow direction. Moreover, whereas other designs with grooves or noncircular geometry are more critical to clean, diaphragm in-line seals with their perfectly circular form are less likely to plug, are self-cleaning and are easy to drain. All product residues or films can be easily cleaned, even by pigging in certain applications. However, if maintenance is required, the process has to be shut down.

7.10.5.2 Double Diaphragm Seals With Diaphragm Monitoring System

Unforeseen process disturbances can damage or even destroy the isolating diaphragm. If a seal with only one diaphragm is used, then the fill fluid will find its way into the process. As the process operators are not warned of diaphragm failure, large amounts of product can be contaminated. Therefore the process operators are required to remove all pressure-measuring instruments from the process after every batch to check the diaphragm for possible damage. If no failure of the diaphragm has occurred, only then can the product batch be released for further processing. On the other hand, in the case of diaphragm failure, the contaminated batches have to be quarantined or discarded. Because of the time delays, unplanned shutdowns and product contamination due to failure of the diaphragm in single diaphragm seals, a more advanced design was required to avoid all these problems. Therefore, a double-diaphragm seal annex diaphragm break-monitoring system has been developed.

In a double-diaphragm seal, the space between the two diaphragms is evacuated, and in this manner a vacuum is created between the two diaphragms (Fig. 7.90). The pressure in this space is continuously monitored with a pressure gauge, pressure switch, or pressure transmitter (Fig. 7.91). If for any reason the primary diaphragm fails, the vacuum is compromised (so, pressure increases), and the monitoring system alerts the process operators by giving a visual, acoustic, or electrical warning. Although the wetted

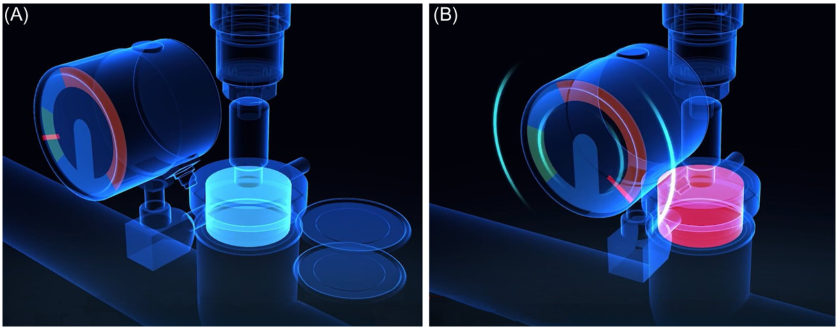


FIGURE 7.90 (A) Double-diaphragm seal: vacuum is created between two intact diaphragms. The pressure in this space is continuously monitored with a pressure gauge, pressure switch, or pressure transmitter. (B) Wetted diaphragm breaks but the second still forms a reliable seal for the process. The space between the two diaphragms is no longer under vacuum. The monitoring system alerts the process operators by giving a visual, acoustic, or electrical warning. *Courtesy of WIKA Alexander Wiegand SE & Co. KG.*

FIGURE 7.91 Diaphragm monitoring system. With regular on-site inspection, a pressure gauge with green-red display will be sufficient to detect failure of the diaphragm in contact with the process. When the pointer goes in the red (right corner of the diaphragm monitoring device), the operator knows that the diaphragm in contact with the process is broken. *Courtesy of WIKA Alexander Wiegand SE & Co. KG.*

diaphragm is damaged, the second still forms a reliable seal to the process and maintains the pressure monitoring until the damage has been rectified. So, there is no need to stop the process immediately to make repairs. As the process integrity is not affected when the first layer of protection (wetted diaphragm) fails, the food manufacturer is not required to stop immediately. Using a double-diaphragm system can thus prevent unplanned shutdowns.

7.10.5.3 Calibration of Pressure Gauges and Pressure Sensors

Pressure gauges and pressure sensors require scheduled, periodic maintenance, and/or recalibration. Pressure transducers can be recalibrated in a calibration laboratory or online.

7.11 TEMPERATURE MEASUREMENT DEVICES

7.11.1 Hygienic Design of Temperature Measurement Devices

To measure temperatures in a hygienic application, bimetal, resistance, or thermocouple technology can be used. Bimetal thermometers can only supply local readings, while resistance thermometers and thermocouples are primarily used to obtain an electrical output for remote readings. However, devices exist that combine resistance and bimetal elements and provide both local and remote capabilities in one package. This allows the user to tap into the process only once, reducing the potential for contamination. Temperature measurement based on electronic detection of a change in resistance is the most common method. The actual temperature sensor elements used integrate either platinum thin-film resistors (Pt100, etc.), or employ other sensing elements with a varying electrical resistance against temperature (NTC or PTC resistors). Also, semiconductor devices are common (Cole-Parmer, 2009; Moerman and Kastelein, 2014)

The temperature-sensing element itself is inserted in a thermowell (Fig. 7.92), which is a closed-end reentrant tube provided with means for a pressure-tight attachment to a particular process equipment component. The dimensions of the tapered and straight thermowells must be chosen as a function of the vibration or stress caused by the process medium flowing through the pipeline. The protective sleeve (thermowell) is typically made of stainless steel and highly polished to a surface finish of $R_a \leq 0.8\ \mu m$. However, special metallic overlays or polymer coatings can be applied to the surface of the thermowell for use in processes involving high-velocity particulates and acidic solutions that may cause, respectively, erosion and corrosion. A paste with high thermal conductivity is used inside the thermowell to bring the temperature sensor in close thermal and mechanical contact with the liquid (in a pipe, recipient, etc.) from which the temperature must be measured.

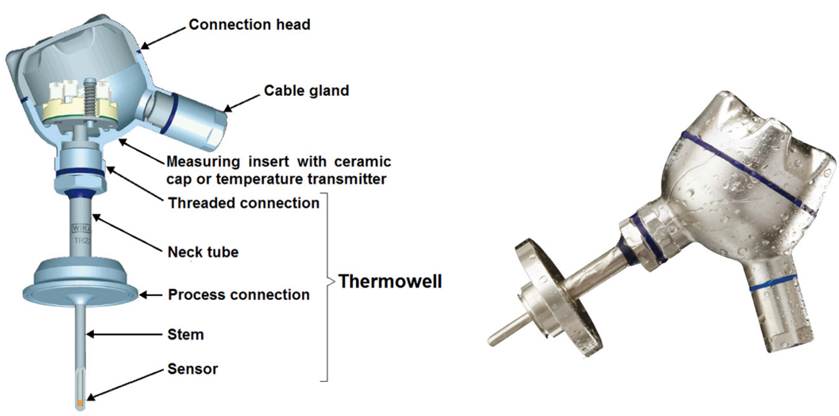


FIGURE 7.92 Design of an electrical thermometer with thermowell. *Courtesy of WIKA Alexander Wiegand SE & Co. KG.*

7.12 INSTALLATION OF TEMPERATURE MEASUREMENT DEVICES

Temperature measurement devices may not be mounted on a tee branch that is too long (Fig. 7.93) because an unacceptably large dead area is then created. Thermowells with flanged process connection (Fig. 7.94) can be integrated in process lines. By means of clamp fittings, they can be installed in standard spherical valve bodies welded into the piping. The sheath of the probe is welded into one of the two blanks which are sealed to the spherical valve body by O-rings fitted into grooves. Thus there is no metal-to-metal joint on the product side. This way of mounting a temperature measurement device provides a dead-space free, flush transition from the process line to the blank containing the thermowell. Thermowells also can be directly orbital welded into the pipeline (Fig. 7.95).

In addition, the thermowell can be directly fitted via an orbital welded pocket (Fig. 7.96). Attention should be given to the quality of the weld, which must be smooth and continuous. Furthermore, to avoid shadow areas, the direction of the flow must be as indicated.

For temperature measurement in tanks and larger vessels, the thermowells can be continuously welded to the tanks with welding balls or welding collars, after which the inner welding seam is polished and passivated. Temperature measurement devices can also be installed via a hygienic process connection sandwiched (detachable seal joints such as O-rings) into

FIGURE 7.93 Temperature measurement device mounted on a upwards sloped tee branch. The length of the up-stand is not larger than its diameter ($l \leq d$). Sloped mounting of the instrument branch decreases the risk of reduced turbulent flow conditions in the instrument branch during cleaning operations. As turbulence in the sloped instrument branch is higher, stagnation of air in the upwards sloped tee is also less likely to occur. *Courtesy of Endress + Hauser AG.*

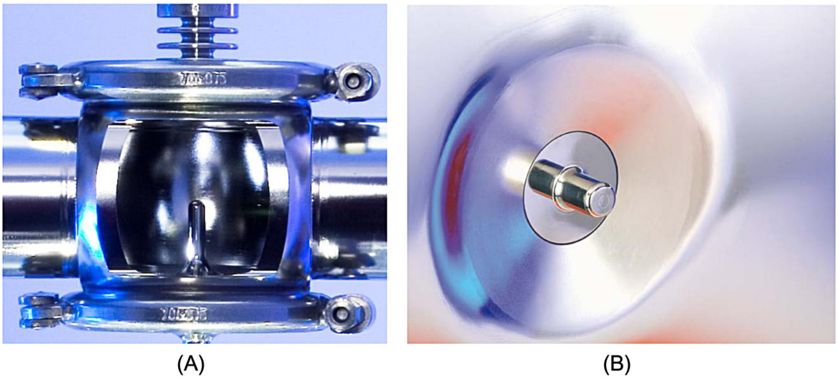


FIGURE 7.94 (A) This thermowell fitting, having the same inner diameter as the adjacent pipeline, is integrated into the process line. The sheath of the probe is welded into one of the two blanks, which are sealed to the standard spherical valve body welded into the piping. Installation in the spherical valve body is done by means of a clamp fitting and O-rings fitted into grooves. In such a way, a metal-to-metal joint on the product side can be avoided. (B) In this example, the temperature measurement device is fitted in a tank by means of an O-ring and clamp fitting. Also here, a dead-space free, flush transition from the temperature measurement device fitting to the tank wall is obtained. *Courtesy of WIKA Alexander Wiegand SE & Co. KG.*

FIGURE 7.95 This flow-through thermowell is directly orbitally welded into the pipeline. The measuring insert can be withdrawn from the thermowell to calibrate the thermometer on-site. *Courtesy of WIKA Alexander Wiegand SE & Co. KG.*

the pipeline (Fig. 7.97). The dimensions of the O-ring and the design of the groove to be used for mounting sensors are critical in achieving controlled compression of the seal. The O-ring needs periodic maintenance with an inspection of the O-ring upon dismantling. Used O-rings should not be reinstalled.

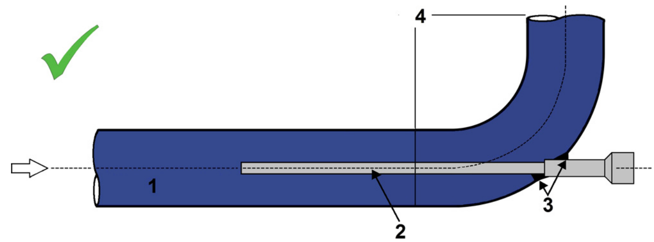


FIGURE 7.96 To avoid dead areas, the temperature probe (2) can be welded flush in the piping, in which the product flows (1) in the opposite direction. This may occur via an orbitally welded pocket. Attention should be given to the quality of the weld (3), which must be smooth and continuous. Welding of the temperature probe into the bend may be done off-line, after which the bend can be built permanently (by welding) or with dismountable joints into the piping system. In the latter case, the bend section is detachable (4) (Lelieveld et al., 2003; Hauser et al., 2007).

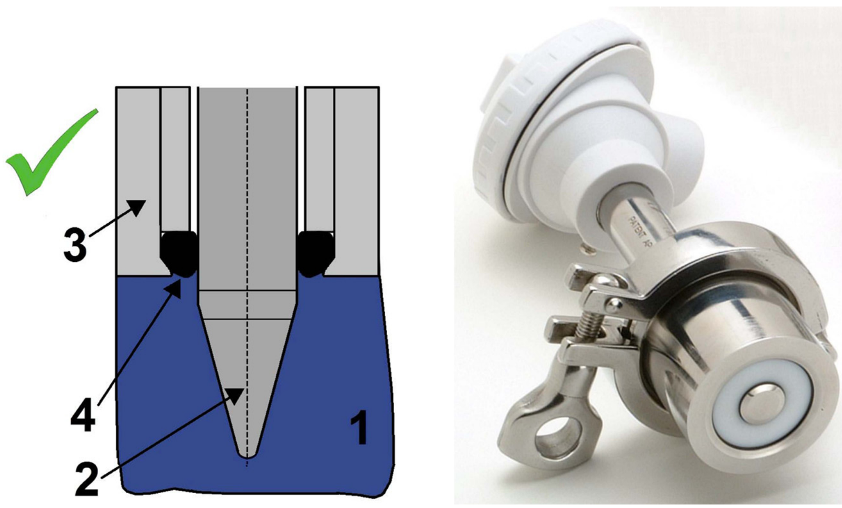


FIGURE 7.97 In the product area (1), a sensor (2) can be installed via a weld-in adapter (3) into and flush with the tank wall. The detachable seal joint (e.g., O-ring, 4) is almost completely enclosed with the surrounding metal protecting the non-product side from the product contact area (Lelieveld et al., 2003; Hauser et al., 2007) (photo, right, courtesy of Weed Instrument Co., Inc. d/b/a Ultra Electronics, Nuclear Sensors & Process Instrumentation).

7.13 CONCLUSIONS

Problems caused by microbial contamination of foods tend to be expensive, particularly if these result in consumer recalls. As a result of the development and application of increasingly mild preservation technologies, processed foods become more sensitive to microbial (re)contamination, requiring greater control of the manufacturing process. One way to achieve this added control is to “build in” hygiene into the equipment used in the food manufacturing facility from the start. The hygienic design of equipment plays an important role in controlling the safety and quality of the products made. Good hygienic design practice has proven to be a powerful tool in reducing or excluding microbial (e.g., pathogens, spoilage microorganisms, toxins of microbial origin), chemical (e.g., lubricating fluids, chemicals used for cleaning and disinfection, coolants, antimicrobial barrier fluids) or physical (e.g., glass, wood, packaging materials, and insects or other vermin) (re) contamination of foods.

Many of these problems can be alleviated by good basic hygienic design practices, including: (1) the selection of appropriate materials of construction, which must resist the harsh conditions encountered in the food industry (low or high temperatures, corrosive cleaning chemicals, steam, etc.), (2) the correct finishing of their internal surfaces (smooth surfaces with low surface roughness or dirt-repelling coatings can reduce biofilm formation), (3) correct joining of equipment parts (preference for welds instead of fixings), (4) use of hygienic fasteners where applied, (5) seals preventing leakage of liquid food and cleaning/disinfectant solutions to outside as well as ingress of microorganisms from the outside, (6) no niches such as pits, cracks, crevices, open seams, gaps, lap seams, inside threads, holes that may accumulate dirt and hamper the cleanability adequate drainage), (7) no dead areas where product may accumulate or removal of residues is prohibited, (8) excellent drainage of all liquids (liquid food, cleaning, and disinfection solutions), (9) maximum access for manual cleaning or a design that allows removal of all soil by means of CIP, (10) measures to avoid contamination of food by non-food grade lubricants. Furthermore, specific hygienic design requirements are given for specific components applied in closed food processing equipment. At first sight, designing closed equipment for producing contaminant-free liquid foods being safe to consume seems a complex task. However, several international standard-setting organizations, for example 3-A, EHEDG, NSF, USDA, as well as national associations, have developed specific hygienic design standards and guidelines for food-equipment manufacturers and the food industry. Today, many if not most manufacturers of equipment for the food industry can supply process equipment that meets the requirements for hygienic and/or aseptic processes.

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REFERENCES

ASME BPE committee, 2014. Bioprocessing Equipment, ASME BPE-2014. American Society of Mechanical Engineers (ASME), New York, 324 p.

Baking Industry Sanitation Standards Committee (BISSC) of the American Society of Baking, 2003. American National Standard for Baking Equipment – Sanitation Standard, ANSI/BISSC/Z50.2-2003, Chicago, 35 p.

Bylund, G., 2015. Building-blocks of dairy processing, Ch. 6, section 6.8 – Piping, valves and fittings, Ch. 21. In: Teknotext, A.B. (Ed.), Dairy processing handbook. Tetra Pak Processing Systems A/B, Lund, Sweden.

Campden Food & Chorleywood Research Association (CFCRA), 1997. Hygienic Design of Liquid Handling Equipment for the Food Industry. In: Timperley, A.W. (Ed.), Technical Manual N° 17, pp. 1–204.

Cocker, R., 2004. Hygienic design and assessment of food processing valves. New Food 7 (1), 8–15.

Cole-Parmer, 2009. The Sanitary Instrumentation Primer: keeping your process application contamination-free, Illinois, 12 p.

FDA, 2009. Grade "A" Pasteurized Milk Ordinance, Silver Spring, Maryland, 382 p.

Haga, R., Murakami, S., Ostrove, S., Weiss, S., 1997. Cleaning mechanism study for biopharmaceutical plant design. Pharm. Eng. 17 (5), 8–21.

Hauser, G., Curiel, G.J., Bellin, H.-W., Cnossen, H.J., Hofmann, J., Kastelein, J., et al., 2004a. Hygienic Equipment Design Criteria, EHEDG Guideline N°8, second ed. EHEDG working group Design Principles, EHEDG, Frankfurt, Germany, pp. 1–16.

Hauser, G., Curiel, G.J., Bellin, H.-W., Cnossen, H.J., Hofmann, J., Kastelein, J., et al., 2004b. Hygienic Design of Open Equipment for Processing of Food, EHEDG Guideline N° 13, 2nd ed. EHEDG working group Design Principles, EHEDG, Frankfurt, Germany, pp. 1–24.

Hauser, G., Curiel, G.J., Bellin, H.-W., Cnossen, H.J., Hofmann, J., Kastelein, J., et al., 2007. Hygienic Design of Closed Equipment for Processing of Food, EHEDG Guideline N°10, 2nd ed. EHEDG working group Design Principles, EHEDG, Frankfurt, Germany, pp. 1–22.

Hauser, G., Eastwood, C.A., Woodall, D.L., Timperley, D.A., Curiel, G.J., Peschel, P., 1993. Welding stainless steel to meet hygienic requirements, EHEDG Guideline N° 9, first ed. EHEDG working group 'Design Principles', EHEDG, Frankfurt, Germany, pp. 1–21.

Höhler, A., Schumacher, B., Schrodt, T., Bühler, H., Nalbach, U., Gasparetti, M., et al., 2007. Hygienic Design and Application of Sensors. EHEDG Guideline N° 37. EHEDG working group "sensors", EHEDG, Frankfurt, Germany, pp. 1–35.

Holah, J., 2000. Food processing equipment design and cleanability. In: Gormley, R. (Ed.), Flair-Flow Technical Manual 377A/00. National Food Centre, Dublin, 39 p.

Jensen, B.B.B., Nielsen, J.B., Falster-Hansen, H., Lindholm, K.-A., 2011. Tank cleaning technology: innovative application to improve cleaning-in-place. EHEDG Yearbook 2011/2012. EHEDG, Frankfurt, Germany, pp. 26–30.

Kopitzke, T., Barnickel, M., Gasparetti, M., Merhof, P., Wahlers, J., 2006. Hygienic Welding of Stainless Steel Tubing in the Food Processing Industry, EHEDG Guideline N° 35, first ed. EHEDG working group 'Welding', EHEDG, Frankfurt, Germany, pp. 1–29.

Ladenburger, D., 2015. The hygienic advantages of the P3-diaphragm in aseptic processing. EHEDG Yearbook 2015/2016, pp. 108–113.

Lelieveld, H.L.M., Mostert, M.A., Curiel, G.J., 2003. Hygienic Equipment Design. In: Lelieveld, H. L.M., Mostert, M.A., Holah, J., White, B. (Eds.), Hygiene in Food Processing, 1st ed. Woodhead Publishing, Cambridge, United Kingdom, pp. 122–166. Book N°88 (Chapter 8).

Moerman, F., 2013a. Vacuum pressure measurement (part1): direct vacuum pressure gauges. Maint. Mag. 21 (114), 28−31.

Moerman, F., 2013b. Vacuum pressure measurement (part 3): vacuum gauges suitable for the food and pharmaceutical industry. Maint. Mag. 22, 61−64.

Moerman, F., Fikiin, K., 2016. Hygienic design of Air Blast Freezers. In: Lelieveld, H.L.M., Holah, J., Gabrić, D. (Eds.), Handbook of Hygiene Control in the food industry, second ed. Elsevier, Cambridge, United Kingdom, pp. 271−316. (Chapter 22).

Moerman, F., Kastelein, J., 2014. Hygiene design and maintenance of equipment. In: Motarjemi, Y., Lelieveld, H.L.M. (Eds.), Food Safety Management: A Practical Guide for the Industry. Academic Press, San Diego, pp. 673−739. (Chapter 26).

Moerman, F., Partington, E., 2014. Materials of construction for food processing equipment and services: requirements, strengths and weaknesses. J. Hyg. Eng. Design 6, 1−37.

Moerman, F., Wouters, P., 2015. Hygiene concepts in food factory design. In: Leadley, C., Sykes, R. (Eds.), Innovation and future trends in food manufacturing and supply chain technologies, 1st ed. Woodhead Publishing, Cambridge, United Kingdom, pp. 81−133. (Chapter 4) N ° 293.

Moerman, F., Rizoulières, Ph, Majoor, F.A., 2014. Cleaning-in-place. In: Lelieveld, H.L.M., Holah, J., Napper, D. (Eds.), Hygiene in Food Processing: principles and practice, 2nd ed. Woodhead Publishing, Cambridge, United Kingdom, pp. 303−383. N° 258. (Chapter 10).

Schonrock, F.T., 2005. Improving the hygienic design of valves. In: Lelieveld, H.L.M., Mostert, M.A., Holah, J. (Eds.), Handbook of Hygiene Control in the Food Industry, 1st ed. Woodhead Publishing, Cambridge, United Kingdom, pp. 263−272. Book N° 116. (Chapter 16).

Wiedenmann, W., 2013. Damage scenarios for valves: identifying the potential for optimisation. EHEDG Yearbook 2013/2014, European Hygienic Engineering & Design Group, Frankfurt, Germany, pp. 87−91.