Chapter 8

Personal Hygiene and Good Maintenance Practices for the Servicing of Food Processing Equipment

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8.1 INTRODUCTION

Food processing equipment, like all industrial plant, is susceptible to failure through breakdown, deterioration in performance owing to wear and tear with time, and to obsolescence due to improvements in technologies. In the past, food manufacturers resorted to inefficient "breakdown" maintenance, which occurred shortly, or a considerable time, after detection of the failure. Breakdowns usually result in the contamination of foodstuffs with foreign bodies from broken parts, potential microorganisms growing in harborage sites such as cracks, crevices and pockets, and lubricating fluids from, e.g., broken bearings. As the failure may be detected too late in this type of maintenance, contamination may already have taken place, which may result in food safety problems, inferior product quality and, finally, costly product recalls. Therefore, food manufacturers now use predictive and preventive maintenance as tools to detect and prevent premature failure. As part of preventive maintenance, the equipment's overall condition and integrity are assessed, frequently requiring the dismantling of equipment. Subsequent servicing often requires further break-in to the system, with the result that preventive maintenance may in itself become a food contamination hazard.

Poor hygiene and bad maintenance practices during maintenance, repair and reassembly of the equipment may bring about food quality and food safety problems. Hence, during "preventive" and "breakdown" maintenance, the maintenance operatives must pay attention to their personal hygiene practices and must respect Good Maintenance Practices according to the principles of proper hygienic design. Training of maintenance operatives in all aspects of

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their job requirements is thus essential to ensure that equipment after reassembly will not compromise the product integrity when returned to service and for a predicted future interval.

This chapter aims to provide guidance to food manufacturers and maintenance operators in the application of appropriate hygiene procedures during the maintenance of food processing equipment and utilities. In Section 8.2 we want to emphasize the importance of maintenance of food processing facilities, which is also required by national and international legislation, as well as by many food safety certification schedules and programs. Because reducing the risk of food contamination during maintenance operations starts during the design process, installation and start-up of the processing equipment, these subjects are discussed in Section 8.3. As the hygienic performance of equipment components may be compromised long before it fails, we handle this subject in Section 8.4. Subjects of Section 8.5 are: purchase and acceptance of parts, tools, lubricants, etc., brought onto the site; hygienic design principles to respect during repair; lubrication according to the principles of hygienic design and hygienic recalibration of measurement devices. Section 8.6 deals with personal hygiene practices as this is of paramount importance in maintaining hygienic conditions in the food factory during service operations. Section 8.7 deals with proper hygiene measures that could be taken before, during and after maintenance operations. Evaluation of the quality of the performed maintenance work and record keeping is part of every maintenance program in the process industry, including the food processing industry, and therefore is the subject of Section 8.8. Maintenance practices must be regularly reviewed and adapted when necessary, requiring a discussion in Section 8.9.

8.2 MAINTENANCE AND REPAIR, A NECESSARY EVIL

Failure of equipment and its components is inherent to all machinery, including food processing equipment. Typical indications of failure of equipment and its components are increase in noise, higher lubricant consumption, temperature rises or increasing leakage. However, food manufacturers can handle this proactively by inspection (regular check of food processing equipment and/or its components with respect to their performance) and preventive maintenance. Equipment maintenance checks should include an assessment of the equipment's overall condition and integrity (e.g., whether it is working properly), the sources of physical contaminants (e.g., damaged, lost or worn parts; rust or loose/flaking paint; broken parts such as needles and blades; loose parts on equipment prone to vibration; polymeric deposits; friction, fatigue, chemical reaction) and the potential microorganism harborage sites (e.g., worn or frayed hoses, gaskets or belts, porous welds, roughened product contact surfaces). Fig. 8.1 shows a small piece of a damaged scraper that was found after a pump. Fig. 8.2 demonstrates a conveyor belt

FIGURE 8.1 Small piece of a damaged scraper found in a failed pump. *Courtesy of Joe Stout, Commercial Food Sanitation LLC - Intralox,* © *2016.*

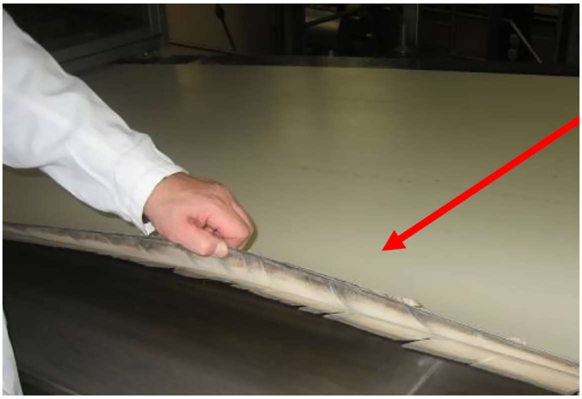


FIGURE 8.2 Damage at the edge of a conveyor belt. *www.ourfood.com, courtesy of Karl Heinz Wilm,* © *2016.*

damaged at its edge. Fig. 8.3 is an example of an air blast-freezer in which ripped-off pieces of a plastic strip curtain are lost as foreign bodies in the product stream. Fig. 8.4 is an example of damage to the gasket and gasket grooves of a plate in a plate heat exchanger commonly caused by overtightening. Fig. 8.5 shows a crack in a plate of a plate heat exchanger due to overtightening or because the plate heat exchanger was opened or closed in the wrong way. Also the surface of heat exchanger plates may show surface damage, usually caused by a hard object getting in the plate heat exchanger (Fig. 8.6). In Fig. 8.7, inspection of the inside of a leaking hose revealed the presence of many cracks, which are quite common after a long period of service in contact with liquid food and aggressive cleaning/disinfecting solutions. Fig. 8.8 shows a seal moved out of position in the food area. Worn parts should be replaced as soon as practical, not only to ensure that production is maintained but also to prevent debris or worn or broken parts from entering the food product or contaminating the production line.

FIGURE 8.3 Ripped-off pieces of a plastic strip curtain have been lost as foreign body contaminants in the product stream, while the remaining plastic strips are extremely dirty. The plastic strip curtain is also no longer suitable to reduce the infiltration of warm humid air, and has become a serious source of microbial cross-contamination, especially for exposed products (Moerman and Fikiin, 2016). *(Frank Moerman, © 2016).*

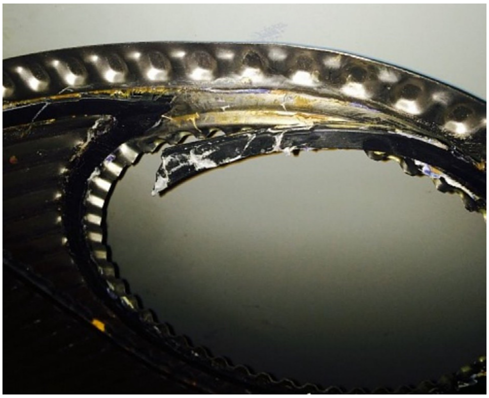


FIGURE 8.4 Damage to the gasket and gasket grooves is caused by overtightening or overpressuring. Even a new gasket will not sit properly and is likely to leak. *Courtesy of PHEX LLC.*

FIGURE 8.5 Plates in a plate heat exchanger may crack by overtightening or when the plate heat exchanger is opened or closed in the wrong way. *Courtesy of Thermo Logistics Ltd.*

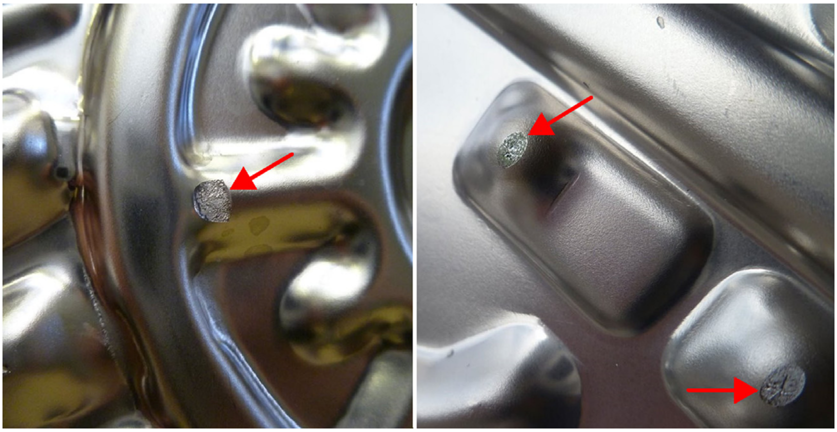


FIGURE 8.6 Plates in plate heat exchangers may suffer from surface damage, usually caused by a hard foreign body getting into the heat exchanger. The damaged spots show increased surface roughness which may promote the adhesion of food constituents (e.g., proteins in milk) and biofilm formation. *Courtesy of Thermo Logistics Ltd.*

FIGURE 8.7 Inside of a leaking hose, revealing the presence of many cracks which are quite common after a long period of service in contact with liquid food and aggressive cleaning/disinfecting solutions. *(Frank Moerman, © 2016).*

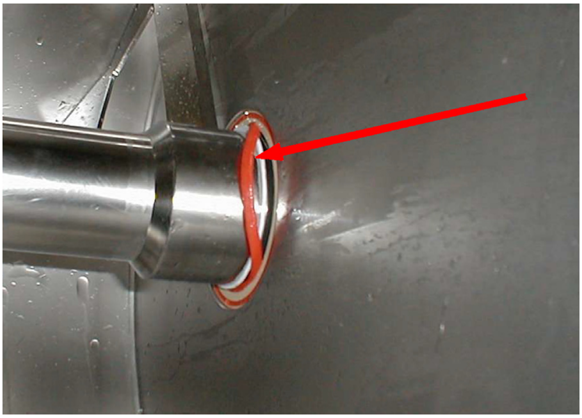


FIGURE 8.8 Worn seal may contaminate the product. *www.ourfood.com, courtesy of Karl Heinz Wilm, © 2016.*

8.3 SCHEDULED PREVENTIVE MAINTENANCE

Scheduled preventive maintenance should be preferred over inefficient "breakdown" maintenance and repetitive repair, more specifically for the following reasons (Jha, 2006):

- to prevent unscheduled downtime, and thus to provide higher throughput;
- to maximize the performance of all process and service equipment;
- to extend the useful life of the process equipment;
- to maintain and/or enhance the energy efficiency of the process and service equipment (consumption of less electricity, fuel, air power, etc.);
- to maintain and improve the quality and appearance of food products (reducing the risk for product recalls);
- to avoid the need to break into the system, hence reducing the introduction of food pathogens and spoilage microorganisms into the system;
- to save on spare parts, lubricants, maintenance chemicals, maintenance tools, etc.;
- to reduce or eliminate property hazards, such as fire;
- to enhance the safety of all food factory personnel;
- maintenance can occur at times during which no food is prepared.

No longer does the maintenance department have the luxury of extended periods of available equipment downtime in order to carry out maintenance. Nowadays the maintenance function is moving toward a more predictive approach. If the failure characteristics of the equipment are known, predictive maintenance can detect the failure well in advance and appropriate actions can be taken in a planned and organized manner. Predictive maintenance makes use of a group of emerging scientific technologies that can be employed to detect potential failures: vibration analysis, thermal imaging, ultrasonic measurement, and oil analysis. The maintenance technicians should be skilled in using these diagnostic tools, and they must have detailed knowledge of the operating characteristics of the equipment to make the correct failure diagnosis. By means of a risk analysis, the manufacturer may define which parts of the system are critical, ensuring that the necessary treatment (to which interval, to which time point, and with which measures) is undertaken. That maintenance schedule should be frequently reviewed during the initial operating period of an installation to establish the optimum maintenance frequency (Liggan and Lyons, 2011).

Unscheduled downtime and "breakdown maintenance" (maintenance when it breaks) can be reduced by:

- Proper selection of the materials of construction. Chemical, physical, and thermal resistance of the materials of construction have an enormous impact on the reliability of equipment (components) and the frequency of maintenance and repair. As an example, selecting wires and cables designed in materials which are not compatible with a specific aggressive environment may directly affect the performance and reliability of the food processing equipment. Wires and cables of the highest quality may extend the mean time between failures.

- Selecting and purchasing the right type of equipment for any specific job. Equipment must have sufficient capacity. If a machine that is of low capacity is consistently being forced to run at high capacity, no amount of preventive maintenance will cure it! From this point of view, training operators in the correct operation of the equipment and in the application of proper and efficient procedures is thus essential. Although time-consuming, it pays off in the long run.
- Equipment shall be appropriately designed within predefined tolerances of use and conform to the required specifications. Define for each piece of equipment or its components the working parameters and their minimum and maximum values. If the maximum operating limits of the equipment (components) are lower than those of the system in which it is being fitted, or if malfunction of the equipment (components) could result in a serious contamination, ensure that the system can handle these over-limit situations.
- Selecting electrical and mechanical equipment with high ingress protection for water and with high thermal resistance, both positive and negative temperatures. Acid or abrasive foods, water, steam, detergent and disinfectant solutions, and extreme heat or cold all create a hostile environment for electrical and mechanical equipment.
- Ensuring proper installation and assembly (e.g., bearings frequently fail due to misapplication, overloading, and misalignment).
- Conducting an inspection program of equipment after delivery.
- A short period of in-plant testing of the equipment to screen the entire population of equipment for leakage, to verify if all components function appropriately so as to ensure that they will fulfill their duty once brought into operation to produce food.
- Correct start-up.
- Avoiding mishandling during maintenance.
- Following the manufacturer's recommendations for scheduling preventive maintenance.
- Implementing regular and correct calibration practices.
- Periodic updating of computerized components. Up-to-date software may improve the equipment's efficiency and prevent possible problems that could cause disruption during production. Also updating of a machine's firmware can help prevent unplanned downtime.
- Replacing original equipment components with higher quality, more reliable counterparts designed to better withstand the harsh conditions encountered in the food industry (e.g., higher quality cables with longer expected life or higher stress resistance).
- Inspecting machines for unexpected signs of wear.

- Implementing a policy of cleanliness. Spills and dried-on gunk attract insects and vermin that may choose to snack on the equipment (e.g., wires and cables) or to nest within equipment (e.g., pipe insulation).
- Detailed recordkeeping of maintenance activities. Items that fail most must be more frequently inspected and replaced. For that purpose, there must be a sufficient stock of spare parts as backup (e.g., wires, cables, and shear pins). However, it is not always possible to keep a backup for every single unit in a plant due to a lack of space for storage or the high cost of the component.

8.4 HYGIENIC VERSUS OPERATIONAL PERFORMANCE

Preventive maintenance is primarily undertaken to make the equipment "failsafe," which means that the equipment is unlikely to break down during production periods. When the equipment is failsafe, downtime and production losses are reduced. Components and replacement parts, however, may become a hygiene risk before they physically fail. For example, as seals in pipe couplings become worn or lose elasticity resulting from extensive heating and cooling cycles, they can become microbial harborage sites before they physically fail and cause pipe leaks. If a component has a predicted failsafe life of 12 months, it may require changing after 9 months because it becomes a microbial harborage risk.

The hygienic performance of components and replacement parts may only be applicable to certain parts of the factory. For example, for ready-to-eat products or other products where microorganisms can lead to food safety or spoilage incidents in particular, hygienic performance may be relevant in equipment past any heat treatment processes. However, the hygienic performance is not always easy to predict, as it is likely to be different for all food manufacturing processes where product constituents, process conditions and cleaning and disinfection programs may all influence the changing physical condition of the components and replacement parts.

Following plant installation and commissioning, a risk assessment on each piece of equipment should be conducted in order to establish preventive maintenance schedules. For most pieces of equipment, there are several different maintenance schedules and levels of maintenance. The main question is: how important is this activity and this piece of equipment to product quality, product safety or legal compliance? So, besides the failure performance, the hygienic performance of components and replacement parts must be taken into account. Based on the risk assessment, the maintenance engineer can then make an estimation of the required frequency of specific maintenance activities. To perform the risk assessment, components in the new equipment must be examined at intervals, e.g., every 2–3 months and up until the predicted failsafe replacement time. During this examination, any signs of deterioration which could lead to a microbial hazard must be monitored. When the examination process is finished, the food manufacturer subsequently may establish which are the high-, medium-, and low-risk components and activities. Gasket inspection or replacement is deemed a high-risk activity and must be scrupulously adhered to. A maintenance schedule may call for replacing gaskets every month. With respect to low-risk components, a complete check can be done once a year, e.g., during a shutdown of the equipment.

8.5 MAINTENANCE ACCORDING TO THE PRINCIPLES OF HYGIENIC DESIGN

8.5.1 Purchase and Acceptance of Parts, Tools, Lubricants, etc., Brought Onto Site

8.5.1.1 Equipment

No equipment, spare parts, tools, etc., should be brought directly into a food production area. They should ideally be held in an external workshop or storage area, or if this is not possible, within the goods-in area. They should be inspected for any damage and to ensure that they meet the specifications as defined by the food manufacturer. This could include a visual inspection, as well as control for the presence of objectionable odors and physical contaminants. If appropriate, an assessment of the equipment's surface roughness using an appropriate stylus instrument may be performed.

Before entrance into the factory, additional information can be gained as to how the equipment must/will be cleaned or maintained in practice. The sanitation manager can examine the equipment and begin to devise cleaning schedules, which might involve the cooperation of the maintenance team to help in planned dismantling and reassembly. The design of any parts trolley (e.g., parts rack) that may be required to store dismantled parts during cleaning is also a task of the maintenance department.

Equipment should be physically cleaned and decontaminated, though ideally this should have been undertaken prior to the equipment arriving at the factory. For new equipment and components, this may be to remove any materials of construction deposits or lubricants used to machine or drive equipment components. For secondhand equipment this even could include food deposits, including potential allergens. Cases are known where the secondhand equipment has introduced strains of *Listeria monocytogenes* and *Salmonella* spp. (prevalent in their original factories) into their new home. Special care should be taken, therefore, before introducing equipment into areas where ready-to-eat foods are prepared. Once equipment has been brought into the food production area and installed in its operational positions, the equipment should be cleaned and decontaminated again.

Equipment finally can be assessed for its operational performance (if this is possible out of its intended point of installation) and an inspection made to ensure all parts are correctly installed and tightly fitted. The maintenance team can also begin to plan potential maintenance schedules and secure the provision of any specialist tools and spare or replacement parts.

8.5.1.2 Replacement Parts

All materials used for maintenance and repair (replacement parts, maintenance tools, reparation aids, etc.) shall be fit for the intended use and, if they are in direct contact with food, must be constructed of materials that will not contribute a food safety risk. Indeed many food manufacturers, particularly those subject to Global Food Safety Institute (GFSI, http://www.mygfsi.com/) audits, request certificates of conformity, or other evidence from the replacement parts manufacturer to confirm its suitability for use.

Further to the requirement for replacement parts intended for food contact to be of approved materials for such purpose, EC Regulation. No. 1935/2004 requires that replacement parts must be traceable. This is to ensure that the food manufacturer is in a position to recall any food products manufactured on lines that have been fitted with replacement parts that are subsequently found to be a health risk. Replacement parts must therefore:

- be traceable to a supplier;
- be traceable when in storage at the food manufacturer's site;
- be traceable as to which piece of equipment or line into which they were installed;
- suitably identified to facilitate their traceability.

Prior to acceptance, all replacement parts should be examined for damage and/or contamination and to ensure that they meet the appropriate specification. All nonconforming, damaged, or contaminated parts should be rejected.

8.5.1.3 Lubricants

Many items of food processing equipment require lubrication to prevent contact between moving and static surfaces, so as to avoid excessive wear and potential overheating. Within Europe, food processing machinery should be designed such that no ancillary substances (e.g., lubricants) can come into contact with foodstuffs (2006/16/EC). However, on occasion, some lubricants may inadvertently come into contact with foods or food contact surfaces and such lubricants must be food safe on incidental food contact. *Food safe* means that these lubricants will not harm the consumer's health if they accidentally come into contact with foodstuffs and are consumed. Historically in the United States, the US Department of Agriculture (USDA) approved lubricants if their ingredients were listed on the FDA Code of Federal Regulations (CFR), Title 21, section 178.3570 lubricants and other sections referenced therein. Lubricants with ingredients meeting this standard, which lists both approved ingredients and the quantity of that substance that is permissible in foodstuffs, were labeled H1 lubricants. The USDA's authorization and inspection program was suspended, however, in 1998. The National Sanitation Foundation (NSF) continued to register food-grade lubricants on a commercial basis as H1 lubricants, and a list of approved products can be found on their website (http://www.nsf.org/). More recently, INS SERVICES (UK) Ltd. have also offered this service (www.Insservices.eu). Alternatively, lubricants can be approved to ISO 21469:2006, which, in addition to requiring lubricants to be formulated from nontoxic materials as listed by the FDA or the European Food Safety Authority (EFSA), also requires them not to affect the organoleptic qualities of the food or to pose additional health risks, such as supporting microbiological growth.

H1 registered lubricants are available in the following categories:

- bearing greases for low temperatures, ambient temperatures, and high temperatures;
- chain lubes for low temperatures, ambient temperatures, and high temperatures;
- gearbox fluids (open and enclosed);
- assembly and antiseize compounds;
- hydraulic fluids;
- compressor oils;
- airline lubricants;
- penetrating fluids;
- can seamer lubricants;
- sugar-dissolving solutions;
- release agents;
- general-purpose sprays and lubricants.

As with all raw material, ingredient and service supplies into the food factory, lubricant manufacturers should be part of a Supplier Approval Scheme. The European Hygienic Engineering & Design Group (EHEDG) guideline N° 23 (Steenaard et al., 2009) includes a number of critical points, together with suggestions for their management. Lubricant hygiene is described in the guideline as: all measures necessary to ensure the safety and wholesomeness of food-grade lubricants. These measures shall cover all stages during preparation, processing, manufacturing, packaging, storing, transportation, distribution, handling, and offering for sale or supply to the customer:

- for H1 approved lubricants, only food safe materials can be used;
- manufactured hygienically;
- quality approval scheme;
- a batch registration system and a raw materials identification system are recommended;

FIGURE 8.9 A clearly damaged grease container on arrival in the factory site. This grease should not be used because it will no longer meet the requirements of a food-safe product (Steenaard et al., 2009).

- analyses can be used to check the purity of the raw materials. Stored raw materials must be systematically checked to ensure that they are not outdated.

All shipments should be delivered in clean containers suitable for the transportation and protection of their contents with respect to integrity and quality and in keeping with good commercial practices and be labeled properly. All packs should be sealed with tamper-evident seals fitted at the point of filling. Deliveries arriving without their seals intact must be rejected (Fig. 8.9).

8.5.1.4 Materials of Construction

Product contact surfaces are all the surfaces exposed to direct contact with the product as well as indirectly impacted surfaces from which splashed product, liquid or solid particles may drip, run off, drop off, or fall into the product. Materials of construction for food processing equipment, process piping and utilities must be compatible with the food product and must be homogeneous, hygienic (smooth, nonporous, nonabsorbent, nontoxic, easily cleanable, impervious, and nonmold-supporting surfaces), and inert (nonreactive to oil, fat, salt, etc. and may not adulterate the food by imparting deleterious substances to it nor affect its organoleptic characteristics), chemically resistant (corrosion-proof, nondegrading and maintaining its original surface finish after sustained contact with product, process chemicals, cleaning agents, and disinfectants), physically durable and mechanically stable (resistant to steam, moisture, cold, heat, cycling temperatures; resistant to impact, stress and fatigue; resistant to wear, abrasion, erosion, and chipping; not prone to cracks, crevices, scratches, and pits; unbreakable), and easy to maintain, in agreement with the guidance described in EHEDG guidelines N° 8 (Hauser et al., 2004a) and N° 32

(Partington et al., 2005). Additional requirements could be availability, welding ability and machinability in different shapes. Notice that materials of construction which are worked (for instance: bent, cut, sheared, extruded, or drawn) during manufacture may require additional treatment (such as surface finishing) following fabrication in order to render them corrosion resistant. Hence, materials of construction should be selected that are suitable for surface treatment (Hauser et al., 2004a). Materials used in the construction of components located in the nonfood contact area may be of a lower grade but must be corrosion resistant and able to withstand all the cleaning solutions normally used.

8.5.2 Hygienic Design Principles to Respect During Repair

Maintenance and repairs should occur according to the principles of proper hygienic design to ensure that safe food is produced once production is resumed. The following recommendations should be followed.

8.5.2.1 Design for Maximum Access

Equipment should be of such a design that cleaning or maintenance of it does not introduce food safety hazards, e.g., consideration should be given to eliminate or minimize the need for physical entry into the system. All equipment parts and components shall be readily and easily accessible for inspection, maintenance and troubleshooting. For that purpose, enough space and clearance should be provided around equipment, process and utility piping, equipment utility connections, etc.

8.5.2.2 Compatible Materials of Construction

Materials of construction used during maintenance and repair must be adequate to cope with the food product produced or process aids they are in contact with, as well as with the harsh conditions encountered in the food processing environment (detergent and disinfectant solutions, lubricants, etc.) (Moerman et al., 2014).

- Corrosion of metals, steels and alloys may result in leaks and impair the smoothness of the surface finish. This increase in surface roughness makes equipment materials of construction more prone to adhesion of food residues and bacteria. The latter finally can give rise to biofilms which could be very difficult to remove.

  Immersion tests with metal coupons (Fig. 8.10) or specific equipment components (Fig. 8.11) allow evaluation of the effect of food products, detergents and disinfectants on the materials of construction used in the manufacturing of food processing equipment and utilities. Static immersion tests of the candidate materials of construction are rapid screening tests. The large numbers of welds and the numerous transitions from one metal to another make process equipment also very sensitive to

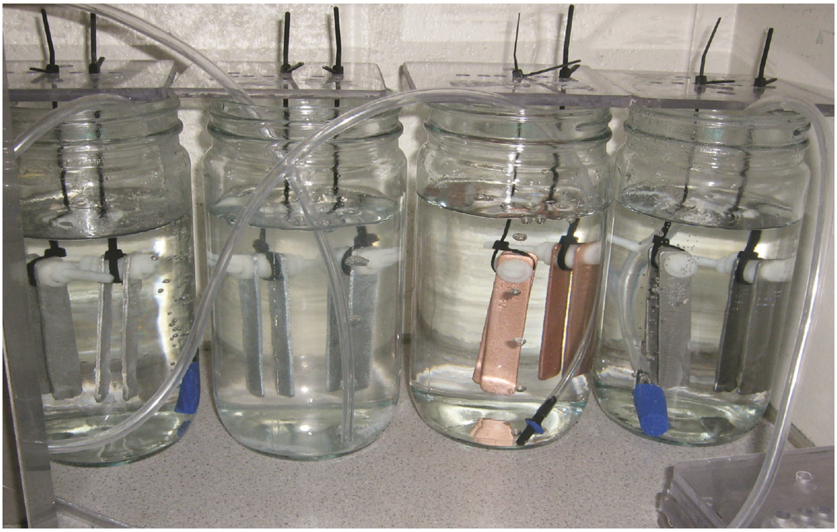


FIGURE 8.10 The compatibility of several materials of construction with detergent and disinfectant solutions can be tested in the laboratory by means of immersion tests conducted with coupons. *Courtesy of Evapco Inc.* Moerman & Fikiin, 2015.

FIGURE 8.11 Bearings made from different materials of construction were subjected to immersion tests in salt brine. Bearings No. 1, 2 and 8 are thin dense chrome plated; bearings No. 3, 5, and 7 are 400 series stainless steel; bearing No. 4 is coated; and bearing No. 6 is black oxide coated. *Courtesy of John Butts, Land O'Frost, © 2016.*

aggressive cleaning and disinfectant chemicals. Hence, if the plant item is to be welded, it is prudent to subject welded coupons to similar tests, as the weld metal and heat-affected zones may have different corrosion resistances in comparison with the unwelded material. To assess the risk of crevice corrosion, a testing procedure that involves the use of castellated washers is often used (Moerman and Partington, 2014; Moerman and Fikiin, 2016).

Several experimental parameters can be changed, such as temperature, detergent/disinfectant concentration, water quality (pH, hardness, etc.), application frequency, etc. It is recommended to perform "challenge tests" under forced conditions, which means that coupons are immersed for several days or even weeks in highly concentrated cleaning and disinfectant solutions, and, if necessary, the food product. At the end of this immersion period, coupons should be rinsed and dried to evaluate the effect of these cleaning and disinfection solutions. Parameters that can be measured are visual appearance, weight loss, thickness, hardness, etc.

The removal of the galvanizing and the release of zinc make galvanized steel unsuitable for application in the product contact and splash area, not least because zinc often contains residual traces of cadmium and lead as impurities. Painted steel never should be used in the splash zone or any other area where food is exposed, because paint may peel off and can splash/fall onto the food products (Fig. 8.12). Paints especially may create a health risk because they often contain toxic substances such as zinc, lead, cadmium, and phenolics. Paint surfaces used in nonproduct contact areas also may crack or flake, and must be repainted immediately.

Care must be taken when selecting a replacement part, because experience has shown that many items that were supposed to be stainless steel

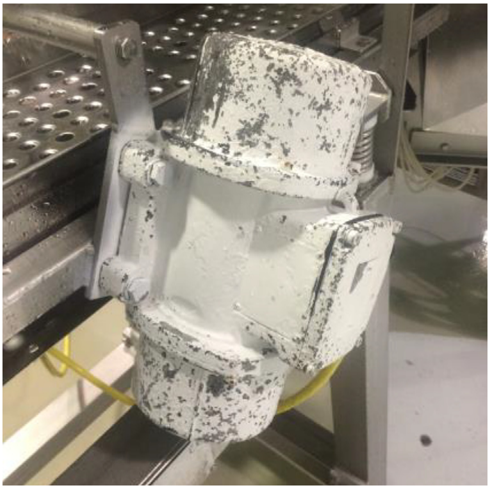


FIGURE 8.12 This motor is constructed from mild steel, and is used to impart vibration to a perforated stainless-steel bed laden with food products. During hose-down operations, the cleaning agents and high pressure typical for traditional manual cleaning procedures have ruptured the physical integrity of the paint and allowed peeled-off paint to splash onto the cleaned conveyor bed. As a result, food products subsequently produced on this process line may become contaminated. *Courtesy of Joe Stout, Commercial Food Sanitation LLC - Intralox, © 2016.*

316L turned out to be 304. Packages containing these items were often marked and labeled as stainless steel 316L. Even 316L stainless steel tanks with inlet ferrules and manway collar in 304 stainless steel have been found. All the raw materials of construction that enter the factory, as well as purchased items, can be tested on their elemental composition using the nondestructive X-ray fluorescence method as a Positive Material Identification technique. By bombarding the surface of the test material with high-energy X-rays or gamma rays, secondary (fluorescent) X-rays emitted from the material can be detected. Each element in a material emits its own unique fluorescent X-ray spectrum, allowing it to be identified. However, commercially available portable handle-held XRF guns (Fig. 8.13) are quite costly and are limited in their ability to precisely and accurately measure the abundance of elements with atomic number $Z < 11$ (e.g., atomic number Z of carbon is 6). For this reason, XRF can't be used to differentiate between stainless steel 316 and 316L. For small food manufacturers, the procurement of an XRF-analyzer can't be justified due to its high cost. They still have to rely on certificates delivered by their vendors, although they still can qualify their vendors by hiring a contractor that is in possession of an XRF-analyzer and experienced in elemental analysis by this technological means.

- Plastics must have good dimensional stability on exposure to high loads, corrosive chemicals, as well as high or low temperatures. Changes in dimension or shape, cracking, and breaking during operation may not occur, as they allow food residues access to areas where they will be

FIGURE 8.13 Quality technician doing Positive Material Identification on a stainless-steel vessel using an X-ray fluorescence gun. *Courtesy of Holland Applied Technologies.*

difficult to clean and pose a contamination risk. They must have high mechanical strength to withstand mechanical shocks, and resistance to aging, creep, brittleness, fatigue, erosion, etc. Excellent resistance to wear and abrasion is required in certain applications such as the transfer of solids, slurries or pastes (e.g., tomato concentrate). These food products may damage the plastic surface, promoting the accumulation of soils and the formation of biofilms, finally negatively affecting cleanability. The plastic material also must be chemically resistant to hydrolysis by steam, acids and alkalis, reducing and oxidizing agents, as well as cleaning agents and disinfectants. The equipment manufacturer should/can test the chemical resistance of the plastic material in the same way as described for metal, steels and alloys. They also must be tested on their thermal resistance (Partington et al., 2005; Moerman and Partington, 2014).

For use in the food contact area, it is important that plastics be odorless, nonporous, smooth and free from cracks, crevices, scratches, and pits, as they may harbor and retain product constituents and/or microorganisms after cleaning. Within the pores, microorganisms are also better protected against the bactericidal activity of disinfectants. And, spherical void expansion may cause changes in the chemical and physical properties of a certain plastic material, hence affecting its cleanability. In food contact applications, it is recommended to avoid additions into plastics, as additives incorporated in plastics may migrate into the product. But in addition to these additives, volatile remnants of monomers (e.g., styrene), oligomers, low molecular weight polymer fragments and certain organic solvents may leach from the polymer material into the food, inducing changes in the organoleptic qualities. It is recommended to delay any exposure of food to recently produced or processed plastics, so as to allow these plastics to release most of their chemical substances before application and during storage. Also, the first food batch should be sent to disposal.

While certificates of conformity are proof that the material is, in principle, safe for food contact and the component is made to specification, they are not evidence that the part specified is technically suitable for a particular application. It is good practice to require the supplier of plastic raw materials or components to provide documentation that the grade of material selected is certified for contact *with the product in question* (requiring studies to evaluate migration of specific substances).

- Rubber compounds are individually developed by the supplier, causing elastomers to differ greatly from one supplier to another. Rubber for food contact must comply with many different normative references (e.g., EN 1935/2004, BfR, FDA and 3-A), as well as the European Commission's REACH Regulation (Regulation on Registration, Evaluation, Authorisation and Restriction of Chemicals). It is a major recommendation to avoid ingredients which are not chemically bonded, as they may be released in the food product). The rubber parts supplier should assist food manufacturers in selecting the most suitable elastomer for their specific operation. This selection must occur in function of the physical and chemical resistance characteristics of the different types of elastomers and the in-use process conditions. Degradation of elastomers by product, detergents, disinfectants, and thermal and mechanical stress proceeds much faster. Moreover, elastomers are more prone to microbiological degradation because they facilitate extensive biofilm formation more than plastic materials do (Moerman and Partington, 2014).

A typical symptom of this elastomer deterioration—mostly due to a combination of aggressive chemicals and elevated temperatures during cleaning processes—is hardening of the material, leading to loss of elasticity and eventually loss of sealing function. The result could be: physical contamination of the product with elastomer particles (consequence of abrading and break-up of the rubber material); leakage of lubricants or refrigerants; loss of bacteria tightness; permanent product and process contamination due to increased adherence and retention of dirt and bacteria in crevices; and insufficient cleaning and problematic disinfection. Moreover, ingress of liquids containing chlorides may occur under partially destroyed gaskets and seals, so that a high chloride concentration may subsist between damaged seals and adjacent metal, favoring crevice corrosion even in stainless steel. To ensure that the rubber remains in good condition, regular inspection is required. Routine replacement of elastomers must be done in function of the physical and chemical stresses imposed on the material.

8.5.2.3 Right Combination of Metals, Steels and Alloys to Avoid Bimetallic Corrosion (Galvanic Corrosion)

In the assembly of food process equipment and services, the right combination of steels, alloys or metals must be used to avoid bimetallic corrosion. Bimetallic corrosion occurs between metals, steels, or alloys with considerably different standard reduction potential (Fig. 8.14). A current will flow from the less noble metal to the more noble metal, resulting in the oxidation (corrosion) of the less noble metal. To determine the compatibility of two metals, steels, or alloys, a galvanic corrosion metal compatibility chart (Fig. 8.15) or diagram (Fig. 8.16) can be used. Also galvanic corrosion of welds may occur if the weld metal is less noble than the surrounding materials joined. Higher alloyed filler metal in comparison to the welded materials may reduce the risk for galvanic corrosion. Note that replacement parts could have another chemical composition than the materials of construction used in the existing plant equipment.

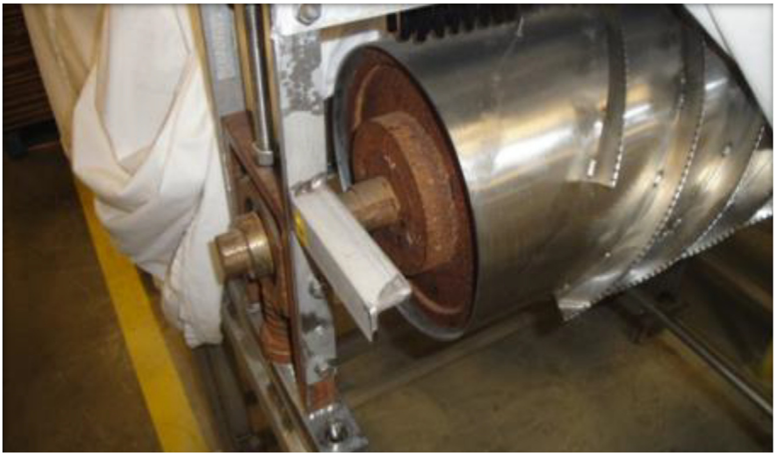


FIGURE 8.14 Stainless-steel shell and knives of the roller are combined with roller ends in mild steel. As mild steel is less noble than stainless steel, it will corrode. Work in black steel and stainless steel must always be kept separate. *Courtesy of organization Sanitary Design Workshop, © 2016.*

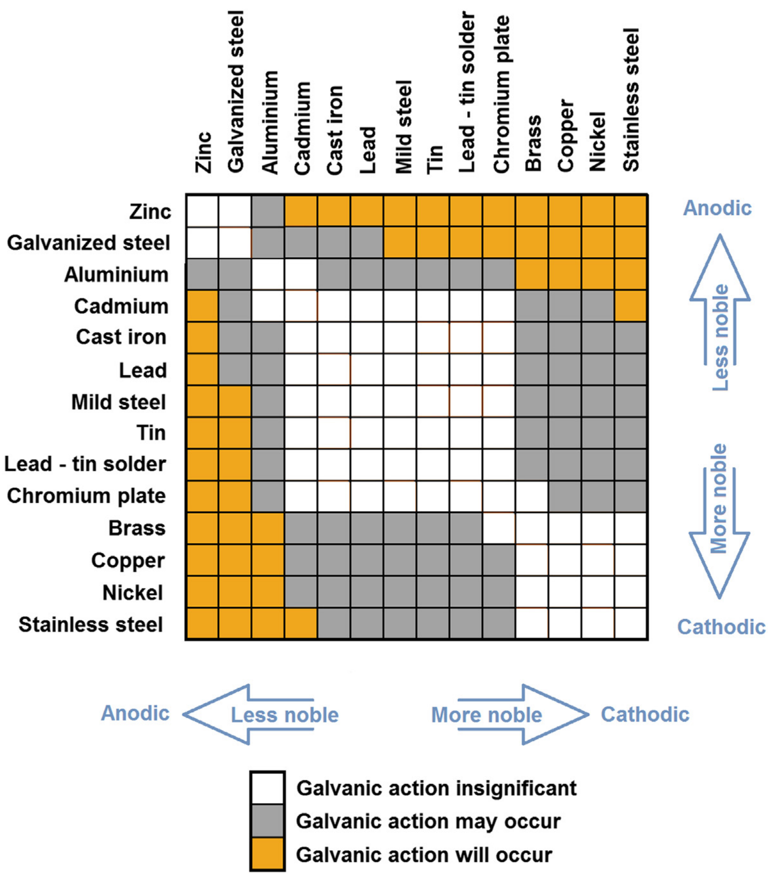


FIGURE 8.15 Galvanic corrosion chart for dissimilar metals, steels, and Dalloys. *Courtesy of Insertsdirect.com Ltd.*

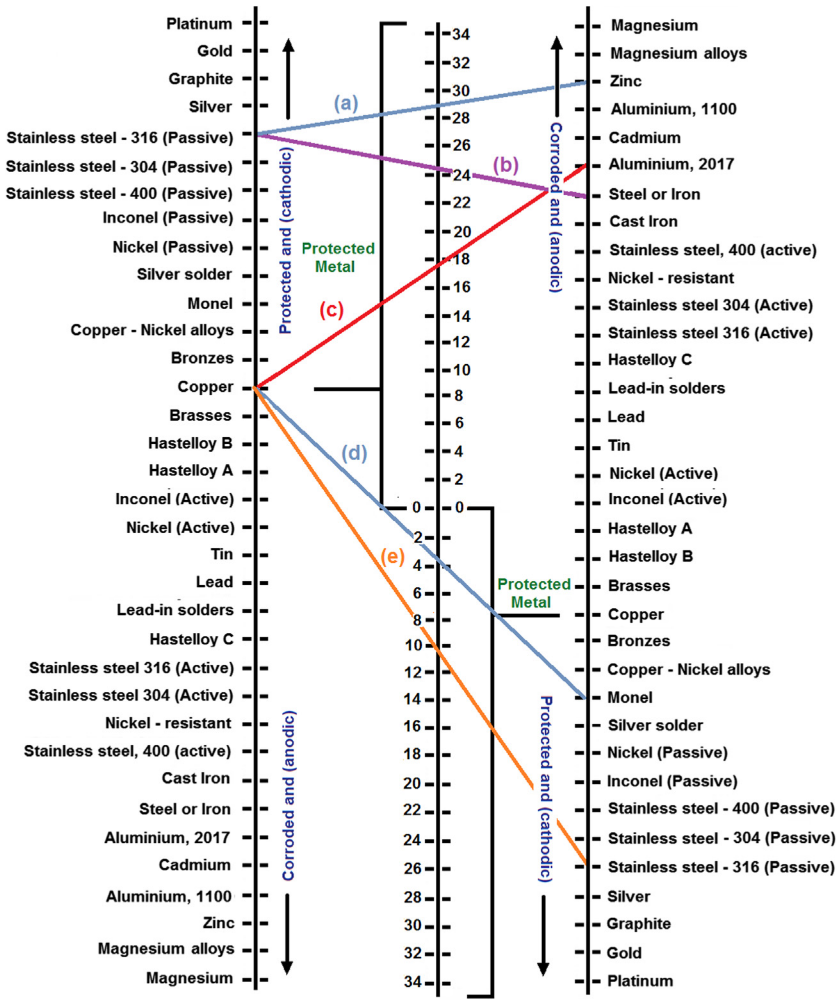


FIGURE 8.16 Galvanic corrosion metal compatibility diagram. Use a rule to line up the two metals, steels or alloys which are being combined. The closer to zero, the lower the risk of galvanic corrosion. (a) Combining stainless steel 316 with zinc (e.g., zinc coating of galvanized steel) will result in severe corrosion of the zinc coating. (b) Combining stainless steel 316 with mild steel (also called carbon steel or black steel) will result in the fast corrosion of mild steel. (c) Aluminum will quickly corrode when combined with copper. (d) Copper slowly corrodes in contact with Monel (contains copper). (e) Copper corrodes when combined with stainless steel 316.

8.5.2.4 Selection, Delivery and Storage of Replacement Parts

Minimize difficult-to-clean materials of construction, components, and spare parts, and avoid the use of piping, valves, joints, and fittings that may allow product build-up or hamper complete draining. Only parts and materials that are approved by the equipment manufacturer should be used to perform maintenance and/or to modify/repair equipment (temporary or permanent) in product-contact areas.

For optimum protection and cleanliness, the equipment supplier should deliver stainless steel 316(L) or 304(L) spare parts that are prepacked in plastic in a clean environment, and in accordance with proper Good Maintenance and Good Manufacturing Practices they should be stored segregated from other nonstainless steel products (e.g., black steel). For example, in Fig. 8.17, the stainless-steel equipment components are wrapped with plastic film, and their inlet and outlet connections are fitted with protective caps to prevent ingress of impurities, insects, and small animals.

Pipes, fittings, valves, components, etc. must be stored in dry, dust-free conditions, at a temperature corresponding to that of the mounting site. If this is not possible, the materials must be brought to the mounting site no later than 24 hours prior to the mounting so that they may achieve the temperature of the mounting room. This is to prevent condensation inside the pipes, which may cause welding defects and lead to rejection of the welds. Furthermore, precautions must be taken to prevent deformation of the stored materials through collision or insufficient support. The body and internal parts must be handled carefully to ensure that the machined surfaces are not damaged (Moerman et al., 2014).

8.5.2.5 Correct Installation Practices

Open profiles are preferred over hollow sections, but consideration should be given regarding their orientation. Open profiles installed in the horizontal plane preferably should have their folding turned downward, although outward turned constructions are allowed as long as they are cleanable. Installed in the vertical plane, open profiles must also have their folding turned outward. In the horizontal plane, open profiles should never have their folding turned upwards. If closed profiles are used, frequent inspection for

FIGURE 8.17 The stainless-steel equipment components are wrapped with plastic film, and their inlet and outlet connections are fitted with protective caps to protect them against corrosion, dirt, pests, etc. during transport and storage. *Courtesy of Zhejiang Jugang Pipe Co, Ltd.*

cracking should be carried out to prevent risk from contamination. Round or square section members turned through 45 degrees that provide sloping surfaces are recommended. Profiles may not create ledges, projections, and pockets where debris can accumulate.

Equipment must be self-draining (e.g., lines must be sloped). Always determine the correct installation situation and direction of fluid flow, so as to ensure appropriate cleanability and drainability. Especially, flow with respect to dead legs is of paramount importance.

8.5.2.6 Making Sheet Joints

Equipment is only as hygienic as the manner in which joints between equipment components are made. Use permanent joints (e.g., weld joints) rather than dismountable joints (O-ring or gasket joints), because the latter type of joints may give rise to projections, protrusions, edges, recesses, metal-to-metal contact, etc.

- Welded joints, ground and polished, are thus preferred over mechanical fixings, such as bolted or screwed joints. However, note that several types of common defects may arise in welded joints (e.g., misalignment, cracking, porosity, inclusions) which can act as a source of microbiological problems. All welds in the product contact area are recommended to be continuously welded and with sufficient weld seam protection (inert shield-gas protection at both sides). They must be smooth and free of pits, crevices, cracks, and pockets (Figs. 8.18 and 8.19), and—where required—must be polished to have the same surface finish ($R_a \leq 0.8$ μm) and appearance, etc., as the surrounding materials. Once the job is completed, any

FIGURE 8.18 Poor weld repair. *Courtesy of Rudi Groppe, Heinzen Manufacturing International, © 2016.*

remaining debris should be brushed away and disposed of. Spot and unfinished welds (Fig. 8.20) are not allowed because they never will give hygienic constructions. They leave open spaces that may accumulate dirt, could provide a habitat for insects and microorganisms, and are difficult to clean.

- Dismountable metal sheet joints make use of fasteners (e.g., screws or bolts) to fix plates, appendages, etc. together, but only should be used if dismantling is unavoidable. Metal sheet joints made by means of fasteners (Fig. 8.21) may lead to metal-to-metal contact corrosion. Joining metal sheets with screws via the product zone is also not allowed, because they create gaps, dead areas, and/or exposed threads where microorganisms may accumulate and grow in the presence of food residues and nutrients. Also hexagon nut-and-bolt pairs (Fig. 8.22A) which protrude in the product zone should be avoided, because they give rise to

FIGURE 8.19 Poor weld repair. *Courtesy of Joe Stout, Commercial Food Sanitation LLC - Intralox, © 2016.*

FIGURE 8.20 Noncontinuous welding of overlapping sheets of metal allow product debris and microorganisms to accumulate between the two sheets of metal. The overlapping sheets of metal also create a step. *Courtesy of John Butts, Land O'Frost, © 2016.*

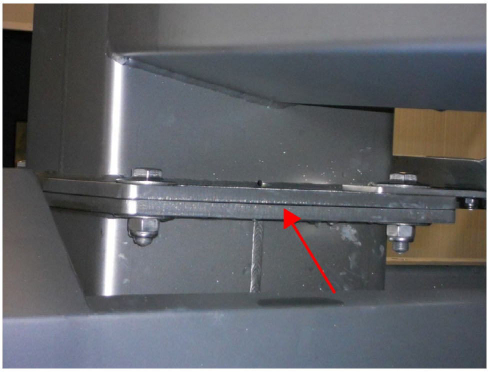


FIGURE 8.21 Metal-to-metal sandwiched area giving rise to a crevice where microorganisms may establish a niche to grow and the framework may rust. *Courtesy of Joe Stout, Commercial Food Sanitation LLC - Intralox, © 2016.*

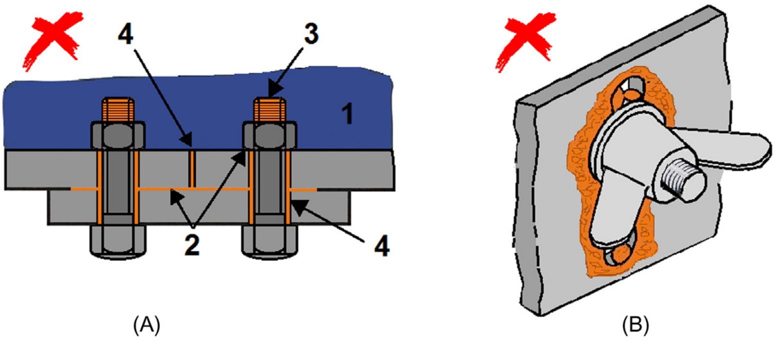


FIGURE 8.22 (A) Exposed bolt ends and nuts in the product zone (1) are not allowed because they give rise to metal-to-metal contact corrosion (2), exposed threads (3), and crevices (4). Debris also tends to adhere to and around fixings and provides nutrients for microbial slime growth. Exposed threads should be cut to the correct length or preferably domed nuts should be used. (B) Wing nuts are often used where adjustment is required but debris collects around and in the exposed portion of the slot behind the nut (CFPRA, 1983; Lelieveld et al., 2003; Hauser et al., 2004b).

metal-to-metal contact corrosion and create gaps, dead areas and/or exposed threads.

However, exposed threads sited on the product side can be covered with a domed nut and metal-backed elastomer gasket (Fig. 8.23). Hexagon-headed bolts with plain bolt head are allowed, although hexagon-headed bolts with domed bolt head are more preferable. Correct design of bolt heads and nuts and their effective sealing is thus essential to render the used bolts hygienic. Metal-backed elastomer gaskets not only may seal the crevice between the bolt-head or domed nut and the food-contact surface, they also will protect the annular clearance between the shaft of the bolt and the hole through which it passes (Figs. 8.23 and 8.24). Wing bolts and nuts, often used where adjustment is required, also should not be used on the product side to avoid metal-to-metal contact

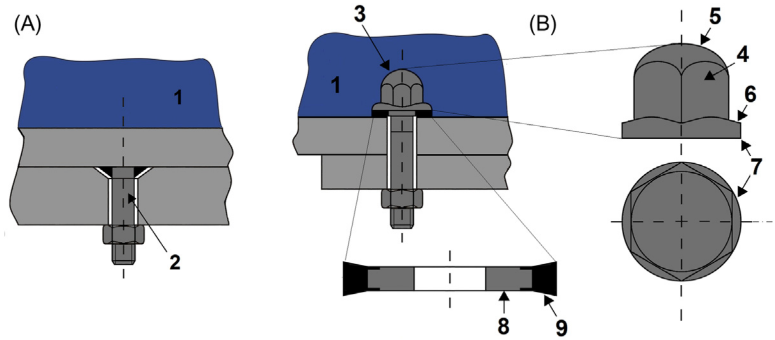


FIGURE 8.23 (A) To prevent crevices at the product side (1), screws, pins, or a stud welded on the nonproduct side (2) should be used. (B) A bolt head (3) that is hexagonal (4), domed (5) and provided with a sloped circular collar (6, 7) is easily cleanable, and the metal-backed (8) elastomer gasket (9) is used to seal the thread (Lelieveld et al., 2003; Hauser et al., 2004b).

FIGURE 8.24 Hexagon-headed bolts with plain bolt head are accepted, although hygienic bolts with domed bolt head are more preferred. The thread of the bolts can be covered with a hexagonal domed nut. Metal-backed elastomer gaskets may seal the crevice between the bolt-head or domed nut and the food-contact surface. *Courtesy of NovoNox KG.*

corrosion, as well as gaps, dead areas and/or exposed threads. Debris may collect in the exposed portion of the slot behind the nut (Fig. 8.22B), as well as around the wing head/nut and in the thread. Nowadays, more hygienic wing heads and nuts with metal-backed elastomer gaskets exist (Fig. 8.25). The hygienic wing nuts may completely cover the thread.

- Rivets only should be used where construction necessitates this type of fabrication. Pop rivets (Fig. 8.26) should not be used, certainly not in the product zone. Use solid rivets instead of pop rivets, even at the nonproduct side (CFPRA, 1983; Lelieveld et al., 2003; Hauser et al., 2004b).

8.5.2.7 Making Pipe Joints

It is strongly recommended that the number of joints, whether welded or detachable, is minimized. Cold bending of pipes is preferred over

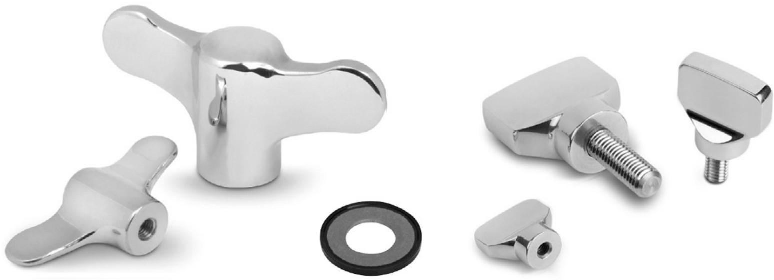


FIGURE 8.25 Cleanable wing nuts free of crevices in which food debris can accumulate. *Courtesy of NovoNox KG.*

FIGURE 8.26 The name plate is fastened with pop rivets. The small holes may accumulate dirt and become a niche for microorganisms to grow. Food debris, dirt, liquids, and microorganisms also may find their way behind the name plate. *Courtesy of Mondelēz International, © 2016.*

prefabricated bends, which have to be installed using joints. Although more hygienic, this is still true for welded joints as they also remain the weaker places in a process system.

- Stainless-steel hygienic tubing joints should be made by automatic orbital welding 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. Piping with the correct interior diameters should be applied because any mismatch in diameters or thickness may result in misalignment (Fig. 8.27) 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. 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. The two components also

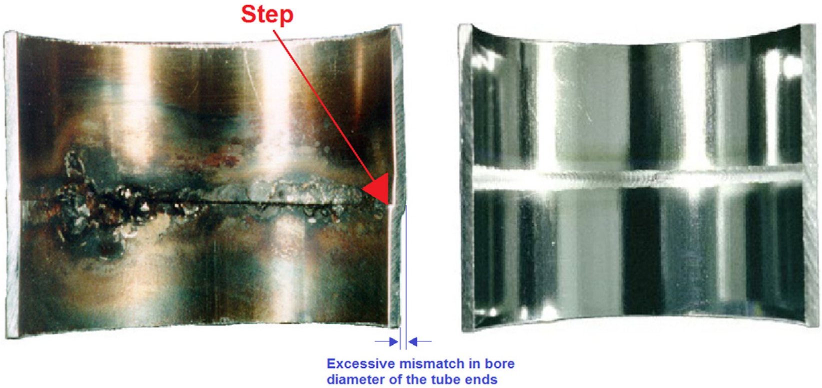


FIGURE 8.27 Step due to excessive mismatch in bore diameter of the tube ends.

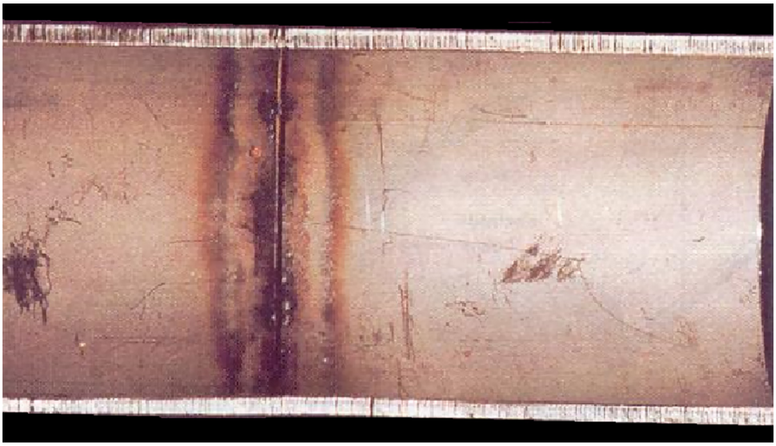


FIGURE 8.28 Crevice in weld because both tube ends are not sufficiently pushed together. (Eastwood et al., 1993).

must be sufficiently pushed together to make a weld without gaps (Fig. 8.28). When tubings are welded together, the weld seams finally must be visually inspected on any discoloration, weld 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 damages while handling endoscopic tools (Hauser et al., 1993; Kopitzke et al., 2006).

- Pipework also may be designed for rapid regular dismantling to permit cleaning. It is important to avoid crevices and gaps where product residues can accumulate and potentially begin to decompose. Therefore, from a hygienic point of view, the use of threaded piping is not recommended. To make detachable joints, the use of conventional O-ring grooves is also not recommended, because these groove designs leave a considerable free space in the groove. Other hygienic design requirements for detachable joints include coaxial alignment of the two mating bores, axial stop for controlled compression of the seal, room for thermal expansion of the seal, and avoidance of sharp edges such that seals are not damaged. Where there are depressions and steps of more than 0.2 mm in the pipe work, the flow of cleaning fluid may not thoroughly wash the surface and proper drainability of the piping will be hampered. Hence, when making bolted flange fittings, a lot of care should be taken to avoid offsets, gaps, penetrations, and voids.

A further aspect to be considered is that the seal material must be compatible with both the system product and also the cleaning/disinfection fluids which may be at a much higher temperature. A number of specific pipe couplings and also seal arrangements have been developed for hygienic applications. Some types are covered by national, international, or in-company standards. Many of these couplings are in use for a considerable time, but are not considered to be compatible with current hygiene requirements in some areas of the food and drink industry. Where pipes are dismantled, using a new seal or gasket on reassembly is a proof of good maintenance practice. Couplings made must be checked for leaks and retightened as necessary.

8.5.2.8 Other Unsuitable and Suitable Fixing Practices

Making fixings during construction, maintenance and repair is often required. It is obvious that these fixings may not create unhygienic conditions to ensure that safe food is produced once production is started or resumed. Therefore the following review of unsuitable and suitable fixing practices:

- Split pins (Fig. 8.29), self-tapping screws, wire hooks (Fig. 8.30), staples (Fig. 8.31), spring tension pins, bushings, etc. are unsuitable fastenings, because they retain food residues very easily and are difficult to clean and disinfect, which finally may result in the growth of microorganisms. Moreover, they may loosen and cause damage to other equipment or endanger the consumer physically.
- Avoid very small fastenings.
- Stainless-steel or dull-nickel plated fixings should be used as specified in the fixings and fastenings handbook.
- Avoid fixings in plastics which cannot be identified by metal detectors. There exist screws, staples (e.g., plastic staples to join conveyor belt ends), and pins in plastic (e.g., modular belts). However, modular belts with stainless steel pins are not available on the market. The use of plastic strips to fasten electric cables is common practice. A plastic strip of a color that is not omnipresent in the food product and food factory can be used. Nowadays, there are plastic strips on the market with metal content

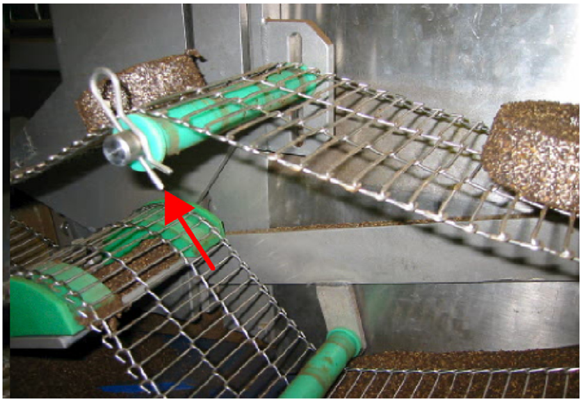


FIGURE 8.29 The split pin (indicated by the arrow) may get lost in the product. *Courtesy of Den Rustfri Stålindustris Kompetencecenter.*

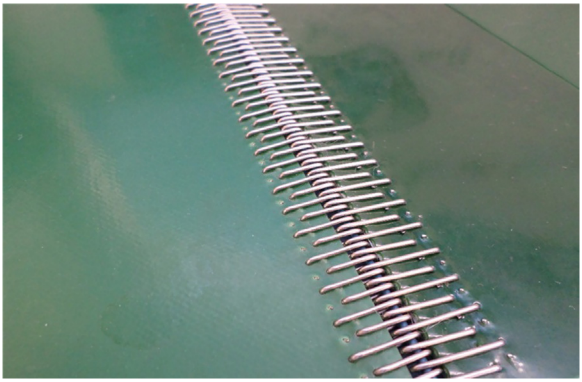


FIGURE 8.30 Wire hooks to make conveyor belts endless are not hygienic. Due to the perforation of the conveyor belt, the reinforcing fabric layer becomes exposed, allowing liquids to penetrate into the interior of the conveyor belt by wicking (capillary action) (Kold et al., 2016).

FIGURE 8.31 Staples to joint belt ends together are not hygienic (Kold et al., 2016).

dispersed throughout the head and strap with the objective that even cut-off sections can be detected by means of a metal detector. However, maintenance operators in the food industry must be prudent with such claims, as cases are known where even a lot of one hundred of these plastic strips could not be detected by means of a metal detector. However, it seems that they successfully can be removed from the product stream by means of magnetic separator systems. Stainless-steel cable ties can be used in very aggressive environments and have higher strength and heat resistance, but have the disadvantage that they can't be detected. The strongest neodymium magnetic separation systems, however, can successfully capture very fine stainless-steel particles that cannot be detected with a metal detector. Coated metal ties are available which are easily detectable. When selecting metal cable ties, one must keep in mind that they must not cause galvanic corrosion.

- Temporary repairs may be necessary and are allowed in emergency situations to stop leaks or product spills. However, hastily improvised repairs using rags, string, electric wire, tapes (waterproof, duct, etc.), twist-ties, cardboard, wood, or other porous or nondurable materials must be avoided, especially in product contact equipment. Where temporary repairs may adversely impact the food safety or quality of a product, they must be labeled, dated, and documented, while the maintenance department must be notified immediately to finally replace the temporary repairs with permanent repairs as soon as possible. Temporary repairs in the product area must be replaced by permanent repairs within 24 h and preferably during the next shift. In maintaining and repairing non – product-contact equipment, tapes, or other temporary repair materials must be replaced with appropriate permanent repairs in a timely manner or at a next scheduled down-time.
- All fastenings should be secured firmly.
- Take care for sufficient space around fixings for cleaning (min. 25 mm).

8.5.2.9 Replacement of Insulation

If old insulation containing asbestos has to be removed, all precautions should be taken to avoid the spreading of asbestos fibers in the food processing environment. The food processing equipment and food product must not become contaminated by these asbestos fibers. During the removal of asbestos, maintenance technicians must use the necessary breathing protection, because asbestos fibers may cause long-term health problems such as lung and peritoneum mesothelioma.

US Department of Agriculture (USDA) standards for food, soap, and cosmetic manufacturing plants prohibit use of insulations which sliver or dust, are toxic, or contain glass. Furthermore, non-chloride-releasing insulation 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, properly sealed to avoid ingress of dust, liqor, air, and moisture, and with joints facing downwards. The finish must resist washing down with high-pressure water, steam, and detergents without appreciable deterioration and may not support fungus, mildew, or bacteria growth.

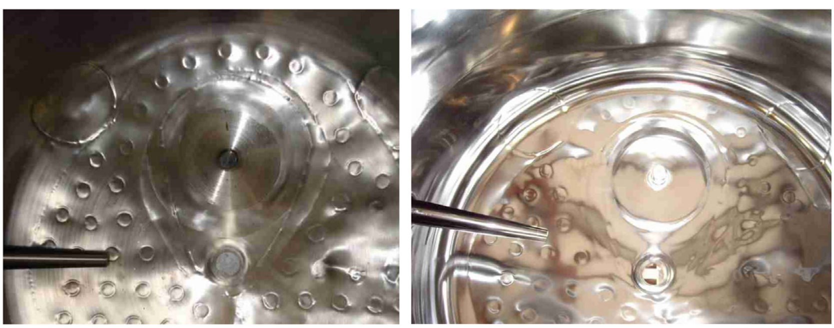
To insulate piping, styrofoam (maximum continuous service temperature is 60–65°C), foam glass, or another rigid foam (e.g., foamed nitrile butadiene rubber) is preferred over fibrous materials. Also here vapor-tight aluminum or stainless-steel cladding must be provided at the outside. Damaged or wet insulation should be repaired or immediately replaced.

8.5.2.10 Installation of Cabling

When a new cable has to be installed, it should not be supported from a previously installed cable. Such a practice leads to an uncleanable and hygienically unacceptable entangled cable bundle, where soil can build up. Electrical cables should be routed, and connections made, in such a manner as to create hygienically acceptable installations conforming to the preset hygiene class applicable for that area. The cables should be fastened individually at a distance (no less than 25 mm) from each other to allow for proper cleaning.

8.5.2.11 Reducing the Surface Roughness of Stainless Steel

Note that surface roughness (R_a) is in fact not a suitable method of specifying product contact surfaces. The technique used for achieving the appropriate microsurface finish is of greater importance than the R_a value. Different surface finishing techniques (glass blasting, ceramic beats blasting, electro-polishing, pickling) successfully achieve a surface roughness R_a of 0.8 μm, but the topography/structure of the surface can differ a lot, giving different cleaning results. Electro-polishing (Fig. 8.32) is preferred over mechanical polishing, as physical



(A) (B)

FIGURE 8.32 Remediation of poor "factory" electro-polished equipment: (A) before mechanical and electro-polishing; (B) after mechanical and electro-polishing. *Courtesy of Ultraclean Electropolish Inc.*

and metallurgical damage takes place during mechanical polishing. Electro-finishing of stainless steel is a cost-effective method of obtaining a bright finish, allowing soil to be more readily observed than on dull surfaces. An electro-polished surface is also durable and less prone to wear and corrosion. A roughness R_a exceeding 0.8 μm (non-product-contact zone) may be acceptable if test results have demonstrated that the required cleanability can be achieved through other design features or more intensive cleaning methods. Specifically, in the case of polymeric surfaces surface roughness is usually higher, but the hydrophobicity, wettability and reactivity may enhance cleanability

8.5.3 Lubrication According to the Principles of Hygienic Design

Food manufacturers should adopt a lubrication management system, comprising a factory survey to select the correct lubricants based on their technical and potential incidental; lubrication frequency; lubrication monitoring, sampling, and testing; recordkeeping for audit purposes; and operative training in the use of lubricants.

EHEDG guideline N° 23 (Steenaard et al., 2009) suggests that leakage of greases from bearings is a frequently occurring problem. Lubricants also often drip and splash from open lubricating points such as chains and open gears. Oil circulation systems, especially when the oil is under pressure from an oil pump, may allow small leaks to occur, which are difficult to detect. Hydraulic systems and hydraulically operated valves are other examples of potential sources of oil leaks. Leaks from oil-filled heat transfer systems are also difficult to detect. Leaks can also cause materials to corrode or to suffer electrochemical attack over a long period of time. Oil-coated machine surfaces, such as chutes used to transport food, are also a source of contamination risk that has to be managed. Apart from introducing toxic chemicals into the food product, lubricants also may introduce physical and microbial contaminants into the food. If a lubricant does not function properly, this may result in wear and tear, with the associated risk of product contamination by abraded particles. As lubricants may get contaminated with water and food materials, multiplication of microorganisms may occur at appropriate temperatures. Cases are known where *Escherichia coli* and *Listeria monocytogenes* in lubricants have given rise to food product contamination.

As incident contamination of food products with lubricants may occur, food-grade lubricants are required. Some food manufacturers use H1 lubricants only for critical lubricating points, with conventional lubricants being used for lubricating points that could not result in incidental product contact. However, wherever possible, it is recommended that conventional lubricants be replaced by H1 lubricants. This considerably simplifies the management of critical lubricating points, as errors do not lead to the use of potentially toxic lubricants at these points. Moreover, the number of lubricants can be considerably reduced. The EHEDG guideline document N° 23 (Steenaard et al., 2009) describes sequential steps by means of which the maintenance department effectively can replace conventional lubricants by H1 lubricants. When changing the oils in reservoirs, it is recommended to drain the system, change the filters, flush the reservoir with a food-grade product (flushing oil or original lubricant), check or change the filters again, fill from the reservoir with the correct food-grade lubricant, and take a sample for analysis. In the case of a grease application, it is recommended to check if the greases used are compatible. Clean the bearing out with a paraffinic oil or solvent, then fill the bearing(s) one-third to one-half full with food-grade grease and purge any grease lines with food-grade grease. It is recommended to seek assistance from the lubricant supplier as required.

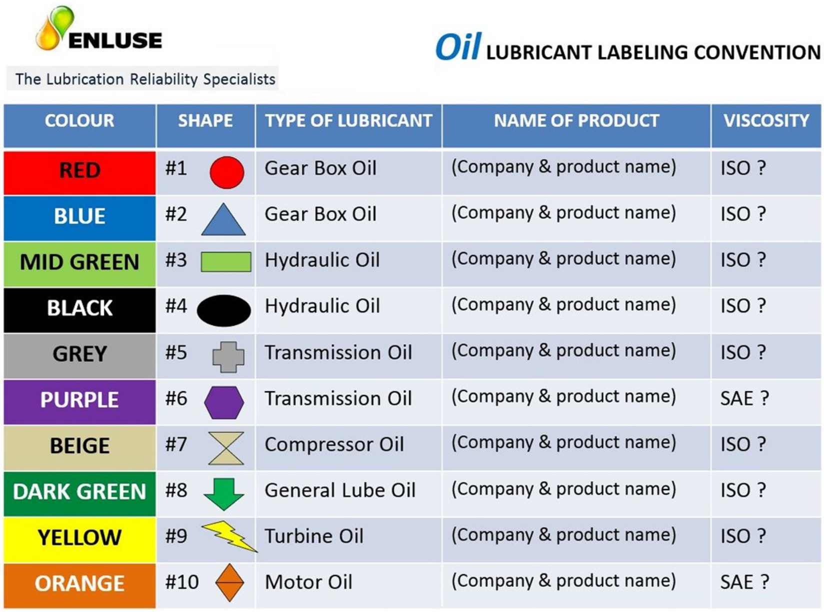
Lubricants may undergo changes during use and may degrade as they become older or are exposed to water and food materials, allowing the growth of food pathogens. It is advisable to carry out regular checks on lubricants to determine whether they are contaminated with microorganisms. Lubrication points where H1 lubricants may become contaminated with beverages are also critical, as such contamination may encourage microbial growth. Therefore, some suppliers incorporate microbial-growth inhibitors in their H1 lubricants. For some applications, such as microbial fermentations, these substances must be effective exclusively against the undesired microbes, so that fermentation is not impaired.

When H1 and non-H1 lubricants are used within the factory, a system must ensure that no errors are made during packaging and labeling of storage and dispensing containers:

- H1 lubricants must be stored separately from toxic substances and dangerous materials. The storage of H1 lubricants in an area where conventional lubricants are also stored can lead to human errors and should be avoided. The use of dedicated transfer and storage containers for H1 lubricants is essential.
- Critical lubricating points must be labeled to reduce the risk of using the wrong lubricant. Text stickers or color codes can be used for this purpose. With the aid of this color code, the maintenance technician knows very well which lubricant he must use. A poster on a wall (Fig. 8.33) could exactly visualize which lubricant fits with which color, allowing prohibition of the use of the wrong lubricants for a given lubrication point.
- To prevent degradation, stored lubricants must not be exposed to extreme temperatures.

The equipment lubrication process should also be undertaken in a hygienic manner with attention to the following:

- Use drip trays where possible in case lubrication points are situated above the product.



ENLUSE
The Lubrication Reliability Specialists

Oil LUBRICANT LABELING CONVENTION

COLOUR	SHAPE	TYPE OF LUBRICANT	NAME OF PRODUCT	VISCOSITY
RED	#1	Gear Box Oil	(Company & product name)	ISO ?
BLUE	#2	Gear Box Oil	(Company & product name)	ISO ?
MID GREEN	#3	Hydraulic Oil	(Company & product name)	ISO ?
BLACK	#4	Hydraulic Oil	(Company & product name)	ISO ?
GREY	#5	Transmission Oil	(Company & product name)	ISO ?
PURPLE	#6	Transmission Oil	(Company & product name)	SAE ?
BEIGE	#7	Compressor Oil	(Company & product name)	ISO ?
DARK GREEN	#8	General Lube Oil	(Company & product name)	ISO ?
YELLOW	#9	Turbine Oil	(Company & product name)	ISO ?
ORANGE	#10	Motor Oil	(Company & product name)	SAE ?

FIGURE 8.33 A poster on a wall could exactly visualize which lubricant fits with which color, prohibiting the use of wrong lubricants for a given lubrication point. *Courtesy of Enluse B.V. (Frank Moerman, © 2016).*

- Use the correct amount of lubricant. Adding too much oil to reservoirs and bearings may cause leaking, which could result in direct food product contamination. The same is true if excessive amounts of grease are applied. Redundant lubricant and grease should be removed.
- To help prevent cross-contamination of different food-grade lubricants, it is recommended to use dedicated lubrication equipment for greases and oils (Figs. 8.34–8.37).
- All containers/implements used for measuring or pouring chemicals are to be restricted from alternative uses (e.g., labeled "for chemical use only") and should be cleaned before use (Fig. 8.37).
- The equipment should be filled carefully with a clean can and a clean funnel (Fig. 8.36), and a suitable cleaned tool should be used to apply grease (Fig. 8.37).
- Any spills must be cleaned up and soiled wipes disposed of correctly. Dirty, greasy, or oily hands should not be placed on any surface with which the product comes into contact.

After the lubrication maintenance has been completed, a paper or electronic job sheet should be completed and records kept for an appropriate period.

FIGURE 8.34 Color coding of lubrication tools prevents cross-contamination and misapplication of lubricants. *Courtesy of Enluse B.V. (Frank Moerman, © 2016).*

FIGURE 8.35 Dedicated lubrication equipment should be used for lubrication and greasing. In high-hygiene areas, the use of a stainless-steel grease gun and disposable funnels is recommended. Color coding of funnels and dispensing drums prevents cross-contamination and misapplication of lubricants. This color coding also may assign lubrication tools to a specific hygiene area. Additionally, color-coded labeling of all lubrication points will further prevent mixing of lubricants (e.g., food-grade and non − food-grade lubricants). *Courtesy of Justrite Manufacturing Company, L.L.C.; courtesy of S & S Concepts Inc.; courtesy of KitchenWerks.*

Storage of maintenance products should follow these stipulations:

- Maintenance products (oils, greases, lubricants, ammonia, glues, chemical products, etc.) should not be left in the food processing environment when maintenance operations have ceased (e.g., during the night, during weekends, during collective holidays).

FIGURE 8.36 The equipment should be filled carefully with a clean can and a clean funnel (Steenaard et al., 2009). *Courtesy of Van Meeuwen Lubrication B.V.*

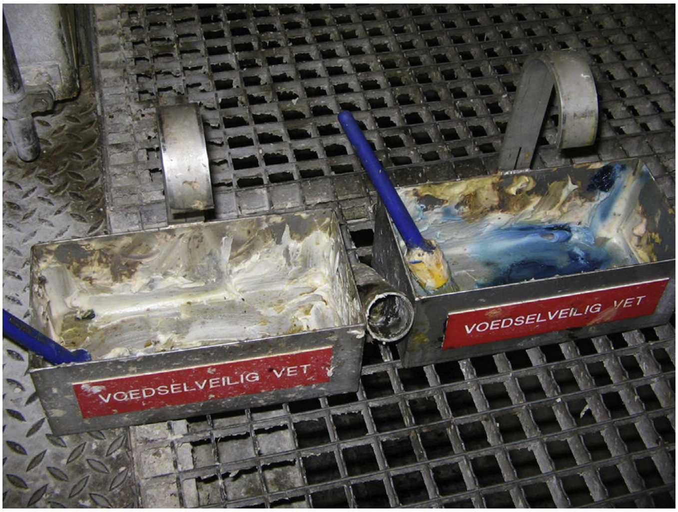


FIGURE 8.37 The blue colored brushes used for applying the lubricant are not suitable. They have turned the lubricant from white into blue. Furthermore, the lubricant stored in the "in-use" container has been cross-contaminated with other non – food-grade lubricants, and has been exposed to the environment for too long, which has allowed dirt, pests, water, microorganisms, etc., to contaminate the lubricant. The container has also not been cleaned for a long time (Steenaard et al., 2009). *Courtesy of Van Meeuwen Lubrication B.V.*

FIGURE 8.38 Incorrect storage: contamination and use of incorrect lubricants can easily occur (Steenaard et al., 2009).

FIGURE 8.39 A correct storage facility helps to prevent contamination. Here, the food-grade lubricants are stored off the floor and in clearly labeled containers (Steenaard et al., 2009) *(Courtesy of Enluse B.V.). Courtesy of Van Meeuwen Lubrication B.V.*

- They shall be stored separately from food products in clearly labeled (identifying the maintenance compound) containers (e.g., bulk supply), that remain closed when not in use. These bulk containers must be stored in dedicated secure storage facilities, that must be kept clean and dry (Figs. 8.38 and 8.39).
- Maintenance compounds that are "in use" or for "immediate use" may be stored in processing and support areas, but only in quantities necessary

for immediate use. When transferred from their original container (e.g., bulk supply) to the new container (e.g., "in use" or for "immediate use"), the latter must be labeled with the name of the maintenance compound.

8.5.4 Recalibration of Measurement Devices

Recalibration is part of every maintenance program in the process industry, including the food processing industry. Instruments and controls used for measuring, regulating, or recording temperatures, pH, acidity, water activity, and other critical factors affecting microbial growth require regular and frequent monitoring for accuracy. Where the accuracy of the measuring instrument is compromised, recalibration is needed. Together with the instrument supplier, the food manufacturer must define the frequency of recalibration of each instrument, as well as the most appropriate method and procedure to do so. A calibration schedule with name, location, frequency and method of calibration should be written for all critical monitoring equipment. Calibrated equipment that is nonconforming (e.g., broken, expired calibration period) must be identified as nonconforming, and not used for critical measurements until it is recalibrated, repaired or replaced. Most operations "tag" their instruments after calibration. The calibration tag may include who did the work, the date the work was done, and the date of the next scheduled calibration. These tags should be made of materials that are water- and oil-resistant so that they will survive the rigors of production, including cleaning.

In no way should the safety of the food manufactured be brought into danger. The following procedures should be observed:

- Preferably, in-place recalibration should be done. The maintenance workers performing the calibration have to follow the hygiene practices applicable in the food factory rigorously (Fig. 8.40).
- The instrument branch as well as the measurement device should be visibly inspected for dirt build-up. They should be cleaned before the start of the calibration process.
- The calibration of certain measurement devices requires the use of calibration liquids. Traditional calibration methods for temperature measurement devices use a bath type where the liquid (e.g., silicone oil for high temperatures, alcohol for low temperatures) is pumped around axially to ensure temperature homogeneity all the way to the surface. In the food industry there is of course a need for "pure" calibration, which means that the sensor may not contaminate the food process after reinstallation. So the silicone oil or anything else that might be located in the bath must be removed from the food contact surface of the sensor before remounting in the process equipment or line. Nowadays, dry calibration of temperature devices is also possible. Calibration of pH measurement devices also requires the use of calibration liquids. Hence, as a general rule, measurement devices should be cleaned and disinfected before reassembly when necessary.

FIGURE 8.40 On-site calibration services have to follow rigorously the hygiene practices applicable in the food factory. *Courtesy of Endress + Hauser.*

Calibration can also be done off-site in an accredited calibration laboratory. Usually measurement instrument suppliers have their own calibration services, which ensures proper calibration according to the highest hygiene standards. Good calibration practices may reduce the risk of food safety hazards.

8.6 PERSONAL HYGIENE PRACTICES DURING MAINTENANCE OPERATIONS IN THE FOOD INDUSTRY

Plant personnel are among the most significant reservoirs and vectors of microorganisms, chemical residues (e.g., allergens) and foreign materials in the food facility, and as such, can be a source of unwanted contamination of products. The transfer of contaminants can occur through a direct route, such as bacteria transferred from the body, skin, mouth, hands or hair to the product, or indirectly via their personal belongings, such as clothing, footwear, utensils, and other tools used in their daily tasks. Because of their activities and movement around the food production site, maintenance operatives should view themselves as more of a hygiene risk than other food operatives and at a very minimum must be obliged to follow the same personal hygiene procedures as all other staff. Therefore, before the onset of maintenance and repair operations, all maintenance workers must comply with the requirements for personal hygiene appropriate to the area where maintenance and repairs will be executed. Many best practices in personal hygiene are well-established in the food industry (Aarnisalo et al., 2006; Smith and Keeler, 2007; NZFSA, 2009; Stier, 2012; Moerman et al., 2014; Margas and Holah, 2014).

- Maintenance technicians suffering from diarrhea, vomiting, uncovered sores or wounds, skin infection, heavy cold, flu, discharges from eyes, ears, nose should not come into the process areas. Particular attention should be paid to contractors, who may be unfamiliar with food hygiene requirements. Like all visitors to the factory they should complete a visitor health check form (a health questionnaire).
- Maintenance workers from contractors should be obliged to follow an introductory training session about personal safety, food safety, and personal hygiene practices before entering the food processing areas. There are many training aids available to food processors in the form of on-line or print manuals, posters and signage, videos, and employee refresher courses. When new hires attend their first orientation, they are typically bombarded with a lot of important information in a relatively short period of time. Providing a follow-up refresher session on personal hygiene policies two weeks after the orientation—even just 30 or 40 minutes to refresh and reiterate policies and protocols on hand washing, outer clothing, sources of cross-contamination, etc.—helps raise employee comprehension. At this point, employees have been in the plant for two weeks and have some experience to better understand how these practices have an impact on food safety.

  Often local community colleges offer simple, short training courses on food safety and hygiene practices for maintenance workers. Contracted maintenance technicians often have this training, allowing them to provide documentation if requested. These types of records are a helpful preparation if the food processing facility is audited for outside contracts or for any regulatory reasons.
- Maintenance workers must wear protective clothing not only to safeguard their clothes during maintenance and repair, but also to protect the product. These items typically include company-provided coats/smocks, plastic aprons or plastic sleeves, when appropriate. Maintenance clothing, like all factory clothing, should be of a food-safe design to prevent foreign bodies from shedding directly (e.g., lint, buttons) or indirectly (e.g., outside pockets from which objects can fall out into product). Whenever possible, smocks should not have outside pockets. Typically many aprons and smocks used in the food industry are constructed and designed to prevent microbial cross-contamination of the product from the employee.

  The protective clothing must be clean. Laundering has to be controlled by the company in order to achieve a greater level of confidence that these items have been cleaned and disinfected adequately before being worn in areas where they may come into contact with finished products. Prior to entering the food processing area where the maintenance and repair work has to be done, the condition of the protective clothing with respect to cleanliness, frayed edges, or loose items such as buttons or snaps must be checked. This is especially the case with maintenance operators of contractors. Preferably, they must be provided with clothing owned by the food manufacturer.

Essentially, protective clothing provided by the company should never be worn outside of the plant premises, should always be worn in the plant production areas, and should be regularly changed. Maintenance and contractor employees who have worked outside the facility, in "raw" or waste areas, must change into clean plant attire prior to entering production areas.

- Nonporous footwear should be worn, especially in the production areas. Footwear should be constructed of material that is cleanable. It should not be made of leather or cloth that will get and stay wet, which is uncomfortable for the wearer and may result in the maintenance technician avoiding the necessary foam sanitizer and foot dips so they don't have to be wet all day. The condition of footwear with respect to cleanliness, frayed edges or loose items must be checked. For access in a dry area, overshoes or shoe covers may be used to cover footwear.

  As footwear can be a vehicle for the transfer of pathogens, footwear must remain at the facility in order to mitigate contaminants carried into the plant from home. It is also good hygienic practice to dedicate footwear to a specific area. The footwear must be cleaned at the facility, and to do so appropriate cleaners and brushes for all maintenance technicians must be available. To decontaminate footwear before entry in the zone where the maintenance or repair work has to be done, foam sanitizers (Fig. 8.41) have proven to be very successful. They also offer the advantage that pallet jacks, forklifts and carts can be decontaminated simultaneously. Foot dips/baths and boot-washers are also quite common in use. Care must be taken that foot dips/baths and boot-washers don't become pools of bacteria, especially because organic material reduces the effectiveness of the disinfectant. Disinfectant solutions in foot dips/baths and boot-washers must be changed regularly. It is also recommended to closely monitor the microbial load and the concentration of the disinfectant, as well as the volume of the disinfectant solution.
- Hair should be kept short and trim, and be covered with a hat, cap, or hairnet. A snood also should be used to cover facial hair.
- In many food factories (especially the smaller ones), as maintenance tasks dictate, maintenance personnel are moving from clean to dirty and/or raw to ready-to-eat areas, as such spreading cross-contamination all over the factory. To prevent cross-contamination between different zones

FIGURE 8.41 Foam sanitizers have proven to be very successful in decontaminating footwear before entry in the zone where the maintenance or repair work has to be done. *Courtesy Nelson Jameson Inc.*

from happening, a segregation of maintenance personnel can be implemented. As with their tools and equipment, mechanics can be dedicated by department, and a system of color coding (protective clothing, footwear, boots, hair covering, hats, etc. in a color specific for a given hygiene zone) may prohibit maintenance technicians from operating in a zone where they are not allowed to perform maintenance or repair work. Due to the color coding, their presence in a wrong zone is quickly detected by other staff members. Segregation of maintenance workers is easier to realize in large factories than in smaller ones. In smaller food factories the number of maintenance technicians is usually limited for cost reasons, requiring them to perform maintenance and repair tasks all over the factory.

- Jewelry, including tongue rings and body piercings, in food processing areas is not allowed, not only because jewelry may get lost in the product stream, but also because rings, watches, bangles, etc. can harbor dirt or bacteria which can affect food.
- All personnel entering the food processing area must always adequately wash and disinfect their hands to prevent contamination of foods and food-contact surfaces with microorganisms, allergens, chemical residues (e.g., lubricant residues, adhesive residues). Handwashing policies should require employees to wash after any type of activity that could contaminate the hands. Wearing sterile gloves could be a supplementary option. Training is an important part of instilling good handwashing practices. A handwashing verification method such as swabs or plate counting may act as a means of controlling that proper handwashing practices

are adhered to. They are effective training tools because people often are amazed when they see what is still growing on their hands after a rudimentary wash.

Handwashing stations must be sufficient in number and placed in convenient locations, to avoid employees skipping the handwashing. As maintenance workers need to wash their hands more frequently than process operators (their hands get soiled with residual food debris, dirt, dust, lubricant residues), handwashing stations must be easy to access and well-stocked so as to avoid maintenance operators omitting to wash their hands.

- Fingernails should be kept short and clean, because long nails harbor moisture and dirt, allowing bacteria to grow.
- Visual aids all over the food factory create continual employee awareness of personal hygiene best practices. The best way to accomplish this is to place signs on bulletin boards in hallways, break rooms and other high-traffic areas that reiterate personal hygiene messages, such as showing the sequence steps of good handwashing procedures or images that show how easily jewelry, tape, and pens can get into the finished product.

8.7 HYGIENE PRACTICES DURING MAINTENANCE OPERATIONS IN THE FOOD INDUSTRY

8.7.1 Recommended Hygiene Practices to Be Taken Before the Onset of Maintenance and Repair Operations

The following pre-service practices may create the necessary hygienic conditions allowing maintenance and repair without compromising the safety of the food produced with that equipment once production resumes (Jha, 2006; Smith and Keeler, 2007; NZFSA, 2009, 2010, Moerman et al., 2014):

- A maintenance program must be available that includes procedures that describe how to do the work. Maintenance technicians can only perform their work in a hygienic manner, if they know exactly what is allowed and not allowed during their activities. Mishandling equipment during maintenance and repair, as well as poor lubrication practices, may compromise the safety and quality of the food produced. Therefore the following procedures must be integral parts of a documented maintenance program:
  - maintenance procedures;
  - lubrication procedures;
  - tool reconciliation procedures;
  - procedures for temporary repairs;
  - procedures for emergency repairs;
  - spare parts inventory program;

- training procedures;
- "hand-over" procedures;
- audit procedures to verify that the work is being done properly.

These procedures should include a title, step-by-step actions to complete the work, who is responsible for the work, how and where records shall be maintained, corrective actions to be carried out, and, finally, procedures for management to verify that the work was not only done, but done properly.

- Some work such as drilling or welding will inevitably produce debris and dust. The area should be examined to assess the potential risk of contamination, and risk areas should be covered. A "Food Safety Maintenance/repair Plan" should be developed and shared with affected employees prior to major construction or renovations.
- Where necessary, traffic inside the food factory should be rerouted.
- Whenever possible, maintenance should be done in a separate room outside the food processing area. As an example, fabrication and repair could occur in the maintenance workshop, but then care must be taken that there is sufficient access for machinery/equipment to be brought into the shop. Weld, thread or cut operations also can be done in any other area screened (isolated) from ingredient or packaging material storage and product handling.
- Alternatively, when possible, production operators should remove food processing equipment from the processing room before repairs will be made, or the maintenance area must be segregated from production by use of tarps. No maintenance work shall be allowed during production if the necessary protection is not ensured.
- Adequate screening is of paramount importance in exposed food areas, to prevent exposed food from becoming contaminated with metal shavings, filings and other airborne particles generated during maintenance and repair, and to protect it from grease removers, lubricants, paints, and paint odors.
- An appropriate number of shields and plastic sheets must be available to contain possible contamination in the work area during on-line repairs.
- The tarps or plastic sheeting (polyethylene or equivalent film) draped over adjacent equipment must be clean and free from dirt and water.
- If it is necessary to stand on machinery, the equipment must be covered to prevent dirt and debris from contaminating the surface. If entry into process equipment is required, a plastic cover film must be laid down on the bottom of the process equipment.
- Maintenance workers must necessarily use many tools in the production area. The maintenance tools of contractors should be company-owned. Where practical, maintenance tools should be dedicated to a specific area, because tools may be a source of *L. monocytogenes*, and other harmful microorganisms, as well as physical hazards (foreign bodies).

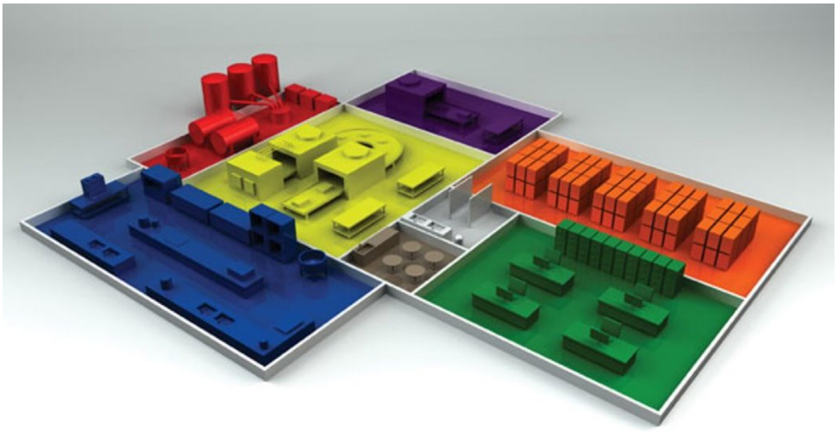


FIGURE 8.42 To improve hygiene and prevent cross-contamination, the production premises may be divided into visually separated zones, where each zone is assigned a specific color. In analogy with the color coding of cleaning tools, every zone can have its own colored set of maintenance tools and its own color-coded service equipment. Color coding is a tremendous tool because it works in all languages and makes these tools easily distinguishable from other production tools for better accountability. *Courtesy of Carlisle Sanitary Maintenance Products.*

No transfer of these hazards may occur from a less to a more hygienic area. By dividing the production premises into visually separated zones (Fig. 8.42) where each zone has its own colored set of maintenance tools and equipment, hygiene can be improved and cross-contamination can be eliminated. Also tool bags, tool boxes, receptacles, and trolleys may be provided with a color code. It is recommended that the color coding be the same as that implemented for cleaning equipment and cleaning tools.

- Segregation of maintenance tools and equipment may result in the following categories: food contact versus nonfood contact, allergenic versus nonallergenic contact, wet versus dry, areas with basic/medium/high hygiene requirements, equipment versus nonequipment (e.g., repair of drains), halal versus nonhalal, kosher versus nonkosher, etc. Tools used in areas where foods are exposed should be exclusively used in these areas.
- To avoid cross-contamination, workshops and storage areas for maintenance tools can also be designated to a specific zone. When each zone has its own workshop, the service crew must not cross less-hygienic areas. It is important to minimize the crossing of flows of people, goods, process equipment, cleaning tools, maintenance equipment, and maintenance tools. Floors as well as air currents may act as carriers of food pathogens, spoilage microorganisms, food debris (e.g., allergens), aerosols, etc. The fewer doors between different zones are opened, the better.

- Color coding also may promote hygienic behavior among employees and help to ensure that they understand the maintenance plans of the company.
- Broken parts of colored maintenance tools are visually more easy to detect if they become a foreign body in the product.
- Tools used for repair and maintenance must not compromise the hygienic status of any product or packaging material. The maintenance tools must be free of rust, peeling paint and niches for bacteria (scratches, cracks, pockets, threads, etc.); and without wooden handles or knurling soft rubber grips. They should be noncorrosive, easy to inspect, clean, and disinfect, with smooth finish and hard plastic grips, and with fitted heads for equipment longevity. They must be designed in such a way that they can't damage the process equipment (Fig. 8.43).
- Maintenance tools and aids preferably should be designed with a minimum of parts. As an example, it is recommended that employees use one-piece ink pens made of metal, rather than plastic cap-and-pen types. This reduces the chance of a pen cap falling into product and ensures that the metal detector will find the entire pen.
- Carbon steel tools with electroplated surface coating are available but have their limitations. The surface coating temporarily prevents the interaction of the free iron in the carbon steel tool with the oxygen in the environment, hence reducing the level of oxidation. However, because of intensive use and frequent cleaning/disinfection, the plating deteriorates

FIGURE 8.43 (A) The maintenance tools suffer from corrosion, are painted (paint may peel off), contain niches and threads; have wooden handles or knurling soft rubber grips; or the tool heads may damage the stainless-steel surfaces of equipment and components. (B) These maintenance tools are made of stainless steel (noncorrosive), easy to inspect, clean, and disinfect, with smooth finish and hard plastic grips, and with fitted heads for equipment longevity. A system of color coding allows maintenance tools to be dedicated for use in specific zones, such as low, medium, or high hygiene areas. *Courtesy of John Butts, Land O'Frost; courtesy of Steritool (Frank Moerman, © 2016).*

with time, causing it to chip, flake, and peel. The tiny flakes and chips from the deteriorating chrome plating finally may become foreign matter in the food product. Furthermore, the exposed ferrous surface of the tool will transfer ferrous contaminants to the surface of a stainless-steel fastener or equipment, which subsequently will result in the formation of iron oxide, even at low levels of humidity. Moreover, bimetallic corrosion may occur. Therefore, stainless-steel maintenance tools suitable for intensive use and easy to clean and disinfect must be used. Stainless steel 316L, however, is not the ideal material of construction for maintenance tools, because it is not capable of achieving the hardness level required for high torque applications. As an example, the small serrations in the jaws of common slip joint pliers would likely wear too easily under normal use if they were manufactured from stainless steel 316L. Precipitation-hardened low carbon stainless steel 465 has proven to be excellent as a material of construction for maintenance tools due to its greater hardness, excellent tensile strength, and sufficient corrosion resistance over a long period of time. Maintenance tools with a long life reduce the need for replacement (Pekarsky, 2007).

- In certain conditions the use of nonmetal tools is preferred over metal tools, especially if the latter can damage process equipment parts.
- When maintenance or repair is performed at height, technicians need to use tools that are secured or tethered to prevent a hazard. Accidental dropping of tools while working at height can have devastating consequences. Smaller objects such as wrenches or sockets can cause severe injury to employees working beneath, while heavier tools such as a hammer can kill them. An injured employee may cost a food producer or maintenance contractor a lot of money: medical bills, workmen's compensation claims, increasing safety insurance policies, potential lawsuits, bad publicity and reputation damage, workforce and labor unions discontent, strikes, etc. A wrench slipping out of a utility worker's hand or a socket slipping out of a tool pouch also could cause damage to sensitive infrastructure (e.g., sensors) and equipment (e.g., damage to insulation, inside damage in a tall tank). A falling tool isn't necessarily going to drop straight down, but often ricochets when hitting several objects on its way down to the ground. It thus can damage a multitude of components.

Reliable retention of tools to prevent them from falling when working at height not only may prevent employees from injury and death and protect equipment against damage, it also may reduce the possibility that tools get into product, and it provides accountability to prevent tool loss. Moreover, a built-in drop-prevention system reduces the chance that tools may be laid on food-contact surfaces or places prone to dirt build up, microbial contamination, etc.

Tools with built-in coils or other fastening devices are available allowing lanyard attachment. These lanyards can be attached to the operator's wrist, belt, harness or other suitable tether site location, while ensuring that the original functionality and quality is maintained (Fig. 8.44). Tools weighing more than 2.5 kg should be attached by lanyard to the operator, more specifically by means of one lanyard hook attached and locked to an approved attachment point on the technician's safety harness, belt, or wrist strap, and another lanyard hook attached and locked to the selected tool (Fig. 8.45). Tools weighing more than 5 kg should be attached by lanyard to a suitable fixed point.

FIGURE 8.44 Although the tool is secured, the lanyard gives technicians unrestricted tool use and doesn't impede mobility or compromise personal safety equipment. *Courtesy of Snap-on Industrial.*

FIGURE 8.45 Means of attachment such as coils or other fastening devices are built into tools, and are not added as an accessory later. *Courtesy of Snap-on Industrial.*

- Ordinary steel wool or steel brushes and scrapers should never be used on stainless steel surfaces, as particles of steel may get embedded in stainless-steel surfaces and rust.
- Utensils such as knives, spoons, scoops, and ladles used for handling or measuring toxic chemicals and other nonfood materials should not be used for food contact.
- Maintenance tools must be used with care so that they cannot be left in the production equipment. Use only the maintenance tools that are required for the job. The fewer tools that are taken in the area where servicing of the equipment must be done, the less chance that tools will get lost in the product stream or will be forgotten once the maintenance/repair job is finished.
- Maintenance tools must be stored off the floor, and in no way should service technicians pick up items from an uncovered floor. Furthermore, replacement equipment and parts must be kept at least 0.5 m away from walls to avoid pest infestation and breeding.
- Maintenance tools must be inspected for broken parts. As soon as the slightest sign of deterioration is observed on a tool, the tool needs to be discarded and replaced with a new one.
- Maintenance tools must be inspected for cleanliness. Where required, they must be recleaned. In all circumstances, it is essential to disinfect maintenance tools before entry in the food processing area. Use cleaners and disinfectants that are less harsh on these tools (less corrosive), while still being effective in the removal of food residues and dirt, and in the inactivation of food pathogens and spoilage microorganisms. Note that the maintenance tools must be thoroughly dried after cleaning.
- Because maintenance staff are a foreign body risk, all unsecured objects (e.g., pens, pocket notebooks, small screwdrivers, pencils behind the ear, nonattached ear plugs, nuts and bolts in shirt pocket) which could fall into the product must be stored in the toolbox or the carrier used to bring parts to the work site.
- Receptacles for maintenance tools should be marked in a clearly visible fashion, to show that they are "only used for maintenance operations."
- Tool bags and boxes, receptacles, and trolleys used by the maintenance staff and contractors should be assessed for their suitability for application in the intended environment (Fig. 8.46). Where necessary they should be cleaned and disinfected before being brought into processing and/or support areas. To do so, the tool bags and boxes should be made of a material that can be easily cleaned, e.g., not fabric. A documented cleaning and disinfection procedure must be implemented for that purpose.
- Doing maintenance work and reparations over exposed product while standing on ladders and platforms is not allowed, because maintenance debris, nuts, bolts, screws, tape, lubricant, or any other dirt, as well as

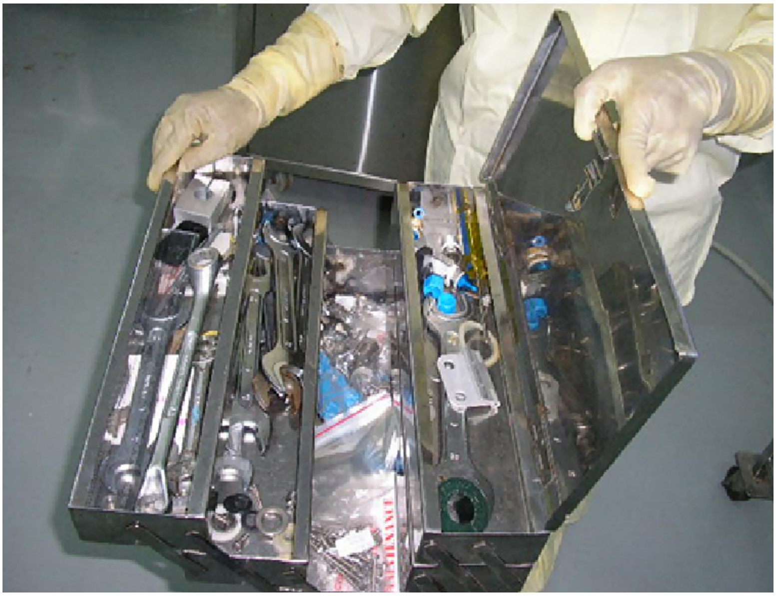


FIGURE 8.46 Toolbox is suitable for use in this high hygienic area. *Frank Moerman, © 2016.*

maintenance tools, may fall onto production lines and into the food products beneath. During maintenance activities at height, production of exposed food products must be stopped. If open process equipment and lines used in the processing of exposed food can't be moved aside, they must be protected by means of covers, and thoroughly cleaned and disinfected once maintenance and repairs are finished.

- Stairs, ladders, scaffolds, platforms, pallet jacks (to move heavy equipment components), cherry pickers, etc. (for work at height) must be free of damage and corrosion, and clean. Where possible, they should be cleaned and disinfected.
- Stairs, ladders, scaffolds, platforms, etc. must be made of impervious, noncorrodable, easy to clean and impact-resistant materials of construction. They must not have sharp corners and niches (scratches, cracks, pockets, threads, etc.) for bacteria to hide. Wooden planking as scaffold platform is not allowed. Work platforms must consist of steel plates (provided with a coating as protection against corrosion) containing a raised antislip material and preferably also kickplates (toeboard) over the whole perimeter of the walkway or platform. Open grating is not allowed. Stairs and ladders are often made of aluminum which has the advantage of being low in weight. Detergent and disinfectant solutions used to clean and disinfect stairs, ladders, etc. may not adversely affect the aluminum (must not induce corrosion).

- Anything that moves within the plant (stairs, ladders, scaffolds, platforms, pallet jacks, cherry pickers, etc.) has to be controlled: use, location, etc.
- Debris from engineering workshops (such as swarf and other unwanted materials) must be prevented from entering processing or support areas. This is especially important where engineering workshops have access ways (e.g., doorways) that lead into processing or support areas. This may be achieved by keeping doors closed, the use of swarf mats, boot washes, etc.

8.7.2 Recommended Hygiene Practices During Maintenance and Repair

The following hygiene practices should be followed during maintenance and repair (Smith and Keeler, 2007; NZFSA, 2009, 2010; Moerman et al., 2014):

- Before maintenance and repair can start, residual product often must be removed from the equipment, line, etc. It is essential to avoid spills and splashing onto ingredients, products, packaging materials or adjacent process equipment. Contaminated ingredients and products, as well as spills, have to be removed as soon as possible. In some cases of product spills, leaking water, etc., enhanced microbiological monitoring for food pathogens may be required.
- As opening of certain systems may endanger maintenance operators (e.g., utilities such as steam piping, compressed air lines, food gas lines), the necessary actions must be taken to avoid any injury.
- Ensure adequate lighting, particularly where detailed or intricate work is required. Lamps with higher light output may permit the factory staff to perform inspections of the food processing equipment and the process environment more easily and profoundly, enhancing the detection of grease, leaking oil, failures, maintenance residues, etc. However, light sources should not be placed above open process equipment, or the lamp should be housed in a shatter-resistant fixture to avoid shattering of glass that may lead to broken fragments falling into open processing equipment. By using a protective PTFE or acrylic coating, one may also maintain the integrity of the lamp in the event of breakage. Light sources used during maintenance operations should not contain mercury. Torches to light dark places within process equipment should be resistant to breakage.
- Glass is not allowed in food processing areas. However, in older facilities, glass still can be found. The only glass (other than jars and bottles for packaging of food and beverages) permitted in food factories should be windows and fluorescent light tubes, light bulbs and lamps. Care should be taken to ensure that glass does not enter food products. As an example, when changing light tubes, light bulbs and lamps, glass should

be prevented from breaking and showering the production line. As a means of protection, while still working at height, put removed lamps, light tubes, and bulbs immediately in a fully secured and lockable damage-resistant container or bag. Where possible, the production line should be moved aside.

- Replace light sources in glass by lamps, light tubes, and bulbs covered with a PTFE or acrylic sheath, or use shatter-proof plastic light sources as substitute. Additionally, shield the lighting with a plastic cover.
- Opening the distribution system will expose the system to particles from the outside environment. To keep the interior of the process equipment and components as free as possible from any exterior contamination, the food producer can protect the equipment openings. Cap open ends on lines while performing the maintenance and repair work.
- Any risk of contamination during maintenance/repair or when altering the system can be minimized by performing maintenance/repair during shutdown periods (e.g., collective holidays) and by using strict specifications on how to conduct activities, such as cutting pipework, and handling pipes and components before the actual installation.
- Avoid placing dirty hands on any surface with which the product comes into contact.
- Precautions should be taken to prevent the distribution of any contamination residues or mechanical damage residues in the surroundings. Doors and windows should remain closed during maintenance operations, to prevent high-velocity air currents from entraining maintenance debris. These high-velocity air currents also may occur in the neighborhood of exhaust openings and the air supply. However, natural or mechanical ventilation (at low air velocity) should be provided to minimize the likelihood of airborne contamination of food and to provide a safe working environment by effectively removing smoke, fumes, combustion gases, toxic gases, oil vapor, metal vapor, obnoxious odors, dust, etc.
- Facilities for good housekeeping in the maintenance area must be present. Maintenance spills must be removed to avoid cross-contamination. It is recommended to collect most of the maintenance debris at its source. Vacuum cleaners (Fig. 8.47) should be applied to extract maintenance debris at the place where the maintenance takes place, drip pans should be used to collect oil, etc.
- Equipment components subjected to maintenance, spare parts and tools should not be placed on the ground or walking surface (e.g., platform deck). Storage should occur (i) in a receptacle, box, carrier or trolley provided with a plastic cover, (ii) on a hygienic rubber mat or plastic pallet provided with a plastic cover, or (iii) hanging on a parts rack. Also they eventually should be designated by color for their intended use. In the

FIGURE 8.47 Vacuum cleaners should be applied to extract maintenance debris at the place where the maintenance takes place.

food processing area, no wooden pallets should be used to store new or replaced equipment components.

- Dirty parts (e.g., caps and gaskets) must not be stored in baskets intended for clean parts.
- Whenever parts and tools are stored in the production area, they should preferably be kept in rooms or lockers reserved for that use.
- Equipment components in service should be clearly indicated and placed in quarantine.
- To facilitate correct reassembly, disassembled equipment parts should be positioned in chronological order of disassembly.
- Take care not to lose nuts, bolts, etc. when removing them from machinery. Because small parts easily can be misplaced, loose bolts, nuts, screws, rivets, washers, etc. should be stored in maintenance receptacles.
- Bolts, nuts, screws, etc. of a lower alloy composition may not be used with stainless steel, because they may induce corrosion.
- Proper access for maintenance should be ensured, e.g., by stepladders or mobile platforms (cherry pickers) to prevent, e.g., maintenance personnel from stepping on the cladding of insulated piping which could result in it becoming damaged. When the insulation is torn, it could become a sanitation problem (harborage of dust, insects and rodents; absorption of moisture from air or spills may allow the growth of molds). Damaged or wet insulation should be repaired or immediately replaced.

- Personnel must be trained and suitably skilled in the correct access, handling and use of approved maintenance compounds, or have access to documented directions. Documented directions must be followed, either at the point where the compound is used (e.g., on the container label), or on information data sheets available to the person using the compound. Processing areas or equipment contaminated by a maintenance compound must be corrected according to the maintenance compound's properties and its effect on the product's fitness for its intended purpose.

8.7.3 Recommended Hygiene Practices After Maintenance and Repair

After maintenance and repair operations, the following practices should be followed (Smith and Keeler, 2007; NZFSA, 2009, 2010; Moerman et al., 2014):

- If emergency repairs were required during production, any product that may have been left sitting for long periods of time or may have become contaminated during repairs should be disposed of or scheduled for reprocessing to prevent any potential for poor quality or contaminated finished product.
- Maintenance tools or machinery must be removed or returned to storage without delay once maintenance or repair work is completed. Therefore, maintenance technicians must verify that all maintenance tools and components are removed after maintenance and repair to ensure nothing is left, as it may enter the product or damage the equipment. An inventory can be made of all tools prior to maintenance. It is good practice to "count-in" all tools and replacement parts taken to a job and "count-out" all tools and removed parts to ensure that everything is removed from the food processing area. It is possible to make someone responsible for tool reconciliation, and that only he receives access to the tool storage place.

  Tool containers with foam cutouts may help technicians in that task. When tools are returned at the end of a project, any open space alerts the technician of a potentially missing tool (Fig. 8.48). Nowadays, electronic tool storage and control systems to automatically track individual tools by user with bar codes, scanners, RFID tags, or other add-ons are available. They are provided with a warning alert system, which is activated when one or more tools are missing, or incorrectly positioned. As a further advancement, these toolboxes can be networked, either wirelessly or by Ethernet and managed by powerful, easy-to-use software. The administrator can view all the boxes on the network, whether they are on- or off-line, and the status of each box—including the number of tools issued, the active users, and all history.

FIGURE 8.48 Tool containers with foam cutouts may support technicians in tool accountability. When tools are returned at the end of a project, any open space alerts the technician of a potentially missing tool. *Courtesy of Snap-on Industrial.*

- To aid in tool identification, tools can be etched with company name, logo, serial number or any other ID marker. The identification number also can be etched into the specific storage space for the tool. The engraving must be designed for minimum dirt accumulation and maximum cleanability. Engraving may not be too deep and too small, and should not have sharp corners.
- Before storage, tools must be cleaned, disinfected, and maintained in a hygienic manner. If tools are not cleaned and disinfected before storage, the storage room can get contaminated with food pathogens, spoilage microorganisms, allergens, maintenance debris, lubricant residues, etc. The maintenance staff must be provided with the necessary facilities to clean, disinfect and maintain their tools, toolboxes, trolleys, etc.
- Broken maintenance and repair tools must be discarded. Making a service technician responsible for control and maintenance of service equipment and maintenance tools guarantees that all service equipment and tools are well-maintained and timely replaced when they are worn or in poor condition.
- If required for continuous use, tools must have a designated storage place (e.g., racks, trolleys, tool boxes, etc.) adequately segregated from ingredients, products and packaging materials, and protected from pest access and harborage.
- Tools dedicated to specific uses must be stored separately.
- The maintenance workshop and storage room for replacement parts, maintenance tools and maintenance aids should be neat and clean, and

FIGURE 8.49 Storage room for replacement parts, maintenance tools and maintenance aids should be neat and clean, and allow storage in dry conditions. *Courtesy of Mondelēz International, © 2016.*

allow storage in dry conditions. No poor maintenance housekeeping is allowed (Fig. 8.49).

- Also maintenance aids such as safety goggles, gloves, sample bags, ink pens, thermometers, tape rolls, etc. must be removed and returned to storage. A "count-in" inventory made prior to maintenance will facilitate their "count-out" and return to storage at the end of the maintenance and/or repair job.
- Handling and storage conditions should be monitored and recorded to assure that the specifications are met and that the controls are effective.
- Any part removed from equipment that is suspected of being microbiologically contaminated must immediately be sealed into a container or plastic bag to ensure that it does not "drip" contamination around the food processing area.
- Maintenance debris (e.g., abraded particles, swarf) may act as an abrasive that grinds off more particles from the pipe or equipment wall. Therefore, it is necessary to flush the system after maintenance and repairs.
- Appropriate waste removal and disposal procedures should be in place. All nuts, bolts, screws, nails should be accounted for and removed. Any other refuse (e.g., packaging materials, broken components, failed parts, drill bits, metal shavings, dirt, dust, spilled oil) must not be allowed to accumulate in production areas, but should be regularly removed to a suitable storage area and without delay. Maintenance waste and refuse should not be collected in ingredient or product containers but disposed of in covered garbage containers labeled with "MAINTENANCE WASTE."
- Damaged, decommissioned, or idle equipment must be removed as soon as it has served its purpose. It must be stored in an appropriate way to ensure that it does not become a source of contaminants or harbor pests. Equipment that could be a source of contamination must be physically isolated from processing lines and product, or removed from processing

FIGURE 8.50 Decommissioned or idle equipment must be stored in an appropriate way to ensure it does not become a source of contaminants or harbor pests. When stored outdoors, it should be placed on a hard standing (e.g., concrete, sealed, or paved area) and covered, which is not the case in this example. Moreover, the equipment is not appropriately covered.

areas. Nothing should be left in a food production facility that is not part of the production process. Damaged or decommissioned equipment that remains in processing areas must be clearly identified as such, to ensure that it is not used. Decommissioned equipment may be stored outdoors, but should be placed on a hard standing (e.g., concrete, sealed, or paved area) and covered (Fig. 8.50).

- When it is necessary to "break in" to the system for maintenance or inspection, documented "Clean Before Use" procedures should be in place to ensure that equipment is clean and will not compromise product integrity when returned to service. Therefore, equipment should be thoroughly cleaned any time maintenance or repairs of any type (e.g., drilling, cutting, polishing and welding) are performed in a food processing facility. The equipment and area should be cleaned with hot solutions of detergent(s) and disinfectant(s) in the right concentration, then rinsed, and finally dried prior to resuming production. Cleanliness and microbiological condition of the equipment should be confirmed by taking indicator and/or food pathogen swabs. The equipment may need to be recleaned, disinfected, and rechecked before being placed into service.
- Cleaning the equipment and area after maintenance and repair also provides the opportunity to check a last time for misplaced tools or parts.
- After servicing, all covers and guards must be put back in place. Missing guards may cause injury to process operators, while missing covers will allow debris, dirt, or water to collect in the equipment.

8.8 EVALUATION OF THE QUALITY OF MAINTENANCE WORK DONE AND RECORDKEEPING

Before production resumes, the food manufacturer must evaluate if finished maintenance operations and repairs meet the expectations with respect to the quality of the maintenance and repairs. From this perspective, the following practices should be followed (Moerman et al., 2014; BRC, 2015):

- Equipment must be subjected to a preoperational check before processing recommences. Have all technical problems been solved and is the equipment operating correctly? Have maintenance and repairs been done in a way that the process equipment allows the production of safe food products once production resumes? Maintenance technicians should read and sign off on Good Maintenance Practices.
- Equipment operating under validated conditions must be revalidated if the repairs and maintenance activity may affect its validated status (e.g., replacing temperature probes/sensors in ovens/freezers).
- Both routine (preventive) and emergency maintenance work should be documented. Maintenance records or job sheets (including when and how the defect/breakdown was repaired, who conducted the work, who has signed off that it was completed, and that appropriate equipment return-to-use procedures were followed) should be completed. Comprehensive maintenance records will assist the food manufacturer to verify that the repairs and maintenance program is working correctly. Where required, maintenance and repair procedures should be adapted. Maintenance records also may provide management with a tool for more intelligent purchasing of new equipment. If the records indicate that a piece of equipment was down often or very expensive to maintain, maybe it is not a brand that one should buy again.
- Regardless of whether maintenance has been carried out in a workshop or within the food production environment, the equipment must be cleaned by the cleaning crew. The cleaning crew must also keep records to document the cleaning and disinfection operations undertaken, as well as any visual, ATP, or microbiological sampling to verify cleanliness.
- Finally, the production department should sign off (e.g., on their daily record sheets) to indicate that they are content to accept the equipment back into production. For that purpose, processors must establish procedures for hand-over.
- Electronic maintenance management systems exist that can support the maintenance staff in documenting their maintenance and repair activities.

8.9 EVALUATION OF THE MAINTENANCE PRACTICES

Maintenance practices should be consistent with Good Maintenance and Manufacturing Practices. It is especially the task of maintenance managers and supervisors to implement and guarantee "Maintenance Best Practice" so as to eliminate the sources of contamination that cause downtime, quality holds and lost profits. The maintenance and quality assurance department must regularly conduct audits to verify if the maintenance staff or contractors have adopted the correct hygiene practices during the preoperational activities and the maintenance operations. Preoperational activities include personal hygiene practices (e.g., garment, footwear, hair protection, washing of hands, etc.), selection of tools, placing barriers, draping of tarps, etc., while maintenance practices include hygiene practices during the maintenance and repair work (e.g., break-in to the equipment while reducing contamination to a minimum, removal of maintenance debris, accountability for equipment parts and maintenance tools).

8.10 CONCLUSION

Food manufacturers who resort to breakdown maintenance instead of preventive maintenance are often not aware of the real cost of an unplanned failure and line shutdown. Not only can less food be produced, but also a workforce of well-paid process operators may be unemployed for many hours. Moreover, contamination of the food produced may already have taken place for a long period, far before the failure occurs. The result is food of inferior quality and risky to consume, which may force the food manufacturer to do costly and painstaking product recalls. The company's reputation may be compromised, with a final result being that the company may be bankrupt. Moreover, breakdown maintenance usually proceeds under pressure in order to reduce costly downtime, and therefore may result in (i) the use of unsuitable materials, (ii) lack of care, or (iii) once-made temporary repairs that tend to be forgotten. In contrary to emergency maintenance, preventive maintenance can provide a food manufacturer with significant cost savings, as it may maintain the high throughput, reduce the amount of low-quality and/or contaminated food, improve the energy efficiency, achieve savings in spare parts and maintenance aids, extend the equipment's life, etc.

However, both during emergency and preventive maintenance, maintenance technicians by the nature of their work run a high risk of contaminating the product, and therefore must show a high level of diligence in the workplace. Correct personal hygiene and maintenance attitudes are required to ensure that the process equipment and utilities, the product area and products are kept free from contamination by undesirable microorganisms, filth, maintenance debris, or machine parts and to comply with the requirements outlined in national and international legislation and regulations, as well as standards. Furthermore, besides legislative bodies, also operators involved in the certification of food operations (e.g., BRC-2015 issue 7, SQF, FSSC 22000) have detected the value of personal hygiene and good maintenance practices during service operations, the result being that preventive maintenance is acknowledged as one of the prerequisite programs in a Hazard

Analysis and Critical Control Points (HACCP) protocol. Therefore, with this book chapter, we aimed to provide food manufacturers and maintenance operators with guidance in the implementation of appropriate hygiene procedures during the maintenance of food processing equipment and utilities.

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