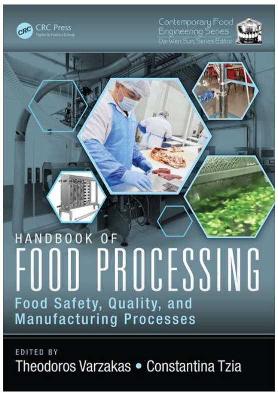

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Hygiene and Food Sanitation

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3 Hygiene and Food Sanitation

Theodoros Varzakas

CONTENTS

3.1 HYGIENE REGULATIONS

On April 29, 2004, the European Parliament and the Council of the European Union adopted the "food hygiene package" that comprises of regulations (EC 2004a–c). EC (2004a,b) are addressed to food business operators (FBO) and EC (2004c) on official controls. The new regulations came into effect on June 1, 2006, and extended the existing principles embodied in Council Directive 93/43/EEC.

EC (2004a), on the hygiene of foodstuffs, applies to all foods and begins at primary production and continues through processing, distribution, and retail; while EC (2004b) lays down specific hygiene rules for food of animal origin. The new requirements apply from primary production to retail and lay down that FBO are responsible for the safety of their products, and they must apply Hazard analysis and critical control points (HACCP) principles. However, an exception was made for producers of primary products (e.g., dairy farmers), even though they should follow the principles of food safety and hygiene codes, and the best way is to use HACCP-based systems (Maunsell and Bolton, 2004).

In particular, the new food hygiene package highlights: (1) the concern of paramount importance to protect human health; (2) the use of procedures based on HACCP principles to identify, control, and monitor critical food safety points in food businesses; and (3) the possibility of adopting microbiological criteria and temperature control measures in accordance with scientifically accepted principles.

With regard to the dairy industry, the new regulations EC No. 852/2004 and 853/2004 have replaced the Dairy Hygiene Directive 92/46/EEC.

The new dairy hygiene legislation is extensively described by Komorowski (2006), while changes from Directive 92/46/EEC are also identified.

Additional requirements to the dairy industry such as Regulations 1774/2002 and 79/2005 (dairy companies disposing milk and dairy products) and of Regulation 183/2005 (dairy products intended to be used as animal feed) are also described by Komorowski (2006).

The report of the EC the Council and the European Union on the experience gained by the member states on the implementation of the new legislation indicates that member states and FBO are generally satisfied with the new hygiene regulations and that they have made good progress in adjusting to them.

On the other hand, the food and veterinary office (FVO) (2008) report has identified shortcomings in the control of the quality criteria of raw milk in countries like Spain, Hungary, and Poland, while some progress was noted in Greece, Cyprus, Belgium, Denmark, and Lithuania.

Moreover, the same report stated that compliance with community requirements pertaining to residues and veterinary medicine controls in foods of animal origin in Greece, Romania, Portugal, and Bulgaria suffered from significant shortcomings. The aforementioned facts illustrate the need for stringent adherence to hygiene regulations (Food Safety Management Systems) by the producers and detail, frequent audits by the competent local authorities as the safety and quality of milk and milk end products are of paramount importance (Papademas and Bintsis, 2010).

3.2 MICROBIOLOGICAL CRITERIA

The microbiological criteria for pasteurized milk and milk products, as end products, are described in the EU Directive 1441/2007, while the EU Directive 853/2004 governs all the quality/safety criteria for raw milk and milk products, for example hygiene of raw milk production (animal hygiene), hygiene at the farm level, temperature control limits, microbiological quality of raw milk, labeling of milk products, and packaging of milk products. These directives are essential for setting up control limits for the identified CCPs.

Microbiological standards (Buchanan, 1995; Buchanan et al., 1998) have been included in European Legislation (EC, 2005).

Apart from the earlier described HACCP principles, the prerequisite program implementation in food businesses, regardless of size or complexity, is considered essential. Recently, the British Standards Institute (BSI) developed the publicly available specification—BS PAS 220 (2008), which specifies requirements for prerequisite programs to assist in controlling food safety hazards. BS PAS 220 (2008) is to be used in conjunction with ISO 22000 (2005a,b). BS PAS 220 (2008) specifies detailed requirements to be considered, including:

1. Construction and layout of buildings and associated utilities
2. Layout of premises, including workspace and employee facilities
3. Supplies of air, water, energy, and other utilities

4. Supporting services, including waste and sewage disposal
5. Suitability of equipment and its accessibility for cleaning, maintenance, and preventive maintenance
6. Management of purchased materials
7. Measures for the prevention of cross contamination
8. Cleaning and sanitizing
9. Pest control
10. Personnel hygiene

It also adds other aspects that are considered relevant to manufacturing operations:

1. Rework
2. Product recall procedures
3. Warehousing
4. Product information and consumer awareness
5. Food defense, biovigilance, and bioterrorism

The microbiological parameters that have been used as indicators in slaughterhouses are total viable count (TVC), total coliforms, Enterobacteriaceae, *Escherichia coli*, fecal streptococci, and *Aeromonads* (Gill and McGinnis, 1999; Algino et al., 2009), while *Listeria* sp., enterococci and bifidobacteria have also been suggested for this purpose (Gill and Jones, 1995; Dencenserie et al., 2008). On the other hand, meat pathogens that have been related in the past to food-borne diseases are *Salmonella*, *E. coli* O157:H7, non-O157 STEC *E. coli*, *Listeria*, *Campylobacter*, *Clostridium perfringens*, and *Yersinia*. The most important are *E. coli* O157:H7, non-O157 STEC *E. coli*, and *Salmonella* (Koohmaraie et al., 2005), mainly found in ruminants' meat.

3.2.1 GOOD MANUFACTURING, GOOD HYGIENIC PRACTICES, STANDARD OPERATING PROCEDURES

Sanitation standard operation procedures (SSOPs) were first implemented in the meat and poultry industries when they came under HACCP regulations. All current indications are that these procedures will be implemented in the egg processing industry. It has been reported that bacterial counts for the surfaces of washed eggs correlate with counts for equipment surfaces and wash water (Moats, 1981). Furthermore, the major contamination source for wash water was found to be the eggs, not the equipment.

The primary sources of contamination in a processing facility have been determined to be direct and indirect contact surfaces, water, air, and personnel (Slade, 2002). Drains, transportation equipment within the plant, and maintenance equipment were also identified as possible sources of contamination during processing. An audit of a processing plant's sanitation program can give a company a better understanding of the program's effectiveness. There are publications that explain sanitation audits (Vasavada, 2001) and rapid methods available for sanitation sampling (Russell, 2001). Furthermore, effective cleaning is not always achieved during sanitation. Many processing plant personnel do not read labels on disinfectants used at the facility (Powitz, 2002).

SSOPs are an integral component of process control and are often the first step in the implementation of food safety regulations. Jones et al. (2001) assessed and compared the efficacies of sanitation programs used in a variety of shell egg processing facilities. In-line, off-line, and mixed operations were evaluated.

Sixteen direct or indirect egg contact surfaces were sampled in various shell egg processing facilities in the southeast United States. Samples were collected at the end of a processing day (POST) and again the next morning before operations began (PRE). Total aerobic plate counts (APCs) were obtained and *Enterobacteriacae* were enumerated. No significant differences ($P > 0.05$) between

POST and PRE bacterial counts were found for the 16 sampling sites. In general, high APCs were found on the wall of the recirculating water tank, both POST and PRE. APCs for the rewash belt were considerably high for all plants sampled. APCs were also high for the vacuum loaders. APCs for washers and washer brushes were relatively low for most plants sampled. PRE and POST levels of plant sanitation, as determined by direct microbial plating, did not differ significantly (Arvanitoyannis et al., 2009).

While it appears that more aggressive cleaning practices are warranted for the shell egg industry, it is also important to determine whether this industry should be held to the same sanitation standards as the meat and poultry industries. Although shell eggs are raw products, bacterial counts for the surfaces of washed eggs are much lower than those for raw poultry carcasses (Lucore et al., 1997). The natural antimicrobial aspects of the egg also help to prevent the proliferation of organisms.

3.2.2 GOOD MANUFACTURING PRACTICES

Within the food factory there should be management procedures aimed at the application of codes of good manufacturing practices (GMPs) (Harrigan and Park, 1991). GMPs provide general rules for the manufacture, handling, and preparation of various kinds of food products. It aims at safeguarding good hygienic and sensory quality traits and may be regarded as an obligation to bestow great care upon production. GMP principles have been developed over a number of years and are now regarded as the foundation on which the production of safe food is based (Upmann and Jacob, 2004). In July 2002, the Food and Drug Administration (FDA) formed a Food GMP Modernization Working Group to examine the effectiveness of current food; GMPs have brought about many changes that have occurred in the food industry since 1986. The Working Group has been researching the impact of food GMPs on food safety as well as on the impact (including economic consequences) of revised regulations. Part of the group's current effort, as of June 2004, is to find out which elements of the food GMPs are critical to retain and which should be improved. FDA is now holding public meetings to obtain public comments to assist in this effort (U.S. Food and Drug Administration, 2004). In the United Kingdom, the Institute of Food Science and Technology publishes guides to GMP (IFST, 2007).

Industries that have adopted the GMPs have the following results, among others:

1. Better quality, safer products, decrease in incidence of consumer complaints
2. Better, more agreeable, cleaner, and safer working environment
3. Greater employee motivation and productivity and improved psychological conditions. (da Cruz et al., 2006)

3.2.2.1 Buildings and Facilities

Establishments should preferably be located away from environmentally polluted areas, areas subject to flooding, areas prone to infestations of pests, and areas where wastes cannot be removed effectively.

Buildings and facilities should be designed to facilitate hygienic operations by means of a regulated flow in the process from the arrival of the raw material to the finished product.

Adequate supply of potable water, natural gas, electricity, fuel, and other utilities should be provided to allow satisfactory operation.

Moreover, adequate drainage and waste disposal systems should be present along with appropriate ventilation systems to minimize odors and vapors, air conditioning, and dust control. Ventilation systems should also be screened to prevent rodent and insect access and should be readily cleanable.

The layout, design, and construction of food premises should permit adequate cleaning/disinfection, protect the product against dirt, particulates, and foreign material; prevent the formation of condensation and mold on surfaces; protect against cross contamination between and during operations; and provide suitable environmental conditions for hygienic processing, and storage of raw materials and products.

Ceilings and overhead fixtures should be smooth, waterproof, impervious, with no ledges and overhang walls to prevent accumulation of dirt, molds, and condensation, and reduce shedding of particles. Light fittings should be covered.

Floors should be made of materials that are impervious, durable, resistant to grease, cleaning agents, and to biochemical and microbial attack, free from cracks, crevices, nonslip surface, easy to clean.

The surface of floors, walls, and partitions requires the use of impervious, nonabsorbent, washable, and nontoxic material.

Floors should have a nonslip finish. They should be constructed in such a way that the liquid flows to drains, and drains should be fitted with stainless steel perforated traps to retain extraneous matter.

Doors should generally be either opened automatically, or provided with heavy-duty plastic strips which permit easy access by personnel and essential traffic (e.g., fork-lift trucks).

Roofing is normally flat or slightly pitched and is supported by trusses or beams can be a source of natural light; opening windows is not recommended.

Windows and sills should be impervious, easily cleanable, and constructed in such a way to avoid accumulation of dirt. Sills should be sloped to avoid their use as shelves.

Adequate lighting in hand-washing areas, dressing and locker rooms, toilet, and rooms where food is examined, processed, or stored should be provided.

Finally, pest control (insects, flies, cockroaches, moths and beetles, rodents) should exist (Marriott, 1997; Corlett, 1998; FAO, 1998; Forsythe and Hayes, 1998; Jarvis, 1999; McSwane, 2000; Arvanitoyannis and Kassaveti, 2009).

3.2.2.2 Equipment

- All surfaces in contact with food should be smooth, not porous, inert, visible for inspection, accessible for manual cleaning, made of nontoxic material, corrosion-resistant, designed to withstand extended use, cleaning compounds, and sanitizing agents.
- Equipment should be readily disassembled for inspection and manual cleaning, designed to protect the contents from external contamination, sanitized with approved sanitizers, and rinsed with potable water if required, equipped with rounded corners and edges (Corlett, 1998; Forsythe and Hayes, 1998; McSwane, 2000; http://www.hi-tm.com/RFA/Mfg-ppsm/3-prereq-5-06.pdf, [Accessed December 2014]).

3.2.2.3 Equipment Supports

Equipment supports include construction materials, structural shapes, and their arrangement.

The most common construction materials are austenitic stainless steels such as AISI 304, 316, and 316L that display good resistance to corrosion in most environments except those containing high chloride content, especially under acidic conditions. Products with high chloride content require special metals such as titanium or alloys such as hastelloy.

Frequently used elastomers used for seals and gaskets include:

Nitrile rubber, nitril/butyl rubber (NBR), ethylene propylene diene monomer (EPDM) (not resistant to oils and fats), silicone rubber, and fluoroelastomer (Viton).

For dry process equipment mild steel supports are very satisfactory.

Structural steel members have the following shapes:

3.2.2.4 Angle Iron

When used in the horizontal plane, the vertical leg should point down. It can also be used in a horizontal plane with the heel pointing up.

3.2.2.5 Channel

Channels should be used with the web in the vertical plane or in the horizontal plane with flanges pointing down.

3.2.2.6 Beams

I or H beams should be used with the web in a vertical plane.

3.2.2.7 Tee

The vertical leg of the tee should be pointing down.

3.2.2.8 Tubing

Round tubing has the advantage of reducing flat surface areas where product spills accumulate. All open ends must be sealed.

3.2.2.9 Formed Channel

Formed channel with a J-like hook at the base of each flange should not be used in a horizontal plane. Dust, dirt, and product spills can accumulate in the J-like hook area (Imholte, 1994).

3.2.2.10 Reliability, Availability, and Maintainability of Equipment

Reliability, availability, and maintainability (RAM) of the equipment play an important role in controlling both the quantity and quality of the products. Ebeling (1997) believed that factors affecting RAM of a repairable system include machinery (number of machines, age, arrangement of machines relative to each other, etc.), operating conditions (skill level, environmental conditions, number of operating personnel, etc.), maintenance conditions (effectiveness of maintenance staff, maintenance planning and control), and infrastructural facilities (spare parts, equipments, and tools). Zerwick (1996) pointed out, in the context of pressure vessels, that a systematic strategy based on RAM principles helps evaluate changes in inspection frequency, maintenance actions or condition monitoring strategies leading to decrease in frequency of planned shut downs, increase of time period between statutory inspections, and reduction in maintenance cost.

Liberopoulos and Tsarouhas (2002) presented a case study of speeding up a croissant production line by inserting an in-process buffer in the middle of the line to absorb some of the downtime, based on the simplifying assumption that the failure and repair times of the workstations of the lines have exponential distributions. The parameters of these distributions were computed based on actual data collected over 10 months.

Liberopoulos and Tsarouhas (2005) carried out a detailed statistical analysis on a set of field failure data obtained from a real, automated pizza production line in a large manufacturer of bakery products and snacks. The data covers a period of 4 years and 1 month. Given the extensive length of the period covered, we hope that this paper will serve as a valid data source for food product machinery manufacturers and bread and bakery products manufacturers who wish to improve the design and operation of the production lines that they manufacture and operate, respectively. It can also be useful to reliability analysts and manufacturing systems analysts who wish to model and analyze real manufacturing systems.

Tsarouhas et al. (2009a) developed a statistical analysis for deriving the reliability and maintainability distributions of the strudel production line at machine, workstation, and entire line level.

The strudel production line consists of several workstations and machines in series supplied with a common transfer mechanism and control system that have different failure modes. When a random failure occurs, the failed machine stops and forces most of the line upstream of the failure to operate without processing, whereas the material (raw, intermediate, or end product) of the line downstream may have to be scrapped due to quality deterioration during the stoppage. The failure impact is the drop of line reliability and production rate.

Descriptive statistics of the failure and repair data was computed, and the parameters of the theoretical distributions that have the best index of fit were estimated. Data collection and analysis from the line is valid for a period of 16 months. Furthermore, the reliability and hazard rate modes for all workstations and the entire production line were calculated. The models can be a useful tool to assess the current condition and to predict reliability for upgrading the maintenance policy of the production line. Then, it can be useful to find ways of improving reliability and maintainability of characteristics.

RAM analysis of the cheese production line over a period of 17 months was investigated by Tsarouhas et al. (2009b). The best fit of the failure and repair data between the common theoretical distributions was found, and the respective parameters were computed. The reliability and hazard rate modes at the entire production line were calculated as well. The models are anticipated to be a useful tool to assess the current conditions and to predict the reliability for upgrading the maintenance strategies of the production line. It was found out that (1) the availability of the cheese production line is 91.20% and went down to 87.03%, (2) the dominant four failure modes have 62.2% of all the failures of the cheese production line, and (3) the average of a failure is every 12.5 operation hours, and the mean time to repair is 66 min. This analysis will be very useful in terms of identifying both the occurring and latent problems in the cheese manufacturing process and, eventually, to solving them.

3.2.2.11 Lighting

All the installation is equipped with suitable lighting. In some cases, artificial, regulated lighting from glow lamps is present. In other cases, natural lighting is provided. In most cases in production areas, lighting fixtures are protected with a plastic cover so that there is no danger of dissemination of glass and product contamination, in the case of breakage.

3.2.2.12 Airing—Ventilation

The ventilation is sufficient and prevents undesirable accumulations of heat, steam, and dust. In most cases ventilation takes place with fans, while in other cases, such as silos, a system of automatic airing with turbines exists.

Natural or mechanical ventilation should prevent excessive build-up of heat and relative humidity, minimize the risk of product contamination, and control environmental conditions.

For example, it has been reported by Arvanitoyannis et al. (2009) that in the aviary all the booths are provided with automatic system of airing with filters that cause positive pressure. Also, in the case of extreme temperature and humidity in the booths, an automatic system of complete control is installed.

3.2.2.13 Waste Disposal

Suitable installations for the right management of waste should exist. Waste should be collected in trucks outside the booths and transported by the enterprise. Solids should be collected at a separate point outside the installation, and made into fertilizers for the fields.

Containers for waste or dangerous substances should be leakproof and made of impervious material. They should also be labeled. Containers used to hold dangerous substances should be lockable to prevent accidental product contamination.

In the case of eggs, human sewage is assembled in a cesspool that exists in the installation, whereas sewage from the candling center is assembled in stainless siphons (absence of rodents) leading to a separate cesspool from that for human sewage. For the dead birds and the not-arranged eggs that cannot be sold in the industries of pasteurization, the enterprise has manufactured a boiler system.

Waste products must be disposed of in a hygienic, environmentally responsible manner so that eggs and egg products for human consumption are protected from contamination (Arvanitoyannis et al., 2009).

- All waste material must be removed frequently from processing rooms and removed from the premises daily.
- Rejected eggs and egg products shall be disposed of in an appropriate tipping site by burial.
- Rejected eggs and egg products shall not be used as animal feed unless they are further heat treated to eliminate pathogens.
- Sanitizers must be disposed of in accordance with Environmental Protection Agency guidelines.

Dead birds shall be collected promptly and placed in waterproof, leakproof containers prior to incineration, burial, or other approved outdoor methods, away from the poultry shed.

- Litter and/or poultry manure can be removed off-site, spread on surrounding land at an effective buffer distance to the poultry shed or stored on-site in a dry weatherproof building at an effective buffer distance from poultry sheds. In the case of mobile shedding, a buffer distance is less relevant.

3.2.2.14 Hygiene Installations in Egg Manufacturing

In the enterprise, two separate spaces of lockers for personnel exist provided with closets.

The first one satisfies the needs of personnel who work in the aviary and the second, personnel who work in the candling center and in the packing area.

There should be separate areas or rooms for the following processes:

- Storage of eggs and unprocessed raw egg products
- Breaking of eggs
- Processing of eggs
- Storage of processed egg products
- Storage of additives
- Storage of cleaning and sanitizing products.

3.2.3 Sanitation

Sanitation is broadly defined as “all precautions and measures, which are necessary in the production, processing, storage and distribution, in order to assure an unobjectionable, sound, and palatable product which is fit for human consumption” (Bakka, 1997). Sanitation is not sterilization (McSwane, 2000). The first step of sanitization is the prewash, with the objective of removing gross dirt, followed by alkaline, and acid washing (to remove proteins, carbohydrates, lipids, and minerals, respectively) (da Cruz et al., 2006). This dirt usually contains microorganisms and nutrients that allow the microbes to grow (Marriot, 1997).

3.3 METHODS TO CONTROL HYGIENE

The use of microbiological analyses of surfaces has appeared as one of the tools to check good hygienic practices and to maintain a high level of hygienic production of foods.

Various types of surfaces are used today in the food industry, such as plastic, stainless steel, glass, and wood. These surfaces are subject to contamination by microorganisms responsible for the cross contamination of food by contact with working surfaces. The HACCP-based processes are now widely used for the control of microbial hazards to prevent food safety issues. This preventive approach has resulted in the use of microbiological analyses of surfaces as one of the tools to control the hygiene of products (Ismail et al., 2013).

A method of recovering microorganisms from different solid surfaces is is essential to control hygiene. No regulation exists for surface microbial contamination, but food companies tend to establish technical specifications to add value to their products and limit contamination risks. They present the most frequently used methods: swabbing, friction or scrubbing, printing, rinsing or immersion, sonication, and scraping or grinding and describe their advantages and drawbacks. The choice of the recovery method has to be suitable for the type and size of the surface tested for microbiological analysis. Today, quick and cheap methods have to be standardized and be especially easy to perform in the field.

In the food industry, methods and techniques to recover microorganisms from surfaces have been developed, but parameters such as the diversity of experimental conditions or samples hinder the choice of the best methods.

Standardized recovery methods for microorganisms on rough surfaces, such as wood that have specific porosity are still lacking. The international standard ISO 18593:2004 presents two techniques currently used for smooth surfaces but does not specify methods for scraped plastic or porous material like wood, for instance.

3.3.1 Street Foods, Hygiene, and Crisis Management

Street foods (SFs) are now sold around the world (WHO, 2010).

In China, you can enjoy a wide variety of SFs such as yangrou paomo (Pita bread soaked in lamb soup), goubuli baozi (a famous brand of steamed stuffed bun), lanzhou lamian (a type of handmade noodle), and other local delicacies.

It has been proved that improper food handling, poor personal and environmental sanitation, and inadequate infrastructure such as drinking water supply and garbage disposal are the main risk factors associated with SFs (WHO, 2010; FAO, 2011). Food safety knowledge and sanitation practices of SF vendors in different countries have been widely studied (Gorris, 2005; Grunert, 2005; von Holy and Makhoane, 2006; Omemu and Aderoju, 2008; Abdalla et al., 2009; Choudhury et al., 2011; Rane, 2011; Kealesitse and Kabama, 2012), and it has been shown that the majority of SF vendors lack appropriate knowledge about the hygiene and sanitation practices, which makes it more difficult for them to ensure the SF safety and quality. In China, the overall food safety has been greatly improved, and there are some ongoing efforts to raise public food safety awareness.

However, food safety crimes such as meat adulteration and contaminated bean sprout processing still occur frequently, arousing public panic about food safety issues (Forum on Health, Environment and Development, 2014).

SFs often reflect traditional local cultures and offer a unique cultural experience to tourists and even to ordinary consumers. With the increasing pace of globalization and tourism, the safety of SFs has become one of the major concerns of public health. There is an urgent need in China to establish a national program to raise the food safety awareness and knowledge of SF vendors.

The safety and hygiene status of SFs in Shijiazhuang city was investigated by Liu et al. (2014). Data on the SF vendors' food safety knowledge and practices, inspectors' regulatory capacity, and consumers' purchasing habits were collected. Potential hazards in the preparation and sale of SFs were analyzed, and strategies for ensuring the safety of SFs were recommended. The study showed that the SF safety risks are primarily due to the use of unqualified raw materials encouraged by ineffective inspections, poor infrastructure at the SF vending sites, and lack of sanitation knowledge among SF vendors. In order to prevent SFs from being contaminated, more stringent and effective routine supervision and food safety practices should be adopted and the environmental conditions and facilities should be improved. Regular training in food processing technology, food safety knowledge, and practical food safety evaluation methods should also be strengthened among SF vendors and food safety inspectors.

Leong and Hancer (2014) examined foodservice managers' perceived level of importance and performance relative to preparedness, implementation, response, recovery, organizational effectiveness, and organizational development related to resolving a food safety, food-borne illness, or food biosecurity crisis. Factor analysis identified three underlying dimensions: (1) sanitation regulations and protocol, (2) foodservice production and sanitary practices, and (3) knowledge of food pathogens. The importance–performance analysis revealed that conformance to sanitary standards was needed to maintain best practices to guard against food-borne illness and food security criticalities. The results emphasized the importance of designing a workable preparedness sanitation management plan that would uphold high operational standards that would facilitate preserving the quality of food and protecting the consumer from experiencing a food-borne illness criticality. Multiple regression results indicated that sanitation management factors had a positive effect on organizational development and organizational efficiency in facilitating a crisis management plan.

Strengthening food safety measures in schools would improve the protection of students and school staff from outbreaks of food-borne illnesses. Liz Martins and Rocha (2014) evaluated the nonconformities in prerequisite programs implementation at school foodservice.

This descriptive study was conducted between October and December (2011) involving 88 school foodservice units at a Portuguese Municipality. Each school foodservice was audited using a hygiene-sanitary checklist including 146 statements by the same nutritionist. Prerequisite program procedures were evaluated after categorization as standard operating procedures, sanitation and hygiene procedures, and procedures for receiving and storing foods. Food safety procedures and practices were compared between cooking and distribution food units and according to the number of meals produced daily.

Nonconformities were detected concerning several safety practices such as incorrect thawing, temperature control of freezing equipment, and cooked food, segregation between stored food and detergents and disinfectants, and procedures used for handling waste, cleaning, and sanitizing.

Only 40% of the foodservice units evaluated recorded the temperature of cooked meals. All foodservice units audited revealed nonconformities in cleaning and disinfection practices of equipment and facilities. Adequate labeling of stored items was properly done at 85% of units. Handling waste was undertaken incorrectly by all food handlers in this survey. Reasons identified for inappropriate personal hygiene practices were mainly lack of resources and conditions for correct hand washing procedure.

No significant relationship was found between food safety procedures and practices and the number of meals produced or served. Distribution food units failed safety checks in aspects such as food-handling practices and temperature control of cooked meals more frequently than cooking units.

Results indicate an urgent need for food safety training of personnel and point out to the need of continuous supervision by managers. It is also important to define standard operating procedures that include food safety components and improve employee motivation and responsibility.

De Oliveira et al. (2014) evaluated and classified the sanitation and hygiene conditions in Porto Alegre/Rio Grande do Sul (RS) public schools using an analysis of surfaces that come in contact with food and a food safety checklist validated for the school environment. The following mesophilic heterotrophic bacteria count medians were observed on each piece of equipment or utensil studied: countertops, 27.3 colony-forming units (CFU)/cm^2; cutting boards, 15 CFU/cm^2; blenders, 14.5 CFU/cm^2; dishes, 2 CFU/cm^2; and refrigerators, 1 CFU/cm^2. The median of the surface measurements analyzed by adenosine triphosphate (ATP) bioluminescence was less than 40 relative light units (RLU)/100 cm^2 for all equipment and utensils, except for the countertop surface which had a median of 52.5 RLU/100 cm^2. The data from 120 schools showed that 33%, 64%, and 3% were classified as high, regular, and low health risk, respectively. The results showed that most schools were exposed to cross contamination with failures especially with regard to environmental hygiene and procedures. Failures related to both factors potentially raise the risk of outbreaks in this environment. The scores used enabled the classification of school meal services and the identification of the points that need more attention. Intervention strategies that target different aspects of food handling, not only knowledge, may be promising in this scenario, which may address problems that mainly involve the food handler and promote changes in food handling practices.

Rotariu et al. (2014) analyzed the current practices used by the Scottish smoked salmon industry that will affect the likelihood of *Listeria monocytogenes* contamination in products. Sixteen visits to smoked salmon premises were conducted between June and November 2011, and interviews were carried out based on a questionnaire. The results indicate that most processors carry out appropriate food safety practices, but some improvements are needed in order to minimize the risk of *Listeria* contamination. It was found that the larger processors achieved better temperature control than the smaller processors.

Approximately half of the visited premises needed to improve their refrigerated storage. The risk of ceiling condensation dripping onto product was a common problem, but the smaller premises were the most affected. Small FBOs require additional information on how cleaning and sanitation throughout the process can reduce contamination of the final product. Furthermore, guidance describing the best way of determining shelf life was requested by small processors. Fifty six percent of the smoked salmon processors (mostly large and medium size) tested the product for *L. monocytogenes* and its prevalence ranged widely (0%–12%) between processors. Those processors having the highest *Listeria* prevalence were also those most concerned about what microbiological testing should be carried out and how to evaluate the quality of their products. Most processors rarely exceeded (i.e., once every several years) the statutory limit set by the European Union (>100 CFU/g or presence in 25 g). The small producers did not undertake product testing for *Listeria* because of the high test costs and lack of technical expertise. Hence, it was concluded that sharing expertise between producers, especially to smaller processors, would be beneficial in terms of consumer protection.

3.3.2 CIP, Hygienic Design, and Sanitation

Cleaning and sanitization of process plants is one of the most critical aspects of food processing to ensure the health and safety of the consumer. Proper cleaning is essential for the production of high quality food products especially those with extended shelf life. Cleaning-in-place (CIP) is now a very common practice in many dairies, processed food, beverage and brewery plants replacing manual strip down, cleaning, and rebuilding of process systems. The primary commercial advantage is a substantial reduction in the time that the plant is out of production and the ability to utilize more aggressive cleaning chemicals in a contained environment that cannot be safely handled with manual cleaning. The definition of CIP is given in the 1990 edition of the Society of Dairy Technology manual "CIP: Cleaning-in-Place" as "The cleaning of complete items of plant or pipeline circuits without dismantling or opening of the equipment, and with little or no manual involvement on the part of the operator. The process involves the jetting or spraying of surfaces or circulation of cleaning solutions through the plant under conditions of increased turbulence and flow velocity."

CIP is not simply the provision of a CIP bulk unit but the integrated process and hygienic design of the complete process. A CIP system will consist of vessels for preparation and storage of cleaning chemicals, pumps, and valves for circulation of the CIP chemicals throughout the plant, instrumentation to monitor the cleaning process, and vessels to recover the chemicals.

CIP is a methodology to remove product residues from a process plant. It is not a means of eliminating microorganisms from the system. This is the role of post-CIP sanitization or sterilization processes using either chemical sanitizers or the application of heat to destroy microorganisms (Hasting, 2008; SPX, 2013).

The latest development in CIP technology is the use of electrochemically activated water (ECA) to produce both cleaning and sanitization solutions at considerably lower cost than normal chemicals. ECA water is produced through the electrolysis of a solution of sodium chloride. In the absence of a permeable membrane, a mixture of anolyte and catholyte will be produced. This is essentially a mixture of sodium hydroxide and hypochlorous acid. When a permeable membrane is positioned between the electrodes, it is possible to separate the two electrolytes. A variation of the flow rate past the respective electrodes enables different concentrations of the two electrolytes to be obtained.

Hygienic design criteria of a process plant have been extensively documented by the European Standard EN 1672-2 (2005), the European Hygienic Design and Engineering Group (EHEDG) and also by such bodies as the United States 3-A authority. The materials of construction of the entire process plant must be resistant to the food and cleaning chemicals to be applied, be nontoxic, smooth, nonporous, and free from crevices.

Hygiene requirements refer to materials of construction, surface finish, joints, fasteners, drainage, internal angle and corners, dead spaces, bearings and shaft entry points, instrumentation, panels, covers, and doors.

Standards are important determinants of quality in fabrication. A decade ago, welding for pharmaceutical applications would have simply been qualified to American Society of Mechanical Engineers (ASME) Section IX of the Boiler and Pressure Vessel Code with reference to ASME B31.3. This assured the structural integrity of the weldments but was not specific about the quality of the weld surface on the inside of the tubing which is essential for bioprocess applications. The 3-A sanitary standards, first implemented by the dairy industry in the United States in the 1950s, offered guidelines for materials and fabrication techniques that mandated fully penetrated welds in sanitary piping systems, and attempted to set guidelines for workmanship and quality control recognizing that weld quality was a determining factor in the ability to maintain a piping system in a sanitary or hygienic condition. However, with the emerging biotechnology industry, it was felt that new standards were needed to meet the higher quality demands for the more complex, often delicate, and very costly bioengineered products. In particular, it was felt that there was a need for design criteria for equipment to enable it to be effectively cleaned and sterilized and an emphasis on assuring weld surface quality once the requirement for strength was met. A need for standardized definitions also was recognized as well as the need to integrate existing standards for vessels, piping, appurtenances, and other equipment for the bioprocess industry without infringing on those other standards. In response to the special needs of the biopharmaceutical industry, the ASME has developed a new standard to provide guidelines for the design and fabrication of facilities in which pharmaceutical products are manufactured by means of bioprocess technology.

The new ASME Bioprocessing Equipment Standard, ASME BPE-1997, was released in October 1997. The BPE Standard applies to all parts of equipment and piping that contact either the product, raw materials, or product intermediates during process development, scale-up, or manufacturing and all equipment systems that are a critical part of product manufacture. This includes systems such as water-for-injection (WFI), clean steam, purified water, ultrafiltration, and intermediate product storage. Piping systems or parts of the system that do not contact the finished product are not covered by the BPE Standard. Pressure vessels and steam-sterilized systems or any other systems which require pressure operation must conform to all applicable requirements of ASME Section VIII and ASME B31.3 Process Piping.

A key feature of the BPE Standard is the concept of hygienic design, where hygienic is defined as “of or pertaining to equipment and piping systems that by design, materials of construction, and operation provide for the maintenance of cleanliness so that products produced by these systems will not adversely affect human or animal health.” In keeping with this concept, the design part of the standard had as its objective to describe and outline accepted practices which have been shown to result in the fabrication of bioprocessing equipment that is both cleanable and sterilizable. It makes the distinction between preferred, recommended, and not recommended designations for particular designs and fabrication practices.

Bioprocess equipment is generally designed to be CIP rather than being disassembled for cleaning (cleaned-out-of-place or COP). The BPE Standard addresses only automated or manual CIP processes and automated steam-in-place (SIP) processes, but not hot water, 176°F (80°C) sanitizing, or other methods of sterilization. In order for CIP and SIP to be effective, the inner surfaces of piping and equipment must be smooth and free of crevices so that it is cleanable and resists colonization by microorganisms. Equipment also must be designed and fabricated so that deadlegs are held to an absolute minimum, where a deadleg in a piping system is defined as a pocket, tee, or extension from a primary piping run that exceeds a defined number of pipe diameters (L) from the ID of the primary pipe (D).

EU Council Directive 2006/16/EC on machinery reports that machinery intended for use with agri-foodstuffs or with cosmetics or pharmaceutical products must be designed and constructed in such a way as to avoid any risk of infection, sickness, or contagion.

Hygiene rules say that

- All surfaces, including their joinings, must be smooth and must have neither ridges nor crevices which could harbor organic materials.
- Projections, edges, and recesses must be minimized.
- All surfaces in contact with food must be easily cleaned and disinfected where possible after removing easily dismantled parts. Inside surfaces curves must be radiused to facilitate cleaning.
- Liquids, gases, and aerosols derived from foodstuffs and cleaning should be completely discharged.
- Design and construction should prevent the entry of liquids or animals and prevent accumulation of soil in areas that cannot be cleaned.
- Design and construction should be such that no ancillary substances (e.g., lubricants) can come into contact with foodstuffs. Compliance should be checked.

ISO 14159:2002 also reports on the safety of machinery—hygiene requirements for the design of machinery.

Hygiene level 5 reports that machinery which conforms to the requirements of this standard will prevent microbial ingress and has been designed for a specific treatment to free the equipment from relevant microorganisms.

European Community Regulation No. 1935/2004: deals with materials and articles intended to come into contact with food. This regulation reports that food contact materials shall be safe. They shall not transfer their components into the food in quantities that could endanger human health, change the composition of the food, or deteriorate its taste or odor.

Seventeen groups established were: active and intelligent materials, adhesives, ceramics, cork, rubbers, glass, ion-exchange resins, metals and alloys, paper and board, plastics, printing inks, regenerated cellulose, silicones, textiles, varnishes and coatings, waxes, and wood.

FDA Regulations CFR Title 21 reports similar findings.

There is a positive relationship between surface finish (roughness average) and cleanability. Diamond stylus measures roughness average.

- Equipment should be installed so that all product contact surface are self-draining and no soil can drip, drain, or diffuse into the product area from the outside.
- Covers on equipment or drip trays under motors must be self-draining away from the product.
- Covers may be removable for cleaning or if they are hinged, the design must be easily cleanable and avoid the accumulation of soil.
- No liquids should remain in closed piping systems and piping should slope 3° toward draining points.
- Dead areas or sharp corners where soil can accumulate must be avoided.

Hygienic design validation includes

- 2/3 dimensional drawings
- Computer-aided CFD modeling
- Equipment visualization and inspection
- Third-party approvals
  - EN 1672, ISO 14159, EHEDG, 3-A
- Cleanability tests (primarily for closed equipment)
  - Microbiological tests, organic tests, commissioning tests

- Specific tests
    - Pasteurizability, sterilizability, and bacterial ingress (Holah, 2014)
- EHEDG certification

Adequate draining (sloping pipework, eccentric reducers, correctly designed tank bottoms, and good pipework support) should be present in the processing plant. The process plant should drain to avoid microbiological growth and also to avoid potential corrosion. Residues of product and/or cleaning fluids can become further concentrated in a heated environment. This applies especially to chloride solutions where a level in excess of 50 mg/L can become highly corrosive.

Vessels with correct internal angles/corners and no dead areas. The welding seams of the vessels should not be in the corners but beyond the corner. Corners should preferably have a radius in excess of 6 mm but as an absolute minimum 3 mm.

Angles and corners of the process plant should be well radiused to facilitate cleaning (Hasting, 2008).

When designing a CIP system, the following information is necessary:

Type of soil, amount of soil, and condition of soil.

The main soil types are as follows:

- Fats (animal, vegetable, and mineral)
- Proteins (build-up from amino acids)
- Carbohydrates (sugars such as glucose and fructose, and polysaccharides such as cellulose, starches, and pectin)
- Mineral salts (normally calcium salts)

The complexity of some soils can be illustrated by soils found in a dairy plant:

- Milk remaining in a pipeline
- Air-dried films of milk
- Heat-precipitated milk constituents (protein and milkstone)
- Fat
- Hard-water salts
- Miscellaneous foreign matter

Hygienic design is an essential factor when choosing new equipment or designing a new plant (NORM CEN 1672-2, 1997; NORM DIS 14159, 1999). The hydrodynamic effects are a major parameter in the definition of the cleaning efficiency and are governed by the flow rate and equipment geometry. Authors have shown that the wall shear stress is the most suitable criterion governing the removal of colloidal particles and microorganisms (Sharma et al., 1992; Visser, 1995; Grasshoff, 1997; Hall, 1998). However, such a criterion is far from being sufficient to explain all the components of the cleanability efficiency.

Lelievre et al. (2003) demonstrated the need for hygienic design to significantly improve food safety. A three-way valve was contaminated with *Bacillus* spores, isolated from a dairy production line, and then suspended in custard. The valve was cleaned by a CIP procedure, including both alkaline and acid phases. The residual localized contamination was assessed directly on the internal surfaces in contact with the food product. Wall shear stress was measured in selected zones by an electrochemical method. Rubber materials (seat areas) are usually considered to be poorly cleanable, yet were found to be more cleanable than adjacent stainless steel zones. This observation emphasizes the importance of the geometry on the cleanability level and the flow pattern during the cleaning process. Despite its low level, the contribution of the mean wall shear stress, together with its fluctuation rate, was demonstrated in a complex piece of equipment. This underlines the importance of the flow pattern in machinery and more generally in production systems which use automatical CIP.

In the upper part of the valve, cleanability was ensured by higher values of local mean wall shear stress, while near its outlet the same cleanability was obtained due to a wide variation in wall shear rates.

Cross contamination of ready-to-eat (RTE) food by food-borne pathogens is a major concern in food processing and preparation areas in the retail sector as well as in hospital and geriatric care facilities. Powered slicers used to slice meats, cheeses, and vegetables are among the most difficult items to clean and are probably the most microbiologically hazardous pieces of equipment used in food preparation (Powitz, 2009).

The cleaning and sanitizing of slicing equipment is particularly important in senior living facilities. Outbreaks of gastroenteritis at long-term care facilities have been associated with *Salmonella*, *Campylobacter*, *Staphylococcus*, *Escherichia*, and *Clostridium* (Standaert et al., 1994; Tallis et al., 1999).

Persistent contamination of deli meat slicers has been attributed to the ability of many bacteria to form biofilms as well as the texture of the food contact surface, the texture of the food product, and the composition of the food (Sheen and Hwang, 2010; Crandall et al., 2011; Koo et al., 2012). The persistence of many pathogens is also influenced by the competitive inhibition of nonpathogenic bacteria that may be left on the equipment after sanitization (Koo et al., 2013).

Mertz et al. (2014) analyzed the microbial diversity and total microbiological ecology of different niches on eight deli meat slicers using standard plate counts as well as culture-independent PCR-denaturing gradient gel electrophoresis (DGGE) analysis. Using APCs it was determined that areas underneath the slicer and on the back plate had the highest total bacterial populations. There was a slight similarity between total APCs by slicer and the number of bacterial genera/species determined by DGGE. The DGGE analysis demonstrated that members of the genus *Pseudomonas* were the most common bacteria to be found on slicers. This may serve as an estimate of the effectiveness of current cleaning and sanitizing practices to remove biofilms, a possible role for competitive inhibition in preventing colonization by pathogens and an indication of the range and diversity of nonpathogens on these food contact surfaces.

3.3.3 CHEMICALS—SANITIZERS

In the food industry, the most common form of fouling is the deposition of proteins. These are nearly always removed by hot alkali (caustic soda) assisted by wetting agents that break up the protein into water-soluble units. Typically 2% caustic soda will be used at temperatures up to 85°C. For highly fouled surfaces up to 4% can be applied. Milkstone and calcium deposits are easily removed by the use of a dilute mineral acid. Nitric acid is the most common although phosphoric acid can also be used. Typically, 0.5% nitric acid at temperatures up to 50°C is used. Over this temperature, heat exchanger gaskets can be adversely affected. Hydrochloric or sulfuric acids should never be used (SPX, 2013).

Chemical detergents include alakalis, acids, and oxidants.

Alkalis (e.g., caustic soda, silicates, and orthophosphates)

- Emulsify oils and fats
- Dissolve proteins, starch, and fats (i.e., organic soils)
- pH 8–14, usually pH10 (alkaline) to pH13+ (caustic) at working strength
- Kill bacteria (under the right conditions)

Acids (e.g., hydrochloric and phosphoric)

- Dissolve scale, rust (i.e., mineral or inorganic soils)
- pH 1–6, usually pH 2–4 at working strength

Oxidants (e.g., hypochlorite, peroxide, and nitric acid)

- Help dissolve protein, starch, and tannin
- Kill bacteria (under the right conditions)

Special formulations have been developed by detergent manufacturers containing added components such as sequestrants. A typical sequestering application is the solubilization of calcium and magnesium salts using EDTA (ethylenediaminetetra-acetic acid) to prevent precipitation by alkaline detergents.

Among the chelating agents, polyphosphates prevent the precipitation of calcium and magnesium carbonates in hard waters by forming complexes with soil components, avoiding their deposition on the equipment surfaces.

Due to the limitations of soaps in hard water, the synthetic detergents that can be used are composed of sodium salts of sulfates or alkyl benzene sulfonic acids.

Quaternary ammonium derivatives can present germicidal properties, as is the case of dodecyl–dimethyl–benzyl ammonium chloride and (*p*-(diisobutyl)phenoxy)ethoxy)ethyldimethylbenzylammonium chloride. These compounds can destroy microorganisms because of their more intense germicidal effect in an alkaline medium (Ibarz and Barbosa-Canovas, 2014).

Sanitation is achieved by the use of hot water, hypochlorite, or one of the peroxide-based sterilants such as Oxonia P4. If hypochlorite (sodium) is used for sanitizing, the strength should not exceed 150 ppm free chlorine, the temperature be kept below 40°C, and the circulation time kept below 20 min. Typically, 100 ppm at 25°C for 2 min is adequate for precleaned surfaces (SPX, 2013).

Sanitizers include quaternary ammonium derivatives, that is, cationic surfactants, that are used for germicidal purposes, as in the case of alkyl dimethyl benzyl ammonium chloride or cetyl trimethyl ammonium bromide. Other compounds used as germicides are those that produce active chlorine, such as sodium hypochlorite (NaOCl) and sodium phosphate hypochlorite, as well as organic compounds that liberate chlorine such as sodium dichloroisocyanurate (Ibarz and Barbosa-Canovas, 2014).

Other chemical biocides used in the food industry include:

Biguanides, aldehydes, amphoterics, alcohols—dry and mid-shift cleaning, chlorine-releasing compounds (oxidizing), iodine compounds, and peracetic acid—80% of closed surfaces.

However, decontamination presents a challenge due to the increased resistance of pathogenic microbes to traditional sanitizers such as sodium hypochlorous acid and benzalkonium chloride (Davidson and Harrison, 2002).

Chlorine dioxide (ClO_2) is a strong oxidant widely applied for sterilization, disinfection, and wastewater treatment. It is commonly used on drinking water and for environmental disinfection. It was also recommended as a commercial sanitizer to replace electrolyzed oxidizing water (Liu et al., 2011), chlorine (Cl_2), hypochlorous acid (HOCl), and hypochlorite (OCl–) (Friedrich et al., 2009; Cruz and Fletcher, 2012).

Contact of chlorine dioxide with organic substances in food or water results in microbial resistance and inactivation, but it also produces four trihalomethane (THM) by-products, that is, chloroform, bromodichloromethane, dibromochloromethane, and bromoform.

Yu et al. (2014) developed an electrolysis method to generate high-concentration ClO_2 for tilapia fillet disinfection. The designed generator produced up to 3500 ppm of ClO_2 at up to 99% purity. Tilapia fillets were soaked in a 400 ppm ClO_2 solution for 5, 10, and 25 min. Results show that total plate counts of tilapia, decreased by 5.72–3.23, 2.10, and 1.09 log CFU/g, respectively. In addition, a 200 ppm ClO_2 solution eliminated coliform bacteria and *E. coli* in 5 min using shaking treatment. Furthermore, ClO_2 and THMs residuals on tilapia fillets were analyzed by gas chromatography/mass spectrometry (GC/MS) and were non-detectable (GC–MS detection limit was 0.12 ppb). The results conform to Taiwan's environmental protection regulations and act governing food sanitation.

Ethylene oxide has been used as a sterilizer in spices, although it can also be used as a disinfectant in processing facilities.

Hydrogen peroxide has been used as a milk preservative, and it can be used in the disinfection of surfaces, although because its germicidal power is low, it should be used in solutions in a high concentration. Ozone is another compound used in disinfection for its oxidative power. Traditionally, in the oenology industry, sulfurous anhydride has been used.

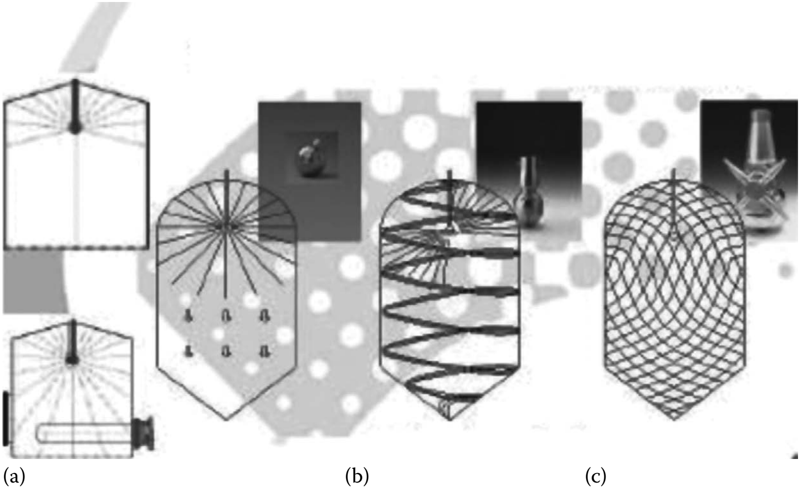

FIGURE 3.1 Vessel cleaning spray patterns: (a) static spray ball, (b) dynamic spray head, and (c) high pressure rotating spray head.

Scouring and wetting of the surfaces inside tanks and vessels is achieved by the use of spray devices. Simple spray balls are the most commonly used (Figure 3.1). However, static spray balls form a film. The holes are positioned to provide maximum impingement in areas of high fouling. These devices run at relatively low pressures (1–2 bar). Rotating jet devices must be used for vessels with a high degree of fouling or with large diameters (>3 m). These operate at higher pressures (5 bar) (SPX, 2013). Rotating spray heads need time validation.

Essential factors for disinfectants include the following:

- Do they work?
  - BS EN 1276 (bactericidal)
  - BS EN 1650 (fungicidal)
  - Practically remove organic matter, ensure correct concentration and contact time
  - Essential that disinfectants are tested at 10°C for use in chilled environments
- Are they safe?
  - Influence of change of “no-rinse” status
  - LD_{50} 2000 mg/kg rat
  - EU biocides directive
- Do they affect the food?
  - Taint test to see if they affect the food

During recent years, quite a number of studies dealt with chemical sanitizers or physical treatments (Ramos et al., 2013) such as high hydrostatic pressure (Schlüter et al., 2009) and UV- or gamma irradiation (Lescano et al., 1993; Sothornvit and Kiatchanapaibul, 2009; Poubol et al., 2010; Hassenberg et al., 2012).

Alternative sanitizers guarantee that a low microbial load, in combination with retaining high produce quality during shelf life, is of great interest.

A promising physical approach is the application of nonthermal plasma (NTP) generated at atmospheric pressure. In the physical context, the terms “nonthermal” or “cold” plasma do not refer to the actual temperature. They reflect the absence of a thermodynamic equilibrium between highly energized electrons and the far less affected main part of gas atoms and molecules, which can, in turn, result in gas temperatures near ambient (Schlüter et al., 2013). A process gas can be transformed into NTP by a strong electric field. Induced excitation and partial ionization of the process gas molecules lead to the concomitant formation of various reactive chemical species, such as ions and radicals, heat, and UV light, which together potentially react with the microbes on the food surfaces (Keener, 2008).

Different principles of plasma generation and a broad range of geometrical arrangements offer both advantages and limitations for each type of plasma source for possible fields of application and result in high variation of antimicrobial efficiency (Ehlbeck et al., 2011).

In a recent study, Fernández et al. (2013) used a commercially available nitrogen plasma jet to inactivate *Salmonella typhimurium* on fresh produce. Showing pronounced tailing effects, bacteria were reduced by 2.72, 1.76, and 0.94 log units on lettuce, strawberry, and potato, respectively, after 15 min.

Similar results were obtained after indirect treatment of romaine lettuce and cocktail tomatoes in the afterglow of a needle array at high voltage, leading to a 1.6 log unit reduction after 10 min (Bermúdez-Aguirre et al., 2013).

In the downstream of an array of dielectric barrier discharges (DBDs), Tappi et al. (2013) observed a reduced enzymatic browning and a tendentially retarded overall metabolic activity in fresh-cut apple slices, as measured up to 24 h after treatment.

In a recent study (Misra et al., 2014), further information on quality aspects was obtained after indirect in-package treatment of strawberries using DBD.

Fresh fruits and vegetables, destined to be eaten raw or minimally processed only, harbor the risk of conveying pathogenic microorganisms. Factors such as weather conditions, which favor survival or growth of microorganisms, and improper handling during cultivation or in the postharvest chain can contribute to outbreaks of food-borne illnesses. Application of chemical sanitizers or physical treatments often shows a limited efficiency or does not meet consumer acceptance. Availability of gentle and effective techniques for disinfection of fresh produce, therefore, is highly desirable. NTP treatment is a promising novel technique to reduce the microbial load on fresh fruits and vegetables. However, knowledge on practical applicability of NTP for fresh fruits and vegetables is very limited. In this study reported by Baier et al. (2014), chlorophyll fluorescence imaging (CFI) was used to elucidate suitable process parameters for application of an atmospheric pressure plasma jet (kINPen 09, INP Greifswald, Germany) on corn salad, a perishable leafy green raw material. Keeping a distance of 17 mm to the plasma jet, corn salad leaves can be treated for up to 60 s at a fixed power (8 W) and 5 L/min of argon mixed with 0.1% oxygen.

Surface temperature on leaves never exceeded 35.2°C. Antibacterial tests were performed on corn salad, cucumber, apple, and tomato and achieved an inactivation of artificially inoculated *E. coli* DSM 1116 of 4.1 ± 1.2, 4.7 ± 0.4, 4.7 ± 0, and 3.3 ± 0.9 log units, respectively, after 60 s treatment time. Additional tests with a dielectric barrier discharge plasma and indirect plasma treatment within a remote exposure reactor, fed by a microwave induced plasma torch, did not result in equivalent levels of quality retention as observed using the plasma jet.

The development of gentle nonthermal disinfection methods aims to provide the industry with new tools to actively improve the microbial status of fresh produce beyond the preventive benefits of good hygiene practices and the limited efficacy of postharvest washing. The presented study shows how cold plasma can be applied to heat-sensitive lettuce leaves without detrimental effects to product quality. The additional microbiological tests offer insights into the antibacterial capacity of cold plasma on different produce surfaces.

The results contribute to prompt the development of appropriate large-scale plasma sources to establish a new plasma-based sanitation technique for fresh fruits and vegetables, which should also be implementable into running process lines.

Both physical (hot water washing, steam vacuuming, and steam pasteurization) and chemical (e.g., organic acids, chlorine, acidified sodium chlorite (ASC), or polyphosphates) decontamination technologies have been developed and are routinely applied in the US beef industry.

There are varying reports on the effectiveness of these technologies. Gill and Landers (2003), in a study involving four US beef plants, concluded that spraying with 2% lactic acid, vacuum-hot water cleaning and trimming were generally ineffective; washing was only useful when the carcass contamination levels were very high and pasteurization with steam or hot water were the only technologies that achieved a consistent effect. However, heating water and/or generating steam are costly operations.

As part of the ProSafeBeef project, studies were undertaken to investigate the antimicrobial effectiveness of a dairy extract (LactiSAL® supplied by Westgate Ltd) against *E. coli* O157:H7, *S. enterica typhimurium* DT104, *C. jejuni*, and *L. monocytogenes* attached to different beef carcass surfaces, steak, and minced beef. Samples were inoculated with approximately 6 log10 CFU/cm^2 of each bacterium and left at room temperature for 30 min to allow for bacterial attachment. Samples were then treated with the plant or dairy extract, stored at 10°C to mimic commercial conditions, and sampled after a 3 h period. *E. coli* O157:H7, *S. typhimurium* DT104, *C. jejuni*, and *L. monocytogenes* reductions (log10 CFU/g cm^{-2}) ranged: from 0.4 (mince) to 6.2 (carcass, facia), 0.5 (mince) to 3.4 (carcass, lean), 1.1 (mince) to 4.6 (carcass, fat), and 0.4 (mince) to 2.2 (carcass, lean), respectively. These compare favorably with those reported for other chemical decontamination methods in the scientific literature (Hugas and Tsigarida, 2008), and it was concluded that LactiSAL®, a "natural," cheap, and environmentally sustainable decontaminant could find application in the beef slaughter industry.

Within a recent EU research project ("ProSafeBeef"), research on food-borne pathogens in the beef chain was conducted by using a longitudinally integrated (fork-to-farm) approach. There is not any "single intervention single chain point" combination by which the pathogens would be reliably and entirely eliminated from the chain, resulting in total prevention of pathogens in beef and products thereof at the consumption time. Rather, a range of control interventions have to be applied at multiple points of the chain so to achieve an acceptable, ultimate risk reduction. Various novel interventions were developed and evaluated during the project and are briefly summarized by Buncic et al. (2014). They include on-farm measures, risk categorization of cattle presented for slaughter, hygiene-based measures, and antimicrobial treatments applied on hides and/or carcasses during cattle slaughter, those applied during beef processing–storage–distribution, use of time–temperature integrator-based indicators of safety, and effective sanitation of surfaces.

In meat processing chain lines, the main surfaces likely to be colonized by microorganisms are essentially stainless steel (used for e.g., pipelines, hooks, and knives), plastic wares (especially Teflon found on, e.g., work plans and conveyor belts), and resins (particularly on floors).

Moreover, some hard or inaccessible-to-clean sites can exist within or on surfaces (e.g., crevices, cracks, and holes), equipments, and utensils (e.g., hollow parts, gaskets, unpolished, or worn materials); they are potential harborage niches for microorganisms which probably constitute reservoirs of the so-called persistent bacteria (Carpentier and Cerf, 2011).

Besides the physico-chemical nature of the support, conditioning due to soiling with food remnants (e.g., meat products) and/or sanitizing procedures is a crucial aspect to consider for microbial pathogen control on surfaces (Jullien et al., 2008; Quinon et al., 2010). Indeed, conditioning affects both the physico-chemical properties of the support (e.g., carbon composition, surface free energy, or Fe/Cr ratio of stainless steel) and the hygienic status by increasing the level of bacterial contamination.

It is also known that the nature of the food soils greatly influences the percentage of coverage and attachment pattern across the surface of *E. coli* O157:H7, for instance (Whitehead et al., 2010).

Currently, cleaning and disinfection products are formulations which may contain different agents (e.g., wetting, foaming, sequestering, degreasing, surfactants, and polyenzymatic cocktails) in addition to biocides. Thus, sanitation procedures use large quantities of chemical products with huge volumes of water released into the sewerage.

The future challenge is to develop ecofriendly cleaning and disinfection products without affecting food safety and improving the control and prevention of surface contaminations (Buncic et al., 2014).

Biocide residue deposition on surfaces after cleaning procedures has been considered as an important factor affecting bacterial attachment (Machado et al., 2011). This residue deposition can mainly occur after each biocide application which can build-up over a period of time, especially in dry cleaning processes (Mousavi et al., 2013). Based on several studies, residue accumulation on surfaces can alter the physico-chemical properties of both cells and surface materials in food plants over time, affecting microbial attachment to surfaces (Machado et al., 2011; Oliveira et al., 2006; Pereira et al., 2006; Wang et al., 2009).

This problem is mostly emphasized in processing environments where wet cleaning is replaced by dry cleaning. The dry cleaning process consists of regular vacuuming of the process environment followed by the application of a sanitizer often containing quaternary ammonium compounds (QACs).

Mousavi et al. (2014) evaluated the attachment of *P. putida* strains (wild type and adapted to QACs) to different surface materials frequently used in food processing. In addition to surface studies, atomic force microscopy (AFM) imaging was performed in order to image and assess deformation, localization, and attachment on the subcellular scale. Results showed that the adapted cells displayed higher adherence to the stainless steel. In addition, QACs treatment of surfaces promoted cell attachment. The results stated that the maximum cell attachment occurred on stainless steel surfaces with a rough surface property followed by polyvinyl chloride (PVC), while the cells adhered poorly to tile surface. In the case of PVC, despite having a low Ra value, high attachment level was observed. The high adhesion level of *P. putida* to PVC can be related to the sudden surface irregularities available on the surface area responsible for the entrapment of the bacteria. However, it should be noted that not only roughness but also other factors including cell and contact material hydrophobicity are considered to be influential physicochemical parameters, controlling adhesion and detachment from surfaces. For example, a significantly lower bacterial attachment was observed in resin flooring with similar roughness value to stainless steel ($P < 0.05$). From a thermodynamic point of view, resin was considered hydrophobic, while pseudomonas strains possessed hydrophilic properties. However, in the case of tile surface with hydrophilic characteristics, it is presumed that roughness property played a major role in cell attachment. AFM studies showed that in stainless steel and PVC, bacteria mostly deformed in order to be positioned in holes and crevice. Therefore, the entrapped cells could not be easily removed by washing. In contrast, in the case of tile, bacteria kept their normal shape and were spread out of surface. Therefore, they could be easily released after washing. Therefore, selection of proper construction materials and sanitation strategy plays an important role in relation to the risk of chemical/microbial contamination in different processing zones in food plants.

Recent food-borne disease outbreaks involving minimally processed tree nuts have generated a need for improved sanitation procedures. Chemical sprays and dips have shown promise for reducing pathogens on fresh produce, but little research has been conducted for in-shell hazelnuts. Weller et al. (2013) analyzed the effectiveness of three chemical sanitizers for reducing *Salmonella* on in-shell hazelnuts. Treatments of water, NaOCl (25 and 50 ppm), peroxyacetic acid (PAA; 80 and 120 ppm), and acidified sodium chlorite (ASC; 450, 830, and 1013 ppm) were sprayed onto hazelnut samples inoculated with *S. enterica* serovar panama. Hazelnut samples were immersed in liquid cultures of *S.* panama for 24 h, air-dried, and then sprayed with water and chemical treatments. Inoculation achieved *S.* panama populations of approximately 8.04 log CFU/hazelnut. Surviving *S.* panama populations were evaluated using a nonselective medium (tryptic soy agar), incubated 3 h, and then overlaid with selective media (xylose lysine deoxycholate agar). All of the chemical treatments significantly reduced *S.* panama populations ($P \leq 0.0001$). The most effective concentrations of ASC, PAA, and NaOCl treatments reduced populations by 2.65, 1.46, and 0.66 log units, respectively.

ASC showed the greatest potential for use as a postharvest sanitation treatment.

PAA, a solution made from the reaction of hydrogen peroxide and acetic acid, is approved for use on fruits and vegetables (CFR 2009a) and has shown slower reactivity to organic matter than NaOCl. Chang and Schneider (2012) found that 60 s in a spray and roller combination process using 80 ppm PAA and 25 or 50 ppm NaOCl reduced *Salmonella* on tomatoes by 5.5, 4.2, and 5.0 log units, respectively. Narciso (2005) reported that 100 ppm PAA produced a 2.1 log unit reduction of spores inoculated onto the surfaces of oranges, which was more than the 1.27 log unit reduction seen by Pao et al. (2006) when using 500 ppm PAA on in-shell almonds inoculated with *Salmonella*. ASC, a sanitizer prepared by reacting sodium chlorite with a GRAS organic acid, is approved for use on meat, poultry, seafood, and raw agricultural commodities (FDA, 2012).

3.3.4 CIP Cycles

Every CIP circuit will have its own unique sequence of operations and cycle times. The different types of cleaning in an automated operation will usually include the following operations:

- Caustic wash
- Full clean (with acid)
- Hot rinse
- Cold clean

Intermediate cleaning while maintaining sterility in the case of a UHT plant where the production run length is compromised by fouling to an extent that a high delta T is required at the heat transfer surfaces to maintain production temperatures. A high delta T can lead to a runaway situation where deposit forms at an exponential rate.

- Pulse cleans (not recommended).
- Snake cleans.
- A two stage caustic wash in the case of heavily fouled equipment—the first wash is routed to drain, while the second wash is recovered and reused.

A CIP cycle is generally made up of a combination of the following steps:

- Initial purge to recover product, either into product tanks or to a product recovery system
- First rinse using recovered water (from final flush of previous CIP cycle) to remove gross soil
- Caustic wash with or without recovery to remove residual adhering debris
- Intermediate rinse to clear caustic from the system
- Acid wash with or without recovery to remove mineral scale
- Final rinse to clear any remaining chemicals from the system
- Sanitation using heat or chemical sanitizer to destroy any residual organisms

3.4 DESIGN OF CIP BULK UNITS

The bulk unit is the heart of a CIP system. A bulk unit consists of a combination of the following:

- Bulk tanks for fresh water, recovered water, dilute caustic, dilute acid (optional), and hot water (optional).
- Product recovery tank (optional).
- CIP supply pump(s).
- As a general rule there should not be more than six circuits per CIP supply pump to avoid overloading of and/or congestion among the routes.
- Filters on each supply line to prevent blockage of the spray balls.
- CIP solution heater(s), either in-line on each circuit or as recirculation heaters on the bulk tanks.
- Restrictor valves on the pump outlets are used to reduce the flow when following a hot cycle with a cold cycle on tank cleans to prevent implosion. Alternatively pumps may be fitted with variable speed motor drives to adjust the flow rate optimally for each CIP cycle.
- Double seat ball valves on bulk tanks are used to reduce risk of accidental leakage of CIP chemicals into the rinse water stream.
- Dosing pumps for concentrated caustic and acid. Dosing pumps for sterilant with injection points on each supply line.
- Recirculation loops for sterilant circulation or break tanks.
- Conductivity transmitters for monitoring the caustic and acid strengths.

- Temperature probes in the return lines for detecting when the return temperature has reached the desired set point and the timers can be started.
- Conductivity probes in the return lines to detect the interface between rinse water and caustic or acid solutions. Also used to ensure that sterilants have been added to the final rinse water.
- Conductivity probe to detect white water when product recovery is incorporated (SPX, 2013).

All cleaning operations begin and end at the primary recirculating unit. A centrifugal return pump moves the solution back to the recirculating unit, where it is either placed back in the tank or directed into the drain. To minimize pump cavitation, the pump is usually equipped with an air vent. A control panel in the unit fully automates the system to carry out the rinsing, washing, and sanitizing.

Tanks or equipment to be spray cleaned must be properly vented to prevent them from collapsing from a vacuum condition occurring when a cold water rinse follows a hot cleaning cycle. Hence, vents of the right size should be provided. Vent size can be determined according to the 3-A Dairy Standards for storage tank design.

Round storage tanks will withstand vacuum conditions compared to square and rectangular ones that might not (Imholte, 1994).

CIP instrumentation also includes pressure gauge and valve feedback-walk the line. Walk the line means agreement of software with hardware on the plant.

CIP system types include total loss system, partial recovery, and total or full recovery system.

A full recovery system is shown in Figure 3.2.

CIP desirable features include the following:

- Compact circuits
- Avoid long pipe runs
- Good surface finish
- Minimal number of fittings
- No vertical pockets or "T" pieces (or other deadlegs)
- Avoid pipe diameter changes
- Support pipe work to avoid sagging
- Achieve natural drainage where possible (Holah, 2014).

Sterilization-in-place is carried out after CIP, prior to production.

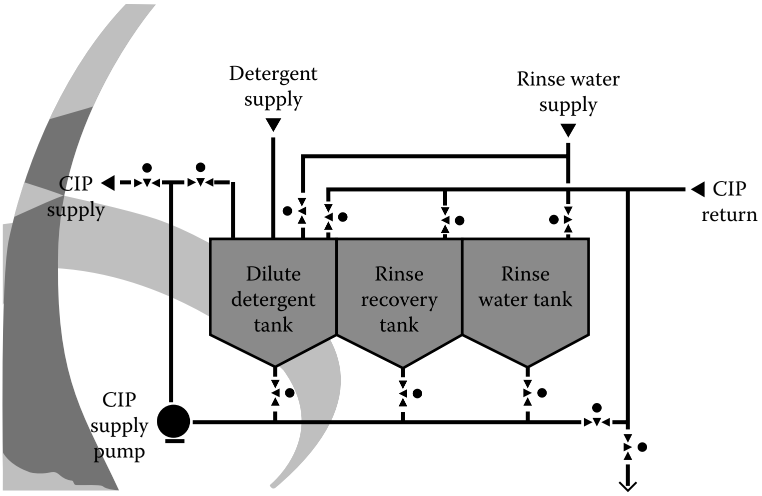

FIGURE 3.2 Full recovery system.

Typical presterilization methods (for low acid) include:

- Process plant presterilization
    - Circulation of water at 130°C for 30 min
- Aseptic tank presterilization
    - Full steam sterilization 135°C for 30 min
- Aseptic filling zone presterilization (system specific)
    - Sterilized H_2O_2, superheated saturated steam, or hot air
- Typical presterilization methods (for high acid) include:
- Process plant presterilization varies for example:
    - 95°C for 30 min
    - 99°C for 30 min
    - 120°C for 20 min
- Aseptic filling zone presterilization (system specific)
    - Sterilized H_2O_2, superheated saturated steam, or hot air (Stevens and Holah, 1993; Holah, 2014).

Experimental and theoretical work has been undertaken to investigate the CIP and fouling-removal capability of a novel patented crushed ice pigging system. The "pig" consists of crushed ice in water with a freezing point depressant. The void fraction is carefully controlled so that the ice/water mix moves like a solid plug in free-flow areas but is able flow like a fluid in constricted areas. The ice pig is able to flow in pipes with sharp bends, through orifice plates, through T's, and even in plate heat exchangers. The experimental work evaluating the "cleaning efficiency" of this system indicated that the ice pig could easily and efficiently remove "soft" fouling; using a volume of ice typically less than one-tenth of the volume of water. The fouling materials tested included jam and fats (food industry), toothpaste (personal hygiene products), and fine slit and sand (river water cooled exchangers) (Quarini, 2002).

3.4.1 CIP, *Bacillus cereus*, and Biofilms

B. cereus is a spore-forming pathogen widespread in nature and frequently isolated from food processing plants.

Indeed, spores are resistant to many of the heat treatments used in the food industry such as pasteurization, and some of the spores are able to germinate and grow at food storage temperatures (Andersson et al., 1995). Moreover, there have been frequent reports of persistent spore or vegetative cell contamination of food processing lines. This is easily explained as spores are known to firmly adhere to a wide variety of materials typically encountered during food processing (Faille et al., 2002), and vegetative cells can become embedded in mixed biofilms (Flint et al., 1997; Svensson et al., 2000). Furthermore, both forms exhibit high resistance to many cleaning procedures (Peng et al., 2002; Jullien et al., 2003).

Seven strains of *B. cereus* isolated from the environment and from patients with diarrheic symptoms were examined by Tauveron et al. (2006) from two angles: their spore surface properties, and their ability to adhere to stainless steel and to resist a CIP procedure. Their results revealed significant differences in their morphology (size of exosporium, length, and number of appendages), hydrophobic character, and surface protein composition. Most of these proteins originated in the vegetative cell and were tightly bound to the external surface of the exosporium, such as EA1 or alanine racemase. Spore adhesion properties also varied from strain to strain. The ability to adhere was higher when spores were surrounded by long appendages, while the largest spores displayed the least resistance to cleaning. These observations suggest that food processing line contamination might be due to a given type of strain with specific surface properties (long appendages and small exosporium), which would represent an increased threat under the milder processing conditions required by consumers (e.g., minimally heat-treated foods) and by legal requirements (to limit effluents caused by hygiene procedures). Elsewhere, no clear relationship of the strain characteristics to the clinical versus food-borne strains could be established.

A practical and quantitative method for assessing complex food equipment cleanability is described. After soiling a positive displacement pump by a composite model food made of custard and isolating *B. cereus* spores from a food processing line, a mild CIP procedure was carried out using basic detergents such as sodium hydroxide and nitric acid (Benezech et al., 2002). After cleaning, surfaces potentially in contact with the contaminated food were overlaid with nutrient agar containing a tetrazolium salt. Residual contaminants appeared as small red colonies, and contamination levels could be defined. A nonparametric statistical analysis was performed to compare the different areas in the pump and three cleanability levels were defined. Geometry appeared to be one of the main factors in hygiene, emphasized by the way the equipment is connected to the CIP circuit.

CIP process involves jetting or spraying of surfaces or circulating cleaning solutions through the plant under conditions of increased turbulence and flow velocity (Romney, 1990).

A feature of CIP regimes, evident in both industrial and laboratory-scale systems, is their variability in effectiveness in eliminating surface adherent bacteria (Austin and Bergeron, 1995; Faille et al., 2001; Dufour et al., 2004). This variability is not surprising as a large number of factors can influence CIP effectiveness, including the nature and age of the fouling layer, cleaning agent composition and concentration, cleaning time, cleaning agent temperature, degree of turbulence of the cleaning solution, and the characteristics of the surface being cleaned (Stewart and Seiberling, 1996; Changani et al., 1997; Lelievre et al., 2001, 2002a,b; Boulange-Petermann et al., 2004). Further, many processing lines will contain areas prone to fouling, such as dead ends, joints, valves, and gaskets (Austin and Bergeron, 1995; Wong, 1998) and surfaces whose chemistry, surface topography (pit and crack formation), and ease of cleaning change with use (Storgards et al., 1999).

In the dairy industry, CIP systems generally involve the sequential use of caustic (sodium hydroxide) and acid (nitric acid) wash steps, chemicals originally selected for their ability to remove organic (proteins and fats), and inorganic (calcium phosphate and other minerals) fouling layers, and in some instances a sanitizer step is also applied (Chisti, 1999).

A laboratory-scale, benchtop flow system was used by Bremer et al. (2006) to partially reproduce dairy plant conditions under which biofilms form and to quantify the effectiveness of caustic and acid wash steps in reducing the number of viable bacteria attached to stainless steel (SS) surfaces. Once bacteria were attached to surfaces, a standard CIP regime (water rinse, 1% sodium hydroxide at 65°C for 10 min, water rinse, 1.0% nitric acid at 65°C for 10 min, water rinse) did not reproducibly ensure their removal. Standard CIP effectiveness was compared to alternative cleaning chemicals such as caustic blends (Alkazolv 48, Ultrazolv 700, Concept C20, and Reflex B165); a caustic additive (eliminator); acid blends (nitroplus and nitrobrite); and sanitizer (perform). The addition of a caustic additive, eliminator, enhanced the biofilm removal compared to the standard CIP regime and further increases in cleaning efficiency occurred when nitric acid was substituted with nitroplus. The combination of NaOH plus eliminator and nitroplus achieved a 3.8 log reduction in the number of cells recovered from the stainless steel surface. The incorporation of a sanitizer step into the CIP did not appear to enhance biofilm removal. This study has shown that the effectiveness of a "standard" CIP can possibly be enhanced through the testing and use of caustic and acid blends. There are many implications of these findings, including the development of improved cleaning regimes and improved product quality, plant performance, and economic returns.

The germicidal efficacy of six sanitizers against food-borne bacteria and spores (*E. coli*, *S. typhimurium*, *S. aureus*, *P. aeruginosa*, and *B. subtilis* spores) and the effect of these sanitizers in simulation of cleaning and sterilizing-in-place were evaluated by Ding and Yang (2013). The most effective sanitizer solution was PAA, which was capable of reducing *E. coli* populations by more than 5 log CFU/g at 60 mg/L.

The rest of the sanitizers resulted in a population reduction of less than 5 log CFU/g at 150 mg/L in phenol coefficient test.

The effect of acid-anionic sanitizer (ABF) and PAA against *E. coli* and *S. aureus* was affected by both the pH and temperature.

The synergism of sanitizers on germicidal efficacy has also been examined in this study. It was observed that the combination of PAA and ABF presented high efficacy against spores of *B. subtilis*.

However, 0.2% PAA in combination with 0.1% ABF reduced 7.6 log spores. The simulation of CIP and sterilization-in-place (SIP) revealed that most of organisms were eliminated during CIP.

B. subtilis spores holding strong attachment and heat resistance could be eliminated with the combination of 0.2% PAA and 0.1%ABF. These findings showed that germicidal efficacy against bacteria and spores was affected by the type of sanitizer, concentration, and environmental conditions, which provides the guidelines in lowering the concentration of sanitizers through synergistic activity and further may be valuable references for sanitation to compete the cycle of good hygiene practices in a proper CIP/SIP process.

CIP and SIP are important to food industries including dairy, beverage, nutraceutical plants, where the processing must take place in a hygienic or aseptic environment (Tamime, 2008; Luo et al., 2012).

3.4.2 Guidelines on Air Handling Systems in the Food Industry to Avoid Microorganisms

The controlled properties of air, especially temperature and humidity, may be used to prevent or reduce the growth rate of some microorganisms in manufacturing and storage areas. The particle content (dust and microorganisms) can also be controlled to limit the risk of product contamination and hence contribute to safe food manufacture. Airborne contaminants are commonly removed by filtration. The extent and rate of their removal can be adjusted according to acceptable risks of product contamination and also in response to any need for dust control. These guidelines are intended to assist food producers in the design, selection, installation, and operation of air handling systems. Information is provided on the role of air systems in maintaining and achieving microbiological standards in food products. The guidelines cover the choice of systems, filtration types, system concepts, construction, maintenance, sanitation, testing, commissioning, validation, and system monitoring. They are not intended to be a specification for construction of any item of equipment installed as part of an air handling system. Each installation needs to take into account the local requirements and specialist air quality engineers should be consulted to assist in the design and operation of the equipment.

Technologies utilized by the dairy industry to reduce emissions from dairy manufacturing plants include cyclones, separating dust particles using centrifugal forces (single and multiple-cyclone separators), wet separation, for example, wet cyclones which spray water into the waste gas stream to increase the weight of the particulates (injection scrubbers, jet scrubbers, rotary scrubbers, etc.), filtration (tubular filters, bag filters), spray scrubbers, and electric static filters (IDF Bulletin, 2012).

Exposure to microbially contaminated surfaces has been identified as the main source for food contamination (Otto et al., 2011). Recently, however, contamination of products by airborne microorganisms has been addressed (Shale and Lues, 2007). Improper sanitary environmental conditions in food processing plants can occur because of suspended biological particles in the air (Sutton, 2004). Therefore, in milk powder and powdered infant formula (PIF) processing facilities, the environmental air intake is strictly controlled (e.g., by the installation of air intake filters and the maintenance of overpressure), especially in high-risk areas. However, (re)contamination of the products after the last heat treatment, for example, during filling and packaging, must be prevented.

Airborne contaminants of biological origin are microscopic, with diameters of 0.5 to 50 μm, and are known as bioaerosols, which may include bacteria, fungi, viruses, and pollen (Stetzenbach et al., 2004; Lee, 2011). Bioaerosols are easily translocated by winds and air currents from one ecosystem to another, making them an important vehicle for the spread of potentially pathogenic organisms (Wijnand et al., 2012).

It is impossible to keep airborne bacteria, yeasts, and molds at zero level in food processing. In dairy production facilities, general handling of ingredients, spray drying, and milling operations can create bioaerosols (Mullane et al., 2008; Dungan et al., 2010; Dungan, 2012). Wet and dry cleaning operations often result in the formation of bioaerosols in the form of water droplets or dry dust originating from sweeping or directly from the exhaust of vacuum cleaners (Abt et al., 2000).

However, standard practice in milk processing and PIF production include the use of high-efficiency particulate air (HEPA) filters for exhaust air of all vacuum cleaners to maintain a high hygienic level (Kandhai et al., 2004; Mullane et al., 2008; Iversen et al., 2009; Jacobs et al., 2011).

Airborne communities (mainly bacteria) were sampled and characterized (concentration levels and diversity) at one outdoor and six indoor sites within a Swiss dairy production facility by Brandl et al. (2014). Air samples were collected on two sampling dates in different seasons, one in February and one in July 2012 using impaction bioaerosol samplers. After cultivation, isolates were identified by mass spectrometry (matrix-assisted laser desorption/ionization-time-of-flight) and molecular (sequencing of 16S rRNA and *rpoB* genes) methods. In general, total airborne particle loads and total bacterial counts were higher in winter than in summer but remained constant within each indoor sampling site at both sampling times (February and July). Bacterial numbers were generally very low (<100 CFU/m^3 of air) during the different steps of milk powder production. Elevated bacterial concentrations (with mean values of 391 ± 142 and 179 ± 33 CFU/m^3 of air during winter and summer sampling, respectively; $n = 15$) occurred mainly in the "logistics area," where products in closed tins are packed in secondary packaging material and prepared for shipping. However, total bacterial counts at the outdoor site varied, with a five- to six-fold higher concentration observed in winter, compared with summer.

Twenty-five Gram-positive and Gram-negative genera were identified as part of the airborne microflora, with *Bacillus* and *Staphylococcus* being the most frequent genera identified. Overall, the culturable microflora community showed a composition typical and representative for the specific location. Bacterial counts were highly correlated with total airborne particles in the size range 1–5 μm, indicating that a simple surveillance system based upon counting of airborne particles could be implemented. The data generated in this study could be used to evaluate the effectiveness of the dairy plant's sanitation program and to identify potential sources of airborne contamination, resulting in increased food safety.

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