Chapter 6

HYGIENIC ASPECTS OF FOOD STERILIZATION SYSTEMS

6.1 INTRODUCTION

The food sterilization system consists of a number of unit operations, e.g. mixing, pumping, homogenization, heating, holding and cooling, connected by pipework and valves. The design of equipment so that it not only fulfils its operational purpose but can also be cleaned adequately and assembled in such a way as to prevent contamination during the handling of sterile material, is a specialized skill which food equipment manufacturers should possess. In the context of engineering design only the principles of good hygienic practice will be outlined so that the food process engineer selecting equipment may be guided as to what to look for in order to achieve satisfactory performance. This is not an easy task and in the absence of prior knowledge and previous experience, equipment should be submitted to hygienic testing using specially constructed test rigs which will simulate the cleaning and sterility maintenance features. It has often been suggested that some type of emblem or logo should be given to food processing equipment to indicate that it has passed certain hygienic tests possibly in relation to a standard soil, i.e. food deposit consisting of actual food, degradation components and extraneous material. However, because of the variability of food products, species and varieties it is difficult to simulate cleanability in real situations and the value of such an emblem could be misleading. With the present state of knowledge it is important to resort to actual testing of the installed system before commencing operation; this applies to the cleanability of the system and its ability to maintain aseptic conditions during the handling of sterile material. Microbiological challenge tests may be carried out to ensure that the system is microbiologically 'tight' and organisms are unable to enter. This will be discussed in a later section.

6.2 BASIC PRINCIPLES FOR HYGIENIC DESIGN

It is comparatively easy to make a list of ideal conditions for the hygienic performances of process plant but far more difficult to achieve these in practice. The desirable characteristics may be listed as follows in the form of seven basic principles (Milleville & Gelber, 1964, 1965).

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

In order to comply with these it is necessary to have chemical, physical and microbiological methods of analysis. In many cases the recent developments in analytical methodology allow these factors to be analysed in a quantitative manner so that they comply with existing food law. The manufacturers of food processing equipment are generally aware of these requirements; however, it is essential that food processor engineers should be aware of their responsibility in making adequate checks that the specification is correct. Details of the test methods which apply to aseptic operations will be discussed in a later chapter.

Apart from the seven principles stated above it is possible to extend the list. Thorpe and Barker (1982) have indicated four more.

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

To some extent these are already contained within the general principles; however, they exemplify and highlight some current problems.

When considering the hygienic operation and performance of food processing equipment there are three recognized standards of attainment.

(a) Chemical cleanness: after cleaning with chemicals and/or detergents it is necessary to rinse the equipment until they cannot be detected.

(b) Physical cleanness: after cleaning the equipment it should not be possible to detect any residual soil.

(c) Microbiological cleanness: after decontamination the number and kind of micro-organisms remaining shall not present a Public Health hazard or create a risk of spoilage of the food product.

Microbiological standards will differ according to the nature of the food product and the processing technology. Including storage conditions for dairy products the following figures (Table 6.1) give a guide to the microbiological condition.

For a detailed discussion and invaluable guide to currently accepted

TABLE 6.1 MICROBIOLOGICAL STANDARDS FOR FOOD CONTACT SURFACES

Condition	*Organisms per square decimetre*
Satisfactory	0–540
Fairly satisfactory	540–2700
Decidedly unsatisfactory	>2700

good hygienic practice in relation to the handling of liquid food products the reader is strongly recommended to consult *Hygienic Design of Liquid Handling Equipment for the Food Industry* (Thorpe & Barker, 1987) which covers at present Section 2 Materials of Construction; Section 3 Vessels — Tanks and Kettles; Section 4 Stirrers and Agitators; and Section 5 Pipe Lines including Couplings. Sections which are currently being produced include homogenizers, pumps valves, heat exchangers, pulpers and finishers, evaporators, deaerators and fillers together with ancillary sensor and control equipment.

6.3 STAINLESS STEEL

The most widely used material of construction for fabricating aseptic processing and packaging machinery is stainless steel. The design engineer should ensure that the material supplied by the manufacturer is suitable for the food product being processed.

As a general guide austenitic stainless steel with 17–18% chromium and 8+% nickel, e.g. 321 531 (En 58B) or 304 516 (En 58E), is satisfactory for the majority of applications; however, where there is a risk of chloride or acid attack a molybdenum containing grade, e.g. 316 516 (En 58J), is more suitable.

It is important to note that each country has its own specifications and the nearest equivalents are given in Table 6.2.

When making a selection of stainless steel it has to be remembered that it must be compatible with the cleaning materials, including hydrogen peroxide and other disinfectants, as well as the food ingredients.

Stainless steel is produced with a variety of surface finishes (IDF, 1985) achieved by mechanical grinding and electropolishing. These are described by the Dairy and Food Industries Supply Associations, USA, as ground: 80–100 silicon carbide grit size; dull buffed: 180–220; polished: 180–240 or for the electropolished grades as bright finishes. There are

TABLE 6.2. SPECIFICATIONS OF MATERIALS SIMILAR TO BS 1449 (1982) PT.2

BS	*US AISI*	*En*	*West Germany Deutsche Stoff No*
304 516	304	En 58E	1·4301
316 513	316	En 58J	1·4401
321 531	321	En 58B	1·4541
Italy UNI	*Japan JIS*	*Sweden SIS*	*France AFIVOR*
× 5 Cr Ni 1810	SUS 27	2332	Z 6 CN 18–09
× 5 Cr Ni Mo 1713	SUS 32	2343	Z 6 CND 17–11
× 6 Cr Ni Ti 1811	SUS 29	2337	Z 6 CNT 18–11

also British Standards which specify finishes, e.g. for stainless steel plate BS 1449, 1982, and for pipes, bends and tees using both clamp and screw-type fittings BS 4825, pts 1–4. The International Standards Organization has a similar set of standards for metal pipes and fittings (ISO 2037, 1980).

The actual structure of the surface is a complex mass of crevices and undulations which contribute to roughness and waviness. Electron microscope studies of food contact surfaces, e.g. Stone and Zottola (1985), show micro-organisms in the troughs and crevices of the surface: consequently considerable work has been carried out on quantifying surface roughness. Although a number of differing definitions of roughness have been used in the past, these have been reduced to two preferred methods, viz.

1. Ra, the arithmetical mean deviation taken above and below a reference line, measured in Europe in μm (micrometres). In the USA the practice is to use the unit micro inch and to base the roughness on the root mean square of the deviation from the centre line. The Ra concept is also known as the centre line average, CLA.

2. R_z uses ten point height irregularities and is defined as the average distance between the five highest peaks and the five deepest valleys within the sampling lengths measured from an arbitrary datum line not cutting the profile.

Details of the measurement of Ra are given in BS 1134 (1972) and ISO/R468 (1980). For ground stainless steel the value of Ra is between 1·0–2·0 μm and for polished surfaces 0·20–1·50 μm.

It is useful to note that the cost of producing stainless steel finishes is inversely proportional to the Ra number; consequently it is necessary to justify the choice of grade of finish. However, the relationship between surface finish and cleanability is still the subject of experimental study. A number of workers have made a study of the effect of surface finish on the cleanability of surfaces, in particular Masurovsky and Jordan (1958), Kaufmann *et al.* (1960*a*,*b*,*c*, 1961), Milledge and Jowitt (1980) and Timperley (1984). The information available to 1981 has been fully discussed by Milledge (1981). The use of direct impingement sprays for cleaning a wide range of different surface finishes has been examined by Timperley (1984) who showed that the time for 99% removal of the micro-organisms on a surface increased significantly in proportion to the Ra number. Whilst there has been considerable discussion on the role of surface finish there appears to be a general consensus of opinion that for surfaces with an Ra less than 1 μm there is no significant difference in cleanability. Since most of this work has been related to milk deposits usually known as milk stone, it would seem appropriate to study the effects of other food product soils on cleanability. A standard test procedure and equipment has been developed by Timperley and Lawson (1980), and this is ideally suited to studying the cleaning requirements for a variety of products. When process engineers are designing processes for new product formulations it is useful to have fouling and cleaning studies carried out before construction is undertaken.

6.4 SANITARY STANDARDS

A large number of standards designated 3-A and E-3-A Sanitary Standards have been formulated by the cooperative effort in industry and regulatory groups in the USA. These include the Dairy Industry Committee, International Association of Milk, Food and Environmental Sanitarians, US Public Health Service, US Department of Agriculture, Dairy and Food Industries Supply Association and The Poultry and Egg Institute of America. The Sanitary Standards represent criteria for cleanability of dairy processing and egg processing equipment. Food process engineers should be aware of these standards and accepted practices, a list of which is given in Appendix 6.

6.5 FOULING

The fouling of heat transfer surfaces by deposition of thermal degradation products is a major problem in the food industry. The problem is confounded, firstly, by the variability of the raw material, secondly by the variability of the processing conditions, and thirdly by the variability of the surfaces which came into contact with the food. The problem identified itself in the early days of milk processing (Burton, 1968) when it was found that the output temperature and the sterilizing efficiency decreased with time due to protein and other products deposited on the surface. The same problem was encountered with fruit juices especially orange juice, the pectin content of which caused the problem, and more recently with the development of other aseptically packaged products, e.g. sauces and soups where a very wide variation of behaviour is found depending upon the composition. The problem has been eliminated to some extent with steam injection and other techniques, e.g. ohmic heating.

In many attempts to eliminate or reduce fouling, research workers have worked on the principle of establishing the mechanics and kinetics of fouling prior to offering a solution. A variety of mechanisms have been proposed and some of these are as follows:

- (i) sedimentation of solid and liquid constituents
- (ii) crystallization of food ingredients
- (iii) chemical reactions including degradation due to elevated temperatures
- (iv) biological growth of micro-organisms — biofilms
- (v) corrosion due to aggressive food components
- (vi) deposits from hard water or minerals present in the product.

The thermal degradation reactions include sugar caramelization, fat polymerization, protein denaturation, starch decomposition and undesirable product interaction which occur at the localized high temperatures in the laminar sub-layer.

The complexity of the fouling process can be seen in the case of milk (Rakes *et al.*, 1986; Burton, 1968; Fryer *et al.*, 1989), the type of deposit from which depends upon temperature. The rate of fouling depends on a wide range of factors, see Table 6.3. Burton (1968) showed that below 110°C the 'milk film' consisted of 50–60% protein (mainly β-lacto-globulin) and 30–35% mineral (mainly calcium phosphate) whereas above 100°C the 'milk stone' consisted of 15–20% protein and up to 70% minerals. It is commonly observed that there is an induction period during

TABLE 6.3 FACTORS AFFECTING FOULING BY MILK, MILK-BASED AND OTHER PRODUCTS

Factor	References
1. Product variables	
a. content	Gynning *et al.* (1958); Burton (1961, 1968)
b. pH	Gynning *et al.* (1958); Burton (1965, 1968); Lalande and Corrieu (1981); Claesson *et al.* (1974)
c. seasonal variation	Burton (1967)
d. age	Burton (1968)
e. ammonia concentration	Lalande and Corrieu (1981)
f. compositional variation	Jelen (1981)
2. Process variables	
2.1 Single	
a. velocity	Bunchero and Gordon (1960); Gynning *et al.* (1958); Thonie (1958); Kern (1966); Morgan *et al.* (1959); Gonionskiy *et al.* (1970); Crozier (1982)
b. exposure time	Burton (1961)
c. wall temperature	Morgan *et al.* (1959); Gonionskiy *et al.* (1970); Burton (1968); Lalande and Corrieu (1981)
d. processing temperature	Thonie (1958); Burton (1961)
e. bulk fluid temperature	Morgan *et al.* (1959); Taborek *et al.* (1972); Kern (1966)
2.2. Combined	
a. heat surface — product temperature difference	Thonie (1958)
b. heating media — product temperature difference	Gynning *et al.* (1958); Gonionskiy *et al.* (1970); Kern (1966)
c. Reynolds Number	Lund and Bixby (1975)
d. other complex dimensionless functions	Lalande and Corrieu (1981)
e. multiple correlations	Swartzel (1983); Fryer *et al.* (1989, 1990)
2.3 Others	
a. pretreatment-heating	Bell and Sanders (1944); Morgan *et al.* (1959); Jelen (1981); Ball (1977)
b. prefouling	Lund and Bixby (1975)

which heat transfer rates and pressure drop characteristics remain constant followed by a fouling period when performance falls increasingly with time. Reviewing the literature, Fryer *et al.* (1989, 1990) indicate that the first layers of the deposit are composed of the mineral salts, in particular calcium phosphate, followed by deposition of protein degradation products. In the absence of precipitable calcium or phosphate ions fouling is considerably reduced. The induction period is one during which the surface is becoming conditioned to accepting the protein aggregates from the bulk of the liquid. If the latter process can be reduced then it may be possible to reduce the fouling.

Apart from studying the problems of mass transfer, other workers have studied the bonding mechanisms which operate between the particles and the walls of the equipments. The forces exerted are strongly attractive and include

(a) macroscopic forces, e.g. gravity and convective forces
(b) electrostatic forces
(c) Van der Waals forces
(d) capillary forces
(e) Debeye dielectric interactions involving solvent effects.

Schubert (1982) considers that one of the major factors involved in deposit formation is the development of bridge type structures between the particles. These may be formed by crystallization of dissolved material, local melting at contact points of fat particles, and particle deformation in combination with thermal and chemical reactions. Hauser and Sommer (1990) have discussed the problem in detail in relation to ease of cleaning.

Monitoring systems for measuring the progress of fouling and for studying the degree of fouling in a standardized manner have been discussed by Fryer and Pritchard (1989). These include measuring the thickness of the deposit by ultrasonic methods, use of the heated radial flow cell, temperature and pressure drop variations and the tapered tube variable velocity device. At the present time relatively little progress has been made in the reduction of fouling in food processing systems. The possibility that oscillating or vibrating flow devices operated under certain well defined conditions will assist is currently being studied. Magnetic treatment of water has been shown to reduce the fouling of pipes and heat exchangers (Busch *et al.*, 1986; Taffe, 1990): perhaps this technique may help to prolong the induction period and reduce the effect of the preliminary stage of cation/anion deposition.

6.6 CLEANING OF FOOD PROCESSING PLANT

6.6.1 Introduction

One of the main aspects of food manufacturing practice is the cleaning of the equipment after production and leaving it in a satisfactory state

TABLE 6.4 GENERAL GUIDE TO FOOD SOIL BEHAVIOUR

Food components	*Solubility*			*Effect of heating*	*Removal characteristics*
	Water	*Alkali*	*Acid*		
Proteins	Insoluble	Soluble	Slightly soluble	Denaturization	Very difficult
Sugars	Soluble			Caramelization	Less easy
Fats	Insoluble	Soluble		Polymerization	Difficult
Mineral salts	Variable		Soluble		Relatively easy

for the next production run. In order to clean plant satisfactorily it is necessary to know the type of deposit and residue in terms of the chemical and physical structure. This requires trials to be carried out to determine the method of cleaning, the concentration of the cleaning solution and its temperature. A guide to the behaviour of food soils is given in Table 6.4.

In practice two methods have been developed for cleaning equipment. The first involves dismantling and manually cleaning with spray devices and brushes and the second uses complex circulation systems described as CIP (cleaning-in-place). The former technique is more suited to open equipment, e.g. conveying systems, whereas the latter is used in continuous heat and cooling systems such as would be used in aseptic technology.

6.6.2 Cleaning-in-place

An important operation in the production of safe sterile food products is the cleaning of the complete plant including the associated pipe work, pumps and valves immediately after use. The CIP technique involves the continuous circulation of cleaning fluids to remove the soil, i.e. fouling deposits. Depending on the nature of the deposit it is usually necessary to have a series of individual cycles which consist of:

1. Pre-rinse water to remove loose soluble material remaining in the equipment.

2. Chemical treatment to dissolve and solubilize the soil; this often involves the use of detergents and other surface active agents as well as sanitizing agents.

3. Final rinse water to remove traces of chemicals.

It is customary when alkali has been used to rinse with a slightly acidic solution to neutralize the alkali. Apart from the chemical nature of the solutions it is necessary to consider two other factors, viz. velocity of flow and temperature. It is necessary to maintain a high degree of turbulence to facilitate the removal of soil and the recommended practical velocity of flow is between 1 and 1·5 m/s.

Timperley and Lawson (1980) showed that the same degree of cleaning of pipes of differing diameters was obtained if the same mean flow velocity of 1·5 m/s was maintained. With regard to temperature it is necessary to consider the material being removed since elevated temperatures must achieve a decrease in the tenacity of the soil, an increase in solubility and an increase in the rate of chemical reactions. However, the deposit may be such that it does not behave in this way but more complex polymerization reactions increase the tenacity of the soil. For many products, e.g. milk and fruit juices, the exact conditions required for cleaning are known; however, for products not previously treated in continuous flow heat exchangers it will be necessary to carry out trials in a suitable pilot plant.

The two most important sources of information especially with regard to milk and dairy products processing are Romney (1990) and IDF (1979). These relate to recommendations for the design and use of CIP systems.

6.6.3 Water quality

One of the major constituents of any CIP system is water and apart from the economic aspects it is necessary to ensure a certain quality. The hardness of the water should not exceed 10 mg/l calcium chloride total hardness and conversely it should not be so soft that corrosion problems may be caused. The danger of using excessively hard water is that scale may be deposited in the holes of the spray devices, causing blocking, or alternatively may be deposited on the surfaces of the heat exchanger. Hard water also interferes with the functioning of many detergents, causing precipitates to be deposited. It is also necessary to ensure that the water is bacteriologically satisfactory; this is achieved by maintaining 1 ppm of free chlorine after chlorination. Despite this requirement it is essential to maintain low levels of chloride ions which can attack some grades of stainless steel and the welds. Methods of chlorinating water which involve excessive chlorination followed by neutralization by sodium sulphate until the desired 1 ppm is achieved should be avoided as these methods produce a large excess of chloride ions. Water should be analysed at frequent intervals to ensure compliance with the quality standard.

6.6.4 Detergents and their action

Some deposits which are water soluble are easily removed whereas others are strongly attached to the substrate metal surface and require special detergents. A brief list of food soils was given in Table 6.3 with their interaction with detergent solutions. These special materials interact with the deposit by virtue of their diffusional properties and chemical reactions or in some cases cause dispersion of the material.

The main inorganic alkalis used for this purpose are sodium hydroxide, sodium orthosilicate, sodium metasilicate, trisodium phosphate, sodium carbonate and sodium hydrogen carbonate, in order of decreasing alkalinity.

The main acidic compounds include nitric, phosphoric and sulphuric together with weaker acids such as hydroxy-acetic acid, gluconic acid and citric acid. Acidic materials are used to remove 'milk stone' from milk pasteurization plants.

In the formulation of blended detergent products sequestering agents, e.g. polyphosphate, salts of ethylene diamine tetraacetic acid and gluconates, are included to remove metallic impurities as well as improve detergency. Surface active agents are also included to facilitate the wetting of the soil, e.g. sodium dodecyl benzene sulphonate and nonyl phenol/ethylene oxide mixtures.

6.6.5 Disinfectants

Originally the dairy industry was only allowed to use steam or boiling water to sterilize the equipment surfaces; however, more than five hundred different chemical sanitizing agents are used for microbial decontamination purposes (MAFF, 1978).

The main categories of disinfectant are as follows:

(a) Halogen based compounds.

The main sources of chlorine are sodium hypochlorite, chlorinated trisodium phosphate, dichlorodimethyl hydantoin, chloramine T and disodium trichloro isocyanate. All these compounds liberate hypochlorite ions $HOCl^-$ in water and these are responsible for the disinfectant properties. They are effective against all vegetative bacteria and viruses; however, spores, yeasts and moulds require much higher concentrations to be effective. However, because of the corrosive nature of alkaline hypochlorite solutions, normal concentrations range from 50–200 mg/l available chlorine and are used at relatively low temperatures (20°C). For example a cold solution containing 100 mg/l will require about 15 minutes contact time for most purposes. Solutions containing hypochlorous acid are not particularly stable and should be made up freshly each time they are required and constantly checked analytically. When being used in equipment which has previously had an acid rinse it is necessary to remove traces of acid prior to sanitizing, otherwise the hypochlorite solution will decompose. This may effectively be done using a water rinse, or if this is not sufficiently satisfactory a weak alkaline solution may be used.

A second class of compounds is based on the halogen iodine and these are known as iodophors. These are compounds in which iodine has been made soluble in water, e.g. nonyl phenol ethylene oxide condensation compounds; they are particularly good sanitizing agents when used under acidic conditions usually obtained by adding phosphoric acid. Iodophors are generally formulated to contain detergents and are generally referred to as detergent sterilizers or sanitizers. The usual strength of free iodine in an acidic solution of pH 3 is between 50–70 mg/l. Iodophors are effective against gram-negative (lactics, clostridia, *Bacillus*, *Staphylococcus*) and gram-positive (e.g. *E. coli* and *Salmonella*) vegetative bacteria as well as viruses, yeasts and moulds; bacterial spores are only inactivated at higher concentrations. This type of sanitizer finds application in spraying and soaking situations because of the tendency to foam; however, special low-foaming formulations are available and should be used in recirculation cleaning. Molybdenum containing stainless steels resist corrosion by iodophors, but with other grades only short contact times should be permitted.

(b) Quaternary Ammonium Compounds (QACs or QUATs).

Quaternary ammonium compounds are the aryl alkyl derivatives of ammonium chloride or bromide (Lawrence, 1968). Long alkyl chains impart good disinfectant properties; some typical examples are dioctyl dimethyl ammonium bromide and lamyl dimethyl benzyl ammonium chloride. These compounds are cationic compounds and consequently should not be mixed with anionic detergents, hence the need to rinse the plant thoroughly prior to using QUATs. They are bacteriocidally most effective against gram-positive organisms and are used in concentrations of 150–250 mg/l of active QA ion. Higher concentrations are required for effective disinfection of yeasts and moulds. They are not particularly suitable for recirculation systems because of the high foaming propensity; however, they are non-corrosive and can be used with normal grades of stainless steel.

(c) Biguanides.

These constitute a class of sterilants based on the guanidine molecule, e.g. chlorohexidine and poly hexa methylene biguanide (PHMB). The former finds use in hospitals, whereas the latter is used for recirculation in the dairy industry since it is non-foaming and active against gram-negative bacteria, e.g. *Salmonella* (Thomas, 1960). However, it is not effective against viruses and bacterial spores. It is generally used in concentrations varying from 100–200 mg/l active PHMB. The efficiency as a sterilant is decreased in the presence of hydrochlorites or hydroxides and good rinsing is required if these have been used previously in the equipment. It can be used in contact with all grades of stainless steel without causing corrosion.

(d) Some other detergents.

(i) Acid anionic detergents are based on phosphoric acid and are most effective against yeasts and moulds, but ineffective against bacterial spores. Only low foaming formulations should be used in recirculation systems.

(ii) Amphoteric compounds are surface active agents based on substituted amino-acids or betaines which contain compensating acid and basic groups. They are most effective against vegetative bacteria but are generally unsuitable for recirculation systems.

(iii) Peroxy-compounds: both hydrogen peroxide and peracetic acid are effective sterilants; being non-foaming they can be used in spraying and recirculation systems. Peracetic acid is used in dilute solution containing between 50–750 mg/l active peracetic acid. It is often used in combination with phosphoric acid in recirculation systems.

(iv) Sodium hydroxide used in 1·5–2·0% m/v solution at 45°C with a contact time of 2 minutes is effective against non-spore forming bacteria.

(v) Ozone: laboratory tests have shown that there is considerable potential for the use of ozone to replace chlorine in recirculation systems. Ozone is effective at very low concentrations, e.g. 0·1 ppm, in removing microbial accumulations on surfaces (Bott, 1990).

For a detailed comparison of sanitizing agents the reader is referred to ICMSF (1988).

6.6.6 Spray cleaning of vessels

The application of detergent/sanitizer solutions in large holding tanks and vessels is generally carried out using spraying devices, e.g. perforated balls or rotating jets of which many types are available. Spray balls are manufactured in a variety of sizes from 25–150 mm and with a 360° coverage. The number of spray heads required for a particular tank depends on its size and shape; the positioning of spray devices depends also on any additional equipment in the tank, e.g. agitators and baffles. The process engineer has the responsibility of ensuring that a particular distribution system is effective and should take particular note of difficult-to-reach positions. The importance of experimental trials should be noted especially in situations which are new, in terms of both product and equipment.

An alternative method of producing a spray is to use a rotating device; this has the advantage of having a long radial throw and often a single device may be used instead of several static balls. A generalized comparison between the two types is shown in Table 6.5.

The choice of spray device is also affected by the nature of the deposit, e.g. sticky residues from gums or sugars require high pressure devices, whereas cellular material from fruit and vegetable products requires longer volumetric flow rates and lower pressures. Fatty products require higher temperatures to remove the residues.

TABLE 6.5 COMPARATIVE ADVANTAGES AND DISADVANTAGES OF SPRAY BALL AND ROTATING JET DEVICES

Spray balls	*Rotating jets*
static	dynamic
high volume/low pressure	low volume/high pressure
good for flooding walls	scrubbing impingement
cheap cost of construction	more expensive
simple construction	more complex
no moving parts	moving parts
not affected by temperature	temperature limit for some types
limited impact of jets	higher impact
higher detergent strength required	lower detergent strength
self cleaning and draining	nozzle blockage may occur
high flow rates	lower flow rates
continuous surface contact	intermittent
overall reliability good	variable reliability
low maintenance cost	higher maintenance cost

6.6.6.1 *Aspects of engineering design*

The common practice when using spray balls is to employ a blanket spray distance of 2 m radial throw at pressures up to 3 kg/cm². However, this depends on the nature of the soil, e.g. soluble types require up to 2·4 m, light insoluble 2·26 m, medium insoluble 1·4 m and for heavy insoluble 1·0 m. For the heavy soils it may be better to use a rotating device. The depth of positioning of spray balls is usually between 1·0 and 1·5 m. The throw distance x can be determined from the dimensions of the vessel where

$$x = \sqrt{a^2 + b^2}$$

where a is the radius of the vessel and b the length from the centre of the vessel to the ball assuming two balls are arranged equidistant from the centre.

The total volumetric flow rate Q is given by

$$Q = C \times F$$

where C is the horizontal circumference at the widest point of the vessel of diameter D, given by πD, and F the minimum circumferential flow in litres/metre/unit time.

The spray ball flow rate can be calculated from the formula

$$Q = (N \times q) + U + D$$

where N is the number of spray holes (excluding the drain hole), q is the flow rate through a single spray hole, U is the flowrate through the spray ball sleeve (usually 45–300 l/h depending on manufacturer) and D is the flow rate from the chain hole.

For a more complete account of this subject the reader is referred to the publications of Romney (1990) and Tamplin (1980, 1981).

6.6.6.2 *Design and operation of CIP systems*

A typical CIP system consists of a series of tanks containing separately water and solutions of alkali, acid, sanitizer/sterilant and detergent additives connected to a manifold and distributed through the processing equipment by a series of pumps and valves. The solution being used may be heated by steam injections or by passing through a plate heat exchanger. The strength of the solution can be monitored by a conductivity probe whilst being pumped around the cleaning circuit; similarly the same probe can be used to determine the completeness of rinsing with water to remove final traces of detergent/sanitizer.