1 Principles of Cleaning-in-Place (CIP)

M. Walton

1.1 Introduction

Cleaning-in-place (CIP) is now a commonplace activity in almost all dairy, beverage and processed-food production plants. The processed food industry has seen a major shift towards CIP over the past 10–15 years, and the beverage industry, which has been broadly in line with the dairy industry technology, has seen increased demands from customers in terms of CIP verification and validation to provide improvements in plant hygiene, finished product quality, and related shelf-life and microbiological considerations.

The highest standards of plant hygiene are an essential prerequisite for the production of any high-quality product being produced for human consumption. The cleaning and subsequent disinfection or sterilisation of any item of processing plant or equipment must be carried out with the utmost care and attention if the final product quality is to be fully assured. In earlier days, cleaning tended to be a manual process; indeed, it still is today in many small-scale operations, especially in the processed food sector, where a combination of manual strip-down clean and rebuild is common. Where manual cleaning is still practised, it is vital that there is meticulous attention to detail, because – for reasons of the health and safety of the operative – only mild and comparatively cool chemical solutions, detergents and disinfectants can be used, and strict adherence to cleaning procedures is critical. In larger-scale operations, and where more complex plant and equipment may be involved, the most usual approach today is to employ CIP, and it is to this aspect of cleaning technology that this book is primarily devoted, with a view to providing an understanding of the concepts and application of CIP in the processed food, pharmaceutical, dairy and beverage sectors.

1.2 Cleaning-in-place (CIP): definition

In the 1990 edition of the Society of Dairy Technology manual *CIP: Cleaning in Place*, CIP was defined 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.*

This was taken from the National Dairyman's Association (NDA) Chemical Safety Code, which was published in 1985; although the NDA has been superseded, their definition of CIP is still felt to be quite appropriate.

1.3 CIP systems: hardware

CIP units comprise vessels for storage and recovery of cleaning solutions, along with valves, pumps, pipelines and field instrumentation to allow cleaning to take place, usually automatically. They vary in complexity and degree of automation, and hence their efficiency and cost-effectiveness are also variable. For example, the single-use CIP units tend to be very expensive to operate (detergent, water and energy requirements are high), but can be much more hygienic as the chance of cross-contamination and potential spore formation is greatly reduced. Full recovery systems with large detergent storage tanks are usually multifunctional and tend to be relatively economic in operation, but need to be closely monitored to prevent the build-up of soil residues in the dilute detergent or recovered rinse tanks due either to the inherent recovery efficiency of the set or perhaps to poor pre-rinsing. It is therefore very important to refresh cleaning solutions on a regular basis.

1.4 The processes of cleaning

The cleaning processes, whether manual or automated and throughout all industry sectors, tend to follow similar principles, and will usually consist of a series of discrete stages or cycles, generally including:

- removal of gross debris (product recovery)
- pre-rinse
- detergent recirculation
- intermediate rinse
- second detergent recirculation (optional)
- intermediate rinse
- disinfection
- final rinse

1.4.1 *Removal of gross debris (product recovery)*

In manual cleaning operations, this tends to refer to removal of any residual product by mechanical means prior to introduction of a water rinse. In CIP applications, removal of gross debris generally involves draining product from the system to be cleaned under gravity, or physically displacing the product using various media, such as compressed air, water or a mechanical pigging device. This stage is often incorporated into the pre-rinse cycle of the cleaning programme with the addition of a divert valve system to facilitate product recovery into a suitable vessel or direct routeing to drain. Control of this feature is quite often via automated valve and timer, but it is also possible to use more sophisticated methods, such as turbidity or conductivity sensors in the return line. It is important to include an override timer into these systems as a ‘failsafe’ in order to avoid filling a product recovery tank with pre-rinse water if the system fails to activate the divert valve: this is not an uncommon situation, with probe and controller maintenance being a critical aspect of successful operation. Product recovery systems are becoming more sophisticated with the introduction of membrane plants that are designed to remove high levels of water from the effluent stream – often termed ‘white water’ in the dairy sector – to allow the recovered solids to be sold on for re-processing: these plants are effective at reducing effluent loading, and can form part of site pollution prevention and control (PPC) systems (e.g. The Environmental Protection Act; Anonymous, 1990).

1.4.2 *Pre-rinse*

Pre-rinse cycles often utilise recovered ‘water’ from the intermediate rinse stage (see Section 1.4.4). This serves two purposes: first, to reduce total water consumption (and effluent generation); and second, to utilise any heat energy and possible residual detergent solution carried into the recovered rinse tank during the rinse recovery stage. It is not uncommon to find heated pre-rinse systems in certain applications, such as cream production, where the hot pre-rinse solution provides a greatly enhanced method of product residue removal. The pre-rinse stage is important because it is not desirable to introduce excessive soiling into the dilute detergent tank. This stage is generally controlled via a timer, sometimes split between product recovery and drain, and these timers are often set at excessive levels to ensure maximum product removal. However, this may not be cost-effective in circumstances where water and effluent costs are high. In general, the pre-rinse cycle for tanks, silos or vessels consists of several ‘burst’ or ‘pulsed’ rinses, as this both improves rinsing efficiency and can reduce water consumption significantly.

1.4.3 *Detergent circulation*

This is where the main task of cleaning takes place, resulting in the soil being lifted from the plant surface and held suspended or dissolved in the detergent solution; for the selection of suitable detergents see Section 1.5.5, but an important attribute of the detergent should be the ability to prevent any soil from being redeposited during recirculation. Recirculation timings need to be assessed by experimentation and a degree of experience, with timing generally varying from 15 min up to 1 h, where exceptionally large and complex circuits are being cleaned. Contact times can be reduced by offsetting the potentially reduced cleaning effectiveness with higher temperatures, higher concentrations, or the use of more sophisticated (and expensive) detergent formulations. Cycle timers are often set to start counting down once the temperature set point has been reached in the return leg: this can lead to excessive cleaning times if the efficiency of the heating system is inadequate. It is important, for example, to ensure that tanks incorporating a water-cooling jacket have the jacket drained prior to CIP. Depending on detergent formulation, foaming can sometimes be a problem, and it is often associated with product contamination. It can also be caused by many other factors, including air entrainment via leaking pump seals; the use of totally softened water supplies can also be a contributory factor. It is also possible to utilise an acidic detergent for the main cleaning step: this is quite common in both the dairy and beverage sectors, where milk residues in ‘cold/raw’ milk areas respond well to acidic detergents, and in the brewing sector, where acidic detergents have significant advantages over alkaline detergents in their ability to clean under CO_2 environments without loss of activity. Combined detergent/disinfectant chemical blends may be used in the cleaning cycle itself, though this approach has comparatively limited application, as they can be adversely affected by high soil loading, and the ratio of detergent to disinfectant can become imbalanced.

1.4.4 *Intermediate rinse*

The intermediate rinse serves to remove all traces of detergent and entrained soil from the plant being cleaned and, in a partial recovery situation, to recover as much detergent (and thermal energy) back to the dilute detergent tank as possible; it also may need to be sufficient to cool the plant down ready for disinfection and/or refilling. The intermediate rinse should use potable water, and is normally cold, although – if a warm secondary detergent step is being incorporated – it may be desirable to use hot water (if available from sources such as recovered and suitably treated condensate). The intermediate rinse is often recovered and reused as the pre-rinse for the next cleaning cycle.

1.4.5 *Second detergent circulation (optional)*

Some systems utilise a secondary detergent cycle, often an acidic detergent to follow an alkaline product in the first detergent stage. This is common practice where built detergents are not being used (sodium hydroxide liquor followed by nitric acid was once very common), and also where there are high levels of process-generated soils, such as in heat exchangers and cheese vats.

1.4.6 *Second intermediate rinse*

This second intermediate rinse will almost always use cold potable water. The quality of this water is critical, if there is to be no disinfection stage. Some sites that do not use a discrete disinfection stage in the CIP cycle ensure the quality of their potable water by treating it with chlorine dioxide.

1.4.7 *Disinfection*

The disinfection cycle is usually undertaken cold, and often uses an oxidising biocide, such as sodium hypochlorite or peracetic acid solution (equilibrium mixture of acetic acid and hydrogen peroxide). Some non-oxidising biocides are also available, but they must be low foaming and fast acting in cold water in order to be effective for CIP. It is also possible to use hot water at the disinfection stage rather than a chemical agent; this is also very effective, but requires a high thermal energy input, which can prove costly.

1.4.8 *Final rinse*

The final rinse stage should be undertaken using cold potable water. Again, the quality of this water is critical, as it can lead to post-disinfection contamination and product spoilage.

1.5 Planning a cleaning project

Above all else, the paramount consideration in the planning of any cleaning project must be safety – not only of the plant and personnel involved, but of the product which that plant is required to process. The mid-1980s saw a dramatic reappraisal of many of the standards and practices previously regarded as acceptable within the dairy industry, following incidents – both at home and overseas – of contamination of products by micro-organisms rarely ever encountered as presenting problems of any significance, other than in raw milk supplies, to the average United Kingdom dairyman. Problems of *Salmonella* spp., *Listeria* spp. and *Yersinia* spp. contamination in finished product have all played their part in accentuating the need for stringent food hazard assessment in every field of activity; cleaning technology is not least among these. The interconnection of 'raw' and 'processed' side plant and pipelines into a single cleaning circuit, or the separate cleaning of 'raw' and 'processed' side equipment from a common CIP set – frequently encountered in the days when the fashion was for large, multi-purpose, centralised cleaning systems – is now generally considered to present unacceptable product risks. The trend is now strongly towards the use of smaller units, specifically dedicated to either raw or finished products, or to the cleaning requirements of individual circuits and plant equipment items. The total separation of the 'raw' and 'processed' sides of a factory – the only point at which the two ever come together being the flow diversion valve of the processing plant – should be the basic design objective of every process engineer. This approach may, in some installations, carry a capital cost penalty, but the advantages in quality assurance and generally lower revenue operating costs weigh heavily on the benefit side. Such an approach need not, of course, preclude the use of a common centralised control system; the need for programme safety interlocks between the individual systems is vital to such an approach.

Before embarking on any cleaning project, however, a considerable number of questions have to be answered regarding the actual equipment to be cleaned and the standards of cleanliness to be achieved.

1.5.1 *What is the physical nature of the plant or equipment to be cleaned?*

Any food manufacturing or processing plant will comprise many different items of equipment: for example, dairies and breweries will have plate heat exchangers, storage tanks, vats, pumps, valves, and interconnecting pipework, as well as specialised items, such as bottle and carton fillers or – on the manufacturing side – cheese plant, evaporators, spray dryers and continuous butter-makers. Each of these will have its own cleaning requirements, and pose its own individual cleaning problems. Food processing plants are probably the most diverse sector in terms of equipment design and cleaning requirements, and full consideration needs to be given to the design of this equipment with respect to CIP. Materials of construction must be considered, not only regarding any metal parts, but also items such as gaskets and similar rubber components, and plastic mouldings, to ensure their compatibility with the cleaning chemicals proposed regarding corrosion or degradation. Questions as to temperature and pressure or vacuum limitations of the equipment must be considered, all aimed at answering the overriding question: 'Can the plant be cleaned safely and effectively by in-place methods, achieving acceptable standards of cleanliness without damage to the plant itself?'

1.5.2 *What standards of cleaning are required?*

It is important to understand that various degrees of cleanliness may be appropriate in different circumstances. It is vital that this is clearly recognised, and the target level of cleanliness defined when considering any cleaning project. Levels of cleaning that might be considered are as follows.

- *Physically clean*: This primarily addresses the aesthetic aspect. The surface appears clean, but chemical residues, often deliberately left to achieve a particular desired effect, may have been allowed to remain. Disinfection of the surface has not been considered.
- *Chemically clean*: The surface is rendered totally free from any trace of chemical residues.
- *Microbiologically clean*: This addresses the degree of microbiological contamination remaining on the surface, and may range from plant that has been 'disinfected' – that is, the number of bacteria on the surface of the equipment has been reduced to a level consistent with acceptable quality control and hygienic standards – to surfaces rendered totally sterile, as is essential in ultra-high-temperature (UHT) and similar aseptic operations.

One can thus reach a situation where the surface involved has been physically cleaned and has, perhaps, been rendered microbiologically clean by chemical disinfection, but traces of substantive disinfectant chemical have been deliberately left on the surface to reduce the risk of subsequent microbiological contamination, and the surface is therefore still chemically 'contaminated'.

1.5.3 *What is the nature of the soil to be removed?*

Soil can be considered as the product residues, scale and any other unwanted deposits of foreign matter that have to be removed from the plant surfaces during the cleaning process. Within the manufacturing or processing dairy, such soil may include fat, protein (both denatured and un-denatured: see IDF, 1997), sugar (possibly caramelised), minerals (both from product and from the water supply), fruit cells and various manufacturing ingredients including gums, starches, stabilisers and emulsifiers – all of which will present different and often complex cleaning problems to the detergent chemist. In the dairy context, soil can be divided into two broad general headings: organic soil, which is mainly of plant or animal origin, and is generally most susceptible to attack by alkaline detergents; and inorganic soil, which is mainly of mineral origin, and is usually most effectively attacked by acidic detergents.

Most soils are, however, a combination of both organic and inorganic deposits. 'Milkstone', for example, is primarily a combination of calcium caseinate and calcium phosphate. The degree of heat denaturation of the soil can also dramatically change its physical condition, and call for widely differing cleaning techniques and chemicals.

1.5.4 *When is the cleaning to be undertaken?*

Within any processing or manufacturing site, there will be a wide variety of plant and equipment, some of which may become available or may have to be cleaned during the day while other processing is still under way. Other plant may not be available or accessible for cleaning until the day's production run has been completed. Where any cleaning operations are undertaken during the production day, it is vital that all other plant and product are totally safeguarded from contamination. This is usually addressed by mechanical safety breaks in pipework. Swinging bend systems provide a physical break between CIP circuits and production pipe runs; they can be fitted with proximity switches to help ensure that the loop has been installed in the correct position prior to CIP, and can provide an electrical interlock that prevents the CIP circuit from being initiated if the proximity switch is not activated. Another method of ensuring the separation of CIP fluid and the process is to utilise either 'block and bleed' valves or 'double seated' valves: these provide extra security within the design, with any leakage past a seal being clearly evident at the valve location. These valves need to be installed in an area that can be easily seen, to avoid potential product or CIP fluid losses in the event of a leak.

1.5.5 *The selection of detergents*

In addition to the points already enumerated, water quality will be a major factor in detergent selection. This, together with a detailed discussion of detergent chemistry, is reviewed in Chapter 4, but the following general points should be considered.

The attributes of detergents

A CIP detergent will ideally exhibit the following attributes:

- organic dissolving power – to solubilise the proteins and fats;
- dispersing and suspending power – to bring insoluble soils into suspension and prevent their redeposition on cleaned surfaces;
- emulsifying power – to hold oils and fats dispersed within the cleaning solution;
- sequestering power – the ability to combine with calcium and magnesium salts, as found, for example, in hard water, to form water-soluble compounds, and to aid detergency and rinseability;
- wetting power – to reduce surface tension, and thus aid soil penetration; and
- rinsing power – the ability to rinse away clearly and completely without leaving any trace of soil or the detergent chemical on the cleaned surface.

The mechanisms of soil removal

During the cleaning cycle, energy is applied to the soil in three basic forms:

- kinetic energy in the form of solution turbulence;
- thermal energy in the form of solution temperature; and
- chemical energy – that is, the chemical reactions between the detergent components and the soil.

A deficiency in one of these energy components may be partially compensated for by an increase in the others, but all three are vital to the total operation. For example, the change from laminar to turbulent flow occurs in pipelines at certain critical flowrates, dependent on the pipe diameter, solution viscosity and temperature conditions. Successful cleaning of pipelines is generally associated only with turbulent flow conditions, 1.5 m s^{-1} being regarded as the accepted target flowrate for pipeline CIP. Where pipelines, plate heat exchangers and similar items of plant can be completely filled with detergent and circulated, this is referred to as a *closed CIP circuit*. Where large items of plant, such as storage tanks, have to be cleaned, it would be impractical to make a closed circuit by filling the vessel. The usual approach is to spray cleaning fluids onto the vessel walls via a spray device and pick up the detergent at the vessel outlet for return to the CIP set via a recovery or scavenge pump. Such a system is referred to as an *open CIP circuit*. These concepts are developed further in Chapter 7. It is generally accepted that temperatures above the melting point of butterfat are necessary where milk-based soils are being addressed. Thus temperatures below 60°C are less likely to yield satisfactory standards. However, as a generalisation, an increase of 10°C will increase the rate of chemical reaction by a factor of between 1.5 and 2.0, and there is a 'pay-off' between thermal and chemical energy input (IDF, 1979). In the beverage sector, CIP is very often carried out at ambient temperatures, but generally at much higher caustic alkalinity levels (2–3 g 100 g^{-1} caustic soda) than those employed in the dairy sector (1.0 g 100 g^{-1} caustic soda). In the brewery sector, consideration must be given to the effects of CO_2 on the cleaning process in terms of its reaction with caustic soda to form carbonate, which exhibits much poorer cleaning performance.

1.6 Conclusions

In summary, the basic principles of cleaning are as follows.

- Consider the physical nature and construction of the equipment to be cleaned.
- Assess the nature of the soil to be removed.
- Select a detergent appropriate to the removal of that soil.
- Bring the soil and the detergent together: that is,
  - (a) at the right temperature
  - (b) under the right conditions of flow and turbulence
  - (c) at the right chemical concentration
  - (d) for the right period of time.

- Rinse away all traces of detergent and soil, with the objective of achieving the standard of cleanliness appropriate to the duty for which the equipment is destined to be used.
- Always undertake cleaning as soon as possible after completion of the production operation.
- Where necessary, undertake a disinfection or sterilisation process immediately before the equipment is returned to processing or production duties in order to reduce the level of microbiological contamination to one consistent with the hygienic standard required for that duty.

References

Anonymous (1990) *The Environmental Protection Act*, HMSO, London.

IDF (1979) *Design and Use of CIP Systems in the Dairy Industry*, Document No. 117, International Dairy Federation, Brussels.

IDF (1997) *Fouling and Cleaning of Heat Treatment Equipment*, Document No. 328, International Dairy Federation, Brussels.