The continuous or semicontinuous flow thermal treatment of particulate foods

It is inherently more difficult to design a sterilization process for liquid foods containing particulates than for homogeneous liquids, due to heat transfer limitations in particulate–liquid mixtures and the additional problems of transport and handling. Here the guidelines for the microbiologically safe thermal sterilization of particulate foods recommended by the Continuous Heat Treatments subgroup of the European Hygienic Equipment Design Group (EHEDG) are summarized. This paper is the 13th in a series of articles featuring the EHEDG to be published in *Trends in Food Science & Technology*. The EHEDG is an independent consortium formed to develop guidelines and test methods for the safe and hygienic processing of food. The group includes representatives from research institutes, the food industry, equipment manufacturers and government organizations in Europe.*

Thermal sterilization is a process aimed at eliminating the risk of food poisoning and, when used in conjunction with aseptic filling, achieving an extended product storage life under ambient conditions. This is achieved by the destruction of vegetative microorganisms and relevant bacterial spores.

In earlier papers, the Continuous Heat Treatments subgroup of the European Hygienic Equipment Design group (EHEDG) has presented guidelines on continuous pasteurization[1] and sterilization[2] to assist in providing assurance that products are microbiologically safe (for list of definitions used see Ref. 1).

This paper presents guidelines on the design of continuous and semicontinuous plants for the heat treatment of particulate foods. Only well-known, widely used techniques form the scope of this paper. More recently developed techniques, such as ohmic heating, are not covered but may form the basis of a future publication. These guidelines have been approved by the EHEDG.

The underlying principles of thermal sterilization are straightforward in that the product to be sterilized is heated to a specified temperature and maintained at or above that temperature for a fixed time. Sterilization is typically applied to low-acid products requiring an extended shelf life at ambient temperature. Continuous or semicontinuous flow sterilization plants are therefore typically operated in conjunction with an aseptic filler or further processing under aseptic conditions.

Although this document concentrates on sterilization processes, the principles are consistent with other heat treatment processes.

For microbiologically safe sterilization, it is essential that the correct sterilization conditions are achieved throughout the product being processed, and reinfection of sterilized product is prevented. Maintenance of the correct sterilization conditions requires that all components of the product achieve the desired sterilizing temperature–time profile, and the plant design, operation and control must be such as to enable this to be achieved. Prevention of reinfection requires that any equipment and packaging that comes into contact with a sterile product can itself be sterilized and is impervious to bacteria.

Liquid foods containing particulates are inherently more difficult to process than homogeneous liquids due to the problems incurred in handling and transporting particulate–liquid mixtures, as well as due to heat transfer limitations resulting from the sizes and shapes of the particles.

Particles can have many different forms and sizes, ranging from those with dimensions in excess of 25 mm (vegetable, fruit or meat components) to those of less than 2 mm (e.g. rice), as well as being of irregular shape and size. In some cases the solids may be elongated, as in the case of fruit juice fibres. The complete product may also contain several types of particles of different size and shape. The proportion of solid particles in the product may also vary widely in different products, such as soups, stews and pies. For the sterilization process the definition of a particulate is any discrete solid within which heat is transferred by conductive rather than convective means.

The process design and evaluation for the sterilization of particulate-containing liquids is more complex than for liquids alone because while the liquid fraction may be heated rapidly in heat exchangers, heat penetration into the centre of the particles is much slower, relying on heat conduction from the outside to the centre. The size and concentration of the particles will therefore have a significant effect on the heating rates that can be achieved in the particle. Any microbiological consideration of a heating process must therefore be based on the temperature profile at the slowest-heating zone of the product, the centre of the particle.

The sterilization process is defined in terms of the lethality or sterilizing value delivered to the coldest zone of the particle.

Lethality (L) is defined as:

$$L = 10^{(T-121.1)/z}$$

where T is the temperature (°C) and z is the temperature rise (°C) giving a tenfold change in decimal reduction

*Readers requiring further information on the EHEDG are referred to *Trends in Food Science & Technology* (1992) Vol. 3 (11), p. 277.

time (the time to reduce the number of living microorganisms by a factor of ten). The sterilizing value (F_0) of a process may be calculated by integrating the lethality over the duration of the process such that:

$$F_0 = \int_0^t L dt$$

where t is the process time.

The temperature of the food particle cannot be measured continuously as it passes through the process, and hence in order to design a suitable process the following steps must be taken:

- select an appropriate sterilizing value;
- develop a model to predict the temperature and hence sterilizing value achieved at the coldest point within the particle;
- validate the sterilizing effect delivered, microbiologically;
- define critical factors controlling the processes and the procedures to be used for their verification.

Depending on whether a fully continuous or semicontinuous process is being used, the heated product will either be pumped through a holding tube or held for a fixed period in a heated or thermally insulated vessel.

The sterilization value should be considered as that delivered at the holding stage alone, and the heating and cooling phases should not be taken into account when the minimum sterilizing value to assure public health is being calculated.

Heat treatment processes

The inherent difference in heating rates for liquids and particulates means that the liquid component of the product will normally be subjected to a significantly higher sterilizing value than the particles. While this causes no problems from a microbiological viewpoint, providing the minimum sterilizing value is exceeded, it may result in thermal overprocessing of the liquid fraction with a consequent loss of product quality. A number of processes are therefore used for liquid–particulate mixtures in addition to those commonly applied for liquids alone, to try to overcome some of these limitations.

The processes generally fall into one of two categories: continuous or semicontinuous. In continuous systems, product flow is continuous, whereas in semicontinuous systems, one or more of the process operations may function in batch mode while others operate continuously.

The choice of system is dependent on many factors related to product quality, product characteristics (particle size, fluid viscosity, susceptibility to fouling), production requirements (capacity, run length) and economics (capital, running costs). In many cases the key factor is the ability of the system selected to handle the particulates without becoming blocked or causing excessive physical damage to the product.

Continuous heat treatment systems

Continuous heat treatment systems can be subdivided into direct, indirect or split-flow systems.

In a direct system the product is heated by the condensation of steam brought into direct contact with the product. There are two types of direct heating: steam injection and steam infusion. In a steam injection process, steam is injected directly into the product, whereas in an infusion process the product is sprayed into a steam atmosphere. Both the steam injection and steam infusion processes have been described in an earlier publication[2].

An indirect system is one in which the heating medium (steam/hot water) is separated from the product by a physical barrier and heat is transferred across the barrier to heat the product. Indirect heating is probably the most widely used technique for the sterilization of liquid foods and is simpler than the direct heating techniques. The process has been described in an earlier publication[2].

An alternative approach is the use of a split-stream process in which the product is separated into a liquid phase and a particulate phase. The two phases are processed continuously but separately, using any of the previously described methods, and are recombined after the holding stage. A possible option for such a system is shown in Fig. 1a. For a sterilization process recombination of the two phases must be carried out under aseptic conditions since both sterilized products must be protected against reinfection.

Semicontinuous processing

Semicontinuous processes address the problem of overprocessing the liquid fraction by separating the liquid and particulate components and processing them independently. In this case the particulates are processed on a batch basis in order to ensure that all the particles receive the same heat treatment. The liquid fraction can be processed continuously using any of the conventional liquid sterilization systems. Figure 1b shows an arrangement for semicontinuous processing with batch heating of particulates, continuous sterilization of liquid and continuous filling. In this case two aseptic buffer tanks are required in order to integrate the batch and continuous operations. A number of sterile barriers are also required so that the buffer tanks can be maintained under aseptic conditions at times when the batch processing system is unsterile, for example when a new batch of particulates has been added to the system. In this example the solids and liquid fraction are mixed in a batch heating system before being transferred to the filler. An alternative option is shown in Fig. 1c, in which the liquid is processed and filled separately from the particles in a two-stage filler. This avoids the need to mix the liquid and solid components and the problem of the settling out of solids in aseptic buffer storage.

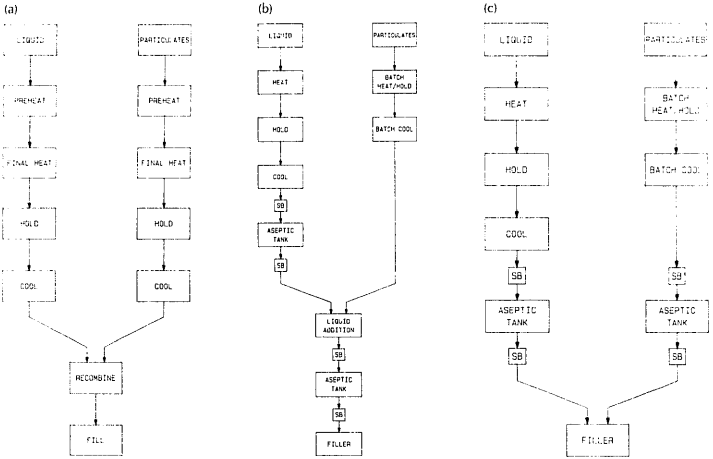

Fig. 1

Schematic diagrams of: (a), a split-flow process; (b), a semicontinuous process; (c), a semicontinuous process with two-stage filling. SB, Sterile barrier.

System components

Any process line consists of a number of components, each of which has its own specific functional requirements to enable it to operate effectively. Some of these requirements are common to all components (for general guidelines, see Ref. 3), while particular features of the products influence the selection and design of particular system components, such as valves and pumps (guidelines in preparation).

Important product characteristics include:

- particle size;
- particle shape;
- particle concentration;
- relative density of particles and liquid;
- rheological behaviour of liquid.

The design should minimize the opportunity for the solid components to sediment or separate out from the liquid fraction, and hence particular care should be taken with solids possessing a significantly higher density than the fluid. Changes in direction resulting from, for example, pipework bends, can result in separation due to centrifugal forces, leading to unhomogeneous flow. This may be particularly important in valve manifolds or heat exchanger distribution plates where uneven distribution may occur, resulting in blockage of all or part of the system.

General requirements for all system components have been described in an earlier publication[2].

Heat exchangers

The primary function of a heat exchanger in a sterilization plant is to deliver the desired heat transfer, whether heating or cooling, for the range of products being processed. The heat exchanger must be capable of functioning reproducibly and reliably on a routine basis. It is the responsibility of the equipment supplier to ensure that the heat exchanger is capable of achieving the desired temperature conditions at all times.

A critical factor in the design is the heat transfer coefficient between the liquid and the particle, as this will control the amount of heat transferred to the particle during its passage through the heat exchanger and holding tube. The residence time distribution must also be known in order that the temperature distribution within the particle at the start of the holding tube can be estimated.

The heat exchanger will not necessarily be designed for maximum heat transfer efficiency. This is because other factors, such as the fouling of heat transfer surfaces and the balance between capital and running costs, must also be taken into account. A wide variety of heat exchangers are used for heating and cooling duties in both direct and indirect systems. Requirements common to all types, in addition to detailed requirements for different

types of heat exchanger, are described in the EHEDG document on liquid sterilization[2]. In addition, all tubular heat exchangers must satisfy the following important requirements.

- If the product contains fibres, for example fruit juices, the cross section should be large enough everywhere to prevent blockage of the flow of product. Designs with spacers are not suitable for products containing fibres.
- It is desirable to ensure that as far as possible the flow of product is upwards through the entire installation, to eliminate the possibility of air being trapped in the system. An upward flow is particularly necessary in the case of low product velocities.
- The provision of access for inspection of cleanliness and corrosion is desirable. In certain countries such inspection provisions may be legally required.
- In some tubular heat exchangers, a shadow effect is unavoidable. This must be taken into consideration in devising the cleaning in-place (CIP) procedure. Often, increasing the velocity of the cleaning fluid will be sufficient. In other cases reversal of the direction of the flow of cleaning fluid may improve cleaning, especially where fruit fibres are present, although this may not be practical in the majority of cases. In cases where a detergent concentrate is added in-line, the potential for low mixing efficiency of tubular heat exchangers must be taken into account. Also, for in-line addition, care must be taken to ensure that vulnerable components, such as gaskets and seals, are not exposed to high concentrations of chemicals at elevated temperatures.

Plate heat exchangers are rarely used for the heating of products containing particulates. The most likely application is for products such as fruit juice with added fibres and pulp. In this case the plates should be of the free-flow type with no metal-to-metal contact points, which can provide a focus for deposition and are difficult to clean.

Scraped-surface heat exchangers are particularly suited to the heat treatment of both viscous products and particulate-containing fluids. They may be of horizontal or vertical design and are typically 150–200 mm in diameter with a rotating dasher assembly, which holds blades that scrape or sweep product from the surface to maintain effective heat transfer. The correct position and orientation of blades and rotational direction should be clearly indicated.

Any cooling medium can be used but direct regenerative heating or cooling with product is impractical. Steam is the normal heating medium. Since the heat transfer area available is generally much less than for other types of heat exchangers, the temperature differences required to achieve required heat fluxes are high. In the case of product heating this can result in increased fouling.

Other factors to be taken into account when selecting and using a scraped-surface heat exchanger are listed below.

- With particulate products, it is necessary to consider the relative densities of the particles and liquid when selecting a horizontal or vertical machine, in order to avoid settling or separation.
- The consequences of blade configuration may be considerable. For example, a fully bladed machine may give plug flow and mass rotation, which gives consistent residence time but may also lead to temperature distribution problems.
- The type of blade and rotational speed can have a major effect on particle integrity.
- During CIP, the velocity through the annular space may be lower than in the rest of the line. Design of an adequate CIP process is therefore essential.

Spiral heat exchangers consist of two strips of sheet metal provided with spacer studs and wound into a cylinder to form a pair of concentric spiral flow passages. Normally alternate edges of the passages are closed so that fluid flows through continuous leak-proof channels. Covers are fitted to each side of the spiral assembly to complete the unit. Full countercurrent flow can be achieved, with one fluid entering at the centre of the unit and flowing from the inside outward. The second fluid enters at the periphery and flows towards the centre. One potential advantage of this type of unit is that with a single flow channel there is less likelihood of uneven flow distribution between parallel channels. This may also result in a self-scouring action when handling fluids with suspended solids. In addition the channel dimensions can be chosen according to the size of the particles and flow rates, by the length of the studs welded to the plate.

Seals between the covers and the spiral body must be suitable for aseptic operation, if installed on the sterile side of the process. Studs should be fully welded to the plate to ensure that no crevice is formed.

Steam injector and steam supply

Key requirements for the steam injector and supply have been described in a previous publication[2].

Holding tube

The operation of the holding tube in a particulates processing system is significantly different from that in a system with a homogeneous product. The holding tube effectively acts as an equilibration tube, such that heat is transferred from the carrier fluid to the particles during their passage through the tube. The liquid temperature will therefore fall as it moves through the tube and the particle temperature will rise. The system is not operating under steady-state conditions. To determine the sterilizing effect achieved, the temperature profile of the slowest-heating point within the particle, as well as the residence time distribution in the holding tube, particularly the residence time of the fastest-moving particle, must be estimated or measured.

Particle residence time is particularly important and must be known with a high degree of confidence, as

processing time requirements will be based on these. The presence of particles in a fluid significantly complicates the flow characteristics and hence the residence time distribution. It is likely that the residence time will depend on the size of the particle, its concentration, the viscosity of the fluid and the holding tube configuration. If a product contains a range of particle sizes, it will be necessary to consider the residence time distribution of all the particle sizes. If the minimum residence time of a smaller particle is significantly less than that of a larger particle, the heating rate of the largest particle may not necessarily be the most critical determinant of microbiological safety, if the more rapid heating rate of the smaller particle is more than compensated for by the shorter residence time in the holding tube. Specification of the correct residence time is the responsibility of the food manufacturer.

Other important requirements for holding tubes are listed in the general guidelines for the sterilization of liquid foods[2].

Process vessels and buffer tanks

Process vessels are those within which a stage of the sterilizing process takes place, typical examples being: the vacuum cooling vessel in a direct injection plant in which the steam injected to heat the product up to sterilizing temperature can be removed by evaporative cooling; and the particulates heating vessel in a semicontinuous process in which the particulates are heated to sterilizing temperature, held to achieve the desired F_0 and subsequently cooled prior to further processing.

Buffer tanks, often referred to as aseptic tanks, can be used in conjunction with continuous sterilization plants to improve plant utilization and flexibility. In addition, with semicontinuous processes they provide a means of integrating the batch and continuous elements of the process.

Both types of vessel may contain a number of internal components, such as fixed baffles and rotating mixers, both to maximize heat transfer performance and prevent separation of the particulate and liquid fractions.

Both types of vessels are pressure vessels and need to be designed to high standards in order to be acceptable for use in such applications, as described in the previous article on sterilization[2].

Product transfer systems

Product transfer is a critical unit operation in the heat treatment of liquid foods with particulates as it affects product quality as well as microbiological safety. A key product quality target is the maintenance of particle integrity.

Product transfer can be achieved in three ways: using a mechanical device such as a pump, using compressed gas as the motive force, or using gravity. Suitable types of pumps for handling particulates may include progressive cavity, lobe, sine, piston, screw, peristaltic and diaphragm pumps. If the pump is fed from a tank, the product in the tank may have to be agitated in order to ensure homogeneous particulate distribution in the liquid phase. The residence time distribution is not normally affected by the type of pump but by the relative velocity between particle and carrier fluid.

It is essential that pumps deliver a constant product flow rate to ensure that the desired residence times are maintained. A constant ratio of liquid to particulates should be maintained, as an undesired change in particle concentration could lead to insufficient heat treatment in the centre of particles and thus compromise product safety. Rotating pump components installed in a sterile area of the process should be fitted with double seals, with the gap flushed with steam or antimicrobial fluid. Cavitation should be avoided as this may cause damage to the internal surfaces or seals and could therefore have a detrimental effect on cleaning.

The use of compressed gas for product transfer is sometimes feasible and may have the advantage of avoiding the need for an additional component (i.e. a pump). Any gas must be passed through an appropriate bacterial filter before being used. Care must be taken in the selection of the gas pressure as it is possible to preferentially transfer the liquid leaving the particles behind. It should therefore only be used in areas where maintenance of a constant flow rate and liquid : solid ratio is not critical.

Valves and back-pressure devices

Valves are used for routeing purposes or to control a process parameter such as flow or back pressure. In applications where particles are being handled the valves must be designed such that the opening for the product is large enough to allow the particles to pass unhampered and with minimum damage. Failure to achieve this may result in bridging of the particles across the valve, followed by blockage. This is likely to severely restrict the types of valves that can be used, particularly for systems handling larger particles.

In the case where the valve movement is linear via a shaft, for example a pneumatic lip seal valve, it may be necessary to ensure that additional lift of the valve seat is provided to allow particulates to pass through. For valves installed in an aseptic area of the plant, an antimicrobial barrier on the shaft of the valve will be required to prevent recontamination of the product when the valve seat is lowered (Fig. 2).

Control of pressure may be achieved in a number of ways:

- using a pressurized storage vessel – the pressure in the vessel in turn may be controlled by controlling the pressure of the gas above the product (e.g. air or nitrogen);
- using a constant back-pressure valve – this would normally be an air-loaded diaphragm valve with the capacity to pass full flow back to the plant feed system in the event of filler stoppage; depending on the configuration of the line it may be necessary to have a sterile barrier installed;
- using a positive displacement pump with speed variation to control back pressure.

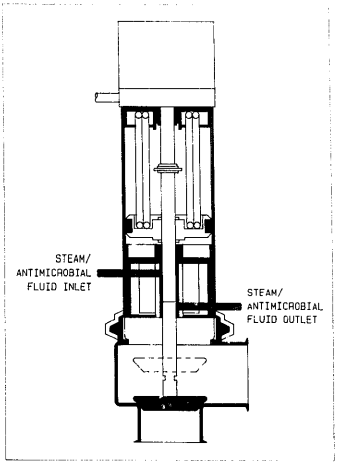

Fig. 2
A high-lift valve with sterile barrier; additional lift is needed to allow particulates to pass through. Red, steam/antimicrobial fluid.

Combinations of these options may be used as well, depending on the subsequent process or packing system and start-up and shut-down requirements.

Sensors

The types of sensors used and the components within which they are housed must not create obstructions in the process line that could lead to product entrapment and eventual blockage. Non-invasive sensors, if available, should be actively considered.

In-line temperature sensors can be susceptible to fibres as well as large particles. A potential solution would be to use surface probes, which by their very nature are non-invasive. They should be insulated in order to ensure that the bulk temperature is monitored. The speed of response of such probes is likely to be different from those placed directly in the line and this should be taken into account in the design of the control system.

Many types of pressure sensors are susceptible to blockage. Tubular diaphragm probes are likely to be most suitable.

Flow meters with internal components in the product flow are unsuitable. Sensors based on magnetic inductive flow and mass principles are more suitable. Ultrasonic flow techniques can also be considered as potential non-invasive methods.

The most suitable level transmitters are those based on weight, such as load cells, differential pressure transmitters and ultrasonic devices.

Aseptic barriers

Aseptic barriers provide a way of separating sterile and unsterile areas of the plant such that product sterility is not compromised. This is normally carried out by means of a number of valves and a typical example is shown in Fig. 3a. Figure 3b shows a similar barrier system to that of Fig. 3a but one that is free from dead legs. The design of the valve must be such that the distance between the seals is larger than the stroke of the shaft.

Process operation

General requirements for presterilization of equipment, production, flow diversion and cleaning in plants for the sterilization of liquid foods have been published previously[2]. For semicontinuous plants, the batch heating vessels are sterilized with the product during the product heating cycle and are therefore not always subjected to a presterilization step.

Process monitoring and control

In sterilization plants there are a number of critical control points, including:

- temperature at the end of the holding tube during production;
- recirculation return temperature during sterilization prior to production;
- product flow rate during production;
- temperature in batch heating vessel during production;
- back pressure in holding tube during production;
- aseptic tank temperature during sterilization prior to production;
- aseptic tank pressure after sterilization and during production;
- aseptic barrier temperatures;
- filling temperatures.

It is essential that the control logic of the plant will provide the appropriate action in response to process deviations. Unacceptable deviations in critical process variables must result in automatic shutdown of the plant. For example, the plant would have to be shut down if the sterilizing temperature fell below the minimum level.

It is essential to record critical process parameters from the plant on a continuous basis. Legal requirements may also necessitate the continuous recording of certain data. In addition, modern data-logging facilities enable a considerable number of variables to be monitored and it is recommended that they are used to provide a record of when the variables are outside the normal operating ranges. This allows the performance of

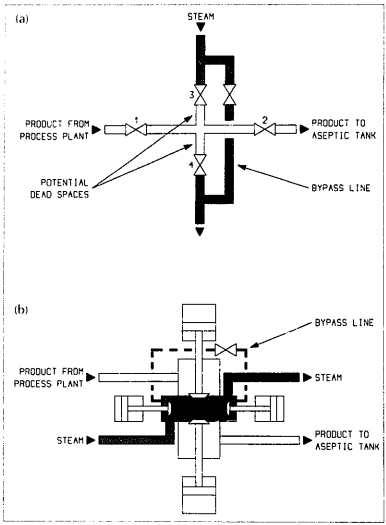

Fig. 3

Sterile barriers. (a) Typical sterile barrier. When the plant and tank are sterile and product is to be transferred to the tank, valves 3 and 4 are closed and 1 and 2 opened. If the process plant becomes unsterile and hence it is necessary to protect the product in the tank, valves 1 and 2 are closed and steam purges the short section of pipe between them. A bypass line must also be fitted such that the back of valve 4 can be steamed, so as to prevent any potential contamination via valve 4. This also prevents condensate accumulation in the steam supply line. A temperature sensor in the outlet line between valve 4 and the orifice/steam trap enables the status of the barrier to be monitored and ensures that the barrier temperature is always sufficient. In some cases an antimicrobial fluid may be used in place of steam within the barrier. Note the potential dead areas. (b) A similar sterile barrier, but one that is free from dead legs, using an aseptic double seat valve. The design of the valve must be such that the distance between the seals is larger than the stroke of the shaft. Red, steam; yellow, product.

the total process to be closely monitored during operation, to ensure that the desired performance standards are being achieved on a routine basis and that the plant is operating to specification. It is particularly important to monitor the process–equipment interactions that can result in adverse effects such as fouling.

Sterilizing plants are controlled by a combination of digital and analogue signals, digital for valve sequences and analogue for control of the major process variables. The major process variables controlled are temperature, pressure, flow and level. For each control variable it is necessary to assess the quality of control required, the speed of response required, the action to be taken if the variable is outside the set range, the likelihood of control problems arising from interaction with other control loops, and the position of the sensor.

For critical variables such as sterilizing temperature, the quality of control needs to be high with a rapid response to changes. If the temperature falls below a preset minimum, plant shutdown must be automatically initiated. By contrast, the level control in a vacuum vessel may be important in terms of ensuring fluid is always present but the quality of control need not be as high or the response time so rapid as for sterilizing temperature. General requirements for the control of temperature, pressure, flow rate and level are the same as those for the sterilization of all liquid foods[2]. The sterilization temperature and the lower temperature limits that define when to terminate sterilization must be based on the minimum acceptable F_0. Specification of the correct temperatures is fully the responsibility of the food manufacturer.

Process validation

Process validation should form a critical element in the design of a sterilization system. For liquid products the sterilization process can be validated by monitoring the temperatures achieved and the flow rate, and thus define the sterilization process delivered to the product. For products containing particulates the inability to continuously monitor the slowest-heating zone within the particulate means that process validation becomes more complex and a direct measurement using a biological method is required. In this case the particle is inoculated with bacterial spores, which pass through the process and are recovered; the surviving spores are counted and the reduction in numbers due to the process is determined. Three methods can be considered for inoculating particles.

- Bacterial spores in a carrier in a particle: In this method the spheres are encapsulated in a carrier and do not therefore come into contact with the food product. The carrier is placed inside the particle and recovered after the process. This method has the advantage that the spores can all be located near the geometric centre and thus give a measure of the sterilizing value delivered to the centre of the particle.
- Particles of food inoculated with bacterial spores: In this method there is no carrier and the particle is directly inoculated with spores. The location and distribution of the spores must be known since if they are uniformly distributed in the particle they will measure an integrated sterilizing value rather than the value delivered to the centre of the particle. The z value for the spores used must be known.
- Simulated particles inoculated with bacterial spores: In this case simulated particles are used rather than

actual food. Alginate gel particles have been shown to give reproducible results, with the spores in alginate systems being stable for extended periods of time. However, the use of such a method will give an integrated sterilization value rather than that at the centre of the particle.

In all three methods, the size of the inoculated particles must be representative of the composition of the product and the residence times of the particles representative of the minimum residence time. This is necessary to ensure that both heating rates and holding times are considered.

The following process parameters should also be validated: particle size control, particle : liquid ratio, influence of clumping or non-uniform pumping of products, critical process measurements such as temperature and flow rate, system components and configuration.

Inspection and maintenance

Requirements for plant inspection and maintenance are the same as for the sterilization of liquid foods[2].

Conclusions

In order to ensure the microbiological safety of a sterilization process the following must be achieved.

- The measuring and control equipment must ensure that temperature, flow and back pressure are maintained.
- Unacceptable deviations in key process variables must result in automatic shutdown of the plant.
- The process must be stopped when fouling becomes so severe as to compromise the microbiological safety of the product.
- The process equipment in the sterile areas of the plant must be aseptic and hence cleanable, sterilizable and bacteria tight.
- The process must be validated experimentally to ensure that all the product receives at least the minimum acceptable heat treatment.

Acknowledgement

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This paper summarizes the guidelines recommended by the European Hygienic Equipment Design Group (EHEDG) subgroup on Continuous Heat Treatments. The full report, by A.P.M. Hasting, S.A. Davies, M. Lalande, H.L.M. Lelieveld, M.A. Mostert, J. Nassauer and L-E. Andersson, is available from: D.A. Timperley, Campden Food and Drink Research Association (CFDRA), Chipping Campden, UK GL55 6LD (tel. +44-386-840319; fax: +44-386-841306).

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