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ADVANCEMENT IN DAIRY PROCESSING: EMERGING TECHNOLOGIES

This bulletin includes technical and latest development on products, systems, techniques etc. reported in journals, companies' leaflets and books and based on studies and experience. The technical information on different issues is on different areas of plant operation. It is hoped that the information contained herein will be useful to readers.

The theme of information in this issue is **Advancement in Dairy Processing: Emerging Technologies**. It may be understood that the information given here is by no means complete.

In this issue:

1. INTRODUCTION

Consumers' increasing demand for palatable, safe dairy foods with long shelf-life has led to development of new processing technologies based on non-heat treatments. There are several emerging processing technologies, some available for commercial applications, other still needing more development work. For commercial applications, they must be sustainable, be economical, be acceptable to the majority of consumers and have minimal environmental impact.

Some non-thermal emerging processing technologies, which have been considered to be employed in dairy processing are mentioned in this issue.

2. PULSED ELECTRIC FIELD TECHNOLOGY

The use of various pulsed-energy technologies should normally be considered as microbiocidal hurdles. New development in the area of pulsed-energy technologies indicate that some of these technologies are on the way to be interesting alternatives to traditional heat treatments for the production of safe, nutritious foods with fresh-flavour characteristics.

Pulsed-energy technologies for treatment of foods utilize high energy levels in short bursts or pulses (microseconds to milliseconds) with the expenditure of average power consumption. The energy is initially generated as electrical energy and accumulated in a storage capacitor.

The most promising technology for dairy products seems to be the Pulsed Electric Field (PEF) Technology.

PEF Technology has the potential to replace, or at least complement, traditional thermal processes for the pasteurization

and sterilization of liquid milk products. Since most PEF operations are performed under mild conditions, often at ambient temperature, the technology offers considerable consumer benefits in terms of better quality (flavour, colour) and comparable or better safety than corresponding thermally processed products. It may also offer processors benefits in terms of lower operational costs than thermal processes[1].

The essential components of a PEF processing system are: (1) a high-voltage power supply (~30 kV);(2) an energy storage capacitor; (3) a pulse generator and switching system; (4) a treatment chamber, containing two electrodes, through which liquid food is pumped; (5) a cooling system; (6) a unit for control and monitoring of voltage, current and electric field strength; and (7) a product delivery and packaging system.

Figure 1 shows a schematic diagram of the PEF processing equipment[1].

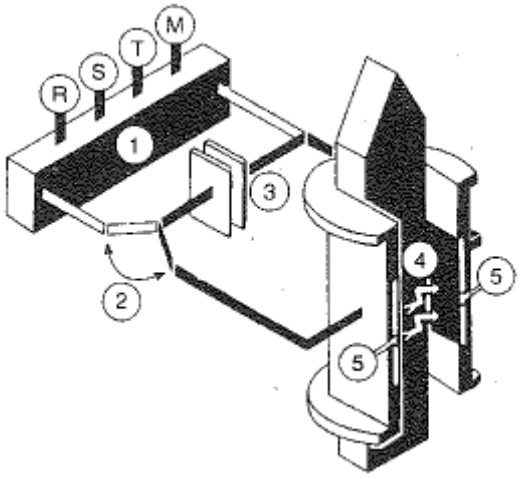

Figure 1 Schematic representation of PEF equipment. 1, High-voltage gnerator; 2, switch; 3, capacitor; 4, medium; 5, electrodes; R, S, T and M, connector points to mains supply.

Energy from the high-voltage power supply is stored in the capacitor, and discharges almost instantaneously at high levels of power. While the discharge is extremely fast (1-30 μs), the time between discharges is comparatively large (1 millisecond to seconds). The number of pulses can vary from 10 to 100. Total treatment times are generally less than 1 second. The strength of the electric field, which passes through the food is directly proportional to the voltage supplied across the electrodes, and inversely proportional to the gap or distance between the electrodes. PEF technology utilizes electric field strengths of 10-50 $kVcm^{-1}$. The design of the treatment chamber is critical to the efficacy of this technology.

The most important aspect of PEF technology in the treatment of liquid milk products is its effect on bacteria. Most vegetative cells can be destroyed by the technology but bacterial spores are much more resistant[(1)]. When a high voltage is applied to a liquid containing microbial cells, a trans-membrane potential is induced across the membrane of the cell. When this exceeds a critical value, about 1 volt, electroporation occurs, that is pores form in the cell membrane As a consequence, the content of the cell is released and the cell dies.

Results show that micro-organisms are more sensitive to PEF in the log phase of growth than in the stationary phase and that fat protects microorganisms against electric pulses. For example is destruction of bacteria in milk containing 3.5% fat less than in milk with 1.5% fat. Under a given set of conditions the degree of microbial inactivation achievable by PEF decreases with increasing conductivity of the food.

There are several reports of PEF being ineffective against endospores. The reason for the greater resistance of spores to PEF is that the electrical conductivity is considerably lower in endospores than in vegetative cells, due to the low water content and relative immobility of ions within the spore core. It has been suggested that spores are more susceptible to PEF at the time of germination

and outgrowth. However, germination is not initiated by PEF. Therefore, processes capable of inducing germination (e.g. treatment with high hydrostatic pressure, heat or ultrasound) may enhance the effectiveness of PEF in inactivation of spores[1].

PEF has a variable effect on enzymes with some being completely or partially inactivated (e.g. milk plasmin), some being stimulated (e.g. lysozyme and pepsin) and some being unaffected (e.g. pectinesterase). In dairy processing, it is of interest that milk plasmin (alkaline protease), which is resistant to heat treatments, even UHT, is largely inactivated by PEF. However, alkaline phosphatase and lipase, which are completely inactivated by HTST pasteurization, are only partially inactivated by PEF.

Milk has been subjected to PEF in several studies and the results are reasonably consistent. Most report 4-5 log reductions of non-sporeforming bacteria. Typical conditions used are 50-55^{o}C at 20 kVcm^{-1}. Lower reduction is observed at lower temperatures (20-40^{o}C). PEF treatment, without pasterization, can achieve a safe product and up to 14 days extension of shelf-life. Experiment shows a reduction from 10^{8} cfu ml^{-1} *Listeria* spp., inoculated in milk, to ~10^{-1} cfu ml^{-1} after treatment at ~60^{o}C. Little or no change in flavour, colour, lipid oxidation, alkaline phosphatase activity, bovine serum albumin, fat globule membrane, casein micelles or coagulation properties has been observed. However, a reduction in vitamin C in milk treated with PEF has been observed. PEF-treated yoghurt containing yeast (10 cfu ml^{-1}), which can reduce its shelf life, had no detectable yeast after storage for 30 days at 7-9^{o}C.

3. HIGH PRESSURE PROCESSING

The application of high pressure, rather than heat, to food enables destruction of microorganisms without causing significant changes to the colour, flavour and nutritional attributes of the food. In addition, high pressure can cause rheological changes in

food, which result in beneficial sensory and structural effects.

Typically, high-pressure processing is performed at 300-1000 MPa (3000-10000 kg/sq. cm) at room temperature for 2-30 minutes[3].

During high-pressure processing, the pressure is instantaneously and uniformaly transmitted in all directions, regardless of shape or volume. Consequently, the food is treated evenly throughout and no particles escape the treatment. This contrasts with process involving heating where different parts of the food can be heated at different rates.

High pressure disrupts noncovalent bonds but has little effect on covalent bonds. Thus, the large biomolecules such as proteins, nucleic acids and polysaccharides, which depend on noncovalent bonding such as hydrophobic interactions and hydrogen bonds to maintain structure and function, are most affected. On the other hand, smaller organic molecules such as those responsible for colours, flavours and nutrients (e.g. vitamins) in which covalent bonding is the dominant, or only type of bonding, are not affected, or affected very little by the pressure treatment. The low temperature at which high-pressure treatments are performed ensures little or no heat-induced change in these components.

A high-pressure system usually consists of four main parts: (1) a high-pressure vessel and its closure; (2) a pressure generation system; (3) a temperature control device; and (4) a materials handling system. Pressure treatment can be performed in batch or semi-continuous operations. In batch operations, a pressure chamber containing the liquid or solid food is pressurized for a given holding time and then decompressed. A variation of the batch method is the so-called pulsed high-pressure process where the pressure is raised and lowered repeatedly at intervals of several minutes. In semi-continuous processing, several vessels are connected in series; while some are under constant pressure, others are being pressurized, unloaded or loaded (Figure 2).

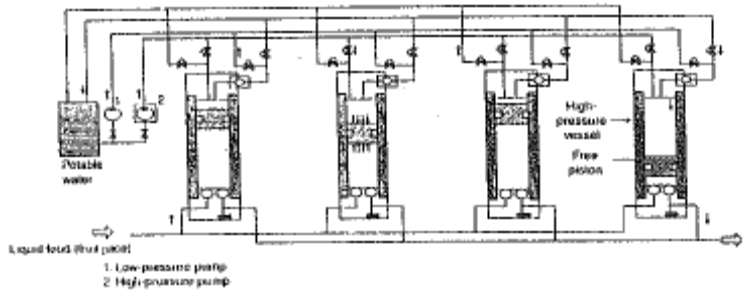

Figure 2 Schematic diagram of a semi-continuous high-pressure system.

This minimizes the operation time and allows a portion of the energy contained in the vessel under pressure to be used to pressurize another vessel, thus reducing operating costs. A continuous system suitable for liquid foods such as milk and fruit juices has been reported, but only on a research scale.

A major function of the high pressure processing of food is destruction of microorganisms. When a microbial cell is subjected to high pressure, the following detrimental changes take place[3, 4]:

i) Cell membrances are destroyed via irreversible changes to the structure of the membrane macromolecules, particularly proteins.
ii) The homogeneity of the intermediate layer between the cell and the cytoplasmic membrane is disrupted.
iii) Membrane ATPase is inactivated.
iv) The nucleic acids and ribosomes involved in the synthesis of proteins are disrupted.

The result is permeabilization of the membranes and concomitant leakage of the cells and organelles, with eventual death of the bacterial cells.

In general, gram-negative bacteria are inactivated at a lower pressure than gram-positive bacteria, and rod-shaped bacteria are more sensitive to pressure

than cocci. The pressure sensitivities of yeast are reported to be intermediate between these two bacterial groups.

High-pressure processing is limited in its inability to destroy bacterial endospores. Because of this limitation, it cannot be used for producing sterile products, and all pressure-treated foods have to be kept refrigerated. It has been concluded that to achieve the shelf-life of thermally pasteurized milk of 10 days at 10^{o}C, a pressure treatment of at least 400 MPa (4000 kg/sq. cm) for 15 minutes or 500 MPa (5000 kg/sq. cm) for 3 minutes is required[3].

While a reasonable shelf-life of milk may be obtained with pressure treatments of 400 or 500 MPa, some strains of the pathogenic bacteria *Listeria monocytogens* and *Staphylococcusaureus* are quite pressure-resistant and may not be sufficiently inactivated. Some mutant strains of *Escherichia coli* are particularly barotolerant.
The risk of the presence of barotolerant pathogenic bacteria in milk must therefore be considered before this technology is adopted for producing 'pasterized' milk.

To date, there has been very limited commercial use of high-pressure treatment of milk or milk products. However, the technology and associated processing equipment have now been developed to the stage where it is feasible to establish processing plants. Milk treated in this way can be used for either manufactured products, such as yoghurt and cheese, or for the liquid milk market. Other liquid milk products such as cream and ice cream mix, used in the production of butter and ice cream respectively, could also be treated to advantage. Pressure treatment of manufactured products such as yoghurt and cheese could be used to produce effects not achievable by alternative means.

Milk treated at pressures of up to 500 MPa for a few minutes has been shown to have a shelf-life at least equivalent to that of HTST-pasteurized milk. Most vegetative cells, including non-sporeforming themodurics, can be eliminated. However, the nature of the bacteria remaining

after such treatments, which limit the shelf-life of the product, requires further investigation. Furthermore, the conditions necessary to achieve an equivalent bactericidal effect in modified milk products and products with high solids contents have not been well defined.

4. CENTRIFUGATION

Centrifugation is a technique for removing bacteria and somatic cells from milk by centrifugal force. It is often referred to as bactofugation because the commercial equipment manufactured by Tetra-Pak Processing Systems is marketed under the trade name Bactofuge^{TM}.

In a Bactofuge a centrifugal force of ~9000 g is used to remove bacteria, and especially the spores formed by specific bacteria strains, from milk. It is a fast process, typically taking less than 1 s for passage of the milk through the centrifuge. Separation of the bacteria is based on differences in the specific gravity (SG) of milk and bacterial cells. Since milk has an SG of 1.028-1.038 g ml^{-1} and bacterial spores have SGs of 1.30-1.32 g ml^{-1}, it is reasonably efficient in removing bacterial spores from milk. However, normal vegetative bacterial cells have much lower SGs (1.07-1.12 g ml^{-1}) and are more difficult to remove from milk by centrifugation.

Bactofugation of milk is always a part of milk pre-treatment. In application where quality milk, for instance for cheese and powder production, is the objective, the Bactofuge may be installed in series with the centrifugal separator (the milk separator), either downstream or upstream of it.

In early equipment, the separated bacteria-rich portion, or centrifuge, represented ~3% of the total liquid flow. This residue could be recovered and added back to the milk after sterilizing it by a UHT process, for example a treatment at 130-140^{o}C for 3-4 seconds. In newer equipment (Figure 3), a continuous centrifuge stream can be recycled

through the centrifuge and a discontinuous, bacteria-rich concentrate of not more than 0.1-0.3% of the milk feed is ejected periodically[5]. This bacteria-rich concentrate can then be sterilized.

The same temperature is often used for bactofugation as for separation i.e. 55-63°C. The bactofuagation reduces the total count of milk by 80-90% (about 1 log cycle). However, it can remove 90-99.5% of anaerobic spore-forming organisms such as *Clostridium* and about 95% of aerobic sporeformers such as *Bacillus.* The gain in shelf-life of refrigerated milk by this centrifugation is about 4-5 days.

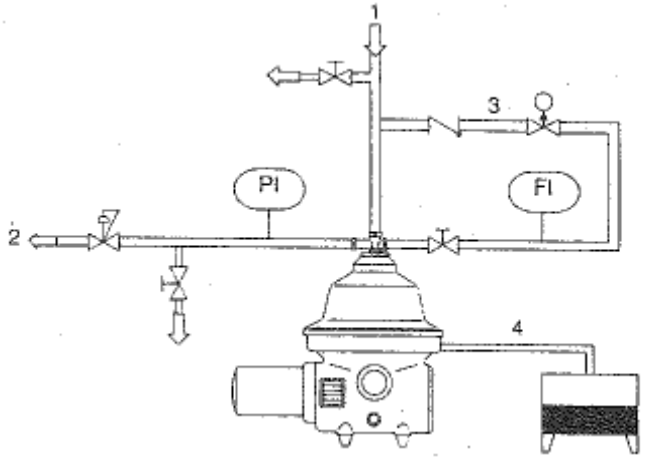

Figure 3 Schematic representation of bacterial clarification of milk by centrifugation with concentrate recycling. 1, Milk feed; 2, bacterially clarified milk, discharge; 3, recycled centrifuge; 4, discontinuously discharged bacterial concentrate.

The major application of centrifugation is in cheese manufacture where it is used to remove butyric acid spores, e.g. *Clostridium (C.) tyrobutyricum* and *C. butyricum.* These organisms, which are not destroyed by normal pasteurization of cheese milk, cause the so-called

"late-blowing" defect in cheese. Experience shows that bactofuging milk once is not always sufficient, particularly at high spore loads in the milk. Double bactofugation is however sufficient in most cases to produce cheese without addition of bacteria-inhibiting chemicals. Without any mechanical means of reducing spores in the milk it is normal to add some 15-20 g of sodium nitrate per 100 litres of milk to inhibit their growth. With single bactofugation and a high load of spores in milk, 2.5-5 g per 100 litres of milk will prevent the remaining spores from germination.

The use of centrifugation is beneficial in the production of UHT milk, concentrates and powders. Used inline, before homogenization and UHT treatment, it allows a reduction in the high-heat temperature by about 15^{o}C to produce UHT products of at least equivalent bacteriological quality. It may also be mentioned that whey, if intended for production of whey protein concentrates as an ingredient in infant formulae, should be bactofuged, after recovery of the fines and fat. This technology is especially useful in products where sufficient heat to destroy sporeforming bacteria is not possible because of its effect on heat-liable milk components, particularly whey proteins.

5. MICROFILTRATION

Microfiltration is a membraneprocess. By means of microfiltration bacteria and bacterial spores can almost fully be removed from a solution[(5)]; this can for instance be advantageous in the manufacture of milk for liquid consumption. Microfiltration is carried out by the use of ceramic membranes and is operated at pressures below 1 bar. A high flux and long operating periods can be achieved. The pore size of the semi-permeable membranes is normally 0.8-1.4 µm. Since milk fat globules are in the range of 1-10 µm, the cream must be removed from the milk before it can be microfiltered. It is the skim-ilk phase that passes through the filter, while the

cream needed for standardization of the fat content in the final product is sterilized. Normally the cream is sterilized together with the bacteria concentrate obtained by simultaneous microfiltration.

Raw milk entering the processing plant, including a microfiltration unit, is preheated to a suitable separation temperature, typically about 60-63^{o}C, at which it is separated into skimmilk and cream. A preset amount of cream, enough to obtain the desired fat content in, for instance, the cheese milk, is routed by a standardization device to the sterilization unit. In the meantime the skim milk is piped to a separate cooling section in the sterilizing unit to be cooled at 50^{o}C, the normal microfiltration temperature, before entering the filtration plant. The milk then enters the microfiltration unit where it is fractionated into a bacteria-rich concentrate (retentate), comprising about 5% of the flow, and a bacteria-reduced phase (permeate). The retentate is mixed with the cream intended for standardization before entering the sterilization unit. Following sterilization at 120-130^{o}C for a few seconds, the mixture is cooled to about 7^{o}C before being remixed with the permeate. Subsequently the total flow is pasteurized at 72^{o}C for about 15 seconds and cooled to for instance renneting temperature, typically 30^{o}C.

The principal effect of the method is the enhanced shelf-life of the product produced. Used for drinking milk, a shelf-life at refrigerated temperature of 20-32 days has been achieved, compared to 6-18 days for normal pasteurized milk[(5)]. While milk with a similar extended shelf-life can be produced by a short-time heat treatment at around 120^{o}C, microfiltered milk is considered to have a better and fresher flavour. A commercial system, which combines both microfiltration and moderate heat treatment (<105^{o}C), can produce commercially sterile milk suitable for ambient storage.

Microfiltration of skim milk reduces the bacterial load by 2-3 logs. However, some spores may be reduced by up to 5 logs. Recently, greater reduction of

sporeforming and other thermoduric microorganisms have been achieved by the use of a high-shear process using polymeric membranes with an effective pore size of 0.3 µm.

Microfiltration is applied to cheese milk[5,6] to remove somatic cells and sporeforming bacteria, particularly *Clostridium* species. This reduces quality defects associated with somatic cells, and the problem of gas production and late blowing in cheese. Microfiltration makes it possible to eliminate the use of chemicals to inhibit growth of *Clostridia* spores in hard and semi-hard cheese.

The ability of microfiltration to remove somatic cells may also be useful before UHT treatment of early-lactation and mastitic milk, in order to retard age gelation during storage.

References:

1. Deeth, H.C. and Datta, N. (2003) Pulsed energy technologies, in **Encyclopedia of Dairy Science,** Vol. 3, Ed. H. Roginski, J.W. Fuquay & P.F. Fox, Academic Press, London, 1333-1339

2. Dunne, C.P. and Kluter, R.A. (2001) Emerging non-thermal processing technologies: criteria for success, **Aust. J. Dairy Technol.,** 56(2), 109-112

3. Datta, N. and Deeth, H.C. (2003) H.gh pressure processing, in **Encyclopedia of Dairy Science,** Vol. 3, Ed. H. Roginski, J.W. Fuquay & P.F. Fox, Academic Press, London, 1327-1333

4. Rademacher, B. and Hinrichs, J. (2002) Ultra high pressure technology for dairy products, **New Processing Technologies for the Future,** Bulletin of the IDF, 374, 12-18

5. Datta, N. and Deeth, H.C. (2003) Other nonthermal technologies, in **Encyclopedia of Dairy Science,** Vol. 3, Ed. H. Roginski, J.W. Fuquay & P.F. Fox, Academic Press, London, 1339-1346

6. Munro, P.A (2002) New processing technologies to create the dairy products of the future, **New Processing Technologies for the Future,** Bulletin of the IDF, 374, 4-7

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