CHAPTER 6

APPLICATION OF HIGH PRESSURE PROCESSING IN THE DAIRY INDUSTRY: A REVIEW

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CONTENTS

6.1 INTRODUCTION

Consumer's demand for minimally processed, fresh, additive-free and shelf-stable products have prompted food scientists to explore other processing technologies as alternative to traditional treatments that rely on heating or cooling operations. Traditional treatments ensure high level of food safety but they lead to degradation of various food quality and nutritious attributes. Considerable efforts have been made by the scientists to minimize the undesirable effects on food quality. As a result, numerous non-thermal processing technologies, particularly high pressure (HP), power ultrasonic, pulsed electric field, ultra violet decontamination, pulsed white light, ionizing radiation, etc., have been evolved. Among these, high pressure processing (HPP) is the most promising technology for food applications. It is also recognized as high-hydrostatic pressure processing (HHHP) or ultrahigh-pressure processing (UHPP). Regardless of its nomenclature, the technology has been cited as one of the best innovations in food processing during the past 50 years [21].

In HPP, food is subjected to very HP in the range of 100 to 1000 MPa at processing temperature from 0°C to 100°C with exposure time of few seconds to 20 minutes. In 1991, the first commercial HP processed product appeared in the Japan, where this technology is now being used for processing products such as jams, sauces, fruit juices, rice cakes and desserts. HPP of food results in:

- Inactivation of microorganisms and enzymes at ambient temperature or even lower temperatures.
- Modification of biopolymers.
- Retention of sensorial attributes of foods such as color, taste, flavor, etc.
- Alteration in product functionality.

Beside microbial destruction, the HP affects protein structure and mineral equilibrium, suggesting its different applications in dairy products. The pioneering research into the application of HP to milk dates back to the end of the 19th century [31]. Comprehensive knowledge about the mechanism and kinetics of pressure induced degradation, denaturation, inactivation of dairy compounds like nutrients, proteins, microorganisms, enzymes, etc. is required for executing this new technology in the dairy industry.

This chapter reviews the mechanism of HPP, basic components of a HPP system, the effects of HP on the physico-chemical and other properties of milk, and applications of HPP in the dairy industry.

6.2 MECHANISM OF HIGH PRESSURE PROCESSING

Application of pressure over the food system results in various physical and chemical changes. During pressure treatment, physical compression of the system occur which results in a volume reduction and an increase in temperature and energy. Following three principles govern the behavior of foods under pressure.

1. **Le Chatelier's principle:** It states that any phenomenon (phase transition, change in molecular configuration, chemical reaction) accompanied by a decrease in volume is enhanced by pressure.
2. **Principle of microscopic ordering**: It indicates that at constant temperature, an increase in pressure increases the degree of ordering of molecules of a given substance. Therefore, pressure and temperature exert antagonistic forces on molecular structure and chemical reactions [6].
3. **Isostatic principle:** It states that pressure is transmitted quasi-instantaneously and uniformly distributed throughout the entire sample, whether in direct contact with the pressurizing medium or insulated from it in a flexible container. Thus, the process time is independent of sample size and geometry, assuming uniform thermal distribution within the sample.

In view of these, at a relatively low temperature (0–40°C) covalent bonds are almost unaffected by HP while the tertiary and quaternary structures of molecules which are maintained chiefly by hydrophobic and ionic interactions are altered by HP >200 MPa [30]. HPP is usually carried out with water as a hydraulic fluid to facilitate the operation and compatibility with food materials [22].

6.3 HIGH PRESSURE PROCESSING SYSTEM FOR FOODS: BASIC COMPONENTS

The non-availability of appropriate equipment hampered early application of HP. However, recent development in equipment design has ensured global acknowledgement of the potential for such a technology in food processing. The advances accomplished in ceramics and metallurgical industry during the 1970s and 1980s has led to the possibility of treating food by this method at industrial level. Similarly, developments in mechanical engineering have permitted large high-pressure vessels to be constructed at reasonable cost with sufficient durability to withstand thousands of pressure cycles without failure.

A typical HPP unit consists of a pressure vessel and pressure-generating device. Food packages are loaded into the vessel and top is closed. The pressure medium, usually water containing a small amount of soluble oil, is pumped into the vessel from the bottom. Once the desired pressure is reached, it can be maintained without further need for energy input. The process is isostatic, so pressure is transmitted rapidly and uniformly throughout the pressure medium and food with little or no heating. Pressure is exerted equally from all sides so that there is no 'squashing' effect and product is not affected.

6.4 MILK SYSTEM

Studies on application of HPP for preservation of milk started in 1899 when Hite et al., demonstrated the extension of shelf life of HP treated milk [31]. HPP of milk results in inhibition and destruction of microorganism, modifications in physicochemical/technological properties and changes in RCT [5]. Further, it leads to disintegration casein micelles into casein particles of smaller diameter, with a decrease in milk turbidity and lightness, and an increase of viscosity of the milk [54]. This section covers the application of HPP in inhibition and destruction of microorganisms in milk and modification in physico-chemical/technological properties will be studied.

6.4.1 APPLICATION OF HPP IN INHIBITION AND DESTRUCTION OF MICROORGANISMS IN MILK

Milk is often regarded as being nature's most complete food. It plays an important role for human nutrition and is one of the most frequently sold food worldwide. Milk is a perishable commodity and spoils very easily. Its low acidity, high water activity and high nutrient content make it the perfect breeding ground for both vegetative and spore forming bacteria, including those which cause food poisoning (pathogens). Spore forming bacteria are thermo-resistant and important for milk deterioration. Heat treatments such as pasteurization, sterilization, ultra-high temperature (UHT) are the main treatment applied to microbial stabilization of milk, since they are simple. The heat processing of milk affects vitamins (losses around 10% of folic acid and 15% of B-complex vitamins) and denatures proteins, resulting in the release of sulfured compounds [29].

Many studies conducted on the inactivation of pathogenic and spoilage microorganisms by HPP have demonstrated that it is possible to obtain 'raw' milk with treatment of pressure about 400 to 600 MPa of a microbiological quality comparable to that of pasteurized (72°C, 15 s) milk depending on the microbiological quality of milk but not sterilized milk due to HP resistant spores [10]. A pressure treatment of 400 MPa for 15 min or 600 MPa for 3 min at 20°C to milk gives shelf life of 10 days at a storage temperature of 10°C [51].

The factors that affect the resistance of microorganism to the applied pressure in food include:

- HP processing conditions (pressure, time, temperature, cycles, etc.);
- Food constituents and the properties; and
- The physiological state of the microorganism.

The bacterial spores are always more resistant than vegetative cells and they can survive at pressure of 1000 MPa. Bacterial spores, however, can often be stimulated to germinate by pressures between 50–300 MPa. Germinated spores can then be killed by heat or mild pressure treatments. Gram-positive microorganisms tend to be more resistant to pressure than gram-negative microorganisms. Gram-positive microorganisms need the application of 500–600 MPa at 25°C for 10 min to achieve inactivation, while gram-negative microorganisms are inactivated with treatments of 300 400 MPa at 25°C for 10 min. Vegetative forms of yeasts and molds are the most pressure sensitive [56].

Studies on the effect of variation in pressure resistance on growth stage (exponential and stationary phase) with respect to growth temperature (8° and 30°C) between two strains of *Listeria monocytogenes*, *Bacillus cereus*, and *Pseudomonas fluorescens* reported that exponential-phase cells were significantly less resistant to pressure than stationary-phase cells for all of the three species studied. Growth temperature had a significant effect at the two growth stages studied. Pressure treatment at 8°C induced significantly less spore germination than at 30°C [45].

On the other hand, studies on Ewe's milk containing 6% fat inoculated with *Listeria innocua* 910 CECT at a concentration of 10^7 CFU/ml showed that low-temperature (2°C) pressurizations produced higher *Listeria innocua* inactivation than treatments at room temperatures (25°C). The kinetics of destruction of *L. innocua* were first order with *D*-values of 3.12 min at 2°C and 400 MPa, and 4 min at 25°C and 400 MPa [27].

In general, the HP induced inactivation was greater on *P. fluorescens* > *E. coli* > *L. innocua* > *L. helveticus* > *S. aureus*. The temperature effect in addition to the HP on microorganisms was different: *P. fluorescens*, *L. innocua,* and *L. helveticus* showed higher resistance to HP at room temperature (25°C) than at low temperature (4°C), whereas *E. coli,* and *S. aureus* showed less resistance to HP at room temperature than at low temperature.

6.4.2 APPLICATION OF HPP IN MODIFICATION OF PHYSICO-CHEMICAL PROPERTIES OF MILK

HPP of milk results in significant effects on many constituents of milk. The structure of casein micelles is disrupted and the whey proteins, α-lactalbumin and β-lactoglobulin, are denatured. The α-lactalbumin is more resistant to pressure than the β-lactoglobulin. HPP shifts the mineral balance in milk and moderately HPs in the range of 100–400 MPa causes crystallization of milk fat. However, milk enzymes seem to be quite resistant to pressure. Pressure-induced effects on individual milk constituents, alters many properties of milk [14]. However, to fully understand the effects of HP treatment on milk and to evaluate the full potential of this process in dairy technology, further research is required in several focus areas, including the reversibility of pressure-induced changes in milk and the physical stability of HP-treated milk.

6.4.3 EFFECTS OF HPP ON APPEARANCE AND COLOR

The earliest and most prominent difference between heat and pressure treatment of skim milk is the appearance of the milk directly after treatment. On heating, skim milk becomes whiter while pressure treated skim milk appears translucent or semi-translucent with slightly yellow hue. On storage, heated milk remains white regardless of storage temperature. Pressure treated milk retains semi-transparent appearances if stored at 5°C while storage at room temperature makes it more turbid [17].

HP treated ewe's milk showed decrease in lightness (L^*) and an increase in greenness ($-a^*$) and yellowness ($+b^*$). This decrease in L^* value is due to disintegration of casein micelle [28]. HPP of skim milk at 600 MPa for 15 min resulted in significant changes in the L^*, b^* and a^* values, that could be also perceived visually [48]. Warming of samples from 4° to 43°C derived back color values of HP milk towards the values of untreated milk, although not to the same initial point. Treatment at 200 MPa at 20°C had only a slight effect on the L^* values, but treatment at 250–450 MPa significantly decreased the L^* value of pasteurized or reconstituted skim milk. Treatment at >450 MPa had little further effect on the L^* values [36]. Cow's milk showed less sensitivity to pressure with respect to color change [47].

6.4.4 EFFECTS OF HPP ON PH OF MILK

HP treatment affects the mineral distribution, chiefly calcium and phosphate and level of ionized minerals. HP treatment raises the concentration of ionic calcium in milk [43]. Increase in the concentration of phosphate in the milk serum, increases the milk pH [65]. Pressure up to 600 MPa had no significant effect on the pH of skim bovine milk. Several succeeding studies have observed increases, of varying magnitude, in the pH of HP treated caprine milk or raw, pasteurized or UHT treated bovine milk. The degree of pH shift depends on magnitude of pressure and temperature. The degree of pH shift was more for higher pressure and lower temperature. Further, the pH shift is more in UHT treated milk than pasteurized or raw milk. Increase in pH is rapidly reversible on subsequent storage at 20°C, but virtually irreversible at 5°C [36, 65].

6.4.5 EFFECTS OF HPP ON PARTICLE SIZE CHANGES

HPP of skim milk at about 300 MPa substantially decreases the size of the particles. The average decrease in size is from about 200 to 100 nm regardless of temperature at pressurization. Pressure treatments in the range of

200 to 300 MPa causes the particle size to increase which is affected by pH of milk, temperature, pressure and duration of pressure processing. Early reports suggested that the denaturation of the whey proteins may be responsible for this aggregation phenomenon [32], but successive studies carried on whey protein depleted systems point out that the aggregation is owed entirely to the casein micelles [2]. Preheat treated milk at 90°C for 10 min has shown that particle size changes similar to those in unheated milk over the entire pressure range, demonstrating that the pre-denaturation of the whey proteins has little effect on the aggregation or disaggregation phenomenon in pressure-treated milk [32]. The changes in particle size of HP treated milk was accompanied by a considerable increase in the level of serum phase casein, and the changes in size and serum phase casein appeared to be correlated [1]. The aggregation of the casein micelles increases as the temperature and the duration of pressure treatment were increased. Pressure treatment of about 250 MPa and at temperatures above 20°C resulted in the formation two distinct populations: one with the particle size larger than the original casein micelles and other with smaller than original size of casein micelle [26]. When the pH of the milk was reduced from the natural pH (6.7) to 6.5, the particle size was decreased with the increase in pressure, with a marked decrease in size above 200 MPa. Study on ewe's milk reported that HP up to 500 MPa produces some modifications on size and distribution of milk fat globules of ewe's milk. HP treatments at 50°C showed a tendency to increase the number of small globules in the range 1–2 μm, whereas at 4°C the tendency was the reverse [28].

6.4.6 EFFECTS OF HPP ON DESTRUCTION OF VOLATILE COMPOUNDS

HPP of milk at room and mild temperatures only disorders moderately weak chemical bonds such as hydrogen bonds, hydrophobic bonds, ionic bonds. Thus, it had no effect on small molecules such as vitamins, amino acids, simple sugars and flavor compounds [13]. HPP of milk at 400 MPa resulted in no significant loss of vitamins B1 and B6 [55]. HP treatments at 400 MPa for 15 min at 40–60°C reduced the proteolytic activity and at

25–60°C maintained or improved the organoleptic properties of milk. This suggests that these combined treatments could be used to produce milk of good sensory properties with an increased shelf-life [25].

6.5 APPLICATION OF HIGH PRESSURE PROCESSING IN CHEESE PRODUCTION

In cheese manufacturing, many research groups have studied the application of HP in making cheese from pressure treated milk, microorganism inactivation in cheese, acceleration of cheese ripening and increased cheese yield. This section covers the research findings of studies conducted on application of HPP in cheese processing.

6.5.1 CHEESE PRODUCTION FROM PRESSURE TREATED MILK

The physicochemical and sensory properties of cheese are the most valued. Therefore, ensuring that the processing technologies applied to them do not affect these unique attributes in a negative fashion is of utmost importance. Milk pasteurization is recognized to adversely affect the development of many sensory characteristics of cheese, leading to alteration in texture and often delayed maturation. HPP did not alter the composition of fresh cheese particularly its total solid, ash, fat and soluble nitrogen contents. However, non-protein nitrogen of HP cheese remained lower than the non-treated fresh cheese. HP treated milk cheese contained higher moisture, salt and total free amino acid contents than pasteurized milk cheese (control) [60]. Table 6.1 summarizes the results of studies conducted on cheese with regard to the impact HP treatments on physicochemical, rheological and sensory properties.

HP treatment (500 MPa) improves sensory characteristics of cheese [40]. Changes in organoleptic characteristics of the cheese are not perceived by sensory judges if it is HP treated within pressure range of 200 to 500 MPa for 15 min [57]. HP treated cheese shows a similar level of lipolysis to cheese made from raw milk; whereas the level of lipolysis in cheese made from pasteurized milk was lower [11].

TABLE 6.1 Effects of HPP Treatments on Quality Parameters of Cheese

Parameter Evaluated	Cheese Variety	Instant of application	HP treatment applied P (MPa)/T (Min)/T (◦C)	HP induced modification	Ref.
Color	**Mato**	1 day	500/5, 10, or 15/10	L^* and a^* decreased, whereas b^* increased compared to control cheese.	[12]
	Cheddar, Turkish white-brined	1 day	50–400/5, 10, or 15/22–25	Increasing pressure intensity and holding time did not affect L^*, but a^* decreased and b^* increased compared to control cheese.	[53]
Rheological properties	**Cheddar**	1 and 4 months	200–800/5/25	Pressures up to 300 MPa applied to 1- month old cheese had no significant effect. At 800 MPa, cheese had similar fracture stress and Young's modulus as control cheese. Pressure applied to 4-month old cheese increased fracture work.	[62]
	Cheddar	1 day	400/10/25	Increased fracture strain and fracture stress values, lower fluidity, flowability, and stretchability increased up to 21 day, but to a lesser extent than in control cheese.	[53]
	Low-moisture mozzarella	1 and 5 Days	400/20/25	Reduced time required to attain satisfactory cooking performance (by 15 day). Increased fluidity, flowability, stretchability, and reduced melting time on heating at 280–^{0}C.	[50]
	Gouda	3 day	50, 225, or 400/1 h/14	Less rigid and solid-like, more viscoelastic, and had less resistance to flow at longer times.	[46]
Sensory properties	**Hispanico**	15 days	400/5/10	Treatments applied to immature cheese limit the formation of volatile compounds. However, differences become less significant during ripening.	[4]
	Ewes' milk cheese	1 or 15 Days	200 or 500/10/12		[38]
	Raw goat milk cheese	1, 3, or 50 day	400 or 600/7/10	Treatments applied at more advanced stages do not cause significant differences compared to control cheese.	[16]

This behavior was explained by heat-sensitive but partial pressure-resistant characteristics of the indigenous milk lipase. Further, hard surface which was apparent in a HP processed milk cheese (500 MPa in the range of 30 ± 5 min at 25°C) was subjected to sensory analysis and sensory judges showed preference for processed cheese over the non-processed cheese regardless of texture attributes [59].

6.5.2 EFFECTS OF HPP ON RENNET COAGULATION TIME (RCT)

HP treatment at <150 MPa had no effect on the RCT, whereas pressure treatment at 200 to 600 MPa significantly reduced RCT [17]. However, RCT was reduced markedly after the treatment at 200–600 MPa. In general, rennet coagulation properties of milk subjected to 200 MPa for 30 min were enhanced [42]. The pressure-induced disintegration of the casein micelles appears to reduce the RCT and the cutting time, whereas the denaturation of the whey proteins increases the RCT and the cutting time, in a similar fashion to that for the heated milk. RCT decreases with increasing pressure and treatment time [34]. Temperature of treatment and pH of the milk has considerable effect on the RCT of HP treated milk. Treatment at 50–60°C (200 MPa) delayed the rennet coagulation of milk [43]. Acidification of milk (pH-5.5) before HP treatment decreased its RCT, whereas alkalization (pH-7.0) had the opposite effect [3]. The strength of the rennet-induced coagulum from heated milk treated at 250–600 MPa for 30 min or 400 or 600 MPa for 0 min was considerably higher than that of unheated unpressurized milk.

6.5.3 EFFECTS OF HPP ON MICROORGANISM INACTIVATION IN CHEESE

Food scientists have employed HP technology in cheese processing to inactivate toxigenic and infectious pathogens such as *Escherichia coli*, *Staphylococcus aureus*, *Listeria monocytogenes*, *Aeromonas hydrophila*, *Salmonella enterica*, and *Yersinia enterocolitica*, as well as spoilage microorganisms such as *Staphylococcus carnosus, Enterococcus* spp., coliforms, yeasts, and molds, and also microbial spores from *Bacillus subtilis, Bacillus cereus*, and *Penicillium roqueforti.* Many studies have revealed that HP treatments cause structural and functional alterations in vegetative cells and spores leading to cell injury or death. These include cell membrane disruption or increased permeability, ribosomal destruction, collapse of intracellular vacuoles, denaturation of membrane-bound proteins, damage to the proton efflux system, inactivation of key enzymes, including those involved in DNA replication and transcription, release of dipicolinic acid and small acid-soluble spore proteins, and hydrolysis of spore core and cortex [7].

The level of microbial inactivation obtained is a function of applied pressure and temperature [58]. The Gram positive *S. aureus* species was more resistant to pressure than the Gram negative *E. coli* species with the latter showing increasing sensitivity to pressure on going from 10°C to 30°C. At lower pressures (<300 MPa), the mold species was more resistant than the bacteria, and was much more sensitive at higher pressures. In the case of *E. coli* and the molds, similar trends and degree of inactivation by HPP were observed for strains within species. Log phase cells are more sensitive to pressure than stationary phase cells. Pressure treatment of ≥ 300 MPa for 5 min to fresh lactic curd cheese effectively controlled the outgrowth of yeasts and extends product shelf-life from 3 to 6–8 weeks [15].

Microbial resistance to HP depends not only on the intrinsic resistance of the microorganisms, but also on the physiological state [44]. The cells of *S. aureus* ATCC 6538 and *E. coli* K-12 in the exponential phase of growth were more sensitive to HPP treatments in Cheddar cheese slurry than cells in the stationary phase [49]. The higher pressure conditions (345 and 550 MPa) and longer exposure times (10 and 30 min) achieved a greater reduction in numbers of undesirable bacteria in the natural microflora of Swiss cheese slurries (coliforms, presumptive coagulase-positive *Staphylococcus*, yeasts, and molds) and in starter LAB added to milk for acid production and flavor development [18]. A greater antimicrobial impact can be achieved with moderate pressure treatments and shorter pressure holding times when combining high temperatures with HPP treatments. However, the use of high temperatures could lead to undesirable effects in certain cheese quality parameters. Treatments at 50^0C caused high whey losses and unacceptable textural characteristics.

6.5.4 EFFECTS OF HPP ON YIELD OF CHEESE

In cheese making process, it is very essential to obtain the maximum achievable recovery of substance from milk, because the higher the recovered percentage of solids, the greater the amount of cheese obtained and therefore gain in economic terms. Cheese yield is influenced by various factors: perhaps the single most important factor is the composition of the milk, which itself depends on the species and breed of animal, the stage of lactation and the somatic cell count of the milk. Furthermore, pre-treatment of cheese-milk can also increase the yield of cheese.

Heat treatment of the milk intended for cheese making can increase its yield. Through incorporation of whey proteins in the cheese curd, this treatment is very common in the manufacture of fresh cheese. However, for the manufacture of semi-hard and hard cheeses, heat treatment adversely affects other cheese making properties of milk: It significantly increases the RCT of milk and reduces the firmness of the rennet-induced coagulum. High pressuring of milk could be a good solution over this. HP treated milk gives higher yields [19]. Arias et al. [3] reported that treatment of milk at 200 MPa had no effect on wet curd yield, although denaturation of β-lactoglobulin was observed at 200 MPa whereas at 300–400 MPa wet curd yield was significantly increased upto 20% and reduced both the loss of protein in whey and the volume of whey. Increased treatment time, up to 60 min at 400 MPa increased wet curd yield and reduced protein loss in whey; and the changes were greatest during the first 20 min of treatment [42]. Authors also reported that increased cheese yield is primarily due to greater moisture retention, secondly due to incorporation of some denatured β-lactoglobulin. Also, the casein micelles and fat globules in HP-treated milk may not aggregate as closely as in untreated milk, therefore allowing more moisture to be entrapped in the cheese [19].

6.5.5 EFFECTS OF HPP ON RIPENING OF CHEESE

Cheese ripening is a time-consuming and expensive process due to high storage costs. Its acceleration is highly desirable. Pioneering research on this topic was performed by Yokoyama et al. [64], who reported significant reduction inthe ripening times of Japanese Cheddar and Parmesan-type

TABLE 6.2 Effects of HP Treatments on the Ripening Process of Different Cheese Varieties

Cheese variety	Instant of application	Treatment applied P (MPa)/t (min or h)/T (◦C)	HP induced changes	Ref.
Proteolysis				
Cheddar	After salting	50/72 h/25	Similar taste and FAA content of a 6 month-old commercial cheese obtained in 3 d (Cheddar: 26.5 mg/g, Parmensan: 76.7 mg/g).	[64]
Cheddar	2, 7, 14, or 21 days	50/72 h/25	Faster αs1-casein hydrolysis and accumulation of αs1-I-casein. Increased pH 4.6 SN/TN below 150 MPa and FAA levels. Total FAA decreased as pressure increased.	[50]
Blue-veined	42 days	400–600/10/20	Accelerated breakdown of β- and αs2-casein and increased levels of PTAh SN/TN.	[63]
Gouda	After brining, 5 or 10 days	50 or 500/20–100/14	No changes in pH 4.6 SN, PTA SN/TN, FAA contentand SDS-PAGE profiles.	[40]
Lipolysis				
Full-fat Cheddar	1 day	400/10/25	Lipolysis was not significantly different from control over 180 d	[53]
Ewes' milk cheese	1 or 15 days	200–500/10/12	Lowest concentration of total FFA at pressure treatments of 400 to 500 MPa applied on d 15 after 60 d of ripening compared to other treatments. Highest levels of FFAs were obtained at 300 MPa applied on day 1 compared to other treatments.	[38]
Blue-veined	42 day	400–600/10/20	Reduced lipolytic activity of *P. roqueforti*.	[63]
Glycolysis				
Full-fat Cheddar	1 day	400/10/25	Concentration of total lactate in HHP-treated cheese was significantly lower compared to the control after 180 d of ripening	[53]

Note: h = time in hours; FAA = free amino acids; SN = soluble nitrogen; TN = total nitrogen; PTA = phosphotungstic acid; FFA = free fatty acids.

cheese without affecting sensory attributes [64]. Many food scientists have assessed the application of HP treatments to accelerate the ripening of cheese (Table 6.2).

HP treatments are able to accelerate cheese ripening by altering the enzyme structure, conforming changes in the casein matrix making it more prone to the action of proteases and bacterial lysis promoting the release of microbial enzymes that promote biochemical reactions [63]. HP treatments also increase pH (0.1 to 0.7 units) and modify water distribution of certain cheese varieties, promoting conditions for enzymatic activity.

The initial hydrolysis of caseins in milk is carried out mainly from the action of plasmin, chymosin, and to a lesser extent by pepsin. HP treatment at 800 MPa for 60 min at 8°C did not inactivate plasmin in 14-day-old Cheddar cheese, while at 20°C and 30°C its activity was reduced by 15% and 50%, respectively compared to controls [33].

Free amino acid (FAA) levels were 16.2, 20.3, 26.5, and 25.3 mg/g after HP treatments at 5, 15, 50, and 200 MPa, respectively, while the FAA level was 21.3 mg/g in the control cheese. There was non-significant difference between the taste of Cheddar cheese HP-treated at 50 MPa and commercial control cheese. With increase of pressure from 100 to 400 MPa, production of total FAA was decreased. Conversely, increasing processing time up to 60 h, total FAA levels were increased. These research studies on Cheddar cheese ripening clearly demonstrate that HPP treatments enhanced proteolysis. HP enhanced proteolysis did not altered the pathways of proteolysis, thus flavor and texture development were very similar to traditional commercial Cheddar cheese. Low to moderate HP treated (50 to 150 MPa) young Cheddar cheese showed accelerated proteolysis, whereas higher HP treated conditions (≥400 MPa) may help to arrest the ripening process at a desired stage, thus maintaining optimum "commercial attributes" for a longer period of time [50].

6.6 EFFECTS OF HIGH PRESSURE PROCESSING ON YOGHURT AND FERMENTED DAIRY PRODUCTS

Yogurt, **yogurt,** or yogurt is a custard-like food with a tart flavor, prepared from milk curdled by bacteria, especially *Lactobacillus bulgaricus* and *Streptococcus thermophilus,* and often sweetened or flavored.

Among the processes involved in fermented milk and yogurt processing, the most important are homogenization, pasteurization and fermentation. Two strategies have been used to improve fermented milk and yogurt quality and preservation by means of HP: making fermented milk and yogurt from HP treated milk and pressurization to inactivate micro-biota.

Acid set gels prepared from HP treated milk showed improved texture (rigidity and resistance to breaking) and syneresis resistance [37]. Most of the viscosity improvement is achieved after pressurization for 15 min at 400 MPa and for 5 min at 600 MPa with slight further increase up to 60 min. Yoghurt firmness increases as pressure increases, and treatments of 350 MPa at 25°C and 500 MPa at 55°C showed no differences in whey syneresis compared with pasteurized milk [24]. During storage at 4°C for 20 days, yogurts made from HP treated milk showed a good stability in terms of firmness and water retention compared with yogurt made from the untreated milk.

Milk treatment with pressures of 400–600 MPa for 10 min at 25°C can achieve similar results as low temperature pasteurization in terms of pathogenic and spoilage microorganisms inactivation [61]. Research studies have described the disintegration of the casein micelles into smaller particles and the simultaneous increase in the amount of caseins and calcium phosphate in the serum phase which improved the water holding capacity of yogurt [35]. Further, the combination of HP and thermal treatment increased the yogurt viscosity and lowered gelation times compared to HP treated samples [24].

6.7 EFFECTS OF HIGH PRESSURE ON CREAM, BUTTER AND ICE CREAM

HPP induces fat crystallization, shortens the time required to achieve a desirable solid fat content and thereby reduces the aging time of ice-cream mix and also enhances the physical ripening of cream for butter making [8]. Studies on the freeze fracture and transmission electron microscopy of cream (30 and 43% fat) subjected to HPP of 100 to 150 MPa at 23°C for pasteurization indicated that pressurization induced fat crystallization within the small emulsion droplets mainly at the globule periphery [9].

Fat crystallization was increased with the length of pressure treatment and was maximal after processing at 300–500 MPa. Further, the crystallization proceeded during later storage, after pressure release. Pressurization treatment improved whipping ability of cream when treated for 2 min at 600 MPa and is possibly due to better crystallization properties of milk fat [23]. Excessive pressurization leads to excess denaturation of whey proteins, which results in longer whipping time and destabilization of whipped cream. Studies on the effects of added whey protein concentrate on the over-run and foam stability of ice cream mix had confirmed the effects of HPP on foaming properties of whey proteins in a complex system [41].

HPP (450 MPa at 25°C for 10 to 30 min.) of dairy cream (35% fat) reduced the microbial load significantly [52]. Pressure-assisted freezing may be of special interest to avoid coarse ice crystallization and obtain a smooth texture in various types of ice creams (including low fat) or sherbets. The Unilever Company–India has patented combinations of HP processing and freezing for improved consistency and smoothness, and slower melting of ice cream [39].

Studies on the effects of HPP on pasteurized dairy creams (35% fat) at 450 MPa and 25°C for 15 or 30 min, or at 10 or 40°C for 30 min indicated that pressurization at 450 MPa at 10 or 25°C did not modify fat globule size distribution or flow behavior [20].

6.8 SUMMARY

The need to meet the demand of consumer for safe, nutritious, natural, economic, convenient and delicious food necessitates the processors to look beyond the conventional thermal food processing technologies. Among various non-thermal technologies, HPP is the promising technology. Comprehensive knowledge of the mechanism and kinetics of pressure induced degradation, denaturation, inactivation of dairy compounds like nutrients, proteins, microorganisms, enzymes, etc., this technology can be effectively applied in rennet or acid coagulation of milk, ripening of cheese, syneresis and firmness in fermented milk product, aging of ice cream mix, ripening and fat crystallization of dairy cream and many other dairy products.

KEYWORDS

- **appearance of milk**
- **butter**
- **cheese**
- **cheese production**
- **cheese ripening**
- **cheese yield**
- **color of milk**
- **cream**
- **fermented milk**
- **high pressure processing, HPP**
- **HPP system**
- **ice cream**
- **inactivation of microorganisms**
- **isostatic principle**
- **le Chatelier's principle**
- **mechanism of HPP**
- **milk**
- **milk processing**
- **particle size**
- **pH**
- **physicochemical properties of milk**
- **Principle of microscopic ordering**
- **volatile compound**
- **yogurt**

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CHAPTER 7

EMERGING MILK PROCESS TECHNOLOGIES: HIGH HYDROSTATIC PRESSURE

ADARSH M. KALLA and DEVARAJU RAJANNA

CONTENTS

7.1 INTRODUCTION

Most of food materials are seasonal and perishable in nature. In the growing season, there may be a local glut, because of insufficient transport facilities, lack of good roads and poor availability of packing materials. In general, the surplus cannot be taken quickly enough to the natural markets in urban areas; and cannot be stored for sale in the off-season because of inadequate local cold storage facilities. Thus the growers do not get a good price for their produce because of the glut and some of it is spoiled resulting in a complete loss. Two approaches are possible for solving this problem. One is the creation/expansion of cold storage facilities in the raw material surplus regions themselves, as also in the major urban consumption centers, to ensure supply of fresh product throughout the year. Another approach is to process the raw material into various products that could be preserved for a long time, and this adds to the value of the product. A goal of food manufacturer is to develop and employ processing technologies that retain or create desirable sensory qualities or reduce undesirable changes in food due to processing. Food processing involves the application of scientific principles to slow down the natural process of food decay caused by micro-organisms, enzymes in the food or environmental factors such as: heat, moisture and sunlight. Much of this knowledge is known traditionally and put into practice by experience and information is handed down through the generations.

The increasing urbanization, rise in middleclass purchasing power and change in food habits have left the consumer demand, driven towards better tasting and additive-free foods with a longer shelf-life. The new information about the links between diet and health has contributed to new demands for foods. At the same time, technological changes in production, processing and distribution, structural change and growth in large-scale retailing, and expansion of trade worldwide have contributed to a rapidly changing market for food products.

The traditional food preservation methods like heating, freezing, dehydration and some of chemical treatments like use of preservatives are most widely used methods. The thermal treatment is one of the most generally used food preservation method. However, thermal treatment reduces possible health hazards arising from pathogenic microorganisms associated with food, but the product quality (taste and flavor) is affected by the heat-induced reactions. The fouling of equipment by deposit formation on walls is governed by specific reactions of food components. These typical undesired reactions reduce the heat transfer coefficient, and increase product losses, resulting in higher operating costs [44].

The increasing popularity of minimally processed foods has resulted in greater health benefits. Furthermore, the ongoing trend has been to eat out and to consume ready-to-eat foods [1]. With this increasing demand for ready-to-eat, fresh, minimally processed foods, including processed fruits and vegetables preserved by relatively mild techniques, and thus ensure product safety and convenience: a high pressure processing (HPP) approach appears to be the best method. The HPP utilizes less destructive method to meet the demand for minimally processed fresh foods, which also meet the ever-increasing food safety standards enacted by FDA and USDA regulations.

This chapter reviews technology of high hydrostatic pressure processing (HHP) with special emphasis on its applications in dairy products (milk and milk products).

7.2 DEFINITION OF HIGH PRESSURE PROCESSING

HPP is a non-thermal method of food processing, where food is subjected to elevated pressures (600 MPa) [39], with or without the addition of heat, to achieve microbial inactivation or to alter the food attributes in order to achieve qualities that are desirable to the consumers. Pressure inactivates most vegetative bacteria at pressures above 600 MPa. HPP retains food quality, maintains natural freshness, and extends microbiological shelf life. The process is also known as HHP or ultra-high pressure processing (UHP).

7.3 HIGH PRESSURE PROCESSING: A BRIEF HISTORY

High pressure technology, to kill microorganisms and preserve food, was discovered in 1899 and has been used with success in chemical, ceramic, carbon allotropy, steel/alloy, composite materials and plastic industries for decades. HPP is similar in concept to cold isostatic pressing of metals and ceramics, except that it demands much higher pressures, faster cycling, high capacity, and sanitation [59, 105]. At the end of 18^{th} century, experiments were carried out by Bert Hite [39] and Royer [83] using high pressure technology for microbial inactivation of milk, fruit juice and vegetables juice [104]. At the Agriculture Research Station in Morgans Town, West Virginia, USA, a high-pressure unit was designed and constructed to pasteurize milk and other food products [39]. This unit could reach pressures in excess of about 700 MPa. The potential use of HP processing was examined for a wide range of foods and beverages, including the pressure inactivation of viruses.

The systemic research was carried out about macroscopic physical behaviors in UHP, such as the compressibility of solid, the phenomenon of melting, the properties of mechanical, the changing of state, and so on [10]. The phenomenon of protein about coagulating at <500 MPa and turning into hard gelatinous body at <700 MPa were investigated. These achievements laid the foundation of UHP applications in food processing [10]. It was pointed out explicitly that the UHP can be used in the commercial processing of fruit juice [20]. The UHP technique was used by Japanese scholars to solve tedious problems in the food processing, which could not solved by heating treatment. The Jam under HPP was produced for the first time [75]. Afterwards, a fresh orange juice "spot squeeze" was sold commercially a compressed food in France. High-pressured food aroused a bigger interest by its unique effect of sterilization, enzyme inactivity and the superiority, which the heat sterilization does not have.

The HPP techniques have also gained momentum in areas of food preservation outside of sterilization and pasteurization. The range of possibilities offered by combining HP with Low Temperatures (HPLT) has allowed the basis of a new field of HP food applications, such as: pressure-supported freezing, thawing and subzero storage. Studies have been conducted to develop and optimize the HPLT processes. New findings regarding the phase transitions of water, with consequential benefits for the food Industry, have recently been revealed [96].

7.4 PRINCIPLES OF HIGH PRESSURE PROCESSING

HPP treatment of food is carried out using batch or semi continuous process. HPP work has been extended to rice products, fish, poultry products and ready to eat meats. HPP treatment can provide fresh like taste, minimal processing and high quality convenient products with an extended shelf life.

HPP has emerged as the most innovative non-thermal food processing technique during past few decades. The most important work involving microbial inactivation in food science by using high pressure is based on principle of isostatic distribution and Le-Chatelier principle.

7.4.1 ISOSTATIC PRINCIPLE

The isostatic principle indicates that pressure transmittance occurs in a uniform and quasi instantaneous manner (Figure 7.1). The food products are compressed by uniform pressure from every direction and then

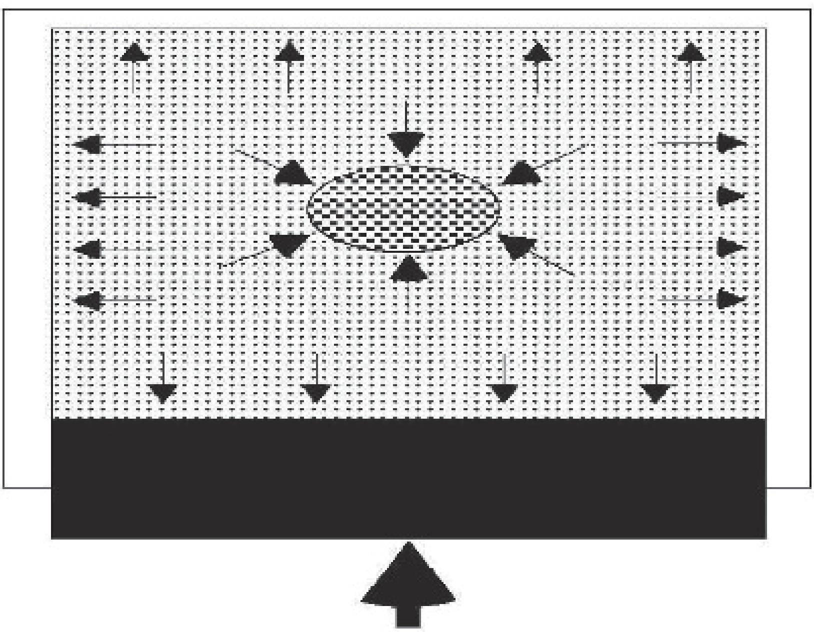

FIGURE 7.1 The principle of isostatic processing.

returned to their original shape when the pressure is released [69]. The pressurization process time is independent of the sample volume. Hence products are compressed independently of product size and geometry. When an aqueous medium is compressed, the compression energy E (in Joule) is equal to:

$$E = \frac{2}{5} \text{ x C x P x } V_0 \tag{1}$$

where, P = pressure (Pa), C = compressibility of solution, and V_0 = initial volume (m^3).

Therefore, energy required for compression of 1 liter water is 19.2 kJ at 400 MPa as compared to 20.9 kJ for heating one liter of water from 20 to 25°C. The covalent bonds of food constituents are less affected than weak interactions due to low energy levels involved in pressure processing [17, 28].

7.4.2 LE CHATELIER PRINCIPLE

The Le Chatelier principle describes the effect of pressure on the basis of absolute reaction rate theory. It states that, if a system at equilibrium experiences a change in concentration, temperature, volume, or partial pressure, then the equilibrium shifts to counteract the imposed change and a new equilibrium is established. This principle is named after Henry Louis Le Chatelier and sometimes Karl Ferdinand Braun, who discovered it independently. The principle has analogs throughout the entire physical world.

Most biochemical reactions cause change in volume. Therefore, biochemical processes are influenced by pressure application. Overall volume change favors the disruption of hydrophobic bonds and dissociation of ionic interactions. Hydrogen bond formation is favored, while covalent bonds are not disrupted by high pressure [52].

7.5 DESCRIPTION OF THE HIGH PRESSURE PROCESSING

In a HPP, the food product is placed in a pressure vessel capable of sustaining the required pressure; the product is submerged in a liquid, which acts as the pressure-transmitting medium. Water may be used as the pressure-transmitting medium, but media containing castor oil, silicone oil, sodium benzoate, ethanol or glycol are also used. The ability of the pressure-transmitting fluid to protect the inner vessel surface from corrosion, the specific HP system being used, the process temperature range and the viscosity of the fluid under pressure are some of the factors involved in selecting the medium. The pressure vessel is the most important component of high hydrostatic- pressure equipment. It is necessary to design the high-pressure vessel to be dimensionally stable to avoid failure. If it fails, it should fail causing leakage before fracture [19].

Industrial HP treatment is currently a batch or semi-continuous process. The selection of equipment depends on the kind of food product to be processed. Solid food products or foods with large solid particles can only be treated in a batch mode. Liquids, slurries and other pump able products have the additional option of semi-continuous production [93].

Currently, most HP machines in industrial use for food processing are batch systems, whereby the product is placed in a high pressure chamber and the vessel is closed, filled with pressure-transmitting medium and pressurized either by pumping medium into the vessel, where the packages of food, surrounded by the pressure-transmitting fluid, are subjected to the same pressure as exists in the vessel itself (Figure 7.2), or

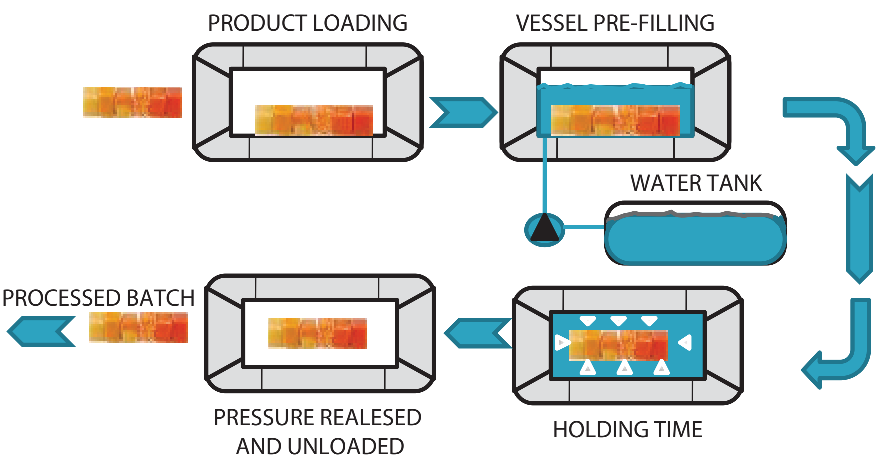

FIGURE 7.2 Batch type high pressure processing system.

by reducing the volume of the pressure chamber, for example by using a piston. If water is used as the pressurizing medium, its compressibility must be accounted for; water is compressed by up to 15% of volume at pressures above 600 MPa. Once the desired pressure is reached, the pump or piston is stopped, the valves are closed and the pressure is maintained without further energy input. After the required hold time has elapsed, the system is depressurized, the vessel is opened and the product unloaded. The system is then reloaded with product, either by operators or machines, depending on the degree of automation possible [93].

The total time for pressurization, holding and depressurization is referred to as the 'cycle time.' The cycle time and the loading factor (i.e., the percentage of the vessel volume actually used for holding packaged product, primarily a factor of package shape) determine the throughput of the system. In a commercial situation and with a batch process, a short holding time under pressure is desirable in order to maximize throughput of product. If the product is able to be pumped, it may be advantageous to pump it into and out of the processing vessel through special high-pressure transfer valves and isolators. To package the product after treatment, additional systems, such as an aseptic filling station, are then required [93].

Current semi-continuous systems use a pressure vessel with a free piston to compress liquid foods. A low-pressure food pump is used to fill the pressure vessel and, as the vessel is filled, the free piston is displaced. When filled, the inlet port is closed and water at high-pressure process is introduced behind the free piston to compress the liquid food. After an appropriate holding time, releasing the pressure on the high-pressure process water decompresses the system. The treated liquid is discharged from the pressure vessel to a sterile hold tank through a discharge port. A low-pressure water pump is used to move the free piston towards the discharge port. The treated liquid food can be filled aseptically into pre-sterilized containers.

A semi-continuous system (Figure 7.3) with a processing capacity of 600 lph of liquid food and a maximum operating pressure of 400 MPa was used commercially to process grapefruit juice in Japan. Multiple units can be sequenced so that, while one unit is being filled, others are in various stages of operation [71]. For any HP system, the working pressure is a very important parameter, not only because the initial price of the

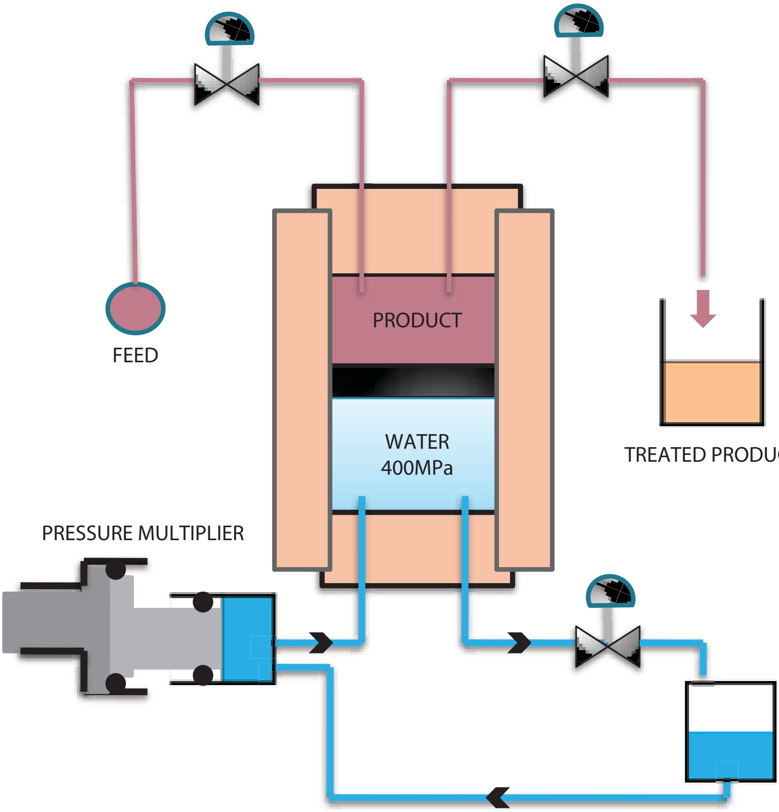

FIGURE 7.3 Semi-continuous high pressure processing system.

equipment increases significantly with its maximum working pressure, but also because a decrease in working pressure can reduce significantly the number of failures, increasing the working life of the equipment [70]. Pressures between 50 and 1000 MPa are commonly used. Keeping the sample under pressure for extended periods of time does not require any additional energy [16]. The work of compression during HP treatment will increase the temperature of foods through adiabatic heating, by approximately 3°C per 100 MPa, depending on the composition of the food [5]. For example, if the food contains a significant amount of fat, such as butter or cream, the temperature rise can be larger. Foods cool down to their original temperature on decompression if no heat is lost to, or gained through, the walls of the pressure vessel during the hold time at pressure.

7.5.1 EFFECTS OF PRESSURE-TEMPERATURE RELATIONSHIPS ON HPP

During the compression phase (t_1–t_2) of pressure treatment, food products experience a decrease in volume as a function of the pressure (Figure 7.4). Both pure water and most moist foods subjected to 600 MPa treatment at ambient temperature will experience about 15% reduction in volume. The product is held under pressure for a certain time (t_2–t_3) before decompression (t_3–t_4). Upon decompression, the product will usually expand back to its initial volume [28]. The compression and decompression can result in a transient temperature change in the product during treatment. The temperature of foods (T_1–T_2) increases as a result of physical compression (P_1–P_2). Product temperature (T_2–T_3) at process pressure (P_2–P_3) is independent of compression rate as long as heat exchange between the product and the surroundings is negligible.

In a perfectly insulated (adiabatic) system, the product will return to its initial temperature upon decompression (P_3–P_4). In practice, however, the product will return to a temperature (T_4) slightly lower than its initial temperature (T_1) as a result of heat loss during the compression (elevated temperature) phase. The rapid heating and cooling resulting from HPP treatment offer a unique way to increase the temperature of the product only during the treatment, and to cool it rapidly thereafter. The temperature increase of food materials under pressure is dependent on factors such as final pressure, product composition, and initial temperature. The temperature of water increases about 3°C for every 100 MPa

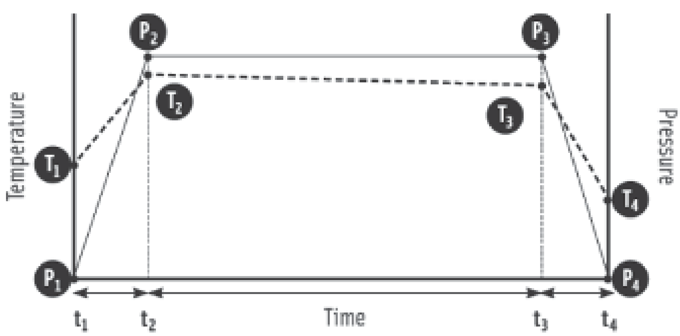

FIGURE 7.4 Pressure–temperature relationship during HPP.

TABLE 7.1 Rate of Temperature Increase (°C per 100 MPa) for Different Foods

Food at 25°C	Temperature increase per 100 MPa, (°C)
2% fat milk	3.0
Beef fat	6.3
Chicken fat	4.5
Mashed potato	3.0
Olive oil	From 8.7 to <6.3
Orange juice	3.0
Salmon	3.2
Soy oil	From 9.1 to <6.2
Tomato salsa	3.0
Water	3.0

pressure increase at room temperature (25°C). On the other hand, fats and oils have a heat of compression value of 8–9°C per 100 MPa, and proteins and carbohydrates have intermediate heat of compression values [72, 78]. Table 7.1 shows the rate of temperature increase (°C per 100 MPa) for different foods.

7.6 OVERVIEW OF TEMPERATURE INCREASE DURING COMPRESSION OF FOODS [92]

7.6.1 EFFECTS OF HIGH PRESSURE ON FOOD CONSTITUENTS

Some of the recent studies have highlighted the effect of HPP on macronutrients and micronutrients of food components. Generally, total protein and total lipid contents are not affected by HPP. Lipids tend to be of greatest interest terms of effect of HPP on the lipid oxidation. Total sugars, sucrose, glucose and fructose are not effect by HPP. Few studies are available that have investigated the effect of HPP. In cabbage, no effect of HPP (up to 500 MPa and 80°C) on total dietary fiber was evident; however soluble fibers were increased, while insoluble fibers decreased at 400 MPa [100]. HPP has shown to enhance glucose retardation/binding in tomato puree [13, 30] suggesting that this technique might be used to develop diabetic foods.

7.6.1.1 Water

Water is a major constituent in most foods and HPP markedly affects water. Water cannot be compressed at normal pressure, but it is partially compressible at high pressure. The water can be compressed upto 4% at 100 MPa and 15% at 600 MPa at 22°C. Foods with high water ratio will show similar trends of compressibility to water. Many physicochemical properties of water are reversibly modified under pressure. Compression of water causes increase in temperature of water @ 2–3°C per 100 MPa [9].

Pressure can increase the ionic product [H+ OH–] of water. It can increase from 10–100 folds with application of 100 MPa pressure. The positive and negative charges are separated under pressure by a driving force called electrostriction. Water molecules rearrange in more compact manner with smaller total volume around electric charges, due to H-bonding and dipole-dipole interactions. The reaction $H_2O = H^+ + OH^-$ causes volume decrease of 21.3 mL per mole at 25°C [45]. Thus, pH of water, weak acids and several buffers decrease by 0.2–0.5 pH units per 100 MPa.

7.6.1.2 Proteins

Proteins are large organic compounds made of amino acids arranged in a linear chain and joined together by peptide bonds between the carboxyl and amino groups of adjacent amino acid residues. High pressure causes denaturation of proteins depending on protein type, processing conditions and applied pressure level (Figure 7.5). Proteins can dissolve or precipitate on application of high pressure. These changes are reversible when pressure applied is in range of 100–300 MPa and irreversible when pressure level applied is higher than 300 MPa.

- The destruction of hydrophobic and ion pair bonds, and unfolding of molecules is called denaturation. At high pressure, oligomeric proteins tend to undergo proteolysis. Monomeric proteins do not show any vulnerability to proteolysis with increase in pressure [90].
- High pressure causes rupturing of non-covalent interactions within protein molecules and further cause's reformation of inter and intra

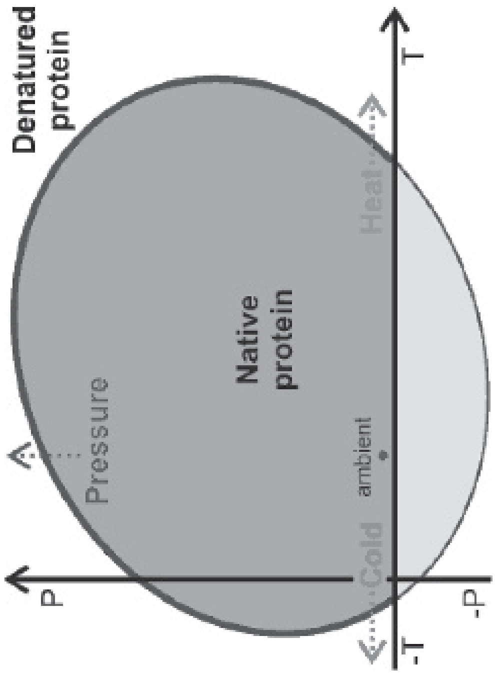

FIGURE 7.5 Elliptical phase diagram of denatured proteins.

molecular bonds. Different types of interactions are responsible for secondary, tertiary and quaternary structure of proteins.

- The quaternary structure is mainly held by hydrophobic interactions that are sensitive to pressure. The tertiary and secondary structures of proteins can be significantly modified at pressures above 200 MPa.
- Final changes in conformation after HPP denaturation can cause full or partial unfolding of polypeptide structure which eventually results in exposure of peptides that can enhance antioxidant activity [60].
- Denaturation is complex process involving intermediate forms leading to multiple denatured products. Secondary structure can even show irreversible denaturation at very high pressure above 700 MPa, leading to irreversible denaturation [6].
- When pressure increases to 100 MPa, temperature of denaturation of protein increases, whereas at higher pressure, temperature of denaturation usually decreases causing elliptical phase diagram of denatured proteins.

- At high pressure, proteins denature usually at room temperature than at higher temperatures.
- Pressure and temperature show antagonistic behavior at molecular level by following principle of microscopic ordering, which says that increase in pressure at constant temperature leads to an ordering of molecules or a decrease in the entropy of the system.
- High pressure has advantage for inducing protein denaturation as these effects are irreversible at pressure level <200 MPa and are not expected to reoccur. Temperature variations can lead to changes in both the volume and the thermal energy of protein but in contrast, at constant temperature under high pressure, the internal energy of the system is independent of pressure, and internal interactions are affected solely by the changes in the volumes of water structure and protein molecules. Denaturation is simply a two stated thermodynamic transition between two states of a protein. Interpretation of denaturation is difficult as the thermodynamic parameters are influenced by binding of the denatured molecules to multiple sites on a protein and this can change the binding of denaturant molecule to multiple sites on a protein and this binding changes the chemical potential of the protein.
- Denaturation induced by pressure means that the volume occupied by the compact folded native conformation is larger than that of unfolded part. Protein unfolding is characterized by a negative molar volume of denaturation. The size of the protein hydration shell increases by attraction of new water molecules by the newly exposed surface amino acid residues but this increase is more than that compensated by the negative contribution from the disruption of electrostatic and hydrophobic interactions and disappearance of voids in the protein not accessible to solvent molecules [63].

7.6.1.3 Enzymes

HPP is most commonly used to inactivate deleterious enzymes, thereby ensuring high quality characteristics of food to be maintained [80]. Effects of HPP on enzymes can be divided in two classes: In first class, we can take pressure which is used to activate some enzymes in food to improve food quality [43]. On other hand, undesirable enzymes in food can be inactivated using high pressure level. In regard to pressure inactivation, there are four distinguished groups of enzymes, based on recovery and loss of activity [62]:

- completely and irreversibly inactivated;
- completely and reversibly inactivated;
- incompletely and irreversibly inactivated;
- incompletely and reversibly inactivated.

Enzymes activity is influenced by pressure induced de-compartmentalization [33]. In an intact food tissue, enzymes and substrates are separated by compartments and pressure can induce membrane damage resulting in leakage of enzyme and substrate which can cause enzymes to contact the substrate. Pressure can cause enzyme inactivation, but there is a minimum level of pressure below which there is no action on enzyme. This pressure inactivation range is dependent on pH, medium, enzyme type, composition and temperature. This has been attributed to an enzyme portion that is irreversibly converted to the inactive form, while a fraction is converted to a pressure-resistant form. Upon pressure release, the pressure-resistant fraction reverts to the equilibrium state, while the irreversibly inactivated enzyme remains unchanged.

It has been found that high pressure enzyme inactivation can be improved by applying pressure cycles. Successive application of high pressure can result in higher inactivation of many enzymes (trypsin, chymotrypsinogen and pepsin). For trypsin and chymotrypsinogen, it has been reported that successive pressure treatments result in a higher degree of inactivation only when pressures above the minimum level required for their inactivation are applied [54].

7.6.1.4 Vitamins

Food vitamins are inevitably and irreversibly damaged during thermal processing and vitamin contents in foodstuffs are closely interrelated to their nutritional quality [67]. Vitamins are highly sensitive to thermal treatments and other similar technologies which can cause great loss of vitamins by leaching. HPP is a cold treatment as it does not involve thermal cooking and is viable for processing of foods containing high amount of vitamins. Vitamins should be determined depending on fact that the amount present in food should be enough to complete nutritional requirement [98].

The effect of HPP on vitamins is mainly focused on ascorbic acid (vitamin C) content; although thiamine, riboflavin and pyridoxal have also been investigated. The majority of these studies have been on fruits and vegetables. Generally, all water soluble vitamins are stable at HPP, with folate showing higher sensitivity [41, 68, 84, 85]. Ascorbic acid has shown to be stable under HPP, unless it is subjected to high pressure and high temperature (>65°C) conditions, where oxidation reactions are enhanced [68]. In addition to its role as antioxidant, it also protects folate against pressure and heat [68].

The HPP does not affect the vitamin content. For example in strawberry nectar, ascorbic acid was decreased only from 1129 to 1100 ppm after HPP treatment [7]. Strawberry coulis puree has high content of vitamin C and HP Treatment (400 MPa/30 min/20°C) caused 88.7% retention of total content. On other hand, vitamin C content in coulis only had 67% retention after thermal treatment (120°C/20 min/0.1 MPa).

An HP treatment does not cause any significant loss of vitamins B6 and B1. Butz and Tauscher [12] found that vitamin B1 concentration was 1.475 and 1.468 μg/mL, respectively in untreated and in treated samples at 600 MPa/30 min/20°C. HPP caused increase in vitamin concentration from 3.725 to 3.794 μg/mL in a model system after pressurization at 600 MPa/30 min/20°C.

In egg yolk, HP treatment caused insignificant effect on vitamin C concentrations even with treatments ranging from 400–1000 MPa, but vitamin C concentration tended to decrease with increasing boiling time. It was found that there was small increase in vitamin C levels in egg yolk and egg yolk ascorbate after pressurization. HP treatment caused extractive effects in foods when they were pressurized at 200, 300 and 400 MPa/20°C/30 min, it caused ascorbate retention of 92.6, 101.34 and 102.6%, respectively. Similar observations were made for thiamine retention in egg yolk as increase of 6.2 and 2.8% in thiamine retention after HP treatment of 600 and 800 MPa, respectively for 30 min at 20°C was found [37].

7.6.2 EFFECT OF HIGH PRESSURE ON MICROORGANISMS

High-pressure treatments are effective in inactivating most vegetative pathogenic and spoilage microorganisms at pressures above 200 MPa at chilled or process temperatures less than 45°C, but the rate of inactivation is strongly influenced by the peak pressure. Commercially, higher pressures are preferred as a means of accelerating the inactivation process, and current practice is to operate at 600 MPa, except for those products where protein denaturation needs to be avoided. A pressure treatment of 600–700 MPa readily kills vegetative cells of bacteria, yeasts and mold; while bacterial spores are more resistant [36, 55]. However, the best results of microbial inactivation can be achieved by the result of a combination of factors.

The cell membrane represents probably one of the major targets for pressure-induced inactivation of microorganisms. The membrane destruction causes the cells to collapse [58]. In addition, HP causes changes in cell morphology and biochemical reactions, protein denaturation and inhibition of genetic mechanisms.

7.6.2.1 Bacteria

The main bacteria that cause food poisoning are *Campylobacter* spp., *Salmonella* spp., *Listeria monocytogenes, Staphylococcus aureus, Escherichia coli* and *Vibrio* spp. Among these, *Listeria monocytogenes* and *Staphylococcus aureus* are probably most intensively studied species in terms of use of HP processing. Generally, Gram-positive bacterias are more resistant to heat and pressure than gram-negative bacteria, and cocci are more resistant than rod-shaped bacteria [27, 88]. Furthermore, it has been suggested that the complexity of the gram-negative cell membrane could be attributable to its HPP susceptibility [64].

The effect of HP treatment on the Gram-positive *Listeria monocytogenes* strain and the Gram-negative *Salmonella typhimurium* strain was determined in stationary phase cell suspensions. Pressure treatments were done at room temperature for 10 min. Increasing pressure resulted in an

TABLE 7.2 Pressure Required to Achieve a 5-log Cycle Inactivation Ratio for Certain Micro-Organisms, for 15 min Treatment [74]

Microorganism	Pressure, MPa
Escherichia coli O157:H7	680
Listeria monocytogenes	375
Salmonella enteritidis	450
Salmonella typhimurium	350
Staphylococcus aureus	700
Yersinia enterocolitica	275

exponential decrease of cell counts. *Salmonella typhimurium* suspended at low pH was more sensitive to pressure treatments [91].

Treating food samples using HP can destroy both pathogenic and spoilage microorganisms. However, there is a large variation in the pressure resistance of different bacterial strains and the nature of the medium can even affect the response of microorganisms to pressure (Table 7.2).

The growth phase of bacteria also plays a role in determining their pressure sensitivity or resistance. Cells in the stationary phase of growth are generally more pressure resistant than those in exponential phase [58], due to the synthesis of proteins that protect against a range of adverse conditions, such as high salt concentrations, elevated temperatures and oxidative stress [38]. It has also been shown that the highest resistance of stationary phase cells to HPP is partly due to the presence of the RpoS protein in *E .coli* and sigB in *Listeria monocytogenes* [81, 101], resulting in an increased bacterial stress response.

7.6.2.2 Bacterial Spores

The mechanism of inactivation of bacterial spores through high pressure has been suggested to have two steps: (a) high pressure will first induce spore germination, and (b) then inactivate the germinated spores. The step of germination is a crucial step, where the spore is monitoring its environment, when conditions are favorable for its growth; it germinates and goes through outgrowth, thus being converted back into a growing cell. During this process, there is a loss of resistance, and is therefore of great interest for a variety of sterilization techniques.

The elimination of bacterial endospores from food probably represents the greatest food processing and food safety challenges to the industry. It is well established that spores are most pressure-resistant life forms. In general, only very high pressures (800 MPa) can kill bacterial spores at ambient temperatures. Alternatively, other processing methods, applied in combination with HP, can be effective for elimination of bacterial spores, by achieving a synergistic or hurdle effect. In particular, HP treatment at elevated temperatures (e.g., HP treatment at up to 90°C) is very effective in the elimination of bacterial spores in foods. Pressure induced inactivation of bacterial spores is also markedly enhanced at temperatures of 50–70°C and perhaps also at or below 0°C.

The most heat-resistant pathogenic bacterium are *Clostridium botulinum* and spores of *C. botulinum*. Also *Bacillus cereus* has been widely studied because of its anaerobic nature and very low rate of lethality. It is recognized as a leading cause of bacterial food poisoning, with a variety of proteinaceous and starchy foods being implicated [97]. Spores of Clostridium spp. tend to be more pressure resistant than those of Bacillus spp. [73].

An alternative to using treatments combining heat and pressure for enhanced killing of bacterial spores is first to cause bacterial spore germination and then use HP to kill the much more pressure-sensitive vegetative cells. The effect of HHP on inactivation of *A. acidoterrestris* (spore forming spoilage bacterium) in orange, apple, and tomato juices showed that the effectiveness of treatment was increased with increase in pressure and temperature. At room temperature, there was no significant reduction of spores in all juice samples, which indicates that in order to use high pressure for spore inactivation; alternate treatment with mild heat is required [50].

7.6.2.3 Yeast and Molds

Many of the yeasts and molds of concern in the food industry are the spoilage agents of fruits beverages, jams, jellies, and vegetable preserves. In comparison, yeasts and molds are relatively HPP sensitive. However, ascospores of heat-resistant molds such as *Byssochlamys, Neosartorya* and *Talaromyces* are generally considered to be extremely HPP resistant [15, 88].

7.6.2.4 Viruses

The first virus to be pressure treated was the plant pathogen, tobacco mosaic virus. Later studies were conducted on HPP inactivation of animal and human viruses. The food industry is mainly concerned with food born viruses such as hepatitis A virus (HAV). Studies on viral inactivation by HPP revealed that some viruses are extremely pressure-resistant. For example, poliovirus is only inactivated by less than one log when subjected to 600 MPa for 1 hour [102]. Other viruses have been found to be very sensitive, such as *feline calicivirus* (FCV), which is completely inactivated by pressures as low as 275 MPa for 5 minutes [46].

The mechanisms of viral inactivation by HPP involve the dissociation and denaturation of the proteins of the virus's coat [87]; or in the case of enveloped viruses, damage to the envelope rather than the damage to viral nucleic acids. The pressure induced changes to the coat can be subtle alterations to capsid proteins or receptor recognition proteins, which can to lead loss of infectivity [26].

7.7 STERILIZATION BY COMBINED HIGH PRESSURE AND THERMAL ENERGY (HPHT)

High pressure high temperature (HPHT) processing or pressure-assisted thermal processing (PATP) involves the use of moderate initial chamber temperatures between 60°C and 90°C and then application of pressure, which causes internal compression heating at pressures of 600 MPa or greater, where in-process temperatures can reach upto 90°C to 130°C. The process has been proposed as a high-temperature short-time process, where both pressure and compression heat contribute to the process's lethality [51]. In this case, compression heat developed through pressurization allows instantaneous and volumetric temperature increase, which in combination with high pressure accelerates spore inactivation in low-acid media. For instance, pressurization temperatures of 90°C–116°C combined with pressures of 500–700 MPa have been used to inactivate a number of strains of Clostridium botulinum spores [28, 56].

Researchers have shown that certain bacterial endospores (*C. sporogenes, Bacillus stearothermophilus, B. licheniformis, B. cereus*, and *B. subtilis*) in selected matrices like phosphate buffer, beef, vegetable cream, and tomato puree [5, 32, 48, 61, 79, 82] can be eliminated after short-time exposure to temperatures and pressures above 100°C and 700 MPa, respectively. Some of these microbial spore inactivation approaches proposed combining [51, 72] of:

- Two low pressure pulses at 200–400 MPa (the first one for spore germination and the second for germinated cell inactivation);
- A low pressure pulse at 200 to 400 MPa for spore germination followed by a thermal treatment at 70°C for 30 min for vegetative cell inactivation;
- Package preheating above 75°C and pressurization at 620 to 900 MPa for 1 to 20 min; and

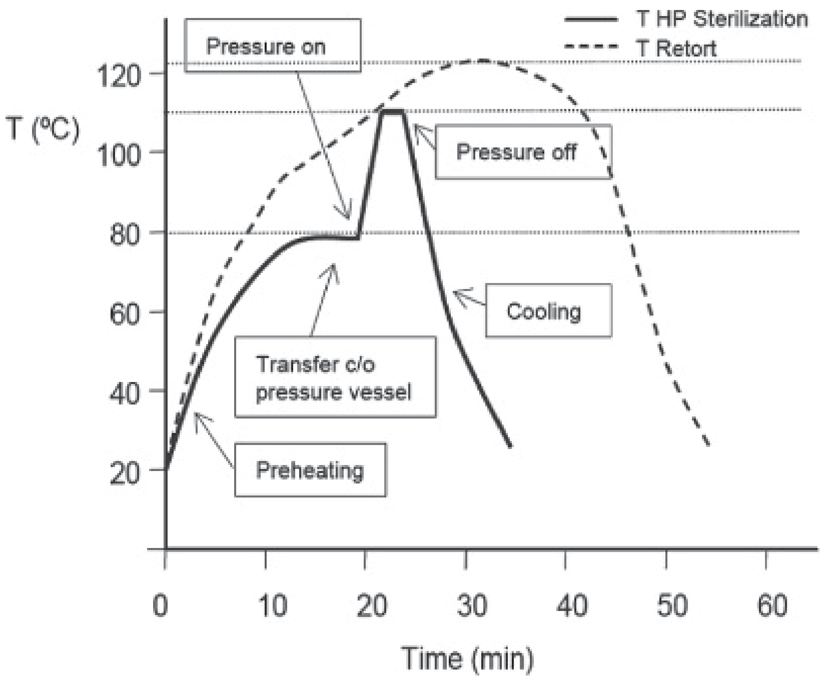

FIGURE 7.6 Product temperature profiles in retort and HPHT processing.

- Package preheating above 70°C and applying two or more pulses at 400 to 900 MPa for 1 to 20 min.

Three of the above-mentioned approaches have proven inconvenient from either a microbiological or an economical perspective. When applying low pressures between 200 and 400 MPa, combined with moderate temperature [cases (a) and (b)], residual dormant spores were detected after treatment [51, 97] making this option unlikely for a commercial process. Moreover, a high pressure multiple pulse approach [case (d)] is not recommended, as additional cycles decrease equipment lifetime and increase maintenance costs [22]. Hence, application of a single pulse above 600 MPa for 5 min or less [case (c)], combined with initial temperatures above 60°C, would be more cost-effective and a safer approach for industrial purposes [21].

7.7.1 ADVANTAGES OF HPHT PROCESSING

The main advantage of HPHT treatment is its shorter processing time (Figure 7.6) compared to conventional thermal processing in eliminating spore-forming microorganisms [57].

This shorter process time and ultimate pressurization temperatures lower than 121°C have resulted in higher quality and nutrient retention in selected products. For example, better retention of flavor components in fresh basil, firmness in green beans, and color in carrots, spinach and tomato puree have been found after HPHT processing [48, 49].

Nutrients such as vitamins C and A have also shown higher retention after HPHT processing in comparison to retort methods [57]. One more benefit of HPHT processing is its use to process non-pumpable foodstuffs like soups containing solid ingredients such as: noodles, barley, and/or cut-up vegetables and meat [21]. The high pressure low temperature processing provides direct product scale-up and higher efficiency for larger volumes of food, compared to thermal processing, due to "instant" hydrostatic pressure transmission.

Similarly, HPHT processing is suitable for larger package sizes, as compression heating to high temperatures is instantly achieved throughout the entire package volume. Nevertheless, the preheating step, or the period of time necessary to reach initial product temperature before pressurization, needs to be considered when evaluating overall processing time. A long preheating time, especially in a large container, may lower product quality retention at the end of the HPHT process.

Although the HPHT process can be seen as advantageous due to its shorter time, yet lower processing temperatures cannot yet be assured for *C. botulinum* in activation until optimal temperature/pressure/time combinations are identified.

7.7.2 HPHT EQUIPMENT

The HPHT process consists of: (a) preheating food packages in a carrier outside the vessel, (b) transferring the preheated carrier into the vessel and

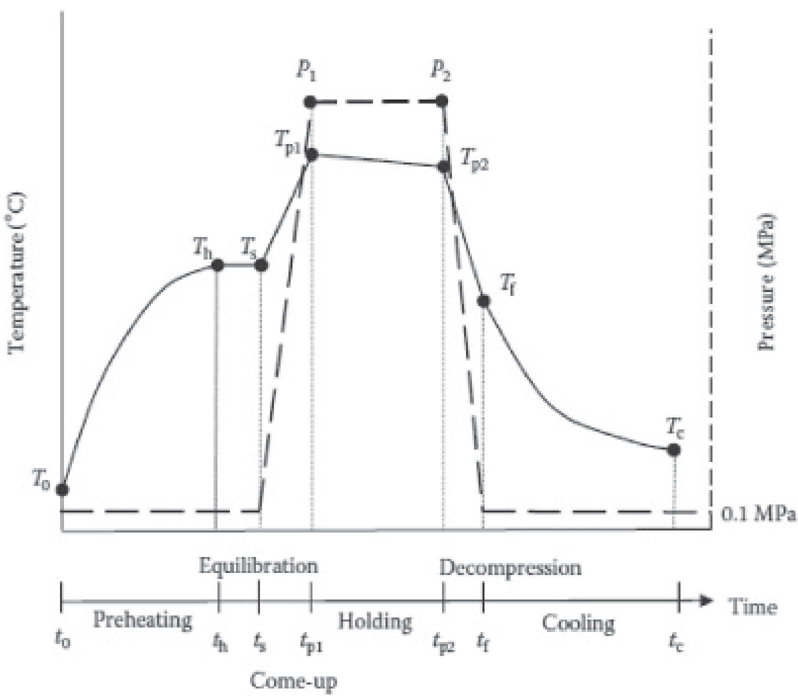

FIGURE 7.7 Temperature profile for pressure-assisted thermal process.

equilibrating up to an initial temperature, (c) pressurizing and holding at a target pressure, (d) releasing pressure, (e) removing carrier from vessel, and (f) cooling down products in the carrier and removing the products. Therefore, the temperature history inside an HPHT-processed food is determined by six main process time intervals [8] (Figure 7.7): (a) product preheating to a target temperature T_h, (b) product equilibration to initial temperature T_s, (c) product temperature increase to T_{p1} due to compression heating, (d) product cooling down to T_{p2} due to heat removal through the chamber, (e) product temperature decrease to T_f during decompression, and (f) product cooling to T_c.

Figure 7.7 shows a typical temperature profile during HPHT treatment, indicating the cooling down experienced in the holding process. Loss of heat is reflected in the difference between initial and final temperature during holding time ($T_{p2} < T_{p1}$), and temperature at the beginning and end of the pressurization–depressurization period ($T_f < T_s$). To achieve sterilization during pressurization, all parts of the treated food must at least reach T_{p1} at pressure P_1 (Figure 7.7), which is the maximum temperature targeted for the maximum pressure holding time. To achieve this goal, a number of variables must be controlled from the start [4]. Thus, understanding the effects of combined temperature and pressure on microbial inactivation distribution will require knowing the temperature within the pressure vessel at specific locations, and at all times during a high-pressure process [14].

In HPHT processing (or pressures over 400 MPa), pressure vessels can be built with two or more concentric cylinders of high tensile strength steel. The outer cylinders compress the inner cylinders so that the wall of the pressure chamber is always under some residual compression at the design operating pressure. In some designs, cylinders and frame are prestressed by winding layer upon layer of wire under tension. The tension in the wire compresses the vessel cylinder so that the diameter is reduced [40]. This special arrangement allows an equipment lifetime of over 100,000 cycles at pressures of at least 680 MPa. The preferred practice is to design high-pressure chambers with stainless steel food-contacting parts so that filtered (potable) water can be used as the isostatic compression fluid [28].

During pressurization at high temperature conditions, a temperature increase is produced in both the compression fluid and food [92].

However, since compression heating in the system steel vessel is almost zero [22, 92], there is heat loss toward the chamber wall. In theory, heat generated by compression is dissipated by a combination of conduction and convection within the pressurizing fluid in the chamber and transfer of heat across the chamber wall into the surroundings [14]. Heat dissipation may cause cooling down of the sample during both come up and holding time, which may there by decrease spore inactivation effectiveness [2, 23]. Thus, it is important to avoid heat loss through the chamber system. Modern systems are required to use several features for heat loss prevention by mainly: (a) adapting a dense polymeric insulating liner with a free moving piston at the bottom or valve to allow adequate pressure transmission; (b) preheating the inflowing pressurization fluid and pipes; and (c) preheating the vessel at a temperature higher than the initial fluid/sample temperature. Successful installation of these features can make the system close to adiabatic. In this way, preservation efficacy at chosen HPHT conditions is maximized.

7.8 APPLICATION OF HPP IN MILK AND MILK PRODUCTS

7.8.1 MILK

The various studies on the inactivation of pathogenic and spoilage microorganisms (naturally present or inoculated) by HPP have been performed in milk and have generally demonstrated that it is possible to obtain 'raw' milk pressurized at 400–600 MPa with a microbiological quality comparable to that of pasteurized milk (72°C, 15 s) [94], depending on the microbiological quality of milk [47, 65] but not sterilized milk due to HP resistant spores. For example, to achieve a shelf life of 10 days at a storage temperature of 10°C, a pressure treatment of 400 MPa for 15 min or 600 MPa for 3 min at 20°C is necessary [76].

In addition to the inhibition and destruction of microorganisms, HP influences the physico-chemical and technological properties of milk. When milk is subjected to HP, the casein micelles are disintegrated into smaller particles [86]. This disintegration is accompanied by an increase of caseins and calcium phosphate levels in the diffusible or serum phase of milk and by a decrease in the both non-casein nitrogen and serum nitrogen fractions, suggesting that the whey proteins become ready to sediment by centrifugation and perceptible at pH 4.6 [42].

The β-blactoglobulin is the most easily denatured serum protein by pressure treatment up to 500 MPa at 25°C, whereas denaturation of the immunoglobulins and ±-lactalbumin only occurs at highest pressures at 50°C. An application derived from this observation is the preservation of colostrum immunoglobulins as alternative to heat treatment, which induces immunoglobulins damage [29].

Studies carried out on free fatty acids (FFA) content (lipolysis of milk fat) in ewe's milk have shown that HP treatments between 100–500 MPa at 4, 25 and 50°C did not increase FFA content, even some treatments at 50°C showed lower FFA content than fresh raw milk [31]. This phenomenon is of great interest to avoid off flavors derived from lipolytic rancidity in milk.

7.8.2 CHEESE MANUFACTURING

The milk pasteurization destroys pathogenic but completely the spoilage microorganisms. It is the most important heat treatment applied to cheese milk to provide acceptable safety and quality. However, milk pasteurization adversely affects the development of many sensory characteristics of cheese, leading to alterations in texture and often delayed maturation [34]. HP technology can be used to increase the microbiological safety and quality of milk to produce high quality cheeses. The HP processing of milk at room temperature causes several protein modifications, such as whey protein denaturation and micelle fragmentation, and alters mineral equilibrium. These changes modify the technological aptitude of milk to make cheese, improving the rennet coagulation and yield properties of cheese milk [95].

7.8.3 ACCELERATION OF CHEESE RIPENING

Techniques accelerating the ripening process without affecting the quality of product provide a significant cost savings to cheese manufactures

[18]. The first attempt of the use of HP to accelerate cheese ripening was first shown in a patent [103]. Experimental cheddar cheese samples were exposed to pressure from 0.1 to 300 MPa for 3 days at 25°C after cheese making. Best results were obtained at 50 MPa, at which pressure a cheese with free amino acid amount and taste comparable to that of a 6-month-old commercial cheese was obtained [103].

HP treatments are able to accelerate cheese ripening by altering the enzyme structure, conforming changes in the casein matrix making it more prone to the action of proteases and bacterial lysis promoting the release of microbial enzymes that promote biochemical reactions [99]. HP treatments also increase pH (0.1 to 0.7 units) and modify water distribution of certain cheese varieties, promoting conditions for enzymatic activity.

7.8.4 RENNET COAGULATION TIME

Rennet coagulation time (RCT) is the time at which the milk coagulum becomes firm enough for cutting after rennet addition. RCT has been reported to reduce markedly at pressure exposure at of 200 MPa. The decreased RCT is related to a reduction in casein micelle size, leading to increased specific surface area and increased probability of inter-particle collision [3, 66]. However at high pressure (400 MPa), RCT again increases as denatured whey proteins are incorporated into the gel and their presences interferes with secondary aggregation phase; thereby, reduce the overall rate of coagulation.

7.8.5 INCREASED CHEESE YIELD

The maximum total solid recovered from the milk during cheese manufacturing is known as the yield of the cheese. Higher the recovered percentage of solids, the greater is the amount of cheese obtained, which has a positive effect in economic terms. During manufacturing of cheddar cheese [24] and semi-hard goat milk cheese [95], higher yields were reported when made from HP-treated milk. The yield of cheddar cheese made from HP treated milk (3 cycles of 1 min at 586 MPa) was 7% higher than that from raw or pasteurized milk. The treatment of milk at 200 MPa had no effect on wet curd yield [3], although denaturation of â-lactoglobulin was observed at 200 MPa; whereas at 300–400 MPa wet curd yield was significantly increased by upto 20% and reduced loss of protein in whey and the volume of whey.

Increased treatment time, up to 60 min at 400 MPa, increased wet curd yield and reduced protein loss in whey. The changes were greatest during the first 20 min of treatment. The increased cheese yield is primarily due to greater moisture retention, secondly due to incorporation of some denatured α-lactoglobulin. Additionally, the casein micelles and fat globules in HP-treated milk may not aggregate as closely as in untreated milk, therefore, allowing more moisture to be entrapped in the cheese [53].

7.8.6 YOGHURT

Firmness of yogurt made from high pressure treated milk has shown to increase with increasing pressure, due to disruption of casein micelles, resulting in a greater effective area for surface interaction. Yoghurt prepared from low fat milk and exposed to 300 MPa/10 min prevents after-acidification (developed acidity after packing) and significantly improved the shelf life. Acidification of yogurt milk with glucono-δ-lactone (GDL) at 200 MPa for 20 min resulted in fine coagulum, homogeneous gel than that of heat treated milk [35, 89].

7.8.7 CREAM, BUTTER, AND ICE CREAM

There are not enough studies carried out on the effects of HPP on cream, butter and ice cream. Pasteurized dairy cream samples (35 and 43% fat) were subjected to 100 to 500 MPa at 23.8°C for 1–15 min [11]. Using the freeze fracture technique and transmission electron microscopy, it was found that pressurization induced fat crystallization within the small emulsion droplets, mainly at the globule periphery. Fat crystallization was increased with the length of pressure treatment and was maximal after processing at 300–500 MPa. Moreover, the crystallization proceeded during further storage at 23°C after pressure release.

The two potential applications of this phenomenon are fast aging of ice cream mix and physical ripening of dairy cream for butter making. Whipping properties were improved when cream was treated at 600 MPa for 2 min [25], probably due to better crystallization of milk fat. When the treatment conditions exceed the optimum, an excessive denaturation of whey protein occurs and results in longer whipping time and destabilization of whipped cream. At <400 MPa, no noticeable effects on whipping properties of cream were found.

The HP processing at 450 MPa and 25°C for 10 to 30 minutes has showed a significant reduction in microbial load of a dairy cream (35%). Inactivation followed apparent first order kinetics, with a decimal reduction time of 7.4 min under the pressure treatment conditions [77].

7.9 CONCLUSIONS

The HPP technology has promised to meet the consumer demand for minimally processed foods, with high nutritional and sensory qualities, which increase self life. From a nutritional perspective, HPP is an excellent food processing technology which has the potential to retain compounds with health properties. Macro nutrients and most of micro nutrients do not appear to be affected by HPP, as in case of thermal treatment. The commercial production of pressurized food has become a reality in Japan, USA, and Spain and many more countries. This is the result of extensive scientific research, technological and technical advances in HPP equipment production and decrease in processing cost.

The range of commercially available HP processed products is relatively small, and the HPP technology has not been commercialized in many developing countries. The main drawback being the novelty of product, high equipment cost and the solid food which cannot be processed in continuous process but rather require batch or semi continuous equipment for its processing. HPP application can inactivate microorganisms and enzymes and modify structure with little or no effect on the nutritional and sensory quality of foods. The combined high pressure and high temperature technology can be claimed advantageous for its shorter processing time. The HPP has a more versatile application in food industries, and provide a unique point of difference for producers. HPP is a paradigm-shifting technology for the food industry that is on-trend with consumer interests. Its use will likely grow as cost declines and food manufacturers identify new applications where HPP can deliver product quality improvements that consumers appreciate and will pay for it.

7.10 SUMMARY

In recent years, consumers have moved on and have changed the selection criteria for food products; they have stressed more on quality and safety of food products. Conventional food sterilization and preservation methods often result in number of undesirable changes in food both in terms of chemical and nutritional value. However, high hydrostatic pressure (non-thermal food processing method) is one such technology that has the potential to fulfill both consumer and scientific requirements. The use of HHP has diverse applications in nonfood industries, but the extensive investigations have revealed the potential benefits of HHP as an alternative to heat treatments. The benefits are diverse in various areas of food processing such as: inactivation of microorganism's and enzymes, denaturation and alteration of functionality of proteins and structural changes to food materials.

In recent years, consumers have stressed more on quality and safety of food products. Conventional food sterilization and preservation methods often result in number of undesirable changes in food both in terms of chemical and nutritional value. However, high hydrostatic pressure can fulfill both consumer and scientific requirements. The benefits are diverse in various areas of food processing such as: inactivation of microorganism's and enzymes, denaturation and alteration of functionality of proteins and structural changes to food materials.

KEYWORDS

- **cell morphology**
- **compression**
- **decompression**
- **elevated temperature**
- **enzyme inactivation**
- **high pressure processing**
- **high pressure vessel**
- **holding time**
- **isostatic**
- **microbial inactivation**
- **microbiological shelf life**
- **minimally processed foods**
- **native protein**
- **non-thermal sterilization**
- **olgomeric proteins**
- **pressure transmitting medium**
- **pressurization**
- **protein**
- **shelf life**
- **spore forming bacteria**
- **sterilization**
- **transient temperature**
- **vegetative cells**

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CHAPTER 8

MICROWAVE PROCESSING OF MILK: A REVIEW

BHUSHAN D. MESHRAM, A. N. VYAHAWARE, P. G. WASNIK, A. K. AGRAWAL, and K. K. SANDEY

CONTENTS

8.1 INTRODUCTION

Microwaves are largely a twentieth-century phenomenon for their use in foods. The first truly useful sources were devised in the 1940s during the wartime development of radars [139]. Microwaves are defined as a part of electromagnetic waves, which have frequency range between 300 MHz and 300 GHz corresponding to wavelength from 1 mm to 1 m. Microwave frequencies of 915 MHz and 2.45 GHz can be utilized for industrial, scientific, and medical applications [54, 80]. Microwaves have been applied in a broad range of food processing such as drying, tempering, blanching, cooking, pasteurization, sterilization, and baking. Microwave heating has considerable advantages over conventional heating methods, especially with regard to energy efficiency. Since heat is transferred from the surface of food to the interior by convection and conduction in conventional cooking method, it may result in a temperature gradient between outside and inside the food [49, 140]. In addition, it requires higher energy consumption and relatively long processing time [135]. In microwave heating, on the other hand, heat is generated (volumetric heating) inside the food in a short time when microwave penetrates through it [92, 96]. Microwaves have greater penetration depth, and this property coupled with volumetric heating can lead to rapid heating rate with short processing time; and also contribute to the minimization of temperature difference between the surface and interior of food [34, 140].

Microwave ovens are now becoming common house-hold appliances because the modern life requires simplified routines and standardization of foods with lesser preparation time and convenience in usage. Microwave energy has been widely used in the food processing industries due to its advantages. It has been widely used in drying, sterilization, pasteurization, tempering, baking, blanching, heating, solvent extraction, digestion, puffing and foaming [32]. The industrial and domestic use of microwaves has increased dramatically over the past few decades. While the use of large-scale microwave processes is increasing, recent improvements in the design of high-powered microwave ovens, reduced equipment manufacturing costs and trends in electrical energy costs offer a significant potential for developing new and improved industrial microwave processes [85].

Microwavable foods satisfy need for speed and palatability. In addition, to meet consumer demand for on-the-go eating, a growing number of microwave products are entering the market in single-serve portable packages [6]. Microwave technology offers a new range of opportunities as a substitute to thermal processing. It offers a technique of heating that requires neither the presence of a hot outer surface nor the need for long conduction lags [115]. An alternative to aseptic packaging, there is an ability of microwaves to heat-treat the products after packaging, which are considered as "electrical- isolators" like plastic, glass, ceramics, porcelain. This technique can be effectively used for traditional Indian dairy products (TIDPs) for in-pack sterilization. Also microwave processing results in excellent retention of nutritional and sensory value, besides having several advantages like savings in energy, cost, time, etc. [124, 136].

The use of microwave oven provides a convenient way to thaw, cook or reheat foods nowadays. Many studies have been conducted to assess the safety as well as possible nutrient loss associated with microwave cooking. The best available evidence supports that the use of microwave cooking resulted in foods with safety and nutrient quality similar to those cooked by conventional methods, provided that the consumers followed the given instructions [56].

In addition, microwave (MV) heating is effective to heat up the prepared (ready to eat, RTE) foods. Therefore, the microwave oven operated in the simple manner became an indispensable home appliance to cook RTE food. Western foods are often considered to be more suitable for microwave cooking and can be ascribed due to fact that those include a majority of baked food products and precooked meat patties that require preheating process, for example, oven-roasting or baking before consumption. In recent years, however, even in the countries like India, where the traditional cooking methods are still popularly used, the application of microwave heating for cooking has been significantly increased. This transforming trend strongly suggests that microwave heating have been widely adopted for cooking various food types.

This chapter discusses the effectiveness and potential of microwave heating technology for different food processing methods and briefly presents a literature review of experimental approaches of microwave heating.

8.2 PRINCIPLE OF OPERATION OF MICROWAVE TECHNOLOGY

8.2.1 GENERAL

According to https://en.wikipedia.org/wiki/Microwave, "*Microwaves are a form of electromagnetic radiation with wavelengths ranging from one* *meter to one millimeter; with frequencies between 300 MHz (100 cm) and 300 GHz (0.1 cm). This broad definition includes both UHF and EHF (millimeter waves), and various sources use different boundaries. In all cases, microwave includes the entire SHF band (3 to 30 GHz, or 10 to 1 cm) at minimum, with RF engineering often restricting the range between 1 and 100 GHz (300 and 3 mm). The prefix micro- in microwave is not meant to suggest a wavelength in the micrometer range. It indicates that microwaves are "small", compared to waves used in typical radio broadcasting, in that they have shorter wavelengths. The boundaries between far infrared, terahertz radiation, microwaves, and ultra-high-frequency radio waves are fairly arbitrary and are used variously between different fields of study*." Frequencies of 915 or 2,450 MHz are mainly used in commercial microwave ovens for food [116].

All microwave ovens have similar design that includes a magnetron device as a power source and a waveguide to bring radiation to a heating chamber. Microwave with 915 MHz frequencies, is used for industrial heating, and 2450 MHz, in domestic microwave oven worldwide. The mechanism through which microwave heating occurs is based on the oscillation and polarization of the charges and the molecules of a dielectric material under the influence of alternating electric field, resulting in the generation of heat. The main cause of heat production is due to dipolar rotation. Factors influencing the microwave heating are frequency, microwave power, speed of heating, mass of the material, moisture content, density and temperature of the material. The two major mechanisms, namely dipolar and ionic interactions, explain how heat is generated inside food [31, 32].

8.2.1.1 Dipolar Interaction

Once microwave energy is absorbed, polar molecules such as water molecules inside the food will rotate according to the alternating electromagnetic field. The water molecule is a "dipole" with one positively charged end and one negatively charged end (Figure 8.1). Similar to the action of magnet, these "dipoles" will orient themselves when they are subjected to electromagnetic field. The rotation of water molecules would generate heat for cooking.

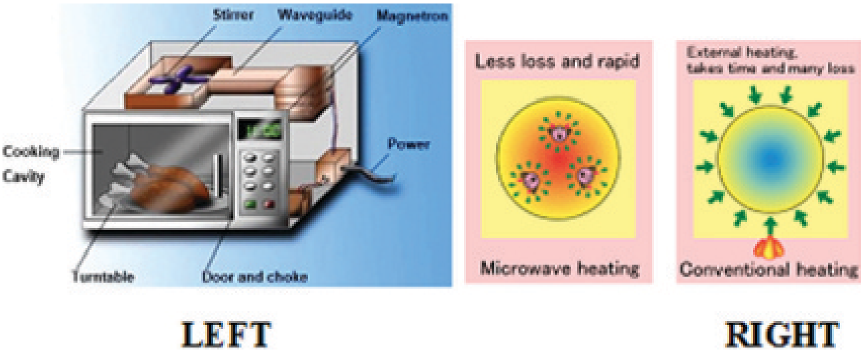

FIGURE 8.1 Basic components of microwave oven (Left); microwave heats object internally (Right)..

8.2.1.2 Ionic Interaction

In addition to the dipole water molecules, ionic compounds (i.e., dissolved salts) in food can also be accelerated by the electromagnetic field and collides with other molecules to produce heat.

Hence the composition of a food will affect how it will be heated up inside the microwave oven. Food with higher moisture content will be heated up faster because of the dipolar interaction. As the concentration of ions (e.g., dissolved salts) increase, the rate of heating also increases because of the ionic interaction with microwaves. Although oil molecules are much less polar than water molecules and are non-ionic, yet food products with high oil content has a fast heating rate because the specific heat of oil is about less than half that of water.

8.2.1.3 Basic Components (Figure 8.1) [17]

- **Cooking cavity** is a space inside which the food is heated when exposed to microwaves.
- **Door and choke** allows the access of food to the cooking cavity. The door and choke are specially engineered that they prevent microwaves from leaking through the gap between the door and the cooking cavity.

- **Magnetron** is a vacuum tube in which electrical energy is converted to an oscillating electromagnetic field. Frequency of 2,450 MHz has been set aside for microwave oven for home use.
- **Power supply and control** controls the power to be fed to the magnetron as well as the cooking time.
- **Stirrer** is commonly used to distribute microwaves from the waveguide and allow more uniform heating of food.
- **Turntable** rotates the food products through the fixed hot and cold spots inside the cooking cavity and allows the food products to be evenly exposed to microwaves.
- **Waveguide** is a rectangular metal tube which directs the microwaves generated from the magnetron to the cooking cavity. It helps prevent direct exposure of the magnetron to any spattered food which would interfere with function of the magnetron.

8.2.1.4 Characteristics of Microwave Heating

a. **The Internal heating:** Microwave energy will reach the object to be heated at the same speed of light. Then it enters into the object as a wave, and by getting absorbed, the object generates heat (Figure 8.1, right) [17].
b. **Rapid heating:** In conventional heating (Figure 8.1, right), the object's temperature rises by spreading heat energy from the surface to inside (external heating). On the other hand, by microwave heating, the object will generate heat on its own by the penetration of the microwave. Not necessary to consider about the heat conduction. That is why rapid heating is possible by microwave. Although the object has to be large enough for the microwave to penetrate, yet the smaller objects will also be heated from inside as the depth of microwave penetration.
c. **High heating efficiency:** Microwave penetrates into the object at the speed of light. You get high heating efficiency because no need to consider the heating losses of air inside the heating furnace.
d. **Rapid response and temperature control**: Microwave penetrates into the object at the speed of light. So it allows rapid response. For example, you can start and stop the heating instantly. In addition, by

the adjustment of microwave output, you can control the amount of heat energy generated inside the heated object.

e. **Heating uniformity**: Each part of the heated object generates heat, so even for those objects with complicated shape, it can be heated relatively uniform. To keep the heating uniformity, stirrer, turn-table, and belt conveyor is used for heating blur related to wave length.

f. **Clean energy**: Microwave does not require a medium, because it propagates only by changes of electric fields and magnetic fields. It can propagate in a vacuum. It reaches the object and penetrates without heating the air. The heated object generates heat by absorbing microwave energy to convert it to heat energy. Therefore, it can be said as clean energy because it doesn't heat the air during process.

g. **Good operation and work environment**: Conventional heating requires a heat source, and the temperature rises not only of heated object, but also of heat source and the heating furnace. So the temperature of room equipped heating furnace goes high because of radiant heat. This is an operation and work environment issue. On the other hand, microwave heating only uses electricity to generate heat of the object. The temperature of the object only raises, not the furnace and there is no radiant heat, so it's possible to keep operational and good working environment.

8.3 MICROWAVE TECHNOLOGY: ADVANTAGES AND LIMITATIONS

8.3.1 ADVANTAGES

- Microwave penetrates inside the food materials and, therefore, cooking takes place throughout the whole volume of food internally, uniformly, and rapidly, which significantly reduces the processing time and energy.
- Since the heat transfer is fast, nutrients and vitamins contents, as well as flavor, sensory characteristics, and color of food are well preserved.

- Minimum fouling depositions, because of the elimination of the hot heat transfer surfaces, since the piping used is microwave transparent and remains relatively cooler than the product.
- High heating efficiency (80% or higher efficiency can be achieved).
- Suitable for heat-sensitive, high-viscous, and multiphase fluids.
- Low cost in system maintenance.

8.3.2 DISADVANTAGES

Today's uses range from these well-known applications over pasteurization and sterilization to combined process like microwave vacuum drying. The rather slow adoption of food industrial microwave applications may be due to following limitations:

- There is the conservatism of the food industry [35], and its relatively low research budget. Linked to this, there are difficulties in moderating the problems of microwave heating applications.
- In order to get good results, industry needs a high input of engineering intelligence.
- Different from conventional heating systems, where satisfactory results can be achieved easily by perception, good microwave application results often need a lot of knowledge or experience to understand and moderate effects like uneven heating or the thermal runway.
- Microwave heating as opposed to conventional heating needs electrical energy, which is its most expensive form.
- High initial capital investment, more complex technology devices, microwave radiation leakage problem.

8.4 MICROWAVABLE PACKAGING MATERIALS

Plastic containers are commonly used for microwave cooking. High density polyethylene (HDPE) can be used for foods with high water content, for foods with high fat or high sugar content, and for foods with high water content, as these foods may reach temperature above 100°C during microwave cooking. Paper and board can also absorb some microwave energy. However, it is not ideal for microwaved food because the strength of the paper would be affected when wet; and not all types of paper are suitable for microwave cooking.

When food is microwaved, heat is also retained in the glass. The degree of energy absorption depends on types of glass. Moreover, microwave energy can be superimposed at the center after passing through the glass containers, particularly the ones with small radius. Microwave oven has now been accepted as a modern domestic appliance for cooking and heating so the market needs innovative food packages which can be micro waved. Microwavable packages are made from a special aluminum laminates that can withstand high temperature, heat-processing treatments such as sterilization and microwave heating. Retort pouches and semi-flexible retortable thermoformed containers are the most popular microwavable packaging currently used. Cast polypropylene, polyester, polyamides, oriented polyamide, aluminum foils form the basic structure of a microwavable packing [56].

8.5 APPLICATIONS OF MICROWAVE TECHNOLOGY IN FOOD THE INDUSTRY

8.5.1 THAWING-TEMPERING

Tempering is the thermal treatment of frozen foods to raise the temperature from below −18°C to temperature just below the melting point of ice. At these temperatures, the mechanical product properties are better suited for further machining operation (e.g., cutting or milling). By using microwaves mostly at 915 MHz due to their larger penetration depth, the tempering time can be reduced to minutes or hours and the required space is diminished to one sixth of the conventional system [81]. Another advantage is the possibility to use the microwaves at low air temperatures, thus reducing or even stopping microbial growth.

Frozen meat, fish, vegetables, fruit, butter and juice concentrate are common raw materials for many food manufacturing operations. Frozen meat, as supplied to the industry, ranges in size and shape from complete hindquarters of beef to small breasts of lamb and poultry portions, although the majority of the material is 'boned-out' and packed in boxes approximately 15 cm thick weighing between 20 and 40 kg. Fish is normally in plate frozen slabs; fruit and vegetables in boxes, bags or tubs; and juice in large barrels. Few processes can handle the frozen material and it is usually either thawed or tempered before further processing [55].

Thawing is usually regarded as complete when all the material has reached 0°C and no free ice is present. This is the minimum temperature at which the meat can be boned or other products cut or separated by hand. Lower temperatures (e.g., −5 to −2°C) are acceptable for product that is destined for mechanical chopping, but such material is 'tempered' rather than thawed. The two processes should not be confused because tempering only constitutes the initial phase of a complete thawing process. Thawing is often considered as simply the reversal of the freezing process. However, inherent in thawing is a major problem that does not occur in the freezing operation. The majority of the bacteria that cause spoilage or food poisoning are found on the surfaces of food. During the freezing operation, surface temperatures are reduced rapidly and bacterial multiplication is severely limited, with bacteria becoming completely dormant below −10°C. In the thawing operation, these same surface areas are the first to rise in temperature and bacterial multiplication can recommence. On large objects subjected to long uncontrolled thawing cycles, surface spoilage can occur before the center regions have fully thawed.

Without doubt, thawing and tempering are most industrially widespread applications of microwave (MW) heating. There are about 400 systems in use in the United States for vegetables and fruits; and at least four in the United Kingdom for tempering of butter. Most of the studies were carried out in the 1970s and 1980s [3, 7], and these have analyzed the behavior and final characteristics of diverse types of meat during MW tempering. Tempered meat shows good final characteristics, and process time is greatly shortened. An attempt made by Cadeddu [18] to apply a microwave tempering tunnel to stretch Mozzarella curd was not successful.

Recently, other possible applications of this technology to for rice balls [60, 142], mashed potatoes [53], or cereal pellets or pieces [110] have been studied, with a few encouraging results in terms of the good physical and sensory properties. However, some studies [21, 61, 62] are mainly focused on reaching a better understanding of the relationship between the equipment (applied powers and cycles of work) and the product (dielectric properties, loads, and geometry).

8.5.2 HEATING OF PRECOOKED PRODUCTS

The heating of precooked products is principal practical application of microwave ovens, both in domestic use and in the catering industry, since a rapid, safe, and hygienic heating of the product can be obtained [15]. The objective of pre-cooking operation is to reduce preparation time for the consumer. In case of cereals, these operations consist basically of treating starch to reduce its gelatinization time during the final preparation of the food product. By toasting cereal flours, Wang et al. [138] obtained pre-cooked rice flour (with 13.4% moisture) after 11 min in a microwave oven (2450 MHz) and Chavan et al. [23] obtained pre-cooked wheat flour (with 14% moisture) after 11 min in a microwave oven (2,450 MHz), with good sensory and nutritional evaluations, which were used in combination with defatted soy flour with additional microwave treatment for 8 min, for porridge and soup products. The precooking process can be accelerated with the help of microwaves as has been established for precooking of poultry, meat patty and bacon [11, 35].

Recently, however, diverse studies have been carried out in an attempt not only to improve the physical and sensory characteristics of the heated product [46, 70], but also to obtain a greater uniformity in product heating [59, 104]. Jeong et al. (2004) [58] carried out microwave cooking of ground pork patties at 700 Watt up to 75°C and found the reduction in cooking time for high fat patties. Bilgen et al. [10] used microwave oven to prepare a white layer cake to achieve desired crumb qualities.

8.5.3 COOKING

Cooking with microwaves has recently become the most adaptable method all over the world. Microwave ovens are now used in about 92% of homes in the US. In this section, various reports on the effects of microwave on cooking parameters such as quality, taste and color retention for various food materials are reviewed. There are numerous reports on the baking of bread and cooking of rice and meat using microwaves. Microwave heating takes the product to the desired temperature in such a short time that product cooking does not take place; the product is hot, but has the appearance and flavor of the raw product [69].

There are several products used in the continuous study of this technology, such as fish [107], beans [88], egg yolk [86], and shrimp [49]. The nutritious characteristics of the food are quite well retained, but it does not reach the typical flavor of the cooked dish; thus it is necessary to combine microwave treatment with conventional technologies [25]. Microwave cooking is used industrially for chicken (1500 kg of chicken/hour) and for bacon (with an advantage over oil frying or infrared heating). Microwave oven is well suited for cooking the food in small quantities, especially for households, though not convenient for mass cooking. Daomukda et al. [30] studied the effect of different cooking methods on physico-chemical properties of brown rice. They concluded that the protein, fat and ash contents in rice cooked by microwave are retained at higher levels (8.49%, 2.45% and 1.42%, respectively) than conventional boiling and steaming methods. Microwave irradiation normally does not induce the Mallard reaction because of the short cooking times and low temperatures [143].

Sharma and Lal [114] reported that there was no significant change on the loss of B-complex vitamins during microwave boiling of cow and buffalo milk in comparison to conventional heating. Microwave cooking reduces cooking times of common beans and chickpeas [77]. In addition, microwave treatment was able to reduce cooking losses, increase the soluble: Insoluble and soluble: total dietary fiber ratios, but did not modify in-vitro starch digestibility. A higher protein concentration in soya milk was obtained by microwave heating of soya slurry than by the conventional methods of heating such as the use of boiling water [2]. Microwave oven heating of soya slurry, which was effective for protein extraction, also made the prepared tofu more digestible.

Iilow et al. [57] reported that microwave cooking resulted in minimum loss of vitamin C in white cabbage, cauliflower, Brussel sprouts and French beans in comparison to the traditional method of cooking. It also had a positive effect on the organoleptic quality of these vegetables. Microwave roasting of soaked soybean produced full-fat soya flour with high vitamin E without burnt color and browning [145]. Variation in the organic acids, sugars and minerals of raw and microwave cooked beetroot, broccoli, artichokes, carrots, cauliflower, fennel, potatoes, chilies, celery, spinach and courgettes have been reported by Plessi [39, 95].

Substantial reduction in the energy consumption was observed with controlled cooking (using microwave oven) of un-soaked rice (14–24%) and pre-soaked rice (12–33%) compared with normal cooking [73]. Conventional cooking of broccoli for 30, 60, 90, 120 and 300 s has been found to reduce total phenolic content by 31.6%, 47.5%, 55.9%, 61.7% and 71.9% in florets and 13.3%, 22.2%, 26.7%, 28.9% and 42.2% in stems; and there was no significant difference in the total phenolic content between microwave and conventionally cooked samples [1].

Because microwave oven is able to heat up foods using the energy of oscillating electromagnetic wave, it is possible to do selective and quick cooking. But the penetration depth of microwave is under about a few inches or below the surfaces of foods. So, if food size is small and the shape of food is flat, the uniform heating through overall volume is possible. It will lead less loss of moisture contents and the greatest energy savings, and the nutrition of foods will be preserved very well. But using conventional method, cooking of multiple foods containing particles of any shape and size together can be achieved through moist-heat method, but at the expense of moisture which keeps some of their nutrition. Therefore, new combination techniques, making the best use of the merits of microwave heating, should be studied.

8.5.4 BAKING

Baking is a thermal process that significantly changes physicochemical properties of dough. Baking process includes three phases: expansion of dough and moisture loss initiates in the first phase; in the second phase, expansion and the rate of moisture loss becomes maximal; and the third phase includes rise in product height and decrease in rate of moisture loss because the structure of the air cells within the dough medium collapses as a result of increased vapor pressure. Baking using microwave energy has been limited due to poor product quality compared to products baked by using conventional energy sources, which can be a reflection of the differences in the mechanism of heat and mass transfer [108]. In products such as breads, cakes and cookies, microwave baking can affect texture, moisture content and color of the final product, which represents a great challenge for research. Some researchers suggest adjustments in formulation and alterations in the baking process, while other investigators study the interactions between microwave energy and the ingredients of the formulation [94, 147].

Microwave baking of pastry products is already carried out on an industrial scale, whereas that of bread dough is still in the experimental phase [9, 19, 91]. Its application to batters in the production of tarts or cakes is also being studied [8, 29, 146]. Apart from the better retention of vitamins and nutrients, the fundamental effect is the greater volume that MW-baked pieces acquire, in the order of 25–30% more than that reached using classical baking. No differences were detected in the flavor. An additional effect is a minor development of molds in microwave-baked products. In the case of bread, an additional source of energy is needed to obtain desired color and texture of the crust.

In studies with bread during microwave heating, there was a rapid loss of moisture and, after microwaving, the mechanical strength of bread was increased greatly [22, 23, 51]. During cake production, after the mixing process, the cake must be deposited into cake pans and rapidly conveyed to the oven. Baking time is inversely related to baking temperature and the optimum baking conditions for cake baking are determined by the sweetener level of the formula, amount of milk used in the batter, fluidity of the batter, pan size and others [5, 144]. The effect of modifications in cake ingredients was studied by Tsoubeci [129]. Sucrose substitution with a blend of whey protein isolate (WPI) and maltodextrin and fat substitution with a special fiber were evaluated in a model cake system during baking by conventional and microwave methods. Substitution of sucrose with WPI and maltodextrin affected the dielectric properties of the batters. Power absorption predictions indicated that the power absorbed by microwave-heated cakes increased when sucrose was substituted. Removal of fat influenced the dielectric behavior of batters whereas substitution with the special fiber compensated for fat in both microwave and conventionally heated cakes. Takashima [126] patented a process to obtain a sponge cake free from bake shrinkage and good-looking voluminous appearance, through a batter prepared by adding a thermo-coagulation protein to a sponge cake premix containing as main ingredient a cereal powder consisting of starch and a pre-gelatinized starch cooked under heat with a microwave oven.

8.5.5 BLANCHING

Blanching is a thermal pre-treatment process, which is an essential step in several food processing techniques such as freezing, canning or drying, generally applied to inactivate enzymes that substantially affect to texture, color, flavor, and nutritive values of fruits and vegetables. Blanching is generally used for color retention and enzyme inactivation, which is carried out by immersing food materials in hot water, steam or boiling solutions containing acids or salts. Blanching has additional benefits, such as: the cleansing of the product, the decreasing of the initial microbial load, exhausting gas from the plant tissue, and the preheating before processing. A moderate heating process such as blanching may also release carotenoids and make them more extractable and bio-available. Blanching with hot water after the microwave treatment compensates for any lack of heating uniformity that may have taken place, and also prevents desiccation or shriveling of delicate vegetables. And while microwave blanching alone provides a fresh vegetable flavor, the combination with initial water or steam blanching provides an economic advantage. This is because low-cost hot water or steam power is used to first partially to raise the temperature, while microwave power, which costs more, does the more difficult task of internally blanching the food product. Microwave blanching of herbs such as marjoram and rosemary was carried out by soaking the herbs in a minimum quantity of water and ex-posed to microwaves [120].

Microwave blanching was observed for maximum retention of color, ascorbic acid and chlorophyll contents than that of water and steam blanching. Microwave blanched samples were found to have better retention of quality parameter than that of microwave dried samples without blanching [119]. In comparison to the traditional method of blanching in hot water, microwave blanching of vegetables has the advantage of avoiding the loss of nutrients (vitamins, etc.) and pigments, which are lixiviated to some extent in the blanching water, ash has been observed for tomatoes [4], carrots [65], beans [64], soybeans [52], asparagus [66], mushrooms [134], and strawberries [141]. Additionally, there is no production of waste water.

Recent studies reveal that enzymatic browning can be limited to some extent in several products such as bananas [20] and potatoes [112]. Nevertheless, some disadvantages of MW application to the blanching process are: the surface dehydration of the product, especially in leaf vegetables such as spinach and cabbages; caramelization in fruits [20, 27]; and the heterogeneous heating of the products, depending on size and shape, which can lead to severe alterations caused by undesirable thermal effects Some authors [25] propose the combination of microwave blanching with other techniques (steam or hot water) in order to minimize product alterations. Microwave blanching operations can be used to inactivate enzymes in fresh vegetables and fruits that lead to premature food spoilage at freezing temperatures [115].

Ramaswamy and Fakhouri [101] studied the microwave blanching of carrot slices and french-fry style sweet potatoes. Premakumar and Khurdiya [98] stated that banana puree prepared from microwave-blanched fruits has higher nutritional and organoleptic qualities as compared to conventional method of blanching. Severini et al. [112] stated that microwave blanching of cubed potatoes can be achieved at 600 watts for 5 min. Brewer and Begum [12] carried out blanching of broccoli, green beans and asparagus and found the reduction in peroxidase activity.

8.5.6 FOOD STERILIZATION AND PASTEURIZATION

Pasteurization and sterilization are done with the purpose of destroying or inactivating microorganisms to enhance the food safety and storage life [13, 33, 89]. Solid products are usually sterilized after being packed, so no metallic materials can be used in packaging when microwaves are used in this process. This factor limits the use of this technique in food sterilization. Possible non-thermal effect on destruction of microorganisms under microwave heating has been reported; the polar and /or charged moieties of proteins (i.e., COO-, and $NH4^+$) can be affected by the electrical component of the microwaves [35]. Also, the disruption of non-covalent bonds by microwaves is a more likely cause of speedy microbial death [67]. Academic and industrial approaches to microwave pasteurization or sterilization cover the application for precooked food like yogurt or pouch packed meals as well as the continuous pasteurization of fluids like milk [34–36].

Due to the rapid heating of the product, a better retention of the nutritional properties in comparison with the current technologies can be obtained [90]. Nevertheless, this is still only being applied on a laboratory scale in many cases, the main reasons for which are high costs and the uncertainty about microbial inactivation. The latter is associated with the heterogeneity in product heating, which does not ensure that all points of the food reach the required temperature to induce microbial death [14, 17]. In this sense, the possible combined application of hydrogen peroxide and a microwave treatment to inactivate some microorganisms has been studied [71]. The 915-MHz microwave-circulated water combination (MCWC) heating technology was validated for a macaroni and cheese product using inoculated pack studies. This study suggests that the MCWC heating technology has potential in sterilizing packaged foods [37, 47, 100].

Pasteurization can be achieved by novel thermal (RF and Ohmic heating) and non-thermal technologies (high hydrostatic pressure, UV treatment, pulsed electric field, high intensity ultrasound, ionizing radiation and oscillating magnetic field) without affecting the color, flavor or nutritive value of food materials [93, 103]. In Ohmic heating, the heating occurs due to the electrical resistance caused by the food materials when a current is passed through them. For a pulsed electric field process, a very high voltage is applied for a very short time through the fluid. This generates mild heat and cell disruption of microorganisms occurs due to electroporation. During a high hydrostatic pressure process, pressures of 100 to 1000 MP a are applied and as a result, large microorganisms or enzymes consisting of large molecules were affected. This technique is used for the aroma components for which the sensory and nutritional qualities need to be maintained. The advantages of a high hydrostatic pressure process are: the release of minimal heat, homogeneous nature of the process and its applicability to packaged materials. Most of the novel and non-thermal techniques provide energy savings up to 70% compared to the traditional cooking methods [93].

Advantage of using microwaves in microorganism deactivation are the possibly high and homogeneous heating rates, also in solid foods and the corresponding short process times, which can yield a very high quality. For both processes, it is extraordinarily important to know or even to control the lowest temperature within the product, where the microorganism destruction has the slowest rate. Since both calculation and measurement of temperature distribution are still very difficult, this is one reason that up to now microwave pasteurization and sterilization can be found very seldom in industrial use, and then only for batch sterilization operation.

8.5.7 FOOD DEHYDRATION

Dehydration process removes moisture from food materials without affecting the physical and chemical composition. It is also important to preserve the food products and enhance their storage stability which can be achieved by drying. Dehydration of food can be done by various drying methods such as: solar (open air) drying, smoking, convection drying, drum drying, spray drying, fluidized-bed drying, freeze drying, explosive puffing and osmotic drying [26]. The application of microwaves to food drying has also received widespread attention recently [35, 44, 45]. The heat generated by microwaves induces an internal pressure gradient that involves vaporization and expelling of the water toward the surface. This greatly accelerates the process, when compared to hot air or infrared dehydration [125], in which the drying rate is dependent on the diffusion of water inside the product toward the surface.

Generally, microwave drying can be subdivided into two cases: the drying at atmospheric pressure and under applied vacuum conditions. Until now, more common in the food industry are combined microwave-air-dryers that can again be classified into a serial or parallel combination of both methods. In the serial process, mostly the microwaves are used to finish partly dried food, where an intrinsic leveling effect is advantageous. Well-studied and still applied examples for a serial hot air and microwave dehydration are pasta drying and the production of dried onions [35].

In the studies on MW applications to drying, changes in drying kinetics of fruits and vegetables have been analyzed, as have the effects of MW power on final product properties such as texture, structure, rehydration capability, and color [42, 59, 68, 72, 78, 79, 99, 106, 128]. A large amount of work has been carried out on potatoes [40, 41], carrots [75, 97], apples and banana [38, 68, 74, 105]. Uprit and Mishra [131] studied microwave convective drying and storage of soy-fortified paneer (SFP) and found that hot air temperature of 53.5° C and microwave power of 111.5 W gave good quality dried SFP cubes of uniform texture and surface, unblemished and with clear color. The dried SFP cubes rehydrated well and had a shelf life of 118 days under accelerated storage conditions (38 ± 2°C, 90% relative humidity). Cui et al. [28] studied the microwave-vacuum drying kinetics of carrot slices.

The desire to eliminate the existing problems in drying and to achieve fast and effective thermal processing has resulted in the increasing interest in the use of microwaves for food drying [123]. CSUF [27] has pioneered the development of microwave vacuum (MIVAC) dehydration. MW-related (MW-assisted or MW-enhanced) combination drying is a rapid dehydration technique that can be applied to specific foods, particularly to fruits and vegetables. The advantages of MW-related combination drying include: shorter drying time, improved product quality, and flexibility in producing a wide variety of dried products [147]. Sangwan et al. [109] dried blanched and chopped onions into microwave oven at 800 W powers for 3 to 4 min and prepared onion powder showed superior quality. Kalse et al. [63] also studied the osmo-microwave drying of onion slices. Sharma et al. [113] developed a small scale microwave dryer for the purpose of drying agricultural produce and carried out drying of garlic cloves in it with superior quality. The energy consumption for drying of pumpkin slices using microwave, air and combined microwave-air-drying treatments has been studied [145]. It was concluded that high energy consumption was observed for air oven drying compared to combined microwave-air-drying treatment and, the lowest energy consumption among treatments was observed during microwave drying.

However, there is one key problem with the above-mentioned techniques. Because of non-uniform heating, the uneven distribution of microwave field can occur. In addition, the overheating and quality deterioration can take place [145]. To overcome these problems, the microwave drying technique has been combined with various other methods. The MW freeze drying (MFD) and MW vacuum drying (MVD) are good examples, wherein drying is assisted by microwaves to produce high quality foods. Especially, conventional fluidized bed dryer combined with microwave heating is good choice for drying products containing fine particles. In the future, various hybrid methods will emerge.

8.6 APPLICATIONS OF MICROWAVE TECHNOLOGY IN THE DAIRY INDUSTRY

Milk is traditionally pasteurized in a heat exchanger before distribution. The application of microwave heating to pasteurize milk has been well studied and has been a commercial practice for quite a long time.

The success of microwave heating of milk is based on established conditions that provide the desired degree of safety with minimum product quality degradation. Since the first reported study on the use of a microwave system for pasteurization of milk [50, 76], several studies on microwave heating of milk have been carried out. The majority of these microwave-based studies have been used to investigate the possibility of shelf-life enhancement of pasteurized milk, application of microwave energy to inactivate milk pathogens, assess the influence on the milk nutrients or the non-uniform temperature distribution during the microwave treatment [71].

Microwave application allows pasteurization of glass, plastic, and paper products, which offers a useful tool for package treatment. The food products that best respond to MW pasteurization treatment are: pastry, prepared dishes, and soft cheeses [16]. The technique has also been tested on milk [118, 130] and fruit juices [41, 117] in devices suitable for continuous treatment. Valero et al. [132] pasteurized raw milk by submitting it to continuous-flow microwave treatment at 80 or 92°C for 15 seconds and found no adverse effect on flavor and chemical composition. The microwave pasteurization of cow milk and its nutritional quality has also been studied by Valsechi et al. [133].

Mishra and Pandey[82] standardized the process using domestic microwave oven for pasteurization of raw milk samples and concluded that milk can be pasteurized in 3.3 min in microwave without any appreciable changes in its physico-chemical properties and it can be stored for 14 hours at room temperature (20–25°C) and for 21 days at refrigeration temperature (5°C). Albert et al. [2] studied the effect of microwave pasteurization on the composition of milk and found no changes in amino acid composition. Geczi et al. [43] concluded that microwave and the convection heat treatments are equivalent in pasteurization and the microwave heat treatment is suitable for primary processing of freshly milked milk [54]. Tochampa et al. [127] also concluded that microwave heating is a good alternative to HTST pasteurization of milk. Wang et al. [138] studied the assessment of microwave sterilization of foods using intrinsic chemical markers. Guan et al. [48] used a pilot-scale 915 MHz microwave-circulation water combination (MCWC) sterilization system to treat macaroni and cheese entrees and observed that the MCWC system provided desired sterility (with a F_0 value of 7 min) within one fourth of the time required by conventional retort methods to produce shelf-stable products. Vyawahare and Meshram [137] studied effect of microwave treatment on physic-chemical, sensory and shelf life of date-*burfi* and observed that microwave treatment is effective in enhancing the keeping quality of date-*burfi* by four and seven days more at 30±1°C and 10±1°C, respectively as compared to non-microwave treated date-*burfi*, which had shelf-life of 3 days at 30±1°C while 14 days at 10±1°C. The microwave treated date-*burfi* was found to be acceptable up to seven days when stored at 30±1°C and twenty-one days in case of storage at 10±1°C.

8.6.1 EFFECT ON MILK NUTRIENTS

Milk is a rich source of vitamins and heat treatment affects some of these nutrients. The effects of microwave heating on several vitamins in cows' milk have been studied by many researchers. Sierra et al. and Unnikrishnan et al. [118, 130] research in milk B1, B2 and B6 vitamins included continuously operating microwave and conventional (tube heat exchanger) heating methods. They found that 3.4% and 0.5% fat milk at 90°C with a heat treatment method did not cause vitamin loss. Most studies report an insignificant loss in vitamin A, carotene, vitamin B1 or B2 in microwave-pasteurized milk, while losses of approximately 17% for vitamin E and 36% for vitamin C have been found. They compared the heat stability of vitamins B1 and B2 in milk between continuous microwave heating and conventional heating having the same heating, holding, and cooling steps. No significant losses in the vitamins were reported during microwave heating at 90°C without holding period, while vitamin B2 was found to decrease by 3%–5% during 30–60 s of holding.

Microwave pasteurization of milk was reported to result in lower levels of denaturation of whey proteins compared to conventional thermal processes and that the denaturation of β-lacto-globulin was almost similar in both processes. Moreover, the process yielded lower microbial counts and lower lactose isomerization [75].

The inactivation of *Streptococcus fecalis, Yersinia enterocolitica, Campylobacter jejuni, and Listeriamono-cytogenes* in milk by microwave energy has been reported by Choi et al. [24]. The complete inactivation of *Y. enterocolitica, C. jejuni,* and *L. monocytogenes* occurred at 8, 3, and 10 min when the cells were heated at a constant temperature of 71.1°C using microwaves.

8.6.2 MICROWAVE BASED DAIRY PRODUCTS

The effects of microwave heating on several TIDP have been studied by many researchers. Dairy products have limited shelf life and deterioration of concentrated dairy product, for example, *Burfi* occurs mainly due to improper traditional packaging techniques, lack of modified technologies and unawareness of hygienic practices especially in *Halwais*. Hence there is a need of an instant and affordable technology such as microwave technology which will be beneficial for dairy industry for extension of shelf life of products. Solanki et al. [122] carried out storage study of microwave treated *Burfi* by subjecting *Burfi* samples to microwaves at different power-time combinations. The shelf life study indicated that there was faster deterioration in non-microwave treated control sample at 30±1°C as compared to microwave-treated *Burfi* samples and the treated samples had 6 days more shelf life as compared to control, for example, non-microwave treated sample. Naresh et al. [87] also carried out the research to know the suitability of microwave heating as a post-heat treatment process to extend the shelf life of *Peda* and inferred that the shelf life of microwave treated (25 and 30 sec) *Peda* samples increased to 15 days and 18 days at room temperature; and 93 days and 126 days at refrigeration temperature as against 12 days and 71 days, respectively for non-microwave treated control sample.

Schlipalius et al. [111] developed the method for the preparation of microwave puffed cheese snack. Monsalve et al. [84] prepared shelf-stable butter containing microwave popcorn. Singh et al. [121]reported the technology of *Ghee* production by microwave oven. Mishra and Pandey [83] also prepared *Ghee* from cream (60% fat) and butter (80% fat) by microwave process and concluded that ghee can be successfully prepared in microwave oven within 25±0 and 19±0.5 minutes for cream and butter, respectively without appreciable losses in vitamin A content and such ghee can be stored up to 13–14 months and 9–10 months for cream and butter, respectively. Rao and Pagote [102] reported the preparation of rennet coagulated milk cake using microwave heating.

8.7 FUTURE ASPECTS OF MICROWAVE HEATING

In the past few years, there has been a surge of interest in the application of microwave heating for industrial purposes. This is primarily due to the worldwide energy crisis and the growing acceptance of and familiarity with microwave ovens. It is well known that conventional means of heat processing irreversibility alter the flavor, color, and texture of many foods. From the point of flavor alone, it is desirable to improve our present methods of processing foods. Some improvements have been made in the direction with a number of food products by use of high-temperature short time processing. Research has been conducted in recent years to ascertain whether it is possible to improve the color, flavor and retention of nutrients in processed foods by means other than heat for processing. Among the alternative means that have been considered to obtain this objective in the food processing is the utilization of several of the radiations of the electromagnetic spectrum.

8.8 CONCLUSIONS

The successful applications of microwave heating technology for processing of various foods have been discussed in this chapter. The microwave heating technology for pasteurization and sterilization contributed to effectively destroy pathogenic microorganisms and significantly reduce processing time without serious damage in overall quality of liquid food as compared to traditional methods. The use of microwave heating for food processing applications such as blanching, cooking, and baking has a great effect on the preservation of nutritional quality of food. Furthermore, microwave heating requires significantly less energy consumption for dehydrating food than conventional method.

In these days, the potential of continuous flow microwave heating at commercial scale and the combination heating methods supplemented with conventional thermal treatment for uniform heating of particulate foods has been widely investigated due to inherent advantages of microwave heating. Although microwave heating technology for a variety of food processing applications provide significant advantages with respect to lethal effect on pathogens, processing time, and energy consumption; yet several other quality aspects of food products processed using conventional methods are still better than microwave in terms of color, texture, and other organoleptic properties of food products. Although microwave energy has wide applications in various food processes, yet it needs significant research aimed at improvements in certain areas.

Specifically, methods to obtain final food products with better sensorial and nutritional qualities need to be explored. Improving the energy efficiency in rice cooking and obtaining good quality product in bread baking are examples of other potentially challenging areas. Microwave processing of food materials needs to be carried out to a great extent at a pilot scale level than at laboratory conditions so that the results might be useful for industrial applications. In spite of the complex nature of microwave-food interactions, more research needs to be carried out for a better understanding of the process. Therefore, the investigation of parameters which can influence the workability of microwave heating such as dielectric, physical, and chemical properties of food products should be carried out [143].

8.9 SUMMARY

In recent years, microwave heating has been increasingly popular all over the world, in particular for modern household food-processing applications, due to increased economic merits in many developing countries such as steady economic growth, high disposable income, etc. This trend also seems to be associated with increased awareness about the benefits of nutritious and healthy foods as well as functionalities of certain phytochemicals in diets, which may act as nutraceuticals. Microwave heating is known for its operational safety and nutrient retention capacity with minimal loss of heat-labile nutrients such as B and C vitamins, dietary antioxidant phenols and carotenoids. This review was aimed to provide a brief yet comprehensive update on prospects of microwave heating for food processing applications, its use is limited such as only for cooking, baking, drying, tempering, pasteurization, sterilization, etc. Nevertheless, many investigations carried out worldwide proved that microwave treatment could be used in the dairy industry for pasteurization and sterilization purposes with special emphasis on the benefits at household level and its impact on quality in terms of microbial and nutritional value changes. Food products undergo deterioration mostly due to improper perseveration techniques. Therefore, there is a need of an instant, advanced and affordable technology such as microwave technology which will be beneficial for dairy as well as food industry for shelf life extension of products.

KEYWORDS

- **baking**
- **blanching**
- **cooking**
- **cooking cavity**
- **dairy products**
- **dipolar interaction**
- **door and choke**
- **drying**
- **foaming**
- **food dehydration**
- **food processing**
- **ionic interaction**
- **magnetron**
- **microwave heating**
- **milk**
- **pasteurization**
- **power supply and control**
- **puffing**
- **shelf life**
- **sterilization**
- **tempering**
- **thawing**
- **waveguide**

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CHAPTER 9

MILK SILOS AND OTHER MILK STORAGE SYSTEMS

VANDANA CHOUBEY

CONTENTS

9.1 INTRODUCTION

Dairy industry employ various tasks in processing and handling various type of milk and milk products and therefore different types of storage system is required for various processes like transport, storage, culturing, intermediate process, maturing process, etc. The use of storage tanks starts from initial till final processing of the milk as milk that is collected at procurement center is chilled and kept in bulk milk cooler, then the milk is transferred to processing unit in insulated tankers. In processing unit, milk is received at RMRD and stored in raw milk storage tanks, which is then clarified and heat treated and stored in holding tanks. Then this milk is forwarded to various sections and stored in intermediate tanks for manufacturing different products.

Design of process and storage tanks for liquid foods must take into consideration: the ease of cleaning and method of cleaning, whether manual or automatic [6]. Storage tanks are made of different shapes: round, oval, cylindrical, different sizes and different design based on the process requirements like some tanks are insulated to maintain temperature, some are double jacketed to attain and maintain temperature, and some time hermetically sealed sterile tanks are also used. Tanks generally employ agitator, temperature indicator, manhole, watch glass and openings for product inlet and outlet pipelines and CIP pipelines.

Most commonly used tanks in dairy are cylindrical in shape that may be either vertical (Figure 9.1) or horizontal depending upon the requirement with adjustable leg with leveling screw to balance any irregularities of floor. All stainless steel welding joints should be continuous with welding material of similar composition [4]. Inner and outer shell of tanks, fittings and mountings and those entire surfaces that come in direct contact with product are generally made of stainless steel excluding the light, sight glass and gasket. Care should be taken so that all the surfaces which come in contact with product must be smooth and seamless so that during processing and after CIP no milk traces gets deposited at joints or welds. Sharp edges or any parts which are harder to clean must be avoided. The inner shell bottom should have slope towards the outlet of the tank to help complete removal of milk. The outer shell is also made of stainless steel and all welds and joint on outer shell must be smooth. Generally stiffeners are used between inner and outer shell and also as supporting unit for the base of the tank. For this purpose, stiffeners can be made of mild steel but should be painted with epoxy primer to avoid rusting. In addition, the tank-wall and tank-ceiling separations should be large enough to allow access to cleaning operations [3].

Construction materials for food processing and auxiliary system equipment that are in contact with foods or cleaning agents should have certain characteristics [5]:

1. *Resistance to corrosive action* of foods or chemicals (cleaning and sanitation agents).

FIGURE 9.1 Milk tanks: cylindrical in shape and vertical.

2. *Suitable surface finish* discouraging buildup of dirt that can accumulate with excessive surface rugosity.
3. *Good mechanical behavior* according to performance of mechanical functions, such as structural strength, resistance to abrasion and physical or thermal shocks, and pressure charges.
4. Easy assemblage and fastening operations using common methods (screw threads, welding, etc.) should not require special techniques. Possible forming of materials into desired shapes, into undulated surface sheets (e.g., plate heat exchangers), sheets and plates, rods, pipes, elbows, etc.

Materials not in contact with food or cleaning agents should meet many of the specifications required for machine construction, such as adequate rigidity and mechanical strength [1].

This chapter deals with types of tanks, components of tanks, design and construction of tanks and uses of different tanks in different sections of plant.

9.2 TYPES OF MILK TANKS

9.2.1 SILO/STORAGE TANKS

These tanks are basically meant for collection, reception and storage of large quantity of milk within the limited space. The capacity ranges from 25,000 to 2,50,000 Liters depending on the requirements. These tanks are placed outdoors to reduce the cost of building.

The silo tanks are usually of double wall, where the inner shell is made of stainless steel with conical head and flat bottom that slopes down with an inclination of 6% towards the outlet of tank to facilitate complete drainage. Outer shell is either made of stainless steel or mild steel with anticorrosion paint for cost cutting purpose. Outer shell also has a conical head and flat bottom. Insulating material is placed between inner and outer shell. Mineral wool is most commonly used insulating material. Accurate calculations for the exact insulating material thickness for silo stored outside the building depend upon the specific climatic condition.

Agitators are used for uniform mixing action in the entire volume to prevent cream separation by gravity without aeration of milk and fat breakage. Generally propeller agitators are used. Electrodes are provided in the tank wall at the top of the tank to indicate complete filling and prevent overfilling by closing inlet valve, at the bottom to indicate low level and in drainage line to indicate complete milk removal from the tank. Temperature of the milk in tank is indicated in control panel. An electric transmitter is used to transmit signal to central monitoring station.

FIGURE 9.2 Milk processing tank.

9.2.2 MILK PROCESSING TANKS

Processing tanks (Figure 9.2) are employed for production of various dairy products by changing the properties of milk, which may require maintenance of certain temperature management and stirring of the components. These are used for treatment, inoculation, maturation, homogenization, assertion, crystallization tanks for whipping cream, fermentation of yogurt and other dairy products. There are many types of process tanks that are designed for specific application. For example, yogurt and cream tanks are commonly manufactured with conical heads and bottoms and cooled using dimpled jackets with vessel shell and bottom cone to maintain optimum processing and operating temperature.

Process tanks are made up of stainless steel and with or without insulation employing various types of agitators depending on the viscosity of the product, process, and monitoring and control equipment. Capacity varies from 160 to 20,000 liters. Heating and cooling system on the shell and the bottom of the tank may be provided with maximum allowable pressure of 3 bars for optional heating/cooling arrangements.

9.2.3 BUFFER TANKS

Buffer tanks are used as intermediate storage tanks between two operations to store the product for short time before it continues in the process line. For example: after heating and cooling, milk is stored in buffer tank from where it goes to filling machine and in case of any break-down milk is stored in buffer tank till the production starts again. These tanks are usually insulated with the mineral wool between the two shells to maintain the temperature of stored product and the inner and outer shell are made of stainless steel. Buffer tanks generally have level indicator, temperature indicator, agitator and cleaning system.

9.2.4 BALANCE TANKS

Balance tanks are usually placed at the inlet of the pump so that the constant level of the product is maintained at the pump inlet. Product is free from air; and pressure in the suction side is uniform to maintain constant

FIGURE 9.3 Bulk milk cooler.

flow. Balance tank is equipped with float lever connected to an eccentrically pivoted roller that operates inlet valve of tank that operates opening and closing of valve. When float moves, downward valve is opened and upward valve is closed. The inlet of the tank is placed at bottom to avoid foam formation and aeration by splashing. However, some deaeration takes place as any air present in the product at entry will rise in tank thus helping the pump to operate more gently.

9.3 BULK MILK COOLER

Bulk milk cooler (Figure 9.3) is used for rapid cooling if milk volume exceeds 2,000 to 40,000 liters. These tanks are generally closed elliptical with top man hole. Tank inner shell, outer shell, piping, fittings, dipsticks, outlet inlet valve, blank flanges, filter body, lockable cover, agitator all are made of stainless steel. The gasket of good grade, for example, nitrile or neoprene rubber material should be used.

The tank should be equipped with agitator for uniform mixing and proper distribution of fat, non-foam inlet and outlet valve, inspection window, level indicator, manhole with locking arrangement, top cover lifting handle and ladder. Temperature sensors must be provided to sense the temperature and transmit signal to digital indicator. Digital indicator is installed in the control panel. Milk cooler are manufactured using CFC

FIGURE 9.4 Milk tanker.

free polyurethane insulation. The tank is also fitted with condensing unit, automatic washing system and control panel to ensure optimal cooling and storage of milk.

9.4 MILK TRANSPORT TANKS/TANKERS

In order to transport larger quantities of milk, tankers are used (Figure 9.4). Tanker with pump, hose, flow meter and other necessary installations is known as "Bulk Milk Pick Up Tank." The capacity varies from 500 to 12,000 Liters or more. Tankers are made of stainless steel in the inner shell with a thick layer of insulation. The outer layer is made up of either carbon steel, aluminum or stainless steel. Presently outer layer of SS is mostly used.

All inside shell welding should be smooth and polished as well as the corners and the edges must be smooth and round so that no residue rests on the inner surface. A manhole with fill connection, vent and cover assembly is required at the top of tanker for inspection, loading and cleaning. A manhole of suitable size must be provided for proper cleaning or an automatic cleaning device must be installed. A sanitary cover assembly is equipped with sanitary rubber gasket and locking device to form a tight seal.

Unloading is usually performed by sanitary pump. A stainless type sanitary valve is placed at the lower side than bottom of tank for complete removal of milk. The pumping of milk is carried through hose pipe from tankers to silo. Hose pipes are either made of rubber or plastics. The strength of the hose pipe should be such that it neither punctures nor collapses as pump starts. A dummy or plug must be placed at both the opening of hose pipe to close it when not in use to keep it free from dirt and dust. The rise in temperature of the milk in tanker is very less than that of the milk in cans. Hence, the milk stored in tankers can be stored at same temperature for longer period of time. The only problem is that if only a small quantity of bad milk is eventually added in the tanker, then it will spoil the entire milk in that tanker. Therefore, care must be taken before loading milk in the tankers from different places.

FIGURE 9.5 Aseptic tank.

9.4.1 ASEPTIC TANKS

Aseptic tanks (Figure 9.5) are intermediate storage tanks between UHT and packing machine. These are hermetically sealed tanks to ensure a certain level of sterility through thermal treatment followed by storage and filling in sterile condition and sterile packaging. A sterile product has a long shelf life at normal room temperature and requires neither cooling nor freezing.

The tank is sterilized by steam at a minimum temperature of 125°C for a period of time. It is then cooled by water circulating through the cooling jacket. During cooling, sterile air is fed into the tank to prevent vacuum formation. During production, sterile air fills the tank space above the product level. The pressure is automatically controlled to maintain the feed pressure required by the filling machine in operation. As an option, it can be equipped with an agitator. This is recommended for products that can separate in the tank during storage (e.g., chocolate milk) and to even out the product temperature. A valve cluster module with control panel directs product flow, sterile air, cleaning liquids, and steam. During production, a steam barrier (110°C) is applied to protect the product from contamination. After the filling machines, the end valve cluster prevents reinfection. The tank is cleaned in place by a central CIP system. Since tank operation includes high-temperature sterilization followed by cooling, the tank is designed to be completely implosion-proof. One of the three stainless legs is equipped with a load cell which measures the content of the tank and shows the reading on the panel. Tank operation is fully automated and production interlocks are included for safety reasons. The operator only has to initiate the process steps: tank sterilization, production and CIP. The tank is operated from its own programmable control in the control panel.

Aseptic tanks are used for supplying milk to several filling machines in case of any breakdown, total shutdown is not required. Aseptic tanks must have special safety armature and high hygiene sensors for control process.

9.5 COMPONENTS OF TANKS

9.5.1 MANHOLE

An oval shaped or round shaped manhole should be equipped at the front end of the tank for cleaning and inspection. Manhole (Figure 9.6) should be provided with leak proof inside and outside swing insulated stainless steel door with locking and tightening device. The door should open inside but with arrangement to take out when required. The gasket should be of good quality air tight and made up of either neoprene or nitrile rubber.

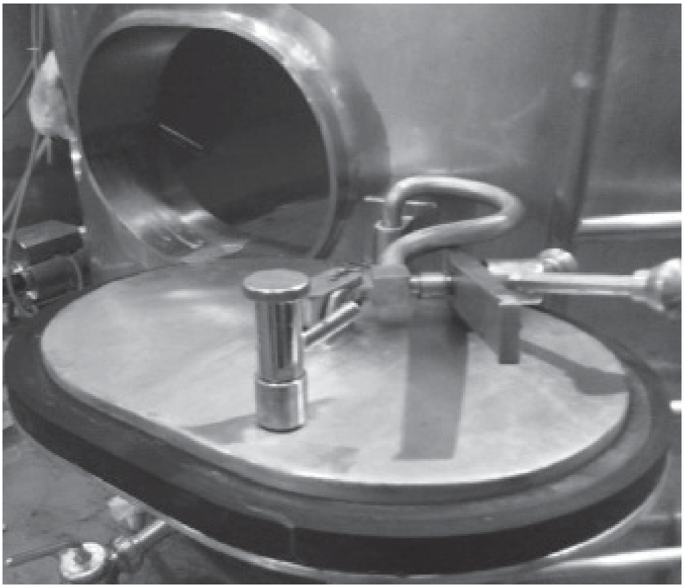

FIGURE 9.6 Manhole.

9.5.2 SPACE FOR CLEANING EQUIPMENT

Removable type stainless cleaning equipment such as spray head or rotary head must be provided at the top of the tank for spraying of cleaning solution over complete inner surface for effective cleaning during CIP. The equipment shall have SS at outer connections.

9.5.3 LIGHT AND VIEW PORTS

A temperature sensor (Figure 9.7) will record the temperature of milk. Light and view port (Figure 9.8) assemblies should be provided at approximately 150 mm of head space when the tank is full. Light assembly must be of stainless steel with lamp holder and view port assembly must also be of stainless steel placed at the top in such a manner that the whole view inside the tank is clear and level mark is easily readable. These fittings should be with few fittings part and simple so as to dissemble it easily for daily cleaning.

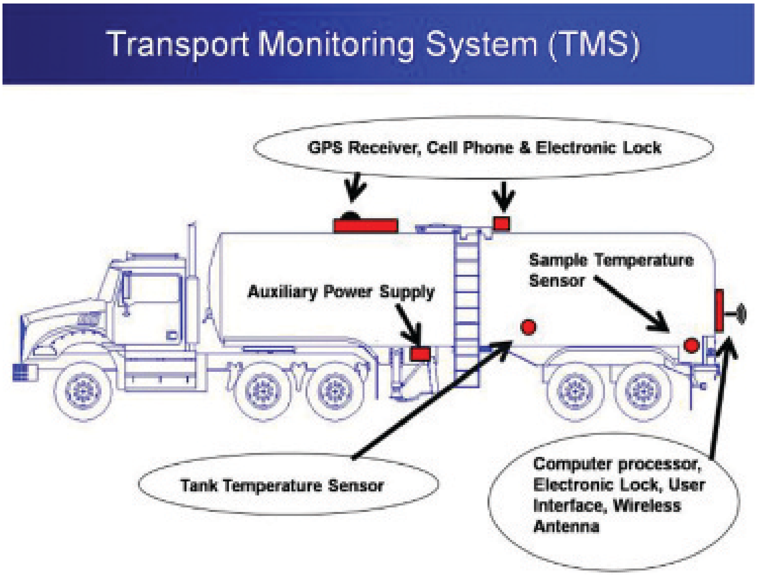

FIGURE 9.7 Temperature sensor. (Source: http://www.rs.uky.edu/regulatory/milk/milktransport/project_slides/index.php)

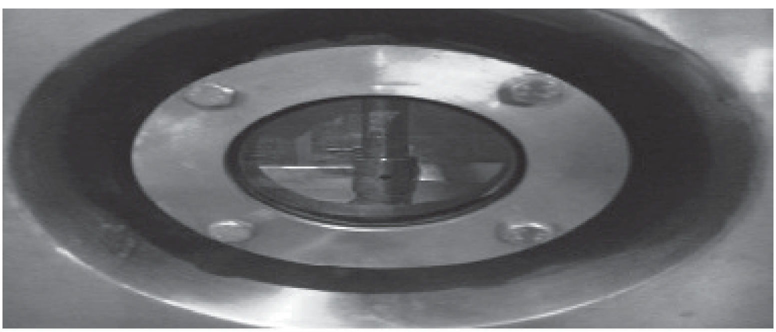

FIGURE 9.8 View port.

9.5.4 SAMPLING COCK

In order to take samples of the tank material a sampling valve must be provided. Sampling cock should be of stainless steel with sanitary design of size more than 5 mm and can be provided anywhere on the outer nozzle pipe or generally located on the manhole cover to avoid an additional fitting in insulation.

9.5.5 AIR VENT

An air vent of stainless steel must be provided on the top of the tank of not less than 150 mm size to prevent vacuum during CIP and emptying and excess pressure during filling of the tank. The air vent must be screened with removable wire mesh cover to prevent entrance of insects. A cover/lid should also be bolted down in an air vent to prevent entry of dirt, dust or other particle falling from the top.

9.5.6 THERMOMETER

Thermometers are provided in the tank to indicate the temperature of the product in the tank. Stainless steel along the inclined thermo-well is welded in the inner and outer shell for thermometer fitting or special stainless steel jackets shall be provided for mounting thermometer on the front of the tank.

9.5.7 LIQUID LEVEL INDICATOR GAUGE

Level indicators are used to give a nearly approximate value of the product in tanks and should be calibrated. The gauge may be of tubular type in which the liquid level rises inside the glass tube carrying a graduated scale. The product in the tank can easily be read against the scale. Or the inner shell of the tank should be calibrated in such a way that there is a clear marking visible at opposite side through sight glass.

9.5.8 AGITATOR

Agitators (Figure 9.9) are necessary to obtain uniform composition, assure uniform distribution of fat and get better cooling efficiency. The speed of the agitator should be slow to ensure uniform mixing and non-separation of fat. Agitator speed depends on size of blade and tank, nature of product and way of agitation. Agitators may be vertical or horizontal:

Vertical agitators have long SS shaft and impellers driven by induction motor and an oil drip proof reduction gear box. The shafts are made of single piece solid rod of SS and need a step bearing in the bottom of

FIGURE 9.9 Agitator.

the tank as the shaft is long and removable. The shaft bearing shall be so located that it does not interfere the drainage of the milk from the tank. Vertical agitator has blades close to bottom thus allowing agitation of even small volume of product.

Horizontal agitators are located close to manhole for easy cleaning and replacement without entering the tank. They have oil less bearing and rotary seals that requires neither lubrication nor packing not fit for low volumes but greater accessibility and cleaning.

9.5.9 LADDER AND TOP PLATFORM

A SS ladder (Figure 9.10) should be welded for easy access to the top of the tank for inspection and maintenance and a platform made of dimpled SS shall be provided on the top of the tank for providing easy and enough space to sight glass and other assembly on top of the tank.

9.6 CLEANING OF TANKS: CLEAN-IN-PLACE (CIP) SYSTEM

Internal cleaning of food equipment can be manual or automatic. In hand cleaning, equipment should be designed to facilitate disassembling for cleaning and subsequent reassembling [2]. Manual cleaning, however, requires a great deal of time and labor. On the other hand, automatic cleaning is carried out without disassembling the equipment, resulting in great

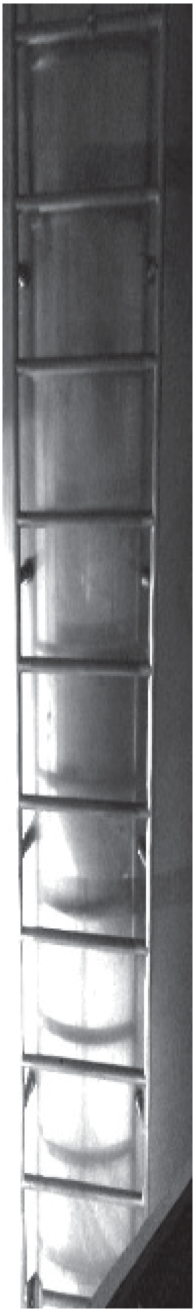

FIGURE 9.10 Ladder.

savings in cleanup labor cost and time. This procedure is referred to as a clean-in-place (CIP) system. When applying a CIP system, following considerations should be taken into account [8–11]:

- The food processing plant, in which the CIP system is installed, must exhibit hygienic design. The design solution for equipment, including construction materials, should permit the installation of this system. In other words, if the CIP system is installed in a running process plant, it must be assumed that similar or better hygienic levels will be achieved.
- Careful selection of cleaning products in conjunction with type of soil removed and materials used to construct food equipment.
- Impact of the CIP system installation on total cost must be estimated, since supplementary capital investment and other operation cost will be needed. Installation of the CIP system must be profitable and economically feasible.

CIP systems are designed according to the product (nature, composition, and quantity), the most suitable cleaning frequency, and the equipment being cleaned (process or storage tanks), pipes, pumps or food processing equipment, such as heat exchangers and evaporators. Thus, the cleaning program should use the most adequate cleaning and sanitizing agents, and the frequency of application should be determined [12]. The selection of the best distribution system (spray-balls, rotating jets, etc.) depends on how the equipment will be cleaned. The main function of these devices is to distribute the cleaning agent uniformly over the entire surface being cleaned. Other designs for cleaning product distribution devices are spray rings and spray cane, used in evaporators, dryers, vacuum chambers, and other equipment of irregular design. All of these distribution devices, including spray-balls, allow the cleaning of more or less difficult points [11].

9.7 SUMMARY

Dairy industry employs various tasks in processing and handling of milk and milk products. Therefore different types of storage system are required for various processing operations like transport, storage, culturing, intermediate process, maturing process, etc. This chapter deals with types of tanks, components of tanks, design and construction of tanks and uses of different tanks in different sections of plant.

KEYWORDS

- **agitator**
- **air vent**
- **aseptic tank**
- **balance tank**
- **buffer tank**
- **bulk milk cooler**
- **CIP**
- **ladder**
- **level indicator**
- **light port**
- **man hole**
- **process tank**
- **sampling cock**
- **silo**
- **spray head**
- **tanker**
- **temperature sensor**
- **UHT**
- **view port**

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