Ultrasound Technology for Dairy Industry

Chetana B. Chaudhari, J. P. Prajapati and Suneeta V. Pinto
Department of Dairy Technology, SMC College of Dairy Science, AAU, Anand-388110.
Email: jashupprajapati@gmail.com

There is growing interest amongst consumersin foods that are minimally preserved and processed. There is currently much emphasis amongst food processors on the development of novel technologies for minimal processed foods. Conventional heating methods for pasteurizing or sterilizing not only kill or reduce the microbes but also reduce the nutritional and organoleptic quality of foods. Ultrasound is one of the non-thermal methods which is being used for foods processing in recent times. As a non-thermal technology, power ultrasound is attracting considerable interest in the food industry. By means of mechanical vibrations of high enough intensity, power ultrasound can produce changes in food either by disrupting its structure or promoting certain chemical reactions (Ercan and Soysal, 2013). The advantages of ultrasound over the heat treatment include; minimization of flavor loss, greater homogeneity and significant energy savings (Earnshaw *et al*., 1995).

Ultrasound

Ultrasound refers to sound waves, mechanical vibrations, which propagate through solids, liquids, or gases with a frequency greater than the upper limit of human hearing. The range of human hearing is from about 16 Hz to 18 kHz. When these waves propagate into liquid media, alternating compression and expansion cycles are produced. During the expansion cycle, high intensity ultrasonic waves make small bubbles grow in liquid. When they attain a volume at which they can no longer absorb enough energy, they implode violently. This phenomenon is known as cavitation. During implosion, very high temperatures (approximately 5000 K) and pressures (estimated at 50000 kPa) are reached inside these bubbles.

Typically ultrasound applications are divided into two broad categories: high and low-intensity applications. Low-intensity applications are mainly characterized by frequencies above 100 kHz with energies below 1 W/cm2. In addition, the ultrasonic wave does not have any significant effect on the material being tested, in contrast to high-intensity applications (McClements 1995; Mason 1998). The proposed mechanisms and reported effects of ultrasonication are:

Heating: As a result of specific absorption of acoustic energy by membranes and biomaterials, particularly at their interfaces, a selective temperature increase may take place (Floros and Liang, 1994). Some investigators claim that localized temperature increase of up to 5000K can be expected for a few nanoseconds in a sound field (Suslick and Hammerton, 1985).

Cavitation: Acoustic cavitation is the formation, growth, and violent collapse ofsmall bubbles or voids in liquids as a result of pressure fluctuation (Suslick and Price, 1999).

Structural effects: When fluids are placed under high intensity sound fields, the dynamic agitation and shear stresses produced affect their structural properties, particularlytheir viscosity (Ensminger, 1988).

Turbulence: High-intensity ultrasound in low-viscosity liquids and gases produces violent agitation, which can be utilized to disperse particles (Ensminger, 1988).

A number of other effects and mechanisms have been reported. Ultrasonic waves of high intensity assist the cleaning of surfaces. This mechanism has been used to prevent binding or formation of filter cake and enhance filtration rates (Floros and Liang, 1994). Under certain conditions, high-intensity ultrasound causes coalescence of manytypes of particles and can be used effectively in low-concentration suspensions.

Ultrasound can be used for food preservation in combination with other treatments by improving its inactivation efficacy.

1. Ultrasonication (US) is the application of ultrasound at low temperature (Zheng & Sun 2006).
2. Thermosonication (TS) is a combined method ofultrasound and heat. The product is subjected to ultrasoundand moderate heat simultaneously. This methodproduces a greater effect on inactivation of microorganismsthan heat alone (Mason *et al*., 1996; Villamiel *et al*., 1999)
3. Manosonication (MS) is a combined method inwhich ultrasound and pressure are applied together. Manosonicationprovides to inactivate enzymes and/or microorganismsby combining ultrasound with moderatepressures (100 to 300 kPa) at low temperatures (Ercan and Soysal, 2013).
4. Manothermosonication (MTS) is a combined methodof heat, ultrasound and pressure. Applied temperature and pressure maximizes the cavitation or bubble implosion in the media which increase the level of inactivation. Microorganisms that have high thermo tolerance can be inactivated by manothermosonication (Chemat *et al*., 2011).

Applications in Dairy Industry

Cheese

When sonication was applied to milk to study the proteolytic activity of the enzymes related lo curdling, the main observable effect was that ultrasound speeds up the hardening of the curd and the final product showed a better firmness because of the activity on the chymosin, pepsin, and other related enzymes (Villamiel *et al*., 1999). Chymosin has a proteolytic activity in liquid milk, coagulating the protein and conferring a solid-like coagulated gel. When ultrasound (20 kHz) was used to enhance the extraction not only the yield and enzyme activity were increased considerably, but also extraction times were much shorter than without sonication. The reason for that could be attributed to the destruction of cellular structure because of the action of ultrasound, increasing the activity of the substances contained in the cells and the migration of proteins and minerals from the cells to the solution. The activity of the chymosin increased with sonication and the nitrogen content of the extract decreased at the same time.

During cheese making, the methods used to test curd firmness are destructive methods (penetrometers, suspended bodies, torsion viscometers, and rotational viscometers) that are not easy to automate. Benguigui *et al*. (1994) used a pulse-echo technique to determine variations in ultrasonic attenuation and velocity during the coagulation process. Ay and Gunasekaran (1994) studied the changes during enzymatic coagulation by ultrasound. They used a 1-MHz transducer and the pulse-echo technique. Ultrasonic velocity did not show any variation during coagulation, but ultrasonic attenuation decreased when coagulation progressed. This change in attenuation is mainly linked to changes in viscosity, which increases the viscous attenuation of ultrasound.

Resonant techniques (sonic frequencies) have been used to classify defects in cheese based on the differences found in the spectrum of cheeses with and without defect. Ultrasonics was also used by Orlandini and Annibaldi (1983) for the same purpose. Even more effective for this purpose can be the use of pulse-echo techniques commonly used in metallurgy. Takai *et al*. (1994) also used the pulse-echo technique to evaluate the size and number of voids in kamaboko by counting the number of ultrasonic echo pulses on the oscillograms. Using this technique, cracked cheeses can be identified. Furthermore, it is also possible to determine the distance of the crack from the surface by assuming a range of velocities that include the maximum and minimum values found for the particular type of cheese. The calculated range for the cheese was 1.84 - 1.98 cm (velocity range 1620 - 1740 m/s), which coincided with the distance measured with a digital gauge (1.9 cm).

Lactose-Free Milk

Lactose-free milk without lactose can be produced by fermentation of lactose-hydrolyzed milk or by the simultaneous addition of β-galactosidase and lactic acid bacteria. These bacteria produce β-galactosidase which hydrolyzes the lactose in fermented milk. Ultrasound has the capability of raising the reaction activity of cells or tostimulate a new action into the cells, for example, in sterol synthesis with baker's yeast or in lactose-hydrolyzed fermented milk. Using ultrasound in the processing of lactose-free milk, the lactose hydrolysis was around55%; using traditional methods to produce lactose-free milk (fermentation), hydrolysis was around 36% (Wang and Sakakibara, 1997).

Ice cream

A narrow ice crystal size distribution is necessary for production of high quality ice-cream with smooth texture and desired sensory characteristics (Russell *et al*., 1999). High power ultrasound treatment of ice cream inside the scraped surface freezer induces crystal fragmentation by cavitation bubbles, and also prevents incrustation on the cold surface due to the high heat transfer rate (Mason, 1998; Zheng & Sun, 2006). Mortazavi and Tabatabaie (2008) have shown that increasing the ultrasound pulse time significantly decreased the freezing process time of ice cream, and improved sensory flavor, texture and mouth feel.

Homogenization and Emulsification

Sonication of fresh cow milk at 20 kHz resulted in a reduction in the size of fat globules. Homogenization at a power level of 40 for 10 min was similar to conventional homogenization. The highest homogenization efficiency and the smallest fat globule diameter were 3.22 and 0.725 µm at power level 100 (450 W) for 10 min, respectively (Villamiel and deJong 2000).

Ultrasonic emulsification is mainly driven by cavitation, wherein the bubbles collapse at the interface of two immiscible continuous and dispersed phases. (Mason, 1998) High amplitude homogenization also improved the water-holding capacity and viscosity and also reduced syneresis of yoghurt produced from ultrasonicated milk (Mongenot *et al*, 2000).

Testing Milk Adulteration

Milk is designed by nature to be a nourishing food for the young, since it is capable of providing almost all the ingredients necessary for the growth of the body. Milk adulteration has usually consisted of adding water. To detect this fraud, Bhatti et al (1986) studied the variation of ultrasonic velocity in two types of milk, cow and buffalo, adulterated with different percentages of water. Ultrasonic velocity of cow and buffalo milk was found to be different due to the differences in composition. In both cases, velocity decreased in line with the water addition and was dependent ontemperature, as were the density and the viscosity of the samples. (Welti *et al*, 2002)

Fouling detection

When dairy products are processed in continuous high-temperature processing plants, the internal walls of the plant can become fouled by burnt on or chemically deposited material. The fouling layer will affect flow rate and also heat flow to or from the product. Withers (1994) developed an ultrasonic sensor to detect and measure the thickness of these films in a dairy plant. The sensor operated by transmitting a pulse of ultrasound across the pipe being tested. The received signal was analyzed in the time domain to determine film presence and thickness. Thickness measurement was possible over a range of 0.5–6.0 mm. Product temperature compensation over a temperature range of 20–140°C was implemented. Changes in product flow rate from 0 to 25 l/min and pressure from 0 to 3 bars had no effect on the ultrasonic measurements.

Conclusion

Ultrasonic is a rapidly growing field of research, which is finding increasing use in the food industry for analysis, processing, modification and preservation of food products. Research in the last decade has shown the potential benefits of ultrasound treatment as an alternative, non-thermal technology for food processing. Ultrasonic processing is still in its infancy and requires a great deal of future research in order to develop the technology on an industrial scale.

References

Ay C. and Gunasekaran S. (1994). Ultrasonic Attenuation Measurements for Estimating Milk Coagulation Time, *Transactions of de ASAE*, 37 (3): 857–862.

Bhatti SS, Bhatti R. and Singh S. (1986). Ultrasonic Testing of Milk,. *Acoustica* 62: 96–99.

Benguigui L, Emery J, Durand D. and Busnel JP. (1994). Ultrasonic Study of Milk Clotting, *Lait*, 74 (3): 197–206.

Chemat F, Huma Z. and Khan MK. (2011). Applications of ultrasound in food technology: Processing, preservation and extraction. *Ultrasonics Sonochemistry*, 18, 813-835.

Earnshaw RG, Appleyard J. and Hurst RM. (1995). Understanding physical inactivation processes: Combined preservation opportunities using heat, ultrasound andpressure. *International Journal of Food Microbiology*, 28, 197-219.

Ercan SS. and Soysal C. (2013). Use of ultrasound in food preservation. *Natural Science.* 5 (8 A2): 5-13.

Ensminger D. (1988). Acoustic and electroacoustic methods of dewatering and drying, *Drying Tech., 6*, 473.

Floros JD. and Liang H. (1994). Acoustically assisted diffusion through membranes and biomaterials: High-intensity ultrasound accelerates diffusion and can be used to improve food processes, *Food Technology*, 79.

Mason TJ, Paniwnyk L. and Lorimer JP. (1996). The uses of ultrasound in food technology. *UltrasonicsSonochemistry*, 3, S253–60.

Mortazavi A. and Tabatabaie F. (2008). Study of ice cream freezing process after treatment with ultrasound. *World Applied Sciences Journal*, 4(2), 188–190.

Mongenot N, Charrier S. and Chalier P. (2000). Effect of ultrasound emulsification on cheese aroma encapsulation by carbohydrates. *J Agric Food Chem*., 48:861–867.

McClements J. (1995). Advances in the application of ultrasound in food analysis and processing. *Trends in Food Science and Technology*, 6: 293–99.

Mason TJ. (1998). Power ultrasound in food processing – The way forward. In: *Ultrasound in Food Processing* Povey M. J and Mason T. J. (Ed.), 105–26. London, UK: Thomson Science.

Orlandini I. and Annibaldi S. (1983). New Techniques in Evaluation of the Structureof Parmesan Cheese: Ultrasonic and X-Rays, *Sci. Latiero-Caseria*, 34: 20–30.

Russell AB, Cheney PE. and Wantling SD. (1999). Influence of freezing conditionson ice crystallisation in ice cream. Journal of Food Engineering, 39(2), 179–191.

Suslick KS. and Hammerton DA. (1985). Determination of local temperatures caused by acoustic cavitation, *IEEE UltrasonicsSymp. Proc., 4*, 1116.

Suslick KS. and Price GJ. (1999). Applications of ultrasound to materials chemistry. *Annual Review of Materials Science*, 29, 295–326.

Tiwarib K. (2009). Ultrasound processing: Rheological and functional properties of food In: Novel Food Processing, Ahmad J (Ed.), CRC press, pp. 85-102.

Takai R, Suzuki T, Mihori T, Chin S, Hocchi Y. and Kozima T. (1994). "Non Destructive Evaluation of Voids in Kamaboko by an Ultrasonic Pulse-Echo Technique, "*J. Japanese Society of Food Sci. and Technol*., 41(12): 897–903.

Villamiel M. and de Jong P. (2000). Influence of high-intensity ultrasound and heat treatment in continuous flow on fat, proteins, and native enzymes of milk. *Journal of Agriculture and Food Chemistry*, 48,472–78

Villamiel M, Hamersveld EH. and de Jong P. (1999). Effect of Ultrasound Processing on the Quality of Dairy Products. *Milchwissenschaft*.; 54: 69-73.

Withers P. (1994). Ultrasonic Sensor for the Detection of Fouling in UHT Processing Plants, *Food Control*, 5(2): 67–72.

Wang D. and Sakakibara M. (1997). Lactose hydrolysis and β-galactosidase activity in sonicatedfermentation with lactobacillus strains. *Ultrasonics Sonochemistry*, 4:255–61.

Welti J. and Gustavo V. (2002). Application of low intensity ultrasonics in the dairy industry, In: Engineering and Food for 21st century, Mulet. A., JA. Carcel, J. Benedito (Eds), CRC press, pp:46.1-48.8.

Zheng L. and Sun DW. (2006). Innovative applications of power ultrasound during food freezing processes -A review. Trends in Food Science & Technology, 17(1); 16–23.