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High power ultrasound: An innovation in the food processing industry

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Power ultrasound is an emerging and promising technology for food processing industry. Pressing demands from consumers for quality food products with natural flavor and taste, free from additives and preservatives, has triggered need for the development of non-thermal process methods which offer maximum quality and safety of food products. Ultrasound is considered as one such non-thermal processing alternative, which can be used in many food processing operations. It travels through a medium like any sound wave, resulting in a series of compression and rarefaction. Due to their important features at ambient or lower temperatures, the non-thermal technologies are regarded as potential and powerful tools in food processing. High energy ultrasound (20-500kHz) is referred to as High power ultrasound (HPU). The physical, mechanical or chemical effects of high power ultrasound are capable of altering material properties. These effects are promising in food processing, preservation and safety. It has been realized that HPU has much to offer to the food industry such as drying, extraction, crystallization, defoaming, emulsification, inactivation of microorganism and enzymes, filtration, separation, etc of valuable compounds from vegetables and food products. In this paper a review of the most recent uses of power ultrasound in the food industry will be discussed.

Key Words : High power ultrasound, Innovation, Food processing industry

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INTRODUCTION

Ultrasound is an oscillating sound pressure wave with a frequency greater than the upper limit of the human hearing range(~20 kHz). Ultrasound is applied to impart positive effects in food processing such as improvement in mass transfer, food preservation, assistance of thermal treatments and manipulation of texture and food analysis (Knorr *et al.*, 2011). Ultrasound is in fact one of the emerging technologies that were developed to minimize processing, maximize quality and ensure the safety of food products. Use of ultrasonics offers great potential in the processing of liquids and slurries, by improving the mixing and chemical reactions in various applications and industries. Ultrasonication generates alternating low-pressure and high-pressure waves in liquids, leading to the formation and violent collapse of small vacuum bubbles. This phenomenon is termed cavitation and causes high speed impinging liquid jets and strong hydrodynamic shear-forces. Substantial ultrasonic intensity and high ultrasonic vibration amplitudes are required for many processing applications, such as nano-crystallization, nano emulsification, deagglomeration, extraction, cell disruption, as well as many others.

The application of ultrasound in food processing can be divided into low and high energy on the basis of frequency

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range. Low energy (low power, low intensity) ultrasound has frequencies higher than 100kHz at intensities below 1 $W.cm^{-2}$, which can be utilized for non-invasive analysis and monitoring of various food materials during processing and storage to ensure high quality and safety. High energy (high power, high-intensity) ultrasound uses intensities higher than $1W\cdot cm^{-2}$ at frequencies between 20 and 500 kHz, which are disruptive and induce effects on the physical, mechanical or chemical/biochemical properties of foods. These effects are promising in food processing, preservation and safety. Until recently the majority of applications of ultrasound in food technology involved non-invasive analysis with particular reference to quality assessment. Such applications use techniques using high frequency (>1MHz) low power (<1W/ cm^2) ultrasound (Mulet *et al.*, 2002). Use of such technologies are found in the analysis of droplet size in emulsions of edible fats and oils (Coupland and McClements, 2001), determination of the extent of crystallization in dispersed emulsion droplets (Hindle *et al.*, 2002) etc. This emerging technology has been used as lternative to conventional food processing operations The advantages of the technology are versatile and profitable to the food industry (Gallego-Juárez, *et al.*, 2010).

Application of high power ultrasounds in food processing :

The following sections will describe the basics and applications of high power ultrasound in food processing :

Drying :

Removal of moisture by drying is one of the oldest method of food preservation. It is based on the use of thermal energy such as sun, hot air, smoking, drum and convection drying (Cohen and Yang, 1995). However, heat can deteriorate the quality of the final product causing undesirable food flavor, color, vitamin degradation and loss of essential amino acids (Mousa and Farid, 2002; Min, *et al.*, 2005; Zhang,*et al.*, 2006). The use of ultrasonic energy in drying is very promising because it can act without affecting the quality of the products, In particular power ultrasound is an attractive means of drying heat sensitive foods because they can be dried more rapidly and at a lower temperature than in the conventional hot-driers. The use of ultrasound in combination with or prior to hot air drying was shown to have potential in increasing the drying rate without significantly affected the quality of the product. High intensity ultrasound in combination with hot air system resulted in adequate drying rates for vegetable drying even at lower temperatures (Gallego-Juarez *et al.*, 2007). Ultrasound enhanced the mass transfer during drying of carrot. The product was dehydrated at low temperature therefore, the product quality was found to improve (Garcia–Perez *et al.*, 2007).

During the ultrasonic pretreatment, banana (Fernandes and Rodrigues, 2007), melons and pineapple (Fernandes, *et al.*, 2008) were found to lose sugar, it could be used to produce dried fruits with lower sugar contents. Ultrasound induced disruption of cells and information of microscopic channels in the fruit structure but did not induce breakdown of the cells. Further, air drying of ultrasonically pretreated banana and melon (*Curcumis melo*) fruits resulted in an increase in effective water diffusivity during air drying leading to a reduction in the drying time of about 25 per cent. Azoubel *et al.* (2009) also indicated that the application of ultrasound during drying of banana could increase the moisture diffusivities, which in turn reduced process time leading to the economy of energy. The rehydration of ultrasonically treated and finally dried sample showed that the percentage rehydration was higher as compared to that of untreated samples.

Osmotic dehydration :

Osmotic dehydration is widely used for partial removal of water from food materials by immersion in a hypertonic solution. However, one of the main problem encountered while applying this technique is the usually slow kinetics of the process. The use of power ultrasound in combination with osmotic dehydration results in higher rate of water loss and solute gain at a lower solution temperature, while preserving the natural flavor, color and heat-sensitive nutritive components. It is due to increased cell wall permeability (lower resistance) owing to the formation of microscopc channels, which facilitated the transport of water and solute. Osmotic dehydration combined with ultrasonic energy reduced total processing time and increased effective water diffusivity in strawberries compared to osmotic dehydration, which alone increased processing time (Garcia-Noguera, *et al.*, 2010). Combined effects of micro-channel formation by high power ultrasound treatment and osmotic pressure differential were largely responsible for reducing drying time.

Application of ultrasound to osmotic dehydration of apple was found to accelerate the ‘water out’ and ‘solute in’ mass transfer rates (Simal *et al.*, 1998). Due to ultrasound pre-treatment, water as well as solute diffusion co-efficients were found to increase up to 117 and 137 per cent, respectively (Carcel *et al.*, 2007). In comparison with pulsed-vacuum treatment, ultrasound treatment resulted in higher water loss and lower solid gain in case of apple. The higher loss of firmness was due to severe cell deformation and structure collapse (Yun and Yanyun, 2008).

Freezing :

Freezing is an important preservation technique that is used in the food industry to preserve the quality of food product and maximize the shelf -life. During freezing, water transforms into ice crystals, which preserve the food structure

(Delgado, *et al.*, 2009). Quick freezing generate small ice crystals whereas slow freezing induce the formation of large ice crystals, which damage the physical structure (*i.e.*, texture) and deteriorate the food quality. Therefore, proper methods of freezing are required to control the ice crystal size in frozen foods. Common methods for food freezing include air blast, plate contact, circulating brine and liquid nitrogen (Heldman, 1992; Knorr, *et al.*, 2004; Li and Sun, 2002b; Sanz *et al.*, 1999). Ultrasound is known for assisting and/or accelerating various freezing operations. Several studies have indicated the potential of using high power ultrasound in accelerating the freezing rate and improving the quality of frozen food plants such as potatoes (Li and Sun, 2002a; Sun and Li, 2003) and apples (Delgado, *et al.*, 2009). High power ultrasound treated frozen potatoes exhibited a better cellular structure as less extracellular void and cell disruption/ breakage appeared than those without acoustic treatment (Sun and Li, 2003). Freezing is also the most important step during the manufacture of ice cream. Ice crystallization in ice cream determines its final quality (Petzold and Aguilera, 2009).

This processing technology offers many advantages including complete preservation of the aroma (including the volatile aroma that characterizes freshly squeezed juice), color, and flavor in the concentrated juice (Dette and Jansen, 2010). Freeze-drying or lyophilization, is the sublimation/removal of water content from frozen food. The dehydration occurs under a vacuum,with the plant/animal product solidly frozen during the process. Shrinkage is eliminated or minimized, and a near-perfect preservation results. Freeze-dried food lasts longer than other preserved food and is very light,which makes it perfect for space travel.

Enzymes Inactivation :

Inactivation of enzyme is an important process for enhancing the stability, shelf -life and quality of many food products. Power ultrasound is used to increase or inactivate enzymatic activities depending on ultrasound intensity. Use of combination of ultrasound with low pressure and heat (manothermosonication or MCT) was reported to increase the inactivation rate of food quality related enzymes such as tomato pectic enzyme (Lopez, *et al.*, 1998; Vercet, *et al.*, 2002), soybean lipoxygenase (Lopez and Burgos, 1995a), horseradish peroxidase (Lopez and Burgos, 1995b) and orange PME (Vercet, *et al.*, 1999). Another application of power ultrasound is for intensifying glucose production from grain sorghum, an important drought-resistant cereal crop used in food (Shewale and Pandit, 2009).

Microbial Inactivation :

For the inactivation of microorganisms in food products thermal pasteurization and sterilization are the most commonly used techniques. However, long time exposure to high treatment temperatures leads to loss of organoleptic characteristics (e.g. off flavor) and nutritional value of food products (Lado and Yousef, 2002). The effect of ultrasound on different microbial species is reported (Piyasena *et al.*, 2003) to be dependent on the shape and size of the microorganisms (bigger cells being more sensitive than smaller ones, and coccal forms are more resistant than rod-shaped bacteria), type of cells (Gram- positive and aerobic being), and physiological state (younger cells being more sensitive than older ones, spores being much more resistant than vegetative cells).

To improve the microbial inactivation in liquid foods, ultrasound is combined with other treatments such as pressure (manosonic), heat (thermosonic), both pressure and heat (manothermosonic) and antimicrobials. Compared to HPU alone, these treatments are more energy-efficient and effective in killing microorganisms. Ugarte *et al.* (2006) indicated that combination of ultrasound with thermal effect enhanced the destruction of *E.Coli* in apple juice. The control of *L. monocytogenes* in orange juice could be achieved by combining high intensity ultrasound with mild heat treatment and natural antimicrobials (Ferrante *et al.*, 2007). The inactivation of *Saccharomyces cerevisiae* was enhanced by incubating with low molecular weight chitosan prior to ultrasound (Guerrero *et al.*, 2005). Scouten and Beuchat (2002) indicated the decontamination of alfalfa seeds inoculated with *Salmonella* or *E.coli* O157 by combined treatments of ultrasound and $Ca(OH)_2$, which could be an alternative to chlorine treatments to avoid contamination.

Filtration and screening :

Removal of suspended particles from liquids is mandatory in many of the food processing operations. Unfortunately conventional methodologies often lead to clogged filters and require either replacement of filters or clean them on a regular basis. The application of ultrasound to filtration or screening processes enables the filtaration process to operate more efficiently and for much larger periods. Ultrasound provides vibrational energy to keep particles in suspension and moving, leaving channels in the filter open and free for solvent elution. It also causes the filter or screen to vibrate, creating a 'frictionless surface', allowing the liquid or smaller particles to pass through more readily (Telsonic, 2007). An additional advantage is an extension to filter life, as clogging and caking are prevented by continuous cavitation at the filter's surface. Ultrasonic oscillations are transmitted simultaneously to the filter and the material being treated, which improve the flow characteristics of the material (Grossner, *et al.*, 2005). All these factors are of significance to commercial filtration processes.

Defoaming :

Foam is a thermodynamically unstable colloidal system in which gas is dispersed in a liquid matrix. Foams are frequently produced as unwanted side effects in many food processing operating. Foaming problems can result in product losses and reduced efficiencies. In the food industry, it is important to remove air and oxygen from milk and drinks to prevent decay and oxidation, which enhance freshness, quality and extend shelf -life. It is also important to avoid foams to maximize production and avoid problems in process control and equipment operation. De-foaming is the process of removing bubbles and air from liquids. High intensity ultrasound (20 kHz) in pulsed operation (1 s/1 s) has been described as an effective procedure to remove foam and dissolved oxygen (80% of foam reduction) with very low energy consumption (40 kJ/l) in super-saturated milk (Villamiel *et al.*, 2000).

Extraction :

The extraction of organic compounds from plants/seeds has been based on the judicious combination of solvent, heat or agitation. High power ultrasound has been shown to be a promising and innovative technique for facilitating the extraction process of a variety of food compounds (e.g. herbal, oil, protein, polysaccharides) as well as bioactive ingredients (e.g. antioxidants) from plant and animal resources (Vilkhu *et al.*, 2008). The beneficial effects of ultrasound are derived from its mechanical effects on the process by increasing penetration of the solvent into the product due to disruption of cell walls produced by acoustical cavitations. Moreover, it is achieved at lower temperature and hence more suitable for enhancing the extraction of thermally unstable compounds (Wu *et al.*, 2001). Application of ultrasound accelerated the efficiency of extraction and preserved structural and molecular properties of hemicelluloses, cellulose, xyloglucan, and water-soluble xylans extracted from buckwheat hulls (Hromadkova and Ebringerova, 2003), sugarcane bagasse (Sun *et al.*, 2004), apple pomace (Caili *et al.*, 2006), and corn cob waste (Ebringerova *et al.*, 1998), respectively . Ultrasound treatment to corn in the conventional wet milling process enhanced starch separation and increased final starch yield in addition to higher paste viscosities and whiteness (Zhang *et al.*, 2005). Application of high intensity ultrasound was shown to improve the extraction of edible oil from soyabean (Haizhou *et al.*, 2004) and flax seed (Zhang *et al.*, 2008) which may reduce the overall cost of production.

Extrusion :

Use of ultrasound in enhancing extrusion processes is a recent development. The energy input provided by ultrasonic excitation of a metal tube or extrusion dye can be achieved by perpendicular attachment of the sonotrode onto the tube or dye. The vibration of the metal reduces the drag resistance and thus improves flow behavior (Knorr *et al.*, 2004; Akbari Mousavi *et al.*, 2007).

Emulsification/Homogenization :

Emulsification is the process of mixing two immiscible phases (e.g., oil and water) with the help of a surface active agent (emulsifier) into homogeneous emulsion. Unless the mixing is spontaneous such as with the formation of micro emulsions, the process requires an energy input by means of mechanical agitation or ultrasonication to facilitate the formation of small droplets. There are a large number of industrial processes that utilize power ultrasound as a means of mixing materials (Canselier *et al.*, 2002). With ultrasound, the drop size is much smaller than that given by mechanical agitation under the same conditions, which makes isolated emulsions more stable. This has been well commercialized in the petrochemical, polymer, chemical, textile, cosmetics and pharmaceutical industries and is now being developed in-line for food products such as fruit juices, mayonnaise and tomato ketchup (Wu *et al.*, 2000). Recently, ultrasound has been used to prepare transparent edible nano emulsions with very small droplets (40nm) using the right proportions of emulsion components and ultrasound power (Leong *et al.*, 2009). Ultrasound emulsification systems are cost saving, easy to use and integrate to existing industrial lines to improve the quality of emulsified products such as milk homogenization before cheese-making to improve the yield of cheese (Soria and Villamiel, 2010).

Viscosity Alteration :

Many food systems exhibit complex flow behaviour and the viscosity is often determined by multiple factors such as pH, molecular weight of the protein, pectin or polysaccharide, hydrogen bonding and other inter- and intramolecular forces. Ultrasound can be applied to either increase or decrease the viscosity and dependent on the intensity, the effect can be temporary or permanent. Cavitation causes shear which in the case of thixotropic fluids causes a decrease in viscosity. This is often a temporary phenomenon. However, if enough energy is applied, the molecular weight may be decreased causing a permanent viscosity reduction (Seshadri *et al.*, 2003). Recently, (Bates *et al.*, 2006) showed that the opposite is also possible. In some vegetable purees the ultrasound actually allows for better penetration of moisture into the fiber network which causes an increase in the viscosity of tomato puree.

Crystallization :

Crystallization is an important process in the production of many food products such as chocolate, butter, margarine, whipped cream and ice cream. To obtain good quality food products with specific sensory attributes (e.g., texture, hardness, smoothness, mouth feel), fat crystallization must be controlled by temperature, cooling rate and application of shear or ultrasound. High powered ultrasound can assist the crystallization process in several ways: influence the initiation of crystal nucleation, control the rate of crystal growth, ensure the formation of small and even-sized crystals and prevent fouling of surfaces by the newly formed crystals (Luque de Castro *et al.*, 2007; Virone *et al.*, 2006). Ultrasonic crystallization technology can be applied to frozen foods where it can be used to control the size and rate of development of ice crystals (Chow *et al.*, 2003). As food is frozen, small crystals form within the matrix. With conventional freezing, the time taken from the initiation of crystallization to complete freezing (the dwell time) can be lengthy, and then during storage the crystals can expand. With cellular materials such as meats, fruits and vegetables the extended dwell time and crystal expansion softens and sometimes ruptures cell walls, resulting in textural softening and the release of cellular liquid on thawing. Freezing using ultrasonics ensures rapid and even nucleation, short dwell times and the formation of small, evenly sized crystals, greatly reducing cellular damage and preserving product integrity, even on thawing (Zheng and Sun, 2006). An added benefit from ultrasonics induced crystallization is the continuous cleaning effect from cavitation, which prevents encrustation of crystals on the cooling elements and ensures continuous heat transfer during the process.

Conclusion :

Ultrasound is considered to be an emerging technology in the food industry. It has advantages of minimizing flavor loss, increasing homogeneity, saving energy, high productivity, enhanced quality, reduced chemical and physical hazards, and is environmentally friendly. When it is applied with pressure and/or temperature its efficiency increases but cautions needed to determine and control nutritional loss. Also, process parameters and applied material change the results. The considerable interest in high-powered ultrasound is due to its promising effects in food processing and preservation, such as higher product yields, shorter processing times, reduced operating and maintenance costs, improved taste, texture, flavour and colour, and the reduction of pathogens at lower temperatures. As one of the more advanced food technologies, it can be applied not only to improve the quality and safety of processed foods but offers the potential for developing new products with unique functionality as well. The application of high power (low frequency) ultrasound, on the other hand, modifies the food properties by inducing mechanical, physical and chemical/ biochemical changes through cavitations, which reduces reaction time and increases reaction yield under mild conditions compared to conventional route. By maximizing production while saving energy, power ultrasound is considered a green technology with many promising applications in food processing, preservation and safety. This implies that the ultrasound is a good alternative method for the food preservation and processing and also no adverse effect on human health has been proven.

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