Chapter 2
An Overview of Ultrasound

2.1 Wave Propagation

2.1.1 General Aspects

Sound is a waveform that propagates away from a source in an elastic media generating density variations. The generation and perception of sound is a consequence of the transmission of mechanical energy through the media. That is, a device that generates sound must perform some kind of mechanical work to a medium. In the case of human voice, sound is generated by the mechanical work produced by the vocal cords in the air (medium of propagation). Similarly, to detect sound, mechanical work must be applied to the detector. In the human hearing system mechanical work is achieved through vibrations in the eardrum. Since mechanical work or energy is associated with the transmission of sound, the elastic and inertial properties of the material in which sound propagation occurs will affect the efficiency of wave propagation. For example, sound propagation in air is slower than in water with values of 343 and 1,497 m s^{-1}, respectively (Leighton 1994).

Acoustic waves are characterized by their frequency (cycles per second), wavelength (distance between cycles), and amplitude (height of the wave). Depending on the frequency of the waveform, sound waves can be classified as *infrasonic, sonic,* and *ultrasonic*. Sonic waves have frequencies between 20 and 20,000 Hz, which correspond to the frequency range of the human hearing. Waves with frequencies below 20 Hz are classified as *infrasonic*, while waves with frequencies above 20,000 Hz are classified as ultrasonic. The detection of sound in nature occurs over the entire spectrum of frequencies where certain animals can detect acoustic waves in the infrasonic range; while others detect sounds in the ultrasonic range. The frequency range of sound detection of different species, including humans, is detailed in Fig. 2.1a. The maximum and minimum frequency values of the detection range are reported in this figure. For example, elephants can detect sounds in the range of 5–12,000 Hz, while moths can detect sounds in a significantly smaller range that include frequencies between 20,000 and 50,000 Hz. Bats and porpoises can detect sounds with frequencies as high as

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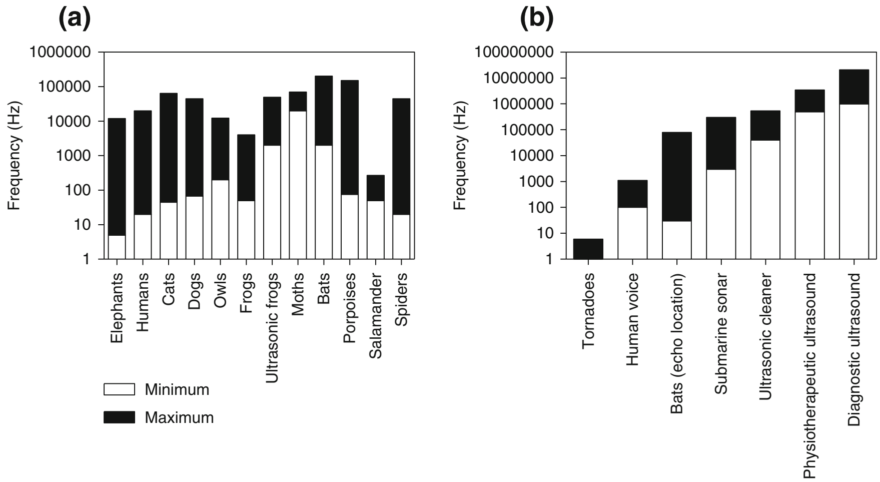

Fig. 2.1 Detection (**a**) and emission (**b**) acoustic frequencies of common acoustic equipment, and different species and phenomena found in nature. The *white* section of the *bar* represents the minimum frequency and the *black* section of the *bar* represents the maximum frequency of detection and emission. Reprinted with modifications from Leighton (1994), with permission from Elsevier

200,000 and 150,000 Hz, respectively, while salamanders can detect sounds at a maximum frequency of 220 Hz (Leighton 1994). Animals not only detect sound, they also emit sound over a wide range of frequencies (Fig. 2.1b). Bats emit sounds of frequencies in the range of 30–80,000 Hz to locate and identify objects. On the other extreme of the frequency scale, acoustic waves, with frequencies between 1 and 10 MHz are commonly used in diagnostic ultrasound techniques (Leighton 1994).

2.1.2 Wave Propagation

When acoustic waves travel through a material they do so at a specific velocity. This velocity is determined by the frequency and wavelength of the wave. Equation (2.1) describes the relationship between acoustic velocity, frequency, and wavelength.

$$c = \nu\lambda \tag{2.1}$$

where c is the acoustic velocity [m s^{-1}], ν is the acoustic frequency [s^{-1}], and λ is the wavelength [m] of the acoustic wave. As previously mentioned, the speed of sound is affected by the characteristics of the material through which the sound is being propagated. If the sound propagates in a liquid or a gas, the speed of sound is a function of the bulk modulus of the material (Eq. 2.2):

$$c = \sqrt{\frac{K}{\rho}} \tag{2.2}$$

where K is the bulk modulus and ρ is the density. When sound waves propagate in the solid, the Young (or elastic) modulus is used instead. The relationship between the Young (E) and bulk modulus (K) is shown in Eq. (2.3) (McClements 1991).

$$E = K + \frac{4}{3}G \tag{2.3}$$

where G is the shear modulus. The change in acoustic velocity as a function of the material properties has been used to evaluate the chemical compositions of vegetable oils (McClements and Povey 1988a, b, 1992), to quantify the structural and mechanical properties of fats (Maleky et al. 2007), to evaluate the rheological behavior of xanthan/sucrose mixtures (Saggin and Coupland 2004a, b), and to evaluate ice formation in frozen food systems (Gülseren and Coupland 2007b).

Table 2.1 shows the speed of sound values in different materials. In general, the speed of sound is the lowest in gases with values in the range of 200–500 m s^{-1}, followed by the speed of sound in liquids, with values in the range of 1,200–2,000 m s^{-1}. The highest values of speed of sound are found in solids, with values in the range of 3,200–6,500 m s^{-1}.

Acoustic waves propagate in the media through *longitudinal or transversal waves* that generate localized displacement of particles or molecules present in the material. These two types of waves differ in the direction of particle displacement that occurs during wave propagation. In longitudinal waves particles are displaced parallel to the direction of the wave, while in transversal waves particles are displaced perpendicular to the direction of the wave. Acoustic waves are usually longitudinal but they can be transversal when they propagate through solids. It is important to note here that when acoustic waves travel through a material they generate only local displacement of particles; there is no movement of particles from one point to the other. Instead, particles oscillate around their equilibrium position as a consequence of wave propagation from the source to the detector. To better understand this concept, Fig. 2.2 shows a typical acoustic wave and the relationship between acoustic pressure and particle displacement (Leighton 1994).

Table 2.1 Speed of sound–c–(m s^{-1}) of some common materials

Solids		Liquids		Gases	
Material	c (m s^{-1})	Material	c (m s^{-1})	Material	c (m s^{-1})
Aluminum[a]	6,400	Ethyl alcohol	1,207	Air (0 °C)	331
Cork	500	Distilled water	1,497	Air (20 °C)	343
Pyrex glass	5,640	Sea water	1,531	Carbon dioxide	259
Gold	3,240	Mercury	1,450	Water vapor (134 °C)	494
Maple wood	4,110	Glycerol	1,904	Nitrogen	334
Stainless steel	5,790	Castor oil[a]	1,500	Oxygen	316

[a] Leighton (1994)

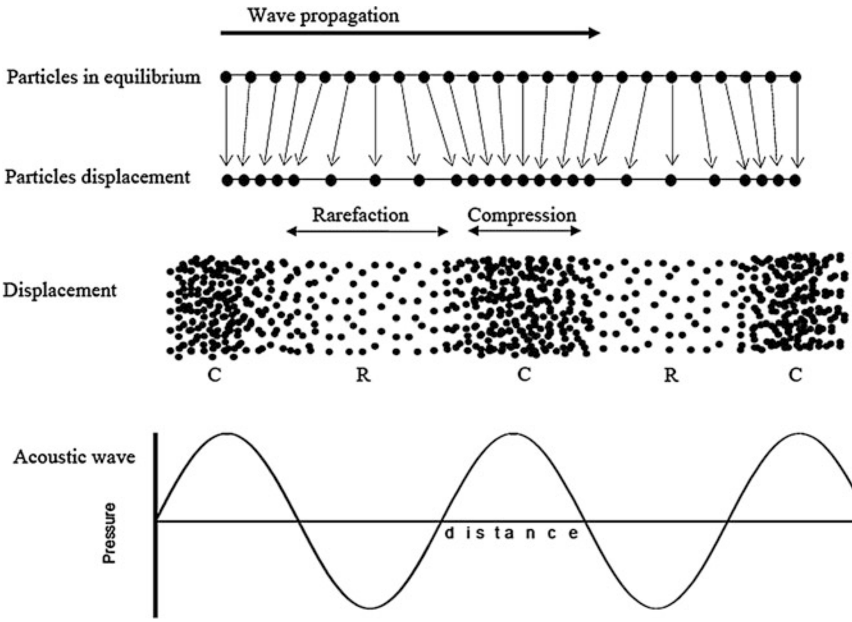

Fig. 2.2 Diagram of the propagation of longitudinal acoustic waves. Wave propagation occurs from *left* to *right* generating the displacement of particles around their equilibrium position. This displacement of particles results in zones of high (compression) and low (rarefaction) density zones in the material that correspond to high and low amplitudes in the acoustic wave, respectively. Reprinted with modifications from Leighton (1994), with permission from Elsevier

The first line of Fig. 2.2 shows particles in equilibrium position. When an acoustic wave travels from left to right in the direction shown by the arrow, particles move around their equilibrium position generating zones of compression and rarefaction. As already mentioned, no net displacement of particles is observed. The oscillation of particles results in gradients in the media where zones of high and low concentration of particles are observed. Highly concentrated zones of particles are observed when the media is compressed, while a low concentration of particles is observed in the rarefaction zones. The compression and rarefaction zones correspond to maximum and minimum amplitudes in the acoustic wave, respectively, as shown in the third line of Fig. 2.2 (Leighton 1994).

2.1.3 Introduction to Ultrasonic Techniques

Within the ultrasound range, acoustic techniques can be categorized into different groups according to the frequency and power of operation. High frequency and low power techniques are classified into *diagnostic* and *high frequency ultrasound*, while low frequency and high power techniques are classified into *power* *ultrasound*. Note that the category of diagnostic ultrasound includes techniques that use higher frequencies than those used by techniques included in the category of high frequency ultrasound. These techniques will be described in the following sections.

2.2 Diagnostic Ultrasound

Diagnostic ultrasound includes a series of pulse-echo techniques commonly used by the medical industry to evaluate the state of internal tissue structures (medical imaging). These are non-invasive, low power (<100 mW cm^{-2}), high frequency (1–10 MHz) techniques. Acoustic waves used for diagnostic applications are so low in intensity or power that they do not impart change to the physicochemical properties of the tissue.

Ultrasound is also used in the medical industry as a therapeutic tool. Low intensity ($\sim$1 W cm^{-2}) ultrasound is used as a deep-heating agent and ultrasound with higher intensities ($\sim$10 W cm^{-2}) can be used to treat oncological diseases. Finally, significantly higher power intensities (10^3 W cm^{-2}) are used in short duration pulses to modify body tissues (Frizzell 1988).

2.3 High Frequency Ultrasound

High frequency ultrasound techniques use frequencies between 100 kHz and 1 MHz, which are lower than those used in diagnostic ultrasound. High frequency ultrasound also use low power levels and therefore they do not induce changes in the material. High frequency ultrasound has been used extensively in several food science applications including monitoring of crystallization of lipids (McClements and Povey 1987, 1988a; Singh et al. 2004; Saggin and Coupland 2002; Santacatalina et al. 2011; Martini et al. 2005a, b, c), characterizing edible oils and fats (McClements and Povey 1988b, 1992), predicting viscoelastic properties of the material (Saggin and Coupland 2001; 2004a, b; Maleky et al. 2007; Mert and Campanella 2007), characterizing emulsions and suspensions (McClements 1991; McClements et al. 1990; McClements and Povey 1989; Coupland and McClements 2001), monitoring crystallization of lipids in emulsions (Hodate et al. 1997; Kashchiev et al. 1998; Kaneko et al. 1999; Vanapalli and Coupland 2001; Gülseren and Coupland 2007a, b; McClements et al. 1993), monitoring dissolution and crystallization of carbohydrates (Gülseren and Coupland 2008; Yucel and Coupland 2010, 2011a, b), and monitoring gel formation (Benguigui et al. 1994; Audebrand et al. 1995; Corredig et al. 2004; Dwyer et al. 2005; Wan et al. 2007) to name a few. A significant advantage of this technique over other tools used to characterize materials is that it is non-invasive, non-destructive, and can be used in concentrated and opaque materials.

2.4 Power Ultrasound

Power ultrasound or high intensity ultrasound uses significantly lower frequencies than those used in diagnostic and high frequency ultrasound. Frequencies used in power ultrasound range between 20 and 100 kHz. When low frequencies and high power (10–10,000 W cm^{-2}) acoustic waves such as those used in these techniques travel through a medium they induce formation of cavities (Rastogui 2011; Bermudez-Aguirre and Barbosa Canovas 2011). Acoustic cavitation and the events associated with this phenomenon are responsible for inducing several physico-chemical changes in the material. These events will be discussed in detail in Chap. 5.

Power ultrasound is a highly invasive technique that uses high intensity acoustic waves to purposely change the properties of materials. Some examples of the use of power ultrasound include therapeutic medicine such as physiotherapy, chemotherapy, ultrasonic thrombolysis, and drug delivery (Mason 2011). Other common uses of power ultrasound include inducing crystallization of materials (sonocrystallization) and inducing or causing chemical reactions (sonochemistry) that would not occur in the absence of ultrasound (Petrirt et al. 1994; Suslick et al. 1997; Gedanken 2004; Mason 1999; Kasaai et al. 2008; Wu et al. 2008).

Sonocrystallization has been used extensively by industries including pharmaceutical (Luque de Castro and Priego-Capote 2007; Krishna et al. 2007; Miyasaka et al. 2006; Louhi-Kultanen et al. 2006; Manish et al. 2005; McCausland 2007), chemical (Mansour and Takrouri 2007; Bucar and MacGillivray 2007; Paradkar et al. 2006; Li et al. 2003, 2006; Ruecroft et al. 2005; Oldenburg et al. 2005; Kaerger and Price 2004; Cains et al. 1998) and food (Bund and Pandit 2007a, b).

In addition to the use of power ultrasound in sonochemistry and sonocrystallization, this technique has recently been used to change the physicochemical properties of proteins (Villamiel and de Jong 2000; Kresic et al. 2008; Jambrak et al. 2008, 2009; Ashokkumar et al. 2009; Martini et al. 2010; Zisu et al. 2010, 2011; Arzeni et al. 2012; Martini and Walsh 2012; Hu et al. 2013). Power ultrasound has been used in food protein suspensions to increase the clarity of whey suspensions, to increase protein solubility, to change suspension viscosity, to decrease particle size, and to narrow particle size distributions. The source and concentration of sonicated protein determine the nature of change induced by sonication.

The use of ultrasonic techniques has caught the attention of the industry given the many advantages offered. Some benefits include: (a) improvements in product quality, (b) reduction in food processing costs, (c) decreased processing times, (d) reduced chemical and physical hazards, (e) environmentally friendly and sustainable, and (f) scalable throughput (Patist and Bates 2008; Chemat et al. 2011).

References

Arzeni C, Perez OE, Pilosof AMR (2012) Functionality of egg white proteins as affected by high intensity ultrasound. Food Hydrocoll 29:308–316

Ashokkumar M, Lee J, Zisu B, Bhaskarcharya R, Palmer M, Kenrish S (2009) Hot topic: sonication increases the heat stability of whey proteins. J Dairy Sci 92:5353–5356

Audebrand M, Doublier JL, Durand D, Emery JR (1995) Investigation of gelation phenomena of some polysaccharides by ultrasonic spectroscopy. Food Hydrocoll 9:195–203

Benguigui L, Emery J, Durand D, Busnel JP (1994) Ultrasonic study of milk-clotting. Lait 74:197–206

Bermudez-Aguirre D, Barbosa Canovas GV (2011) Chapter 16: power ultrasound to process dairy products. In: Feng H, Barbosa-Canovas GV, Weiss J (eds) Ultrasound technologies for food and bioprocessing. Springer, New York, pp 445–465

Bucar DK, MacGillivray LR (2007) Preparation and reactivity of nanocrystalline cocrystals formed via sonocrystallization. J Am Chem Soc 129:32–33

Bund RK, Pandit AB (2007a) Rapid lactose recovery from paneer whey using sonocrystallization: a process optimization. Chem Eng and Proc 46:846–850

Bund RK, Pandit AB (2007b) Sonocrystallization: effect on lactose recovery and crystal habit. Ultrason Sonochem 14:143–152

Cains PW, Martin PD, Price CJ (1998) The use of ultrasound in industrial chemical synthesis and crystallization. 1. Applications to synthetic chemistry. Org Process Res Dev 2:34–48

Chemat F, Huma Z, Khan MK (2011) Applications of ultrasound in food technology: processing, preservation and extraction. Ultrason Sonochem 18:813–835

Corredig M, Alexander M, Dalgleish DG (2004) The application of ultrasonic spectroscopy to the study of the gelation of milk components. Food Res Int 37:557–565

Coupland JN, McClements DJ (2001) Droplet size determination in food emulsions: comparison of ultrasonic and light scattering methods. J Food Eng 50:117–120

Dwyer C, Donnelly L, Buckin V (2005) Ultrasonic analysis of rennet induced pregelation and gelation processes in milk. J Dairy Res 72(303):310

Frizzell LA (1988) Biological effect of acoustic cavitation. In: Suslick KS (ed) Ultrasound: its chemical, physical, and biological effects. VCH Publishers Inc., Weinheim, pp 287–303

Gedanken A (2004) Using sonochemistry for the fabrication of nanomaterials. Ultrason Sonochem 11:47–55

Gülseren I, Coupland JN (2007a) The effect of emulsifier type and droplet size on phase transitions in emulsified even-numbered *n*-alkanes. J Am Oil Chem Soc 84:621–629

Gülseren I, Coupland JN (2007b) Ultrasonic velocity measurements in frozen model food solutions. J Food Eng 79:1071–1078

Gülseren I, Coupland JN (2008) Ultrasonic properties of partially frozen sucrose solutions. J Food Eng 89:330–335

Hodate Y, Ueno S, Yano J, Katsuragi T, Tezuka Y, Tagawa T, Yoshimoto N, Sato K (1997) Ultrasonic velocity measurement of crystallization rates of palm oil in oil-water emulsions. Coll Surf A 128:217–224

Hu H, Wu J, Li-Chan ECY, Zhu L, Zhang F, Xu X, Fan G, Wang L, Huang X, Pan S (2013) Effects of ultrasound on structural and physical properties of soy protein isolate (SPI) dispersions. Food Hydrocoll 30:647–655

Jambrak AR, Mason TJ, Lelas V, Herceg Z, Herceg IL (2008) Effect of ultrasound treatment on solubility and foaming properties of whey proteins suspensions. J Food Eng 86:281–287

Jambrak AR, Lelas V, Mason TJ, Kresic G, Badanjak M (2009) Physical properties of ultrasound treated soy proteins. J Food Eng 93:386–393

Kaerger JS, Price R (2004) Processing of spherical crystalline particles via a novel solution atomization and crystallization by sonication (SAXS) technique. Pharm Res 21:372–381

Kaneko N, Horie T, Ueno S, Yano J, Katsuragi T, Sato K (1999) Impurity effects on crystallization rates of *n*-hexadecane in oil-in-water emulsions. J Cryst Growth 197:263–270

Kasaai MR, Arul J, Charlet G (2008) Fragmenetation of chitosan by ultrasonic irradiation. Ultrason Sonochem 15:1001–1008

Kashchiev D, Kaneko N, Sato K (1998) Kinetics of crystallization in polydisperse emulsions. J Coll Interface Sci 208:167–177

Kresic G, Lelas V, Jamrak AR, Herceg Z, Brncic SR (2008) Influence of novel food processing technologies on the rheological and thermophysical properties of whey proteins. J Food Eng 87:64–73

Krishna MV, Babu JR, Latha PVM, Sankar DG (2007) Sonocrystallization: for better pharmaceutical crystals. Asian J Chem 19:1369–1374

Leighton TG (1994) Chapter 1: the sound field. In: Leighton TG (ed) The acoustic bubble. Academic Press, New York, pp 1–66

Li H, Wang JK, Bao Y, Guo ZC, Zhang MY (2003) Rapid sonocrystallization in the salting-out process. J Cryst Growth 247:192–198

Li H, Li HR, Guo ZC, Liu Y (2006) The application of power ultrasound to reaction crystallization. Ultrason Sonochem 13:359–363

Louhi-Kultanen M, Karjalainen M, Rantanen J, Huhtanen M, Kallas J (2006) Crystallization of glycine with ultrasound. Int J Pharm 320:23–29

Luque de Castro MD, Priego-Capote F (2007) Ultrasound-assisted crystallization (sonocrystallization). Ultrason Sonochem 14:717–724

Maleky F, Campos R, Marangoni AG (2007) Structural and mechanical properties of fats quantified by ultrasonics. J Am Oil Chem Soc 84:331–338

Manish M, Harshal J, Anant P (2005) Melt sonocrystallization of ibuprofen: effect on crystal properties. Eur J Pharm Sci 25:41–48

Mansour AR, Takrouri KJ (2007) A new technology for the crystallization of dead sea potassium chloride. Chem Eng Commun 194:803–810

Martini S, Walsh MK (2012) Sensory characteristics and functionality of sonicated whey. Food Res Int 49:694–701

Martini S, Bertoli C, Herrera ML, Neeson I, Marangoni AG (2005a) In-situ monitoring of solid fat content by means of p-NMR and ultrasonics. J Am Oil Chem Soc 82:305–312

Martini S, Herrera ML, Marangoni AG (2005b) New technologies to determine solid fat content on-line. J Am Oil Chem Soc 82:313–317

Martini S, Bertoli C, Herrera ML, Neeson I, Marangoni AG (2005c) Attenuation of ultrasonic waves: influence of microstructure and solid fat content. J Am Oil Chem Soc 82:319–328

Martini S, Potter R, Walsh MK (2010) Optimizing the use of high intensity ultrasound to decrease turbidity in whey protein suspensions. Food Res Int 43:2444–2451

Mason TJ (1999) Sonochemistry: current uses and future prospects in the chemical and processing industries. Philos T R Soc A 357:355–369

Mason TJ (2011) Therapeutic ultrasound and overview. Ultrason Sonochem 18:847–852

McCausland LJ (2007) Production of crystalline materials by using high intensity ultrasound. US 7,244,307 B2

McClements DJ (1991) Ultrasonic characterization of emulsions and suspensions. Adv Coll Interface 37:33–72

McClements DJ, Povey MJW (1987) Solid fat content determination using ultrasonic velocity measurements. Int J Food Sci Tech 22:491–499

McClements DJ, Povey MJW (1988a) Comparison of pulsed NMR and ultrasonic velocity techniques for determining solid fat contents. Int J Food Sci Tech 23:159–170

McClements DJ, Povey MJW (1988b) Ultrasonic velocity measurements in some liquid triglycerides and vegetable oils. J Am Oil Chem Soc 65:1787–1790

McClements DJ, Povey MJW (1989) Scattering of ultrasound by emulsions. J Phys D Appl Phys 22:38–47

McClements DJ, Povey MJW (1992) Ultrasonic analysis of edible fats and oils. Ultrasonics 30:383–388

McClements DJ, Povey MJW, Betsanis E (1990) Ultrasonic characterization of a food emulsion. Ultrasonics 28:266–272

McClements DJ, Povey MJW, Dickinson E (1993) Absorption and velocity dispersion due crystallization and melting of emulsion droplets. Ultrasonics 31:433–437

Mert B, Campanella OH (2007) Monitoring the rheological properties and solid content of selected food materials contained in cylindrical cans using audio frequency sound waves. J Food Eng 79:546–552

Miyasaka E, Ebihara S, Hirasawa I (2006) Investigation of primary nucleation phenomena of acetylsalicylic acid crystals induced by ultrasonic irradiation—ultrasonic energy needed to activate primary nucleation. J Cryst Growth 295:97–101

Oldenburg K, Pooler D, Scudder K, Lipinski C, Kelly M (2005) High throughput sonication: evaluation for compound solubilization. Comb Chem High T Scr 8:499–512

Paradkar A, Maheshwari M, Kamble R, Grimsey I, York P (2006) Design and evaluation of celecoxib porous particles using melt sonocrystallization. Pharm Res 23:1395–1400

Patist A, Bates D (2008) Ultrasonic innovations in the food industry: from the laboratory to commercial production. Innovat Food Sci Emerg Technol 9:147–154

Petrirt C, Lamy M, Francony A, Benahcene A, David B (1994) Sonochemical degradation of phenol in dilute aqueous solutions: comparison of the reaction rates of 20 and 487 kHz. J Phys Chem 98:10514–10520

Rastogui NK (2011) Opportunity and challenges in application of ultrasound in food processing. Crit Rev Food Sci Nutr 51:705–722

Ruecroft G, Hipkiss D, Ly T, Maxted N, Cains PW (2005) Sonocrystallization: the use of ultrasound for improved industrial crystallization. Org Proc Res Dev 9:923–993

Saggin R, Coupland JN (2001) Oil viscosity measurement by ultrasonic reflectance. J Am Oil Chem Soc 78:509–511

Saggin R, Coupland JN (2002) Measurement of solid fat content by ultrasonic reflectance in model systems and chocolate. Food Res Int 35:999–1005

Saggin R, Coupland JN (2004a) Rheology of xanthan/sucrose mixtures at ultrasonic frequencies. J Food Eng 65:49–53

Saggin R, Coupland JN (2004b) Shear and longitudinal ultrasonic measurements of solid fat dispersions. J Am Oil Chem Soc 81:27–32

Santacatalina JV, Garice-Perez JV, Corona E, Benedito J (2011) Ultrasonic monitoring of lard crystallization during storage. Food Res Int 44:146–155

Singh AP, McClements DJ, Marangoni AG (2004) Solid fat content determination by ultrasonic velocimetry. Food Res Int 37:545–555

Suslick KS, Mdleleni MM, Ries JT (1997) Chemistry induced by hydrodynamic cavitation. J Am Chem Soc 119:9303–9304

Vanapalli SA, Coupland JN (2001) Emulsions under shear—the formation and properties of partially coalesced lipid structures. Food Hydrocoll 15:507–512

Villamiel M, de Jong P (2000) Influence of high-intensity ultrasound and heat treatment in continuous flow on fat, proteins and active enzymes in milk. J Agric Food Chem 48:472–478

Wan Q, Bulca S, Kulozik U (2007) A comparison of low-intensity ultrasound and oscillating rheology to assess the renneting properties of casein solutions after UHT heat pre-treatment. Int Dairy J 17:50–58

Wu T, Zivanovic S, Hayes DG, Weiss J (2008) Efficient reduction of chitosan molecular weight by high-intensity ultrasound: underlying mechanism and effect of process parameters. J Agric Food Chem 56:5112–5119

Yucel U, Coupland JN (2010) Ultrasonic characterization of lactose dissolution. J Food Eng 98:28–33

Yucel U, Coupland JN (2011a) Ultrasonic attenuation measurements of the mixing, agglomeration, and sedimentation of sucrose crystals suspended in oil. J Am Oil Chem Soc 88:33–38

Yucel U, Coupland JN (2011b) Ultrasonic characterization of lactose crystallization in gelatin gels. J Food Sci 76:E48–E54

Zisu B, Bhaskaracharya R, Kentish S, Ashokkumar M (2010) Ultrasonic processing of diary systems in large scale reactors. Ultrason Sonochem 17:1075–1081

Zisu B, Lee J, Chandrapala J, Bhaskaracharya R, Palmer M, Kentish S, Ashokkumar M (2011) Effect of ultrasound on the physical and functional properties of reconstituted whey protein powders. J Dairy Res 78:226–232

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