Journal of Food Engineering 190 (2016) 48–53

Contents lists available at ScienceDirect

Journal of Food Engineering

journal homepage: www.elsevier.com/locate/jfoodeng

Hysteresis of ultrasound velocity in pork lard and water during a thermal cycle

A. Wesolowski [a, *], J.J. Sienkiewicz [b], K.A. Skibniewska [a], D. Luczycka [c], D. Choszcz [d]

[a] Chair of Foundations of Safety, University of Warmia and Mazury in Olsztyn, Poland
[b] The State Higher School of Computer Science and Business Administration in Łomża, Poland
[c] Faculty of Life Sciences and Technology, Wrocław University of Environmental and Life Sciences, Poland
[d] Chair of Heavy Duty Machines and Research Methodology, University of Warmia and Mazury in Olsztyn, Poland

ARTICLE INFO

Article history:
Received 17 October 2015
Received in revised form
4 June 2016
Accepted 6 June 2016
Available online 10 June 2016

Keywords:
Ultrasounds
Fat
Water
Meat
Hysteresis
Thermal cycle

ABSTRACT

Today, quick measurement methods, including methods of determination of food composition, are becoming increasingly important. The answer to the growing need is a non-destructive and very quick ultrasonic method. To determine the composition of a material with this method, it is necessary to determine the velocity of ultrasonic wave propagation in individual ingredients, which may vary depending on whether the material is cooled down or heated up, i.e. its hysteresis. The aim of this study was to determine if hysteresis occurs in ground meat during a thermal cycle.

The key ingredients of ground meat are proteins, fat and water. Since there is currently no method available to obtain protein in a form allowing acoustic measurements thereof, samples of pork fat and process water were analyzed. The thermal cycle involved cooling down and heating the samples in a temperature range of 10–40 °C. The measurements were performed by the transition method, using two heads of ultrasonic l-wave with a frequency of 2 MHz. The occurrence of hysteresis during the thermal cycle within the analyzed temperature range was confirmed in lard samples, while in the case of water, hysteresis proved to be negligibly low. To minimize the uncertainty of the quantification of the composition of ground meat by the ultrasonic method the industrial applications must provide for the hysteresis of ultrasound velocity in fat.

1. Introduction

Quality of the product is the key matter determining success in food industry. Quality assessment is still based on nonobjective organoleptic methods generating incoherent results (Cheng-Jin and Da-Wen, 2006). So, objective, quick and non-destructive methods of food products quality assessment, additionally creating possibility to conscious quality changing, are still wanted. Accurate knowledge of concomitant phenomenon is extremely essential.

Currently, it is the thermal method of food preservation that is most widely applied (Valero et al., 2007). The application of thermal methods involves changing the temperature of the material. The response to the same temperature level may vary depending on whether the material is being heated up (temperature up-scaling) or cooled down (temperature down-scaling). This phenomenon is called hysteresis, and is well known in physics and engineering. In measurement systems, hysteresis is treated as error or measurement uncertainty. Dunn (2005) defined the notion of hysteresis error, which is calculated with equation (1):

$$e_H = \frac{y_{up} - y_{down}}{FSO} \quad (1)$$

Where: e_H – hysteresis error, y_{up} – output value that occurs at temperature up-scaling, y_{down} - output value that occurs at temperature down-scaling, FSO – full-scale output.

Thus far, the existence of hysteresis in ultrasound velocity has been confirmed for methanol, ethanol, water, glycerol (Koc and Vatandas, 2006), and palm oil (Hodate et al., 1997).

Non-destructive methods of material testing are becoming increasingly popular. They were first used to assess food quality ca. 50 years ago. In the beginning, the technique was used to determine the thickness of backfat in the carcass, employing ultrasonic reflection techniques (Zacharias and Parnell, 1972). The later

* Corresponding author.
E-mail address: ika@uwm.edu.pl (A. Wesolowski).

http://dx.doi.org/10.1016/j.jfoodeng.2016.06.004
0260-8774/

development of ultrasonic techniques in food testing was based mainly on the measurement and analysis of the velocity of propagation and attenuation of the l-wave and, less frequently, the s-wave in the material.

The interest in those methods arises mainly from the fact that they are very quick, accurate, non-invasive and non-destructive. Furthermore, those methods can be easily automated and performed online. The ultrasonic methods can be applied to materials that are opaque or non-conductive (Coupland and Saggin, 2003; Benedito et al., 2000).

Currently, ultrasonic methods are finding increasingly frequent applications in food composition testing. In the case of products containing fat, the studies so far covered the degree of fat distribution in margarine, butter and chocolate (Narine and Marangoni, 1999), the fat content in milk (Wagner and Winder, 1975), the content of solid fat in oil (McClements and Povey, 1987; Miles et al., 1985), and the assessment of the composition of oils and the degree of potential counterfeiting thereof (McClements and Povey, 1987; Raghupati et al., 1980). Also studied were the rheological properties of castor oil, olive oil, peanut oil, sunflower oil and rapeseed oil (Gladwell et al., 1985; Benedito et al., 2002), as well as the composition of meat preserves (McClements, 1997; Benedito et al., 2001; Simal et al., 2003), fish (Ghaedian et al., 1998), chicken (Chanamai and McClements, 1999), and milk (Elvira et al., 2005). Ultrasound was also applied to assess the thickness of backfat and the dorsal muscles in porkers (Daszkiewicz and Wajda, 2003).

To determine the composition of complex materials Wood's equation is used (Wood, 1955), which shows the correlation between the velocity of propagation of the ultrasonic l-wave and the composition of the analyzed material (2).

$$\frac{1}{c^2} = \sum_{j=1}^{n} \Phi_j \rho_j \sum \frac{\Phi_j}{c_j^2 \rho_j} \tag{2}$$

Where: c – velocity of propagation of the ultrasonic wave in a complex material, Φ_j, ρ_j, c_j are the content percentage, density and wave propagation velocity, respectively, for the j-ingredient of the material.

In the case of quantifying the fat, water and protein in ground meat, after the derivation of correlation (2), correlation (3) was obtained.

$$\frac{100}{c^2} = \frac{\Phi_f}{c_f^2} + \frac{\Phi_w}{c_w^2} + \frac{\Phi_p}{c_p^2} \tag{3}$$

Where: Φ_f, Φ_w, Φ_p – the content percentage of fat (%), water and protein, respectively; c_f, c_w, c_p – the ultrasonic velocity in the fat, water and protein, respectively (m/s).

Correlation (3) includes the wave propagation velocity in individual material ingredients. The correlation does not indicate the previously mentioned phenomenon of hysteresis ultrasonic velocity. Hence, the determined meat composition may differ, depending on the preservation process applied to the analyzed material, e.g. heating or cooling down.

Thus far, there has been no method available for isolating protein from ground meat in a way enabling ultrasonic measurement of the protein. The authors' previous experiences suggest that in this type of material hysteresis either does not occur at all, or occurs to a minor extent. The objective of the study was to confirm the occurrence of hysteresis of UT velocity in animal fat and in water.

2. Materials and methods

2.1. Raw material

The study was conducted on lard purchased in a retail outlet, manufactured by Grupa Animex S.A. in Ostróda, within the shelf life. The lard is animal fat produced by rendering down fatty raw materials acquired from pigs. The product is white, uniform and soft at room temperature. According to the manufacturer's data, the melting point of the lard is 36–44 °C. The purchased lard was stored at 0–2 °C and protected from light.

The process water used in the study was taken from the municipal water main in Olsztyn. The water originates from a natural deep-water intake, without the addition of disinfectants. The process water was free from microbes; the general hardness was 269 mg/L of $CaCO_3$.

2.2. Test site

The test site (Fig. 1) consisted of a specially made measurement module (Fig. 2), an ultrasonic wave generator (Panametrics Waltham MA 5800 PR), combined with two single ultrasonic l-wave heads (INCO, 2 MHz, 20 mm, 2L0°20C). The signals were monitored with a dual-channel digital oscilloscope (Tektronix TDS 1012B, Tektronix Inc., Portland, OR, USA). The oscilloscope was connected to a PC via the RS 232 serial port to acquire data. The active surfaces of the ultrasonic transducers were arranged coaxially at 50 mm opposite each other. The temperature of the lard and the factor were measured using three k-type thermocouples, working together with a digital multimeter (Keithley Instruments Inc. Cleveland OH, model: Keithley 2700).

The dimensions of the measurement module chamber were 145 × 145 × 50 mm, i.e. 1050 cm^3. When taking the measurement, the chamber was approximately 80% full, which constituted a volume of 840 cm^3. The measurements were carried out in ten replicates at each temperature while mixing the material. It can be assumed that 310 cm^3 of the material was studied and the volume was of a comparable quantity order. The duct through which the cooling/heating liquid would circulate was made of a metal sheet and insulated from the surroundings with styrofoam. The walls, in which the ultrasonic heads were installed, were made from 5 mm-thick acrylic glass.

2.3. Measurement of ultrasonic wave propagation velocity

The ultrasonic wave propagation velocity was determined with the assumption that the wave moves through the material in a uniform linear motion, indirectly by measuring the transition time of the wave through the material, according to correlation (4).

$$c = s \cdot t^{-1} \tag{4}$$

where: c – the ultrasonic wave propagation velocity (ms^{-1}), s – the distance between transducers (m), t - wave propagation time in the material (s).

Due to the fact that, for structural reasons, the distance between the transducers was fixed, the ultrasound velocity would depend solely on the propagation time thereof.

Because of the significant attenuation of the ultrasonic wave in the material, the transition method was applied in the measurements, wherein one of the heads operates as the transmitter and the other as the receiver.