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Study of ultrasonic cavitation during extraction of the peanut oil at varying frequencies

Lei Zhang [a], Cunshan Zhou [a,*], Bei Wang [a], Abu El-Gasim A. Yagoub [b], Haile Ma [a,*], Xiao Zhang [c], Mian Wu [a]

[a] School of Food and Biological Engineering, Jiangsu University, 212013 Zhenjiang, China
[b] Faculty of Agriculture, University of Zalingei, P.O. Box: 06, Zalingei, Sudan
[c] Department of Mathematics and Statistics, Mississippi State University, Starkville, MS 39762, USA

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ABSTRACT

The ultrasonic extraction of oils is a typical physical processing technology. The extraction process was monitored from the standpoint of the oil quality and efficiency of oil extraction. In this study, the ultrasonic cavitation fields were measured by polyvinylidene fluoride (PVDF) sensor. Waveform of ultrasonic cavitation fields was gained and analyzed. The extraction yield and oxidation properties were compared. The relationship between the fields and cavitation oxidation was established. Numerical calculation of oscillation cycle was done for the cavitation bubbles. Results showed that the resonance frequency, f_r, of the oil extraction was 40 kHz. At f_r, the voltage amplitude was the highest; the time was the shortest as reaching the amplitude of the waveform. Accordingly, the cavitation effect worked most rapidly, resulting in the strongest cavitation intensity. The extraction yield and oxidation properties were closely related to the cavitation effect. It controlled the cavitation oxidation effectively from the viewpoint of chemical and physical aspects.

1. Introduction

In recent years, ultrasonic technology has been widely used in food physical processing mainly through cavitation phenomenon [1,2]. Ultrasound has many advantages such as avoiding of chemical use and keeping the flavor of foods original. High heat and mass transfer improve the extraction or degradation efficiency of the effective food components [3,4]. Oscillation of cavitation bubbles occurs due to the interaction between ultrasound and material, and the collapse of the oscillated bubbles introduces shock waves. At the same time, high temperature and pressure appear in the local area. Free radical might be introduced via ultrasonic cavitation processing, which changes the material structure [4,5].

The ultrasonic extraction of oils is a typical technology of physical processing. At present there are mainly three kinds of oil extraction: leaching by using organic solvent, extraction through pressure, and enzyme treatment. However, there are some disadvantages of these methods, such as, low efficiency, protein denaturation in the meal [6], and high cost [7]. The above-mentioned imperfection of the existing extraction method could be avoided by the ultrasonic extraction. Yao reported that the extraction yield of *camellia* oil was 40.41% by using an ultrasound (solid-liquid ratio: 1/5.94 g/mL, extraction time: 37.78 min, ultrasonic power: 400 W). The extracted oil owned light color and good stability. The ultrasonic treatment slightly changed the fatty acids composition of the oil [8]. Zhang et al. found that the ultrasound treatment (solid-liquid ratio: 1/7 g/mL, extraction time: 48 min, ultrasonic power: 120 W) improved the extraction yield (94.95%) of walnut oil as well as influencing the oxidative indices, such as acid value and peroxide value [9].

In spite of the improvement in the extraction yield; ultrasonic processing system might enhance simultaneously oil oxidation. Researchers found that the ultrasonic oil extraction technology developed the metallic and rancid odor, induced the chemical and physical changes in the oil components as well as changed to a certain extent the oxidative stability of the oil [10,11]. Thus, the effects of ultrasonic cavitation on the oil extraction process need deep studying. The ultrasonic frequency is found directly related to the cavitation phenomenon and hence it is an influential factor that affecting quality of the oils, especially the oxidative stability [12]. As a result, the mechanism of cavitation in terms of oil oxidation should be investigated profoundly in the ultrasonic fields, with the aim of obtaining a high oil yield and simultaneously controlling flexibly the oxidation process. Ultimately, ultrasonic cavitation fields need monitoring and analyzing during the oil extraction and the synergistic relationship between the physical

* Corresponding authors at: School of Food and Biological Engineering, Jiangsu University, 301 Xuefu Road, Jingkou District, Zhenjiang, Jiangsu 212013, China.
E-mail addresses: cunshanzhou@163.com (C. Zhou), mhl@ujs.edu.cn (H. Ma).

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fields and cavitation associated with the oil oxidation could be built on this basis.

Compared with other plant oils, oxidation of the peanut oil is easy to occur. It might be produced by oxygen, heat and moisture during the extraction process. Oxidative rancidity lowers quality of oil, which may make people suffer from essential fatty acids deficiency, vitamin deficiency, cancer, tumor, cardiovascular disease, *etc*. [13].

Therefore, the purpose of this research was: (1) to study the influence of the ultrasonic frequency on the extraction yield and oxidative stability of oils, and (2) to gain the oscillation behavior of cavitation bubbles in different ultrasonic fields. Thus, the mechanism of ultrasonic cavitation could be explained during the extraction process via frequency analysis and numerical calculation. It is trying to control cavitation oxidation effectively from chemical and physical aspects.

2. Materials, experimental setups and methods

2.1. Experimental materials and apparatus

Peanut (*Arachis hypogaea L.*) seeds were purchased from the supermarket. The contents of moisture, ash and fat of the peanut seeds were 4.1 g, 2.4 g and 48 g/100. The peanut seeds were red-coated and full without moldiness or heat loss. All chemical reagents were purchased from Sinopharm Chemical Reagent Co., Ltd (Shanghai, China).

The ultrasonic processing system was developed independently by our research team, some ultrasonic frequencies were provided. The effects of different ultrasonic fields, arising from the different frequencies, on the oil extraction were researched.

2.2. Oil extraction and ultrasonic treatment

The peanut seeds were dried in an electric thermostatic drying oven (1010-3B, Shanghai Experimental Instrument Co., Ltd) at 55 °C for 3–4 h, and then the red coat of the seed was easily peeled off. Hundred grams of peanut kernels were ground to powder by using 100 g portable universal high-speed grinder (DFT-100A, Wenling Linda Machinery Co., Ltd). After that, 100 g of the peanut powder was uniformly mixed with 600 mL *n*-hexane at a solid-liquid ratio of 1/6 g/mL. And then, the suspension was put into the reactor of the ultrasonic processing system to extract the oil.

The ultrasonic processing system is shown in Fig. 1. The ultrasonic electrical signal was generated by an ultrasonic generator. Hereby, the electric energy pulse was supplied to the flat-plate ultrasonic transducer with alternating current (AC) of 220 V, which converted to high-frequency mechanical oscillation by the transducer in the reactor. In this study, the ultrasonic transducers were the components with capacitive reactance, and stuck to one side face of the ultrasonic reactor. A different transducer was used for each frequency. The resonance frequencies of the transducers were 20 kHz, 28 kHz, 40 kHz and 60 kHz. Each ultrasonic transducer had an output power of 300 W. The whole irradiated object volume was 2600 mL, including 2000 mL of distilled water and 600 mL of the peanut solution. The peanut solution was put in a conical flask and then immersed into the water in the reactor. So that the level of the reaction solution was lower than the level of the distilled water and hence the solution was affected by the ultrasonic waves generated the distilled water. The ultrasound parameters were measured during the reaction process. The power density was about 115 W/L and kept constant during the entire time of the test. The ultrasonic system worked at pulsed mode with an on-time and off-time cycle of 3 s, according to its specification. The total treatment time of ultrasonic oil extraction was 60 min, during which the ultrasonic waves exactly irradiated for 30 min. The temperature of the solution in the reactor was measured by a temperature sensor. The temperature of the reaction solution was kept within 30 °C by controlling the temperature of the circulated distilled water in the reactor by using a low-temperature water pump. Different oil extraction experiments were performed at different single ultrasonic frequencies (20 –60 kHz). The whole ultrasonic processing system was controlled by programmable logic controller (PLC). After the ultrasonic treatment, the solution was centrifuged (TDL-40B-II, Henan Bailing Machinery Co., Ltd) at a speed of 3000 rpm for 10 min, and a supernatant was obtained. Finally, the extracted oil in the supernatant was separated from *n*-hexane by a rotary evaporator (R-210, BUCHI Labortechnik AG).

A control oil sample was gained by the leaching method. Peanut powder (100 g) was uniformly mixed with *n*-hexane (600 mL), and stood for 60 min under the room condition. Then, the solution was centrifuged, and the oil was extracted from the supernatant as before. The extraction yield was calculated using the following formula [14]:

$$\text{Extraction yield } (\%) = [\text{Oil weight } (\text{g})/\text{Initial sample weight } (\text{g})] \times 100\ \% \quad (1)$$

2.3. Monitoring of ultrasonic fields

During extraction of the oil, the ultrasonic cavitation fields were monitored in real-time. The voltage fluctuations of different ultrasonic cavitation fields of the reaction solution (oil in *n*-hexane) were measured by a core device called polyvinylidene fluoride (PVDF) sensor. The instantaneous pressure could be transformed to the electrical signal by PVDF, and recorded and stored via an oscilloscope (GDS-800, Good Wilzl Instrument Co., Ltd) in the form of voltage signal. The oscilloscope was used with the bandwidth of 250 MHz, and sampling rate of each channel was 100 Msa/s. The effective area of PVDF was 10 mm × 10 mm, the thickness was 30 μm, and the sensitivity was 2×10^{-8} V/Pa. A resistance of 50 Ω in parallel connection was to improve stability of the signal acquisition, and the distortion might be avoided. The experimental process sequence graph is displayed in Fig. 1.

2.4. Oxidative stability test

2.4.1. Peroxide value (PV)

According to the national standard method named "GB/T 5538-2005/ISO 3960: 2001" and preliminary tests, PV was calculated according to the following formula [15]:

$$P = \frac{1000(V - V_0)c}{2m} \quad (2)$$

where V is the dissipative volume of the standard solution of sodium thiosulfate during titration, mL, V_0 is the dissipative volume of the standard solution of sodium thiosulfate in the blank test, mL; c is the concentration of the standard solution of sodium thiosulfate, mol/L, and m is the mass of the oil sample, g.

2.4.2. Acid value and acidity

The hot-ethanol method was used to measure the acid value according to the national standard method called "GB/T 5530-2005/ISO 660: 1996". The acid value (S) was calculated based on the following equation [16]:

$$S = \frac{56.1 \times V \times c}{m} \quad (3)$$