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INVESTIGATION OF ACOUSTIC POWER RADIATED BY ULTRASONIC PROCESSOR INTO VEGETABLE OILS

Zbigniew Kobus, Beata Ślaska-Grzywna, Dariusz Andrejko

Department of Food Engineering and Machinery, University of Life Sciences in Lublin,
Doświadczalna 44, 20-236 Lublin, phone: (081) 461 00 61 int.147, e-mail: zbigniew.kobus@up.lublin.pl

Summary. In this paper an influence of ultrasonic amplitude and temperature on acoustic power radiated by ultrasonic processor was studied. Three kinds of vegetable oils: rapeseed, soybean and olive were sonificated. The ultrasonic amplitude was ranged from 7 μm to 35 μm. The frequency of generator was 20 kHz. There was obtained non-linear relationship between ultrasonic amplitude and acoustic power for all investigated oils. It was also found that an increase of temperature results in a significant decrease of the acoustic power emitted by processor into vegetable oils.

Key words: power ultrasound, acoustic power, vegetable oils.

INTRODUCTION

An idea of using vegetable oil as a diesel fuel emerged around the year 1900. The fuel from vegetable oils has a number of advantages over the diesel. It is renewable, non-toxic and biodegradable [Shahid and Jamal 2008]. Vegetable oils have good heating power and products of their burns have no sulfur or aromatic polycyclic compounds. Additionally, due to the fact that vegetable oils are produced from plants, their application leads to a complete recyclable CO_2. However the oil use as diesel fuel was limited due to its high viscosity (near 10 times higher than petroleum fuel) [Stavarache *et al.* 2005]. In order to obtain the properties of vegetable oils similar to diesel fuel ones, vegetable oils have to be modified. It can be achieved by four methods:

- blending vegetable oils with diesel fuel,
- micro-emulsification with solvents such as methanol, ethanol and butane,
- pyrolysis or cracking,
- transesterification [Ramadhas et al. 2004].

The most frequently applied way of making fuel diesel from vegetable oils is transesterification [Hanh et al. 2008]. The transesterification is the process of exchanging glycerol contained in fat or oil with another alcohol (methanol, ethanol or butane) (Fig. 1).

According the stoichiometric note the reaction requires 1 mole of a triglyceride and 3 moles of alcohol. As a result we obtain 3 moles of alkyl esters and 1 mole of glycerol. As alcoholysis is an equilibrium reaction, an excess of the alcohol is used to increase the yields of alkyl esters and to allow its phase separation from the created glycerol [Schuchardt et al. 1998].

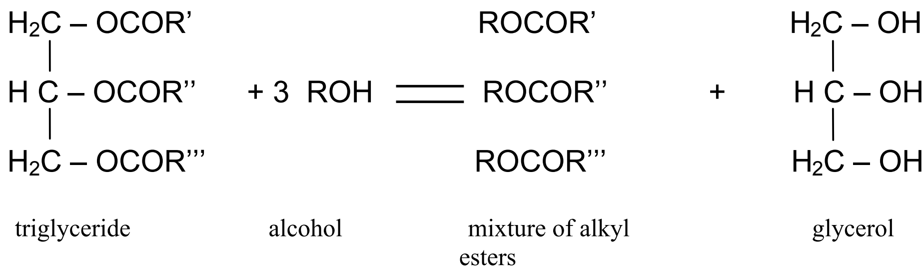

Fig. 1. Transesterification of vegetable oils

Triglycerides and alcohols are not totally miscible, so that a vigorous mixing is required to increase the area of contact between the reactants. One of the ways of emulsification of immiscible liquids is an application of ultrasound. Ultrasound during chemical processing enhances both the mass transfer and chemical reactions [Mason and Lorimer 1989, Śliwiński 2001, Mason and Lorimer 2002]. It offers a potential for shorter reaction time, cheaper reagents and less extreme physical conditions. Also, tests with an application of ultrasound for transesterification of vegetable oils make it possible to enhance the reaction yield [Hanh et al. 2008].

Efficiency of high-intensity ultrasound depends on many variables, among other things: physico-chemical properties of liquid and intensity of ultrasonic field [Löning *et al.* 2002, Raso *et al.* 1999]. Additionally, these variables vary during ultrasonic treatment of liquid. Because of this, it is a very important issue to evaluate the intensity of ultrasonic field and its eventual changes during sonication.

THE AIM OF THE STUDY

The aim of the work was to investigate an influence of amplitude and temperature of ultrasonic treatment on intensity of acoustic field in vegetable oils.

MATERIALS AND METHODS

Material:

The study was performed on liquids, which are often used in the process of bio-diesel production: rapeseed oil, soybean oil and olive oil.

Determination of oil viscosity:

The viscosity of oils was measured using Brookfield rotational viscometer (Brookfield Engineering Laboratories: model LVDV-II+PRO) at temperature 21°C. A sample of 500 ml was loaded into a glass beaker of 600 ml size for all experiments. The temperature was maintained constant by submerging the beaker in a thermostatic bath (VEB Prüfgeräte-Werk Medingen, Germany). A spindle S-62 working at rotational speed of 4 rpm was used. A computer program Rheocal V3.1 was used to register results and control the viscometer.

Measurement of ultrasonic power:

The power measurements were carried out in a simple standard setup with an immersion probe system as shown in Figure 2.

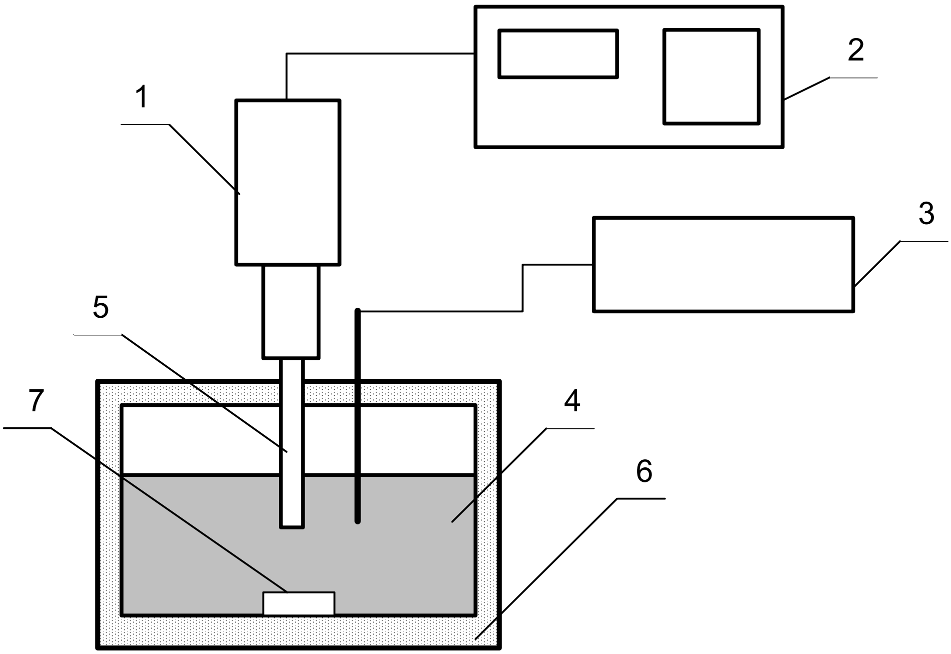

Fig 2. Experimental setup for power measurements of ultrasonic processor 1 – ultrasonic transducer, 2 – generator with wattmeter, 3 – thermocouple, 4 – liquid, 5 – ultrasonic probe, 6 - thermal isolation, 7 – magnetic stirrer

The apparatus used in this investigation was Ultrasonic Processor VC 750 (Sonics and Materials, Inc.) with the horn of 25.4 mm diameter. The maximum amplitude of the probe was 35 μm. The frequency of generator was 20 kHz. The power output of the generator can be set up to the maximum power of 750 W by adjustment of the amplitude. The quantity of the amplitude (as a percentage of the maximum amplitude) was given on a display and was kept constant by generator. Five levels of the maximum amplitude: 20%, 40%, 60 %, 80 % and 100% were tested in the study. The temperature of the liquid was measured with thermocouple type T(Cu – CuNi) located 10 mm beside the horn tip. In all experiments the liquid was stirred by magnetic stirrer. The volume of the liquid was 100 ml.

To determine the power input into the liquid the thermal method was applied which consists in measuring the temperature changes of a mass of liquid used to absorb the acoustic power. The acoustic power was calculated from the equation:

$$P_L = Mc\frac{dT}{dt}, \tag{1}$$

where:
P_L –acoustic power [W],
M – mass of the liquid [kg],
c – heat capacity of the liquid [$J \cdot m^{-1} \cdot K^{-1}$],
T- temperature of the liquid [K].

RESULTS AND DISCUSSION

Viscosity of vegetable oils:

The viscosity of vegetable oils was shown in Table 1.

Table 1. The viscosity of vegetable oils at the temperature of 21ºC

Kind of oil	Viscosity [mPa·s]	Standard error
olive	73.9	1.8
rapeseed	63.1	1.7
soybean	57.4	1.5

From among the investigated oils the highest viscosity was found in olive oil whereas the smallest viscosity in soybean oil.

Influence of amplitude on acoustic power:

The acoustic power of the ultrasonic processor can be set up by an adjustment of the ultrasonic amplitude. The results of these experiments were shown in Figure 3.

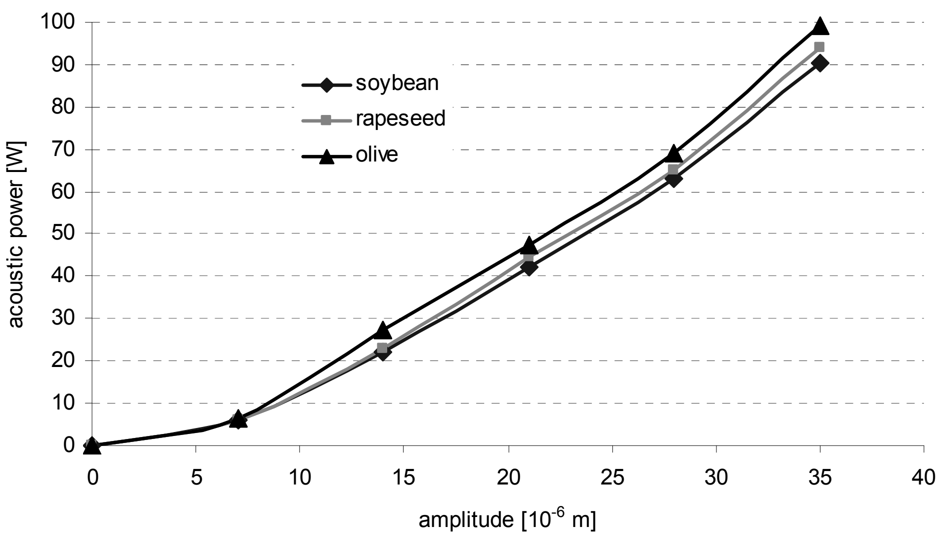

Fig. 3. Influence of ultrasonic amplitude on the acoustic power produced by ultrasonic processor in vegetable oils

There was obtained a non-linear relationship between ultrasonic amplitude and acoustic power for all investigated oils. The best fitting of regression line was obtained for a second order polynomial (Table 2). The results correspond with theoretical relationship between power input and amplitude [Löning *et al.* 2002].

Table 2. Regression equations describing the influence of amplitude on the specific power densities

Kind of oil	Equation	Coefficient of determination
olive	$P = 0.044A^2 + 1.33A - 1.48$	$R^2 = 0,99$
rapeseed	$P = 0.047A^2 + 1.08A - 1.34$	$R^2 = 0,99$
soybean	$P = 0.046A^2 + 1.03A - 1.22$	$R^2 = 0,99$

Influence of temperature on acoustic power:

The temperature can influence an efficiency of ultrasound-aided processes. It is caused by change in intensity of acoustic power under the influence of change in physical properties of treating liquid.

The influence of temperature on acoustic power emitted by ultrasonic processor was shown in Figures 4-6.

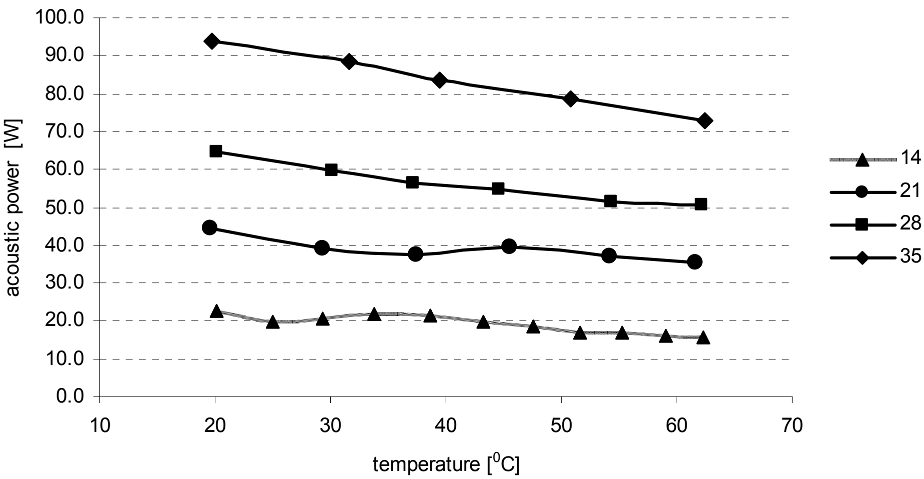

Fig. 4. Influence of temperature on acoustic power emitted by ultrasonic processor into rapeseed oil

An increase of temperature caused a decrease in acoustic power produced by ultrasonic processor for all tested vegetable oils. The highest decrease of acoustic power was observed in the case of olive oil, the smallest in the case of soybean oil. There was no influence of ultrasonic amplitude on the character of relationship between acoustic power and the temperature of the tested liquid.

The decrease of acoustic power under an influence of increasing temperature can be explained by change in physical properties of sonificated oils. An increase in temperature results in a decrease of oil viscosity. A decrease of viscosity causes a decrease in the force required to keep constant amplitude of ultrasonic vibrations in treating oil (the ultrasonic processor is designed to keep constant amplitude). This, in turn, results in a smaller demand for energy. As a consequence, the ultrasonic processor takes less electric energy and this smaller amount of energy is converted into acoustic energy. An increase of temperature causes higher reduction of viscosity in the case of higher viscosity oil (olive oil). This ultrasonic treatment of higher viscosity oil results in a higher reduction of viscosity expressed in absolute values.

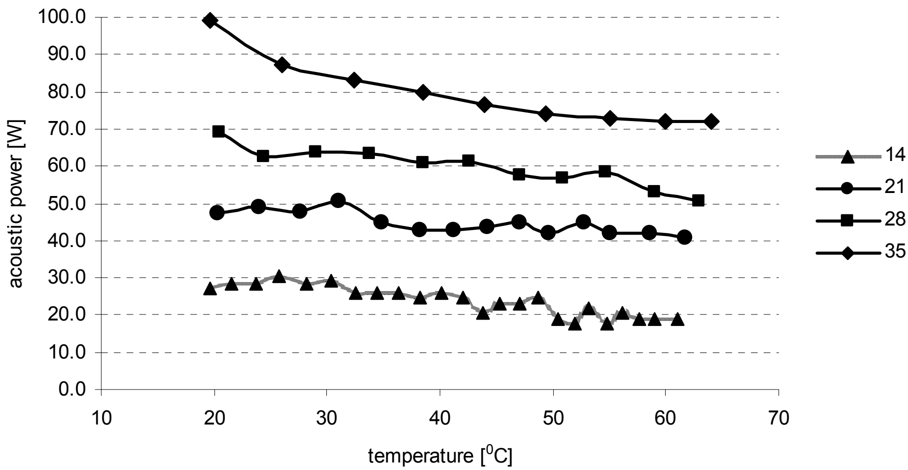

Fig. 5. Influence of temperature on acoustic power emitted by ultrasonic processor into olive oil

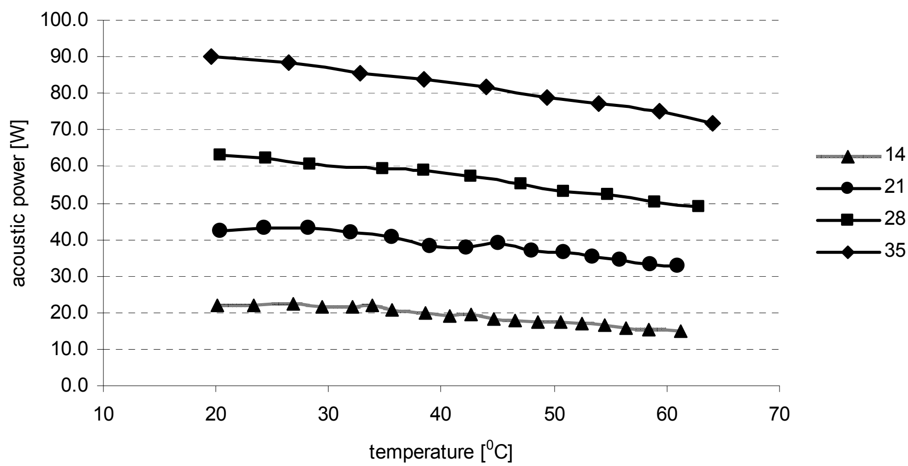

Fig. 6. Influence of temperature on acoustic power emitted by ultrasonic processor into soybean oil

An additional reason for the reduction in acoustic power of ultrasonic processor may be the loss of heat. Although a thermal insulation vessel was used, heat was lost by thermal conduction of the horn as well as during an evaporation of the oil in the vessel. The higher temperature of treatment, the higher the heat losses were. This, in turn, in the case of this measurement method resulted in the smaller values of acoustic power.

CONCLUSIONS

The temperature of vegetable oils treatment and amplitude of ultrasonic vibration play a great role during the sonification process. These parameters influence the amount of acoustic energy emitted by ultrasonic processor into vegetable oils. The acoustic power increases in a non-linear way side by side with an increase of ultrasonic amplitude. This relationship can be described by a quadric equation.

An increase in the temperature of sonificated oil results in a reduction of acoustic power produced by ultrasonic processor. It is caused by a decrease in the viscosity of the treated oil, which in turn lowers the so called load of acoustic probe.

From among the tested liquids the highest acoustic power was observed in oil of the highest viscosity (olive oil).

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BADANIE INTENSYWNOŚCI OBRÓBKI ULTRADŹWIĘKOWEJ W OLEJACH ROŚLINNYCH

Streszczenie. W pracy przedstawiono wyniki wpływu amplitudy drgań ultradźwiękowych i temperatury na moc akustyczną emitowaną przez procesor ultradźwiękowy do olejów roślinnych. Sonifikacji poddano trzy rodzaje olejów roślinnych: olej rzepakowy, olej sojowy i olej z oliwek. Częstotliwość fal akustycznych wynosiła 20 kHz, a amplituda drgań zmieniała się od 7 μm do 35 μm. Dla wszystkich olejów uzyskano nieliniowy wzrost mocy akustycznej wraz ze wzrostem amplitudy drgań ultradźwiękowych. Stwierdzono także znaczny spadek mocy akustycznej emitowanej przez procesor do badanych cieczy wraz ze wzrostem temperatury.

Słowa kluczowe: ultradźwięki dużej mocy, moc akustyczna, oleje roślinne.