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# INFLUENCE OF PHYSICAL PROPERTIES OF LIQUID ON ACOUSTIC POWER OF ULTRASONIC PROCESSOR

Zbigniew Kobus, Elżbieta Kusińska

Department of Food Engineering and Machines, University of Life Sciences in Lublin, Doświadczalna 44, 20-236 Lublin, e-mail: zbigniew.kobus@up.lublin.pl

**Summary.** In this paper the energy transformation during ultrasonic treatment was studied. The measurements of two different locations of an ultrasonic treatment: the electrical power input at the transducer (displayed at the frequency generator) and the acoustic power dissipated in the liquid medium were carried out. The raw materials were water and ethyl alcohol. An influence of physical properties of the liquids on density of acoustic power and efficiency of an ultrasonic transducer was shown.

**Key words:** power ultrasound, energy conversion, efficiency of ultrasonic transducer.

## INTRODUCTION

Ultrasounds are known as an excellent tool for an improvement of biological, physical and chemical processes. The ultrasonic field intensifies extraction, filtration and emulsification, accelerates germination of seeds and improves the yield of chemical reaction [Mason *et al.* 1996, Śliwiński 2001, Mason and Lorimer 1989].

Efficiency of high-intensity ultrasound depends on many variables [Löning *et al.* 2002, Raso *et al.* 1999]. Among the most important variables are: the reaction medium characteristics (viscosity, surface tension, acoustic impedance, presence of solid particles), treatment parameters (temperature) and ultrasonic generator performance (type of processor, frequency and power input). In practice there are three types of laboratory ultrasonic apparatus (with electromechanical transducers) which are commercially available. They are the following: ultrasonic cleaning bath, ultrasonic probe (or horn) system and the cup-horn system [Mason and Lorimer 2002].

The ultrasonic bath is the most popular and the cheapest piece of ultrasonic equipment but its disadvantage is reduced power compared with probe system and often fixed intensity of ultrasounds. The advantage of horn and cup-horn systems is the possibility of the acoustic power control. Processors in the systems are designed to deliver constant amplitude. The change of amplitude (which we can adjust) causes a change of ultrasound intensity. It means that when the resistance to the movement of the probe increases, additional power will be delivered by the power supply to ensure that the excursion at the probe tip remains constant.

An ultrasonic processor transforms the electrical energy into other kinds of energies as shown in Fig. 1.

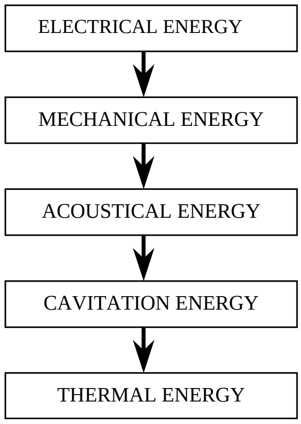


Fig. 1. The energy transformation chain during ultrasonic treatment

First the electrical energy is converted to mechanical energy in the form of oscillation of the piezoelectric crystal. This mechanical energy is converted into the acoustical energy in the form of ultrasonic waves which progress through a liquid medium. The ultrasonic waves cause the molecules of the liquid to oscillate about the mean position. During the compression cycle the average distance between the molecules decreases, while during the rarefaction the distance increases. If the average distance between the molecules exceeds the critical molecular distance necessary to hold the liquid in contact, the liquid breaks down and cavitation bubbles are formed. This phenomenon, referred to as cavitation, creates millions of shock waves in the liquid, as well as elevated pressures and temperatures at the implosion sites. Although the cavitational collapse lasts but a few microseconds and the amount of energy released by each individual bubble is minimal, the cumulative effect causes extremely high levels of energy to be released into the liquid. This energy is responsible for bringing out the desired physical and chemical effects. Finally the energy is transformed into heat.

In this complex energy conversion process many different technique of measuring acoustic power can be used [Faďd *et al.* 1998, Margulis and Margulis 2003, Ratoarinoro *et al.* 1995, Swamy and Keil 2002, Valérie and Didier 2007.]. These methods rely on the measurement of a primary or a secondary effect of the propagation of the wave in the irradiated material [Berlan and Mason 1998]. Zieniuk [1976] suggested a partition of these methods into three classes:

– methods giving absolute energy values: thermal measurements,

– methods based on acoustic pressure: capacitive or piezoelectric probes, optical methods, etc.

– methods based on non-linear effects: radiation force, etc., and with other subdivisions depending on whether the method can be used for total or local power measurements, under the condition of a free or a restrained field.

Among the existing methods of measuring acoustic energy thermal methods are currently the most common. They are very reliable and have been used for this purpose by different authors [Raso 1995, Margulis and Margulis 2003].

In order to compare the results of different experiments and to guarantee constant and reproducible reaction condition, the knowledge of acoustic power produced by processor is required.

## THE AIM OF THE STUDY

The aim of the study was to investigate an influence of physical properties of two different liquids on acoustic power produced by ultrasonic processor.

## MATERIALS AND METHODS

### Material

The study was performed on liquids which are the main solvents in ultrasonic extraction processes: water and ethyl alcohol. Their physical properties (important from ultrasonic treatment point of view) were shown in Table 1.

Table 1. Physical properties of water and ethyl alcohol at temperature 20°C

| Liquid | Density [kg·m$^{-3}$] | Viscosity [mPa·s] | Acoustic impedance [MRyl] |
|---|---|---|---|
| Water | 998 | 1.0 | 1.494 |
| Ethyl alcohol | 789 | 1.2 | 0.95 |

### Ultrasonic device

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

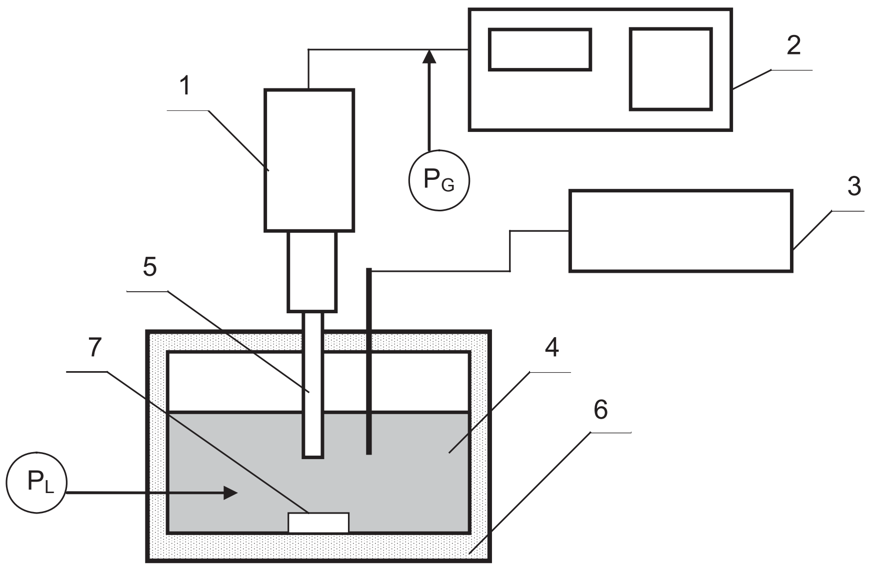


Fig. 2. Experimental setup for power measurements of ultrasonic processor: 1 – ultrasonic transducer, 2 – generator with wattmeter, 3 – thermocouple, 4 – liquid, 5 – ultrasonic probe, 6 – thermal isolation, 7 – magnetic stirrer

The apparatus used in this investigation was Ultrasonic Processor VCX 750 (Sonics and Materials, Inc.) with the horn of 25.4 mm diameter. The maximum amplitude of the probe is 35 μm. The frequency of generator is 20 kHz. The power output of the generator can be setup up to a maximum power 750 W by adjustment of the amplitude. The quantity of the amplitude (as a percentage of the maximum amplitude) is given on the display and is 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 the experiments the liquid was stirred by magnetic stirrer. The volume of the liquid was 100 ml.

**Measurement of power output**

The energy quantities were recorded at two different locations in the system (see Fig. 1). The power output of the generator $P_G$ was measured by wattmeter built-in the generator.

To determine the power input into the liquid 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].

The specific power densities related to the sonificed liquid volume were introduced:

$$I_G = \frac{P_G}{V}, \tag{2}$$

and

$$I_L = \frac{P_L}{V}, \tag{3}$$

where:
$P_G$ – electric power of ultrasonic generator [W],
$P_L$ – acoustic power of ultrasonic generator [W],
$I_G$ – electric power density of ultrasonic generator [$W*cm^{-3}$],
$I_L$ – acoustic power of ultrasonic generator [$W*cm^{-3}$],
$V$ – liquid volume [$cm^3$].

The recorded power densities were used to describe the efficiency of the immersion horn:

$$\eta_{horn} = \frac{I_L}{I_G}. \tag{4}$$

## RESULTS AND DISCUSSION

The power output of the ultrasonic processor can be set up by an adjustment of the ultrasonic amplitude. Therefore, the power densities $I_G$ and $I_L$ were recorded at different ultrasonic amplitudes during sonification of liquids.

The results of these experiments for water are shown in Fig. 3.

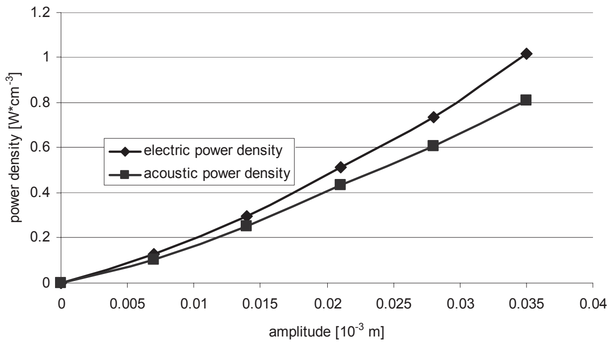


Fig. 3. Influence of ultrasonic amplitude on the specific power densities for water

The specific power densities increase in a non-linear way with increasing ultrasonic amplitude. The best fitting of regression line was obtained for a second order polynomial (Tab. 2). The results correspond with theoretical relationship between power input and amplitude [Löning *et al.* 2002]:

$$P = \varpi^2 \beta m \xi^2, \tag{5}$$

where:
$P$ – power input [W],
$\omega$ – circular frequency [rad*s$^{-1}$],
$\beta$ – total resistive constant leading to damping,
$m$ – inertia of the oscillator,
$\xi$ – amplitude [m].

Fig. 4 shows the influence of amplitude on the specific power densities for ethyl alcohol.

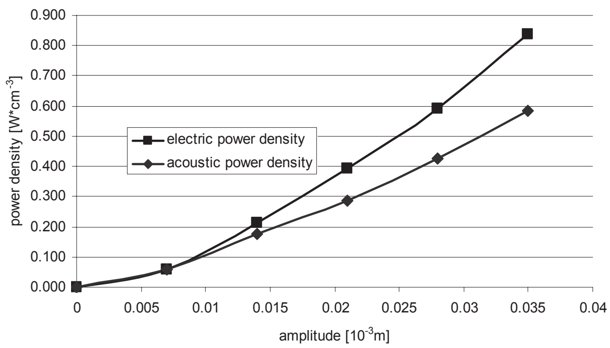


Fig. 4. Influence of ultrasonic amplitude on the specific power densities for ethyl alcohol

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

| Liquid | Power density | Equation | Coefficient of determination |
|---|---|---|---|
| Water | electric | $I_G = 352\xi^2 + 16.69\xi - 0.0022$ | $R^2 = 0,99$ |
| | acoustic | $I_L = 217.54\xi^2 + 15.86\xi - 0.0067$ | $R^2 = 0,99$ |
| Alcohol | electric | $I_G = 401.34\xi^2 + 10.26\ \xi - 0.0108$ | $R^2 = 0,99$ |
| | acoustic | $I_L = 209.12\xi^2 + 9.506\xi - 0.0046$ | $R^2 = 0,99$ |

In this case was also observed non-linear growth of the specific power densities increasing with amplitude. However, there were noticed lower values of the specific power densities. The differences between water and alcohol were 17.7% for $I_G$ and 27.9% for $I_L$ in the case of 35 μ amplitude, respectively.

This effect can be explained by the so called acoustic load of ultrasonic probe. The ultrasonic processor produces ultrasound with constant amplitude. Keeping the constant amplitude is dependent on the resistance of the irradiated medium. The resistance of the medium corresponds with acoustic impendance. The acoustic impendance $Z$ of liquid can be described by the following equation:

$$Z = \rho\ c, \tag{6}$$

where:
$\rho$ – density of medium [$kg \cdot m^{-3}$],
$c$ – speed of sound in the medium [$m \cdot s^{-1}$].

The acoustic impendance of ethyl alcohol in temperature 20°C was only 63% of water. In order to keep the constant amplitude, the ultrasonic processor has to supply larger amount of electrical energy, which is converted into acoustic energy. Because of this the specific power densities for water are higher then for alcohol ethyl.

Fig. 5 shows the influence of acoustic amplitude on efficiency of ultrasonic horn in water and ethyl alcohol.

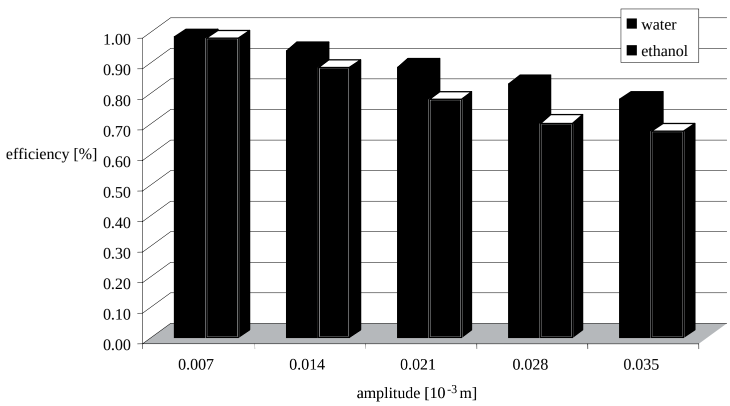


Fig. 5. Influence of acoustic amplitude on efficiency of ultrasonic horn in water and ethyl alcohol

The efficiency of the transducer decreases with an increasing amplitude. This effect can be explained in the following way. Firstly, an increase of amplitude causes an increase of dielectric and mechanical power losses in the transducers. This phenomenon was observed in the research by Lin and Zhang [2000]. Secondly, an increase of acoustic amplitude causes an increase of cavitation intensity, and this changes the load of ultrasonic transducer [Yan *et al.* 1997]. Partially an explanation for this stronger decrease of acoustic efficiency can be given by non-negligible heat losses at higher amplitudes. An increase of amplitude results in an increase of differences in temperature of liquid after ultrasonic treatment. Although a thermal insulation vessel was used, heat is lost by thermal conduction of the horn as well as an evaporation of the liquid in the vessel.

The differences in efficiency of ultrasonic horn between water and ethyl alcohol can be given by the stronger decrease in acoustic load of horn in the case of ethyl alcohol.

## CONCLUSIONS

The main way of power adjusting in ultrasonic processor is the change of the acoustic impendance. The relationship between acoustic power and amplitude can be described with a quadratic equation. The acoustic power produced by ultrasonic processor is dependent on the kind of liquid. This phenomenon can be explained by the so called load of acoustic probe which depending on "resistance" of liquid. The "resistance" of liquid is function of many variables. The most important of them are acoustic impendance and viscosity. The resultant of these variables makes the ultrasonic processor require different amounts of energy to keep the constant amplitude. Because of this, the power density produced by ultrasonic processor in water is higher than power density in ethyl alcohol.

The efficiency of the horn decreases with increasing amplitude. The main reasons of this fact are dielectric and mechanical power losses in the horn and changes in acoustic load of the horn.

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## WPŁYW FIZYCZNYCH WŁAŚCIWOŚCI CIECZY NA MOC AKUSTYCZNĄ WYTWARZANĄ PRZEZ PROCESOR ULTRADŹWIĘKOWY

**Streszczenie.** W pracy przedstawiono transformacje energii w trakcie obróbki ultradźwiękowej cieczy. Zmierzono dwa rodzaje energii wytwarzanej przez procesor ultradźwiękowy: energię elektryczną dostarczaną do przetwornika ultradźwiękowego (wyświetlaną na generatorze ultradźwięków) oraz energię akustyczną promieniowaną do obrabianej cieczy. Materiałem badawczym była woda i alkohol etylowy. Wykazano wpływ fizycznych właściwości badanych cieczy na gęstość energii akustycznej produkowanej przez procesor ultradźwiękowy oraz sprawność przetwornika ultradźwiękowego.

**Słowa kluczowe:** ultradźwięki dużej mocy, transformacje energii, sprawność przetwornika ultradźwiękowego.