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On the ultrasonic atomization of liquids

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Abstract

This paper deals with an experimental study of liquid atomization phenomena. For this study an experimental set-up was designed and constructed. A special criterion to start the recording of the process with a high speed digital camera was developed. The frequency dependence of atomization threshold is considered. The theoretical predictions for atomization threshold are also checked. The agreement between the predictions and the experimental results fit qualitatively with the data well until a frequency of 22 kHz. For frequencies beyond this value the tendencies are the opposite.

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1. Introduction

The atomization of liquids is always an object of interest from both scientific and technical aspects. The first reported use of ultrasound to produce a fog from a liquid was published by Wood and Loomis, in 1927. In this remarkable paper Wood et al showed a complete experiment at high frequency producing atomization of liquids at 300 kHz. From the Wood paper a great number of papers devoted to study the ultrasonic atomization phenomena

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have been published (Söllner, 1936; Harmon, 1955; Crawford, 1955; Sorokin, 1957; Rozenberg and Eknadiosyants, 1960; Lang, 1962). More recent researches are addressed to find correlations between ultrasonic generated droplets and some of the problem variables (Rajan and Pandit, 2001). Also researches have been done of more complex liquids such as melted metals, for instance (Lagutkin et al., 2004). Even research has been done in atomization of multiphase liquids (Avvaru et al., 2006). In summary even being an old problem and very old phenomena several aspects of ultrasonic atomization remain open until today, showing the need for research in both aspects experimental and theoretical. In this paper an experimental research about ultrasonic atomization of liquids is presented. Then research covers a wide range of frequencies making the results more complete and with valuable data for uses in laboratory and in the industry. The range of frequencies covered is from 6 kHz to 40 kHz, that is to say, is the more used frequency range in the industrial uses of ultrasound. The variables considered are the vibration amplitude of atomizing device, the threshold of atomization and the droplet size.

2. Material and methods

For this research a complete experimental set-up was developed. To build the experimental set-up, nine high-power ultrasonic transducers were designed and constructed. Also the power ultrasonic transducers were fully characterized. A study to determinate the control variables of the problem was done, the control variables must allow the determination of ultrasonic excitation of atomizing transducer in the instant that atomization starts; this furnishes the atomization threshold at the working frequency. A special criterion to produce the start of data acquisition was developed; it solves the problem of detection the onset of atomization.

2.1 The transducer design

The transducers used in this experiment are piston-like sources. To obtain high displacement amplitudes in the tip of transducer, a stepped horn type transducer was designed and constructed. The active part of the transducer is a pre-stressed sandwich transducer (Neppiras, 1973). The design was optimized modeling the final device using finite element software. For instance, in the figure 1a the simulation results for a transducer of 22 kHz of resonance frequency it is presented. In the figure 1b a picture with the transducers set used in this research it is shown.

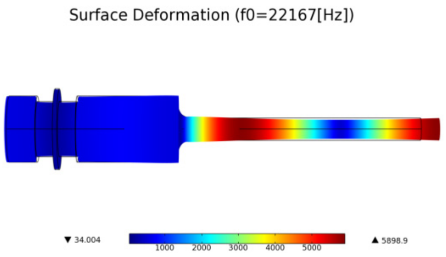

Figure 1a.- Example of power ultrasonic simulation. The transducer tip presents the greater displacement.

Figure 1b.- Ensemble of transducer for atomization experiments.

For the experimentation a set of nine of these transducers was designed and contructed, the ensemble of the transducers can be appreciated in the figure 1b.

2.2 Experiments

For the experimentation it is necessary to know the vibration amplitude just in the tip of the transducer. To know the vibration amplitude in all experimentation time, a curve between the feeding current and the vibration amplitude was done.

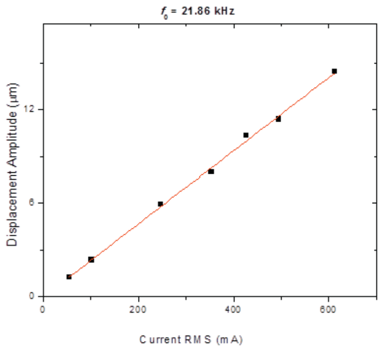

Figure 2.- Curve vibration amplitude vs current feeding

The relationship between the feeding current and the vibration amplitude in the tip of the transducer is quite linear, this allows the determination of vibration amplitude for any current, and of course, in the threshold amplitude of atomization.

2.3 Threshold detection strategy

Little amounts of liquid to be atomized were deposited in the tip of the transducer, afterwards the vibration amplitude were increased until it reach a level enough to produce atomization. To know the vibration amplitude just where the threshold was reached, the feeding current were recorded and afterwards the curve for each transducer were used to determinate the vibration amplitude, for instance the figure 2 curve for 21.86 kHz transducer. It is very dificult to catch just on time the threshold of atomization, to solve this problem the camera was programed to start the filmation when a modification of liquid profile appears in the camera fovea (focus). Once the camera starts operating, the current measurement and the camera recording were syncronized. An examination of recorded information allows the determination of atomization threshold.

2.4 Experimental set-up

The experimental set-up is shown schematically in figure 3a. In the figure 3b a picture of the experimental system can be appreciated.

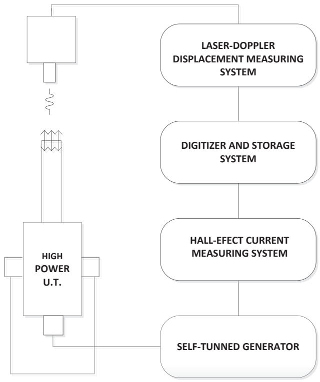

Figure 3a.- Schematic of experimental set-up.

Figure 3b.- Picture of experimental set-up

3. Results

In the figure 4a theoretical predictions for threshold amplitude for distilled water are shown, in the figure 4b the experimental threshold amplitude for the same frequencies are shown. It is clear that the threshold amplitudes predicted are lower than the experimental ones by a third. However the tendency curve is similar for frequencies up to 22 kHz. For frequencies above 22 kHz the experiments show increasing values in the atomization threshold whereas the theoretical predictions continued lowering in a monotone way.

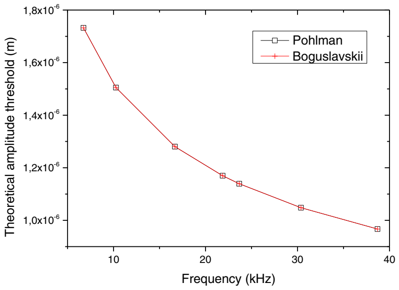

Figure 4a.- Theoretical amplitude threshold.

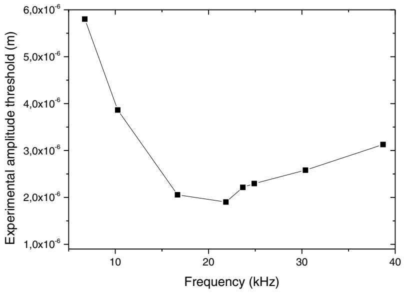

Figure 4b.- Experimental amplitude threshold.

The theoretical predictions were done using the atomization theory developed by Yu. Ya. Boguslavskii and O. K. Éknadiosyants in 1969. This theory predicts the atomization threshold from a theoretical model based in a paper published by Sorokin in 1957. The theory predicts a threshold for capillary waves formation and when a critical amplitude, At, is overcome by a little amount, the capillary waves become unstable, their amplitudes grows exponentially and the atomization starts. The expression to predict the atomization threshold is:

$$A_{\text{crit}} = \left(\frac{2\eta}{\rho}\right)\left(\frac{\rho}{\pi\sigma \text{f}}\right)^{1/3}$$

Where, η is the kinematic viscosity, ρ is the density, σ is the surface tension and f is the frequency.

4. Conclusions

From the figures 4a and 4b it is clear that the theoretical predictions are wrong, in excess of the experimental results. This shows a lack of research, theoretical as well as experimental, in the field of ultrasonic atomization. However the tendency of both curves, theoretical predictions and the experiments, are similar. The predictions show a monotone decreasing of atomization threshold with the frequency, however, the experiments shows an opposite tendency for frequencies greater than 22 kHz. This could shows that there is an important frequency dependent term not included in the theory. Nevertheless the experimental data obtained is valuable and can be employed in the design of high power ultrasonic atomizers. Also the methodology developed can be used to establish the atomization threshold for more complex liquids.

Acknowledgements

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References

A. E. Crawford, ‘Production of spray by high power magnestostriction transducers’ J. Ac. Soc. Of America 27, 1 176 (1955).

B. Avvaru, M. N. Patil, P. R. Gogate, A. B. Pandit, ‘Ultrasonic atomization: Effect of liquid phase properties’, Ultrasonics 44, 146-158 (2006).

D. B. Harmon Jr. ‘Drop sizes from low speed liquids’ Journal of Franklin Institute 259, 6, 519, 522 (1955).

K. Söllner ‘The mechanism of the formation of fogs by ultrasonic waves’, Transactions of Faraday Society, 32 1532-1536, (1936).

L. D. Rozenberg O. K. Eknadiosyants, ‘Kinetics of ultrasonic fog formation’ Akusticheskii Zhurnal, 6, 3, 370-373, (1960).

Neppiras E. A. ‘The pre-stressed piezoelectric sandwich transducer’ Proceedings of Ultrasonic International Conference, pp 295-301 (1973).

R. Lang, ‘Ultrasonic atomization of liquids’, J. Ac. Soc. of America, 34, 4, 6-8 (1962).

R. Rajan, A. B. Pandit, ‘Correlations to predict droplet size in ultrasonic atomization’ Ultrasonics, 39, 235-255 (2001).

S. Lagutkin, L. Achelis, S. Sheikhaliev, V. Uhlenwinkel, V. Srivastava, ‘Atomization process for metal powder’, Materials Science and Engineering A, 383, 1-6 (2004)

V.I. Sorokin, ‘The effect of fountain formation at the surface of a vertically oscillating liquid’. Soviet Physics, Acoustic 3 281-291 (1957).

W. R. Wood and A. L. Loomis, ‘The physical and biological effects of high frequency sound-waves of great intensity’ Phil. Mag. 4, 7, 417-436 (1927).

Yu. Ya. Boguslavskii and O. K. Éknadiosyants ‘Physical mechanism of the acoustic atomization of a liquid’ Soviet Physics – Acoustics, vol 15, N° 1, pp 14-21 (1969).