ON SONOCAPILLARY EFFECT

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Abstract

Sonocapillary effect, comprising the increase of depth and velocity of penetration of liquid into canals and pores, is one of the main mechanisms of crushing hard particles and cleansing of surfaces from impurities in the ultrasound cavitation mode. The paper describes experimental measuring of sonocapillary pressure. The integral difference of pressure readings between the phase of compression and rarefaction was measured at the capillary end by means of a miniature piezosensor. The resulting measurement is alternate and correlates to the height of liquid rise in the capillary. This is what comprises a certain pressure differential ΔP_0, which is compensated by the weight of the liquid inside the capillary and is, in effect, the sonocapillary pressure With the help of a digital camera a video and some still images of the cavitation area have been produced, which show that it is localised at the end of the capillary in the form of a pulsating solitary bubble or bubble cluster. In the latter case the maximum sonocapillary pressure is changed reaching the value of 1atmosphere.

Introduction

Sonocapillary pressure is normally determined by means of measuring the pressure necessary to squeeze the liquid out of the capillary in the presence of an ultrasound field and depends on the diameter of a capillary, its position with regard to the emitter, the temperature and physical characteristics of the liquid, and the ultrasound field parameters. There are many hypotheses with regard to the nature of the sound capillary effect [1]: meniscal, vibratory, radiation pressure, hydrodynamic, cavitational. However, with the ultrasound pressure values being below the cavitation threshold, only an insignificant rise of capillary liquid is observed. When a capillary is placed in the developed cavitation area in the form of a cluster the height of the liquid rise is a power more than the one resulting from the surface tensile forces, radiation pressure or ultrasound being applied to the meniscus. In such area an abnormally high constant pressure is observed under the capillary section [2,6].

All physical characteristics of the liquid and parameters of the induced ultrasound field influence the cavitation threshold and determine the pressure profile curve in the developed cavitation zone. This profile curve is asymmetrical, with the area of lower half-periods not being equal not being equal to the upper ones, they are cut off at the cavitation threshold level and have a small dip due to pressure decrease in the vicinity of expanding bubbles. Upper half-periods have a bigger amplitude and high frequency sharp peaks due to the collapse of bubbles. Thus, application of such type of pressure creates a constant and usually positive pressure constituent which can be referred to as sonocapillary pressure.

Description and results of the experiment

The cavitation area is formed centrally in the spherical piezoelectric concentrator, which works on two frequencies, radial (30kHz) and thickness (200kHz) resonances and is photographed with a digital camera SensiCam Fast Shutter (PCO, Kelheim, Germany) with an exposure of up to 100ns and with a light flash (ИСШ-400, duration 1μs). A glass capillary or a tube is mounted to the centre of the concentrator. Fig. 1 shows cavitation area in the centre of the spherical concentrator.

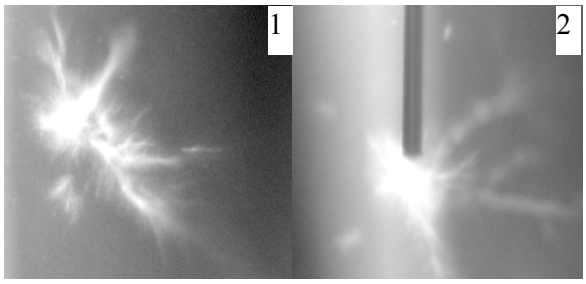

Figure 1 : Cavitation areas in the centre of the sphere in 0,5% NaCl, f=31kHz, V=120V, 1- without sensor, 2- with sensor (d=0.6mm).

Fig. 2 shows values of rms acoustic pressure for various liquids along the axis of the concentrator focal area, with them being quasi-permanent inside this area at both 200kHz and 30kHz. This proves indirectly that a developed cavitation zone is formed in the centre of the sphere when intensity is higher than threshold. The measuring was performed by means of miniature piezosensors with sizes 1,3 mm. The liquids used were tap water, ethylated spirits, 50% solution of glycerine and 0,5 % NaCl in water.

The process of rising liquid in the capillary is unstable, with the upper boundary changing and liquid sometimes leaving the capillary altogether, or with a “pumping” mode being created when the

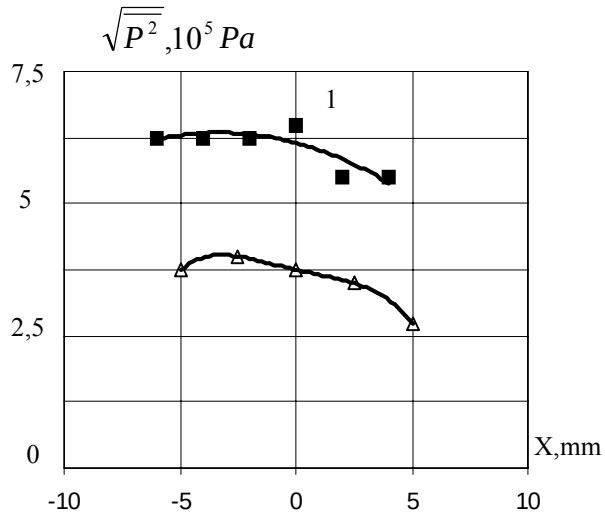

Figure 2 : The distribution of mean acoustic pressure along the axis crossing the focal area of the concentrator in water. V=262,5V, 1 - f = 30 kHz, 2 - f = 200 kHz.

liquid is overflowing. Evidently, the powerful Eckart flows occurring due to energy loss because of cavitation, vortex development and stream-gas plugs carry the bubbles from under the capillary and change the pressure distribution in the upper cavitation area. Hence, there are certain difficulties in the systematization of experimental data.

Fig.3 shows height values (H_m) and the speed of tap water rising (U) in the capillaries from the acoustic pressure amplitude, (H_m=h-h_c), where h is the total height of the rise, h_c – height of the rise due to capillary forces. The data have a significant variance. However, it can be noted that the height and the velocity of liquid rise are proportional to the acoustic pressure amplitude and, up to a certain level (7atm), grow with its increase; then the dependency on the value of acoustic pressure stops until the total disappearance of the effect with amplitudes higher than 10 atm. The maximum height of the rise was often impossible to measure due to insufficient length of capillaries, the majority of which being no more than 40 cm long. The squares in Fig.3a show data for the capillary with diameter d_c=0.9 mm, height of 0.9 m.

The most significant variance in results was achieved when working with spirits. The height rise and velocity deviate greatly in their values. We explain this by the specifically two-phase mode of the flow, the creation of steam-gas plugs and the increase of hydrodynamic resistance up until the stoppage of the flow inside the capillary. Fig. 4 shows cavitation areas formed at the capillary end, and the state of liquid inside the capillary for ethylated spirits, 50% glycerine, and water at the same ultrasound field parameters. It does not appear viable to measure the acoustic capillary pressure accordingly to the liquids' height rise ΔP_o=ρgH_m due

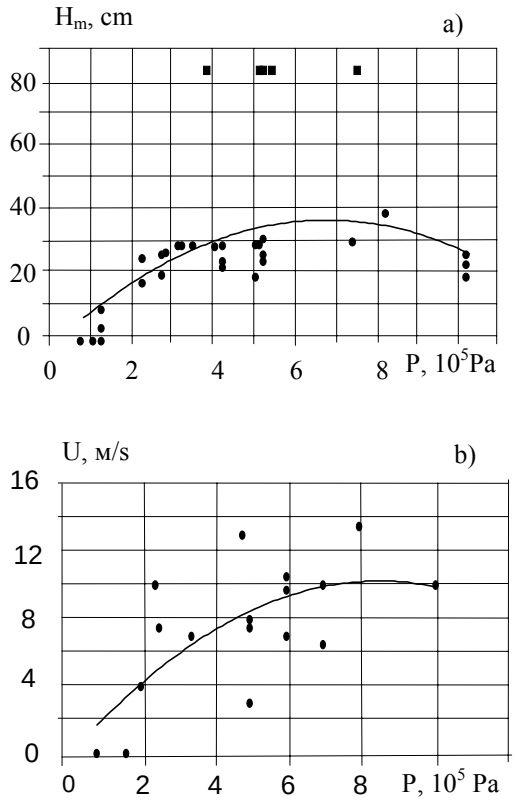

Figure 3 : The dependence of the height of the rise of water H_m (a) and mean velocity U (b) in the capillary (d_c=0,7 mm) on the acoustic pressure amplitude, f=30 kHz, V=90 V.

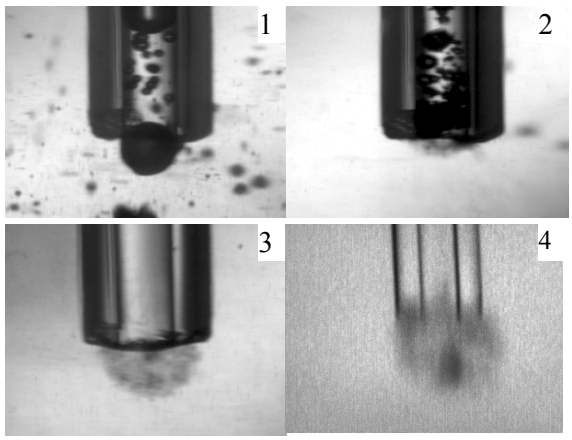

Figure 4 :Shape of cavitation area and state of various liquids inside the capillary (d_c=0,6 mm) at the same ultrasound field parameters: f=28 kHz, V=90 V. 1, 2 - spirits, 3 - 50% glycerine, 4 - water.

to a large variance in the data and the influence of a large number of parameters which are difficult to register.

The paper is mainly focused on the new method of the acoustic capillary pressure measurement as an integral difference between the positive and the negative pressure phases. It was registered on to a high-frequency Schlumberger tape-recorder with a permitting frequency band of up to a 170 kHz. Further, the signals of positive and negative phases,

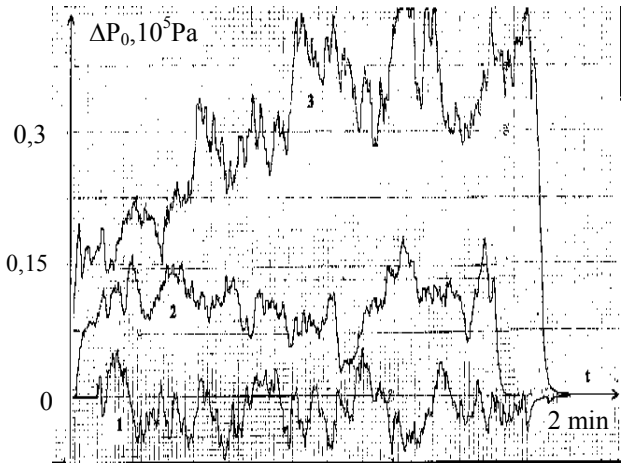

Figure 5 : Integral pressure difference at various emitter voltages in water; 1-V=40V, H_m=0; 2 - V=90V, H_m= 85 cm; 3 - V=120V, H_m > 85 cm.

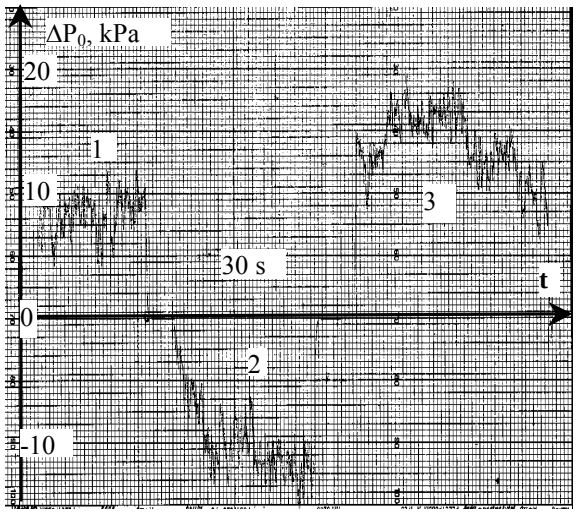

Figure 6 : Integral pressure difference ΔP_0 at the end of the capillary. 1 - water, 2 - spirits, 3 - 50% glycerine.

which have gone through the various integrating circuits with a time constant equal 30 periods of an ultrasound wave, were passed on to the deducting circuit with a time constant equal to 120 periods of the wave, and were registered with a Robotron self-registering device. This difference was measured depending on the voltage of the emitter (Fig.5) and for different types of liquid (Fig.6). It deviates with frequencies about several Hertz and is synchronized with surface undulations of the liquid in the capillary.

Its mean value increases proportionally with the emitter voltage (with ultrasound wave amplitude of up to 10 atm.), varies for different liquids, and can assume a negative value (Fig.6) when the liquid leaks out of the capillary. At the same voltages at the emitter and for the same type of liquid, its value corresponds to the acoustic capillary pressure determined by the method of squeezing the liquid out

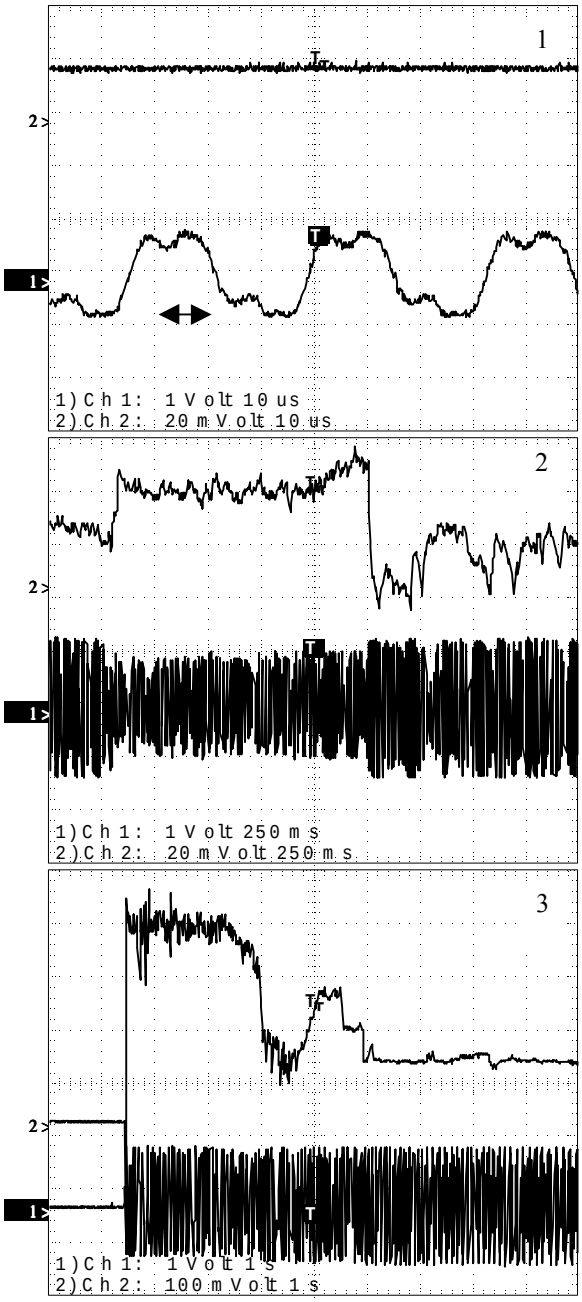

Figure 7 :Sonocapillary pressure (Ch 1) and pressure profile (Ch 2) of ultrasound wave (3μV/Pa), 1- without a bubble, 2- with a bubble, 3- with a cluster.

of the capillary in the presence of an ultrasound field [3,4]. It must be noted, that for each specific type of installation, size of the concentrator, physical characteristics of liquids and parameters of the ultrasound pressure field at the capillary end a specific type of a pressure field is established, and the measured quasi-permanent pressure value ΔP_o is changed. Fig.5 shows, that with the increase of the concentrator voltage up to 120V, this pressure value does not settle immediately, and it takes a certain time (about a minute in this particular case) to get to a quasi-permanent regime. Fig.6 shows the data for three different types of liquid under the same experimental conditions. For water and spirits these

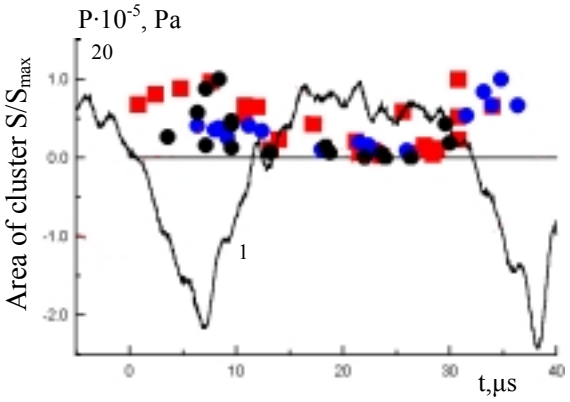

Figure 8 : Cluster area dynamics and pressure profile (1) of the ultrasound field.
● - water, ■ - 50% glycerine.

values are approximately the same in the absolute values, but have opposite phases, and for the water solution of glycerine, this value is 30% higher.

Also, as a rule, the height of the liquid rise in capillaries and tubes is higher for water and glycerine than for the pure water, despite the fact that the viscosity of glycerine is higher than that of water. It is known, that when the viscosity is 50-100 Ns/m^2, which correlates to the viscosity of a 50% glycerine solution in water at 20–30°C, conditions are created for the increase in the amplitude of the positive pressure peaks and in the speed of bubble collapse [5]. It might be possible that this resulted in the increase of the sonocapillary pressure (Fig.6). Fig.7 shows sonocapillary pressure for 3 different types of cavitation area at the end of the pressure sensor located in the centre of the sphere: without "large" bubble (1), with the bubble (2), and with bubble cluster (3) (on channel 2), and the pressure profile (on channel 1) in the centre of the sphere. The signals were registered with a TDS 210 digital oscillograph (1ns per 8bit point). It is evident that in the case of cluster formation (3) the sonocapillary pressure increases 5 times and reaches 1 atm., in comparison with 0.2 atm when a "large" bubble is formed (2). The most stable symmetrical spherical cluster is formed at the capillary end in the 50% glycerine solution, with less stable and not always symmetrical in water, and a totally unstable in spirits. Fig.8 graphically shows the dynamics of the clusters' area together with the ultrasound wave profile in the centre of the spherical concentrator.

Conclusions

The analysis of the experimental data alows us to make the following conclusions: 1) the main mechanism of the sonocapillary effect is the ultrasonic cavitation. 2) Non-linear effects of cavitation and the type of signal from the pulsating and collapsing bubbles determine the pressure profile in the area of the developed cavitation, adopting different types: spherical symmetrical or asymmetrical cluster, solitary bubble or group of bubbles. The asymmetry of the pressure profile depends on the type and sizes of the cavitation area, and on the characteristics of the liquid: density, viscosity, surface tension, steam tension, gas saturation, amplitude and frequency of the ultrasound. The same parameters determine the value of the cavitation resistance of the liquid and the value of energy losses to create cavitation. 3) The value of the acoustic capillary pressure is determined by the integral pressure difference of the positive and negative phases of the signal measured at the cut off point of the capillary. It is quasi-permanent, but oscillates with the frequency of about several Hertz range, it also depends on the emitter voltage, the above mentioned liquid characteristics, and can be of both positive and negative values. 4) to calculate the height and the speed of the rise of the liquid in the open capillary one has to resolve a hydrodynamic equation of the movement of one или two-phase mixture with the pressure equal to the acoustic capillary pressure at one end of the capillary.

Acknowledgements

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