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The effect of shock wave and bubble coalescence in spherical cloud of cavitation bubbles on maximum temperature inside central bubbles

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Abstract. We present a theoretical analysis of the influence of shock wave propagating in bubble cluster and bubble combining in expansion phase on maximum temperature inside central bubbles. By using adiabatic model and assumptions for simplifying the problem we find that these parameters have significant effects on temperature rising in compression phase. In particular, the shock wave, in comparison to bubble combining, has a greater impact on the maximum temperature.

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Key words: shock wave, adiabatic model, compression phase, bubble combining

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1 Introduction

Single-bubble sonoluminescence (SBSL) was discovered in 1989 by Felipe Gaitan [1]. It is a light emission phenomenon from a single bubble in liquid irradiated by an ultrasonic wave. Although the driving pressure is usually a simple harmonic wave, the evolution of the radius of the bubble is complicated (slowing growth and rapid collapse). The bubble expands up to nearly ten times of its initial radius, then collapses extremely quickly and results in adiabatic heating of the gas inside the bubble. The collapse is followed by afterbounces with roughly the eigenfrequency of the bubble. Indeed after the expansion phase of the bubble in the first half cycle, severe collapse takes place in the second half-cycle and at the end of collapse light pulse is emitted. The pulse width of the light has been experimentally measured to be less than 50 ps [2,3]. It was shown that the light pulse is emitted periodically with the frequency of the ultrasonic wave [3]. The spectrum

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is broadband and can be fitted by a black-body formula with the effective temperatures ranging from 6000 to 25000 K [4-7].

Many different theories have been developed to explain sonoluminescence, but most researchers now agree that the observed light pulses are due to shock wave and compressive heating of the gas/vapor plasma to incandescent temperatures. Sonoluminescence has been studied a lot in the literature and has been attracted a great deal of attention for both multiple bubble sonoluminescence (MBSL) and single bubble sonoluminescence (SBSL). For a good review see [8,9]. Particle density, temperature and pressure during the implosion of cavitation bubbles depend on the experimental conditions. It seems that by choosing a suitable liquid and optimization of the effective parameters such as initial radius, acoustic pressure amplitude, initial temperature of the liquid and acoustic wave frequency the temperature and pressure can be greatly enhanced.

In 2002 Taleyarkhan optimized the experimental conditions and claimed that, in his experiment, the temperature and pressure in bubble center was so high that fusion has occurred. In fact, the goal of Taleyarkhan experiments was to create a suitable condition to have thermonuclear fusion during the compression of cavitation bubbles, and this means that the maximum temperature of Taleyarkhan experiment raises 100 times in comparison to typical sonoluminescence experiments [10].

In order to get this result a fundamental change in experimental technique was made, which allowed one to increase the kinetic energy of the liquid, accelerated toward the bubble's center, several times. Thus the effect of shock wave compression was enhanced drastically. They increased the amplitude of standing acoustic wave up to 10 times. It is worth to mention that in most of liquids cavitation can be occurred, when they are under the high tension as above. The test liquid used in experiments was a well-degassed organic liquid. Because of the high molecular weight $(M=64)$ and lower adiabatic constant $(\gamma=1.125)$ the speed of sound in acetone ($C_G=\sqrt{(R\gamma/M)T}$, R is the universal gas constant) is less than other common liquids that could be utilized. This leads to the formation of stronger shock waves. In recent years, the result of this experiment have been confirmed or challenged by many researchers [11-17].

In this work, the effects of various parameters including shock wave in cluster and coalescence of bubbles in expansion phase on maximum temperature inside the bubble are numerically investigated. This was done by using adiabatic model and applying some assumptions for simplifying the problem. It is important to note that the effects of these parameters are investigated theoretically and for full analysis of the problem and also comparing the results with experimental data we need to consider the other effects such as mass and heat diffusion, shock wave propagation inside the bubble in compression phase and chemical reactions among the particles inside the bubble.