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Role of Acoustic Pressure on the Dynamics of Moving Single-Bubble Sonoluminescence

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Abstract**—**Role of acoustic driving pressure on the translational-radial dynamics of a moving single bubble sonoluminescence (m-SBSL) has been numerically investigated. The results indicate that increase in the amplitude of the driving pressure leads to increase in the bubble peak temperature. The length and the shape of the trajectory of the bubble depends on the acoustic pressure and because of the spatially dependence of the radial dynamics of the moving bubble, its peak temperature varies during the acoustical pulses. The results are in good agreement with the experimental reports on m-SBSL.

Keywords**—**Bubble dynamics, Equation of the gas state, Hydrodynamic force, Moving sonoluminescence.

I. Introduction

Single-bubble sonoluminescence (SBSL) is the light emission from intense heating of gas inside rapidly collapsing bubble, which is irradiated with ultrasound in liquids. The SBSL in low viscous liquids is obtained by levitating the bubble near the pressure antinode of the ultrasonic standing wave [1]. Bubble levitation occurs because of a balance between the time-averaged acoustic radiation (Bjerknes) force and the time-averaged buoyancy force [2],[3]. In high viscous liquids SL bubble is not locally stable and often moves in a quasi periodic circular trajectory [4]-[5]. This alternative state of SBSL is called moving single-bubble sonoluminescence (m-SBSL) [6].

Since its discovery in 1989 [1], many studies have been done on the effects of ambient and external parameters on the dynamics and mechanism of light emission of SBSL [7]. Experimental and theoretical reports indicate that in the shape and mass diffusive stability conditions [8], [9], increase of the amplitude of the external ultrasonic wave leads to the increase in the gas temperature inside the bubble and its light emission intensity [7], [10].

In the present work we numerically calculated the translational-radial dynamics of a sonoluminescing bubble in N-methylformamide and investigated the role of the acoustic pressure on the bubble dynamics and the interior gas temperature. We saw that in a general state like what is observed in m-SBSL in sulfuric and phosphoric acid, increase of the acoustic pressure amplitude leads to increase in bubble peak temperature and change in the moving bubble trajectory [4],[5]. Variation of bubble peak temperature which leads to variation in the measured light intensity, previously has been reported for a spatially unstable air bubble in water [11]. Our calculations shows that because of dependence of bubble surrounding pressure field to its position, the bubble interior temperature varies during acoustical cycles because the compression ratio (R_{max} /R_{min}) changes due to the maximum bubble radius variation.

II. Theory

In the present work we used the coupled radial-translational equation of motion which recently has been extracted by Toegel et al. [12]. Although the Toegel et al. equation agrees with some measured bubble parameters such as velocity but fails in calculation of internal parameters such as temperature. We are interested to investigate the bubble interior temperature and its temporal radial evolution as well as its translational motion, we used a quasi-adiabatic equation of state for the gas inside the bubble.

In Ref. [12], Toegel et al. used an isothermal van der Waals equation of state which is not suitable for investigation of the Radial evolution of the realistic sonoluminescing bubble.

A. Bubble radial oscillation

The equation of the bubble radial evolution is the well-known Rayleigh-Plesset equation [13]:

$$\left(1-\frac{\dot{R}}{C}\right)R\ddot{R}+\frac{3}{2}\left(1-\frac{\dot{R}}{3C}\right)\dot{R}^2=\frac{R}{\rho C}\dot{P}_g-\frac{4\mu\dot{R}}{R}-\frac{2\sigma}{\rho R}+\left(1+\frac{\dot{R}}{C}\right)\frac{P_g-P_{acous}-P_0}{\rho} \quad (1)$$

Where, R, C, ρ, μ, and σ are the bubble radius, sound

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velocity in the liquid, liquid density, liquid viscosity and

surface tension at the bubble wall, respectively. P_0 is the ambient pressure and P_g is the pressure of the gas inside the bubble [14], [15]:

$$P_g = (P_0 + \frac{2\sigma}{R_0})\frac{(R_0^3 - h^3)^{\Gamma}}{(R(t)^3 - h^3)^{\Gamma}} . \tag{2}$$

Here, R_0, h and Γ are the ambient radius of the bubble, van der waals hard-core radius and polytropic exponent, respectively.

To calculate the temperature of the gas inside the bubble, we supplemented the Rayleigh-Plesset equation with the following differential equation [16]:

$$\dot{T}_g = -[\Gamma(Pe(t)) - 1]\frac{3R^2\dot{R}}{R^3 - h^3}T_g - (T_g - T_{w0})\chi_g / R^2 \tag{3}$$

In which $\Gamma(Pe(t))$ is the variable transition function from isothermal behavior to the thermal behavior of the bubble interior [17].

In (1) P_{acous} is the spatially distributed pressure around the bubble wall in the liquid:

$$P_{acous} = -P_a \sin(\omega t)(1 - \frac{\pi^2 |\vec{X}|^2}{6R^2_{fl}}) \tag{4}$$

Where, P_a, ω, $\vec{X}$ and R_{fl} are the amplitude of the driven pressure, the angular frequency of the sound field, the moving bubble position and the radius of the flask, respectively.

B. Equation of bubble translational motion

Translational motion of SL bubble has been calculated by double integrating of bubble translational acceleration, $\ddot{}$, obtained from full force-balanced translational-radial dynamics of the m-SBSL [12]:

$$R(t)^3\,\ddot{}\; = \frac{d}{dt}[(18\mu R + 3R^2\dot{R})(\quad - \quad) + 3R^3\,\dot{}\; - 2R^3\quad] \tag{5}$$
$$-3R^2\dot{R}\,\dot{}\; + 3\frac{\Theta_r\Theta_t}{R^2}[(6\mu R + 3R^2\dot{R})(\quad - \quad) + 3R^3\,\dot{}\; - 2R^3\quad - R^3\,\dot{}\;]$$

where, μ is the kinetic viscosity (shear viscosity / density) of liquid, and are the velocity field of the standing wave and SL bubble velocity vector relative to an inertial frame, respectively. is the gravitational acceleration and $R(t)$ is the temporal radius of the SL bubble which is described by (1). In (5) Θ_r and Θ_t are the introduced switches by Toegel et al. [12] and turn on the history force effect on the bubble translational-radial dynamics.

II. NUMERICAL RESULTS AND DISCUSTIONS

The results of our numerical calculation have been shown in

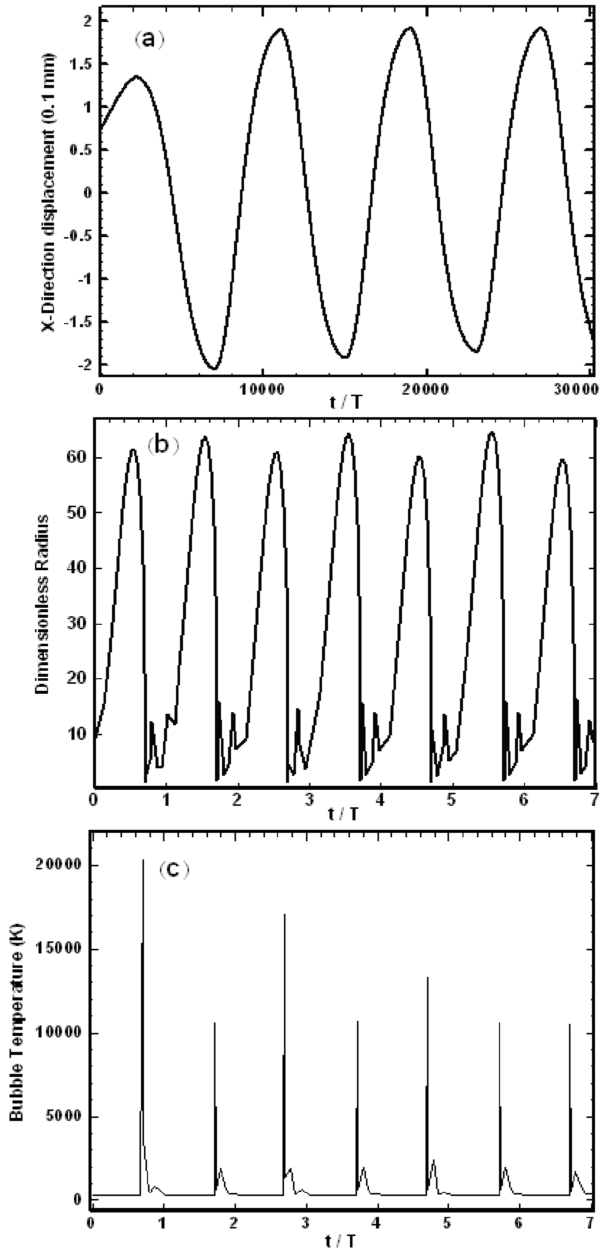

Fig. 1 calculated dynamics and temperature of moving SL bubble in N-methylformamide, with Pa=1.6 atm, R_0 =9.0 μm, and ω=30 kHz. (a) displacement of the radial oscillating bubble in X-direction, around the central antinode of the standing sound field in the liquid, during 30000 acoustical cycle. (b) bubble radial oscillations in seven acoustical cycles. Variations of the maximum radius of the bubble are because of the spatially distribution of sound pressure around the moving bubble. (c) bubble interior temperature during seven acoustical cycles. Peak temperature variations of the bubble interior are because of the various strength of the bubble collapses.

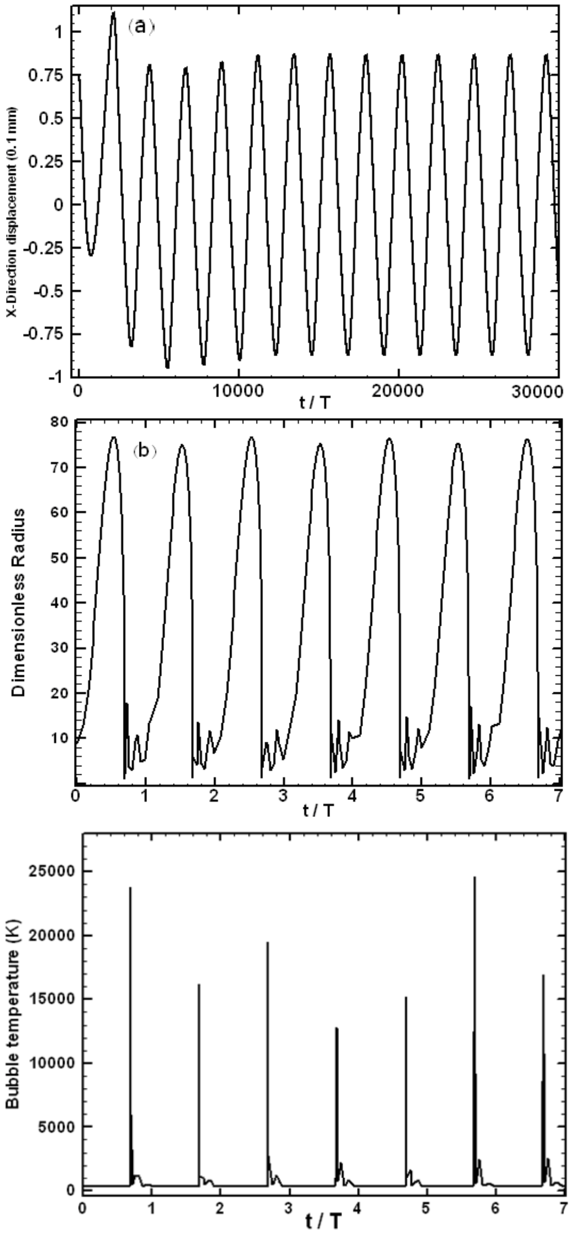

Fig. 2 calculated dynamics and temperature of moving SL bubble in N-methylformamide, with Pa=1.8 atm, R_0 =9.0 μm, and ω=30 kHz. (a) bubble displacement in X-direction during 30000 cycles, Comparison with Fig. 1 indicates that increase in acoustic amplitude results in the frequency of quasi periodic bubble trajectory. (b) bubble radius during seven cycles. Increase in the pressure amplitude increases the bubble maximum radius. (c) bubble interior temperature during seven acoustical cycles.

Figs. 1 to 3. In the calculation we set frequency of acoustical wave, ω=30 kHz, kinetic viscosity, μ=1.65 m^2 s^{-1} And surface tension, σ =0.038 Nm^{-1}. Also the bubble ambient radius, R_0 =9.0 μm and the amplitude of driving pressure has been set equal to 1.6 and 1.8 atm. In Fig. 1 moving bubble displacement, radial dynamics and interior temperature have been shown for the case of driving with the pressure amplitude of 1.6 atm. As we see in Fig.1 (a) oscillating bubble has a quasi-periodic displacement around the central antinode of the sound field in the liquid. Horizontal axis indicates the number of acoustical pulses. In Fig. 1 (b) the radial dynamics of the same bubble in seven cycles has been shown. Since the sound pressure around the moving bubble wall depends to the bubble instantaneous position in the liquid, the radial dynamics of the bubble is not as regular as SBSL radial dynamics in low viscous liquids. Here, different bubble maximum radius during the acoustical cycles results a variation in the strength of the bubble wall contraction. The various bubble peak temperatures in Fig. 1 (c) are the result of the above mentioned occurrence. Some experimental observations has been reported for air bubbles which are in good agreement with our results [11].

In Fig. 2 the effect of increase in the amplitude of sound pressure has been shown. In Fig. 1 (a) we see that the amplitude of bubble quasi-periodic displacement around the sound antinode decreases and its frequency increases. In Fig. 2 (b) we see that increase in the pressure amplitude led to increase of the bubble maximum radius. Thus due to the increase in the strength of the bubble collapse, peak temperature of the bubble has been increased in Fig 2 (c). Variation in the peak temperature of the bubble interior also exists in this condition.

In Fig. 3 the trajectory of the bubble of fig. 2 has been shown. In general accordance with experiment [6] the sonoluminescing bubble moves in a quasi-periodic trajectory around the central antinode of the standing sound field in the N-methylformamide.

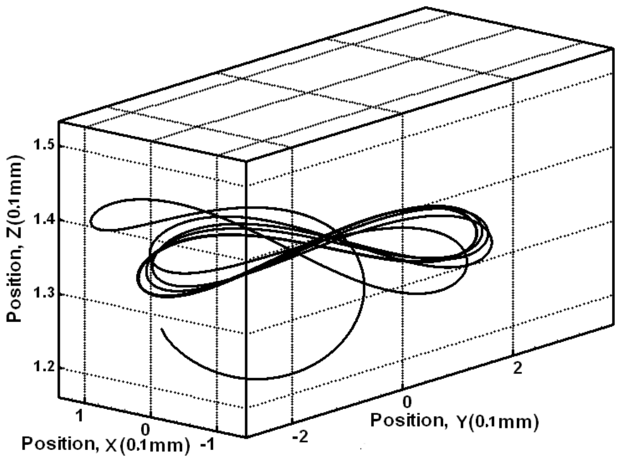

Fig. 3 trajectory of the bubble in fig. 2

III. Conclusion

With a quasi-adiabatic simulation of m-SBSL we were able to investigate the bubble translation and radial dynamics simultaneously. Numerical results showed that the increase of bubble trajectory increases the strength of the bubble collapse and consequently the bubble compression ratio increases. Due to the spatially dependence of the sound pressure around the bubble, a variation in the peak temperature of the bubble interior, which is consistent with the experimental report, is observed.

REFERENCES

[1] D. F. Gaitan, Ph.D. thesis, University of Mississipi, 1992; D. F. Gaitan, *et al*., . "Sonoluminescence and bubble dynamics for a single, stable, cavitation bubble, " *J. Acoust. Soc Am*., vol. 91,pp. 3166-3183, 1990.

[2] A. I. Eller, "Force on a biubble in a standing acoustic wave," *J. Acoust. Soc. Am.* vol 43, pp. 170-171, 1968.

[3] L. A. Crum, "Bjerknes force on bubbles in a stationary sound field," *J. Acoust. Soc. Am.* vol 57, pp. 1363-1370, 1975.

[4] D. J. Flannigan, K. S. Suslik, . "Dynamics of a sonoluminescing bubble in sulfuric acid, "*Phys. Rev. Lett*., vol. 95, pp. 044301, 2005.

[5] A. Troia, D. M. Ripa, R. Spagnolo, "Moving single bubble sonoluminescence in phosphoric acid and sulphuric acid solution, " *Ultrason sonochem*, vol. 13 pp. 278-282, 2005.

[6] Y. T. Didenko,W. B. McNamara, and K. S. Suslick, *Nature (London),* vol 407, pp. 887, 2000.

[7] M. P. Brenner, S. Hilgenfeldt, and D. Lohse, "single-bubble sonoluminescence, *Rev. mod. phys*., vol 74, no. 2, pp. 425-484, 2002.

[8] M. P. Brenner, D. Lohse, D. Oxtoby, T. F. Dupont, . "Mechanisms for stable single-bubble sonoluminescence, *Phys. Rev. Lett*., vol. 76, pp. 1158, 1996.

[9] M. M. Fyrillas, A. J. Sezri, . "Dissolusion or growth of soluble sphericsl oscillating bubbles-the effect of surfactants , " *J. Fluid. Mech*., vol. 289, pp. 295, 1994.

[10] A. Moshaii, R. Rezaei-nasirabad, Kh. Imani, M. Silatani, R. Sadighi-Bonabi, . "Role of thermal conduction on single bubble cavitation, " *Phys. Lett. A*.,vol. 372 , no. 8, pp. 1283, 2008.

[11] Ch. R. Thomas, R. A. Roy, and R. G. Holt, "Bubble dynamics near the onset of single-bubble sonoluminescence , " *Phys. Rev. E.*, vol. 70,pp. 066301, 2004.

[12] R. Toegel, S. Lutter, D. Lohse, "Viscosity Destabilizes Sonoluminescing Bubbles, " *Phys. Rev. Lett*, vol. 96 pp. 114301, 2006.

[13] B. Keller, M. miksis, . "Bubble oscillations of large amplitude, "*J. Acoust. Soc. Am.*, vol. 68, pp. 628, 1980.

[14] Lofstedt, R. K. Weninger, S. Putterman, and B. P. Barber, ''Sonoluminescing bubbles and mass diffusion,'' Phys. Rev. E., vol. 51,pp. 4400-4410, 1995.

[15] B. P. Barber, R. A. Hiller, R. Lo¨ fstedt, , S. J. Putterman, K. R. Weninger, ''Defining the unknowns of sonoluminescence,'' *Phys. Rep.,* vol. 281, pp. 65–143, 1997.

[16] Hilgenfeldt, S., S. Grossmann, and D. Lohse, ''Sonoluminescence light emission,'' *Phys. Fluids*, vol**.** 11, pp. 1318–1330, 1999.

[17] A. Prosperetti, , ''Thermal effects and damping mechanisms in the forced radial oscillations of gas bubbles in liquid,'' *J. Acoust. Soc. Am*. vol. 61, pp. 17–27.