Proceedings of the ASME 2010 3rd Joint US-European Fluids Engineering Summer Meeting and 8th International Conference on Nanochannels, Microchannels, and Minichannels
FEDSM-ICNMM2010
August 1-5, 2010, Montreal, Canada

FEDSM-ICNMM2010-31258

INFLUENCE OF SURFACTANTS ON BUBBLE ENTRAINMENT

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ABSTRACT

A drop impacting on a liquid surface may entrain a bubble resulting in sounds from the bubble oscillation in addition to that of the initial drop impact. This subject has received considerable interest with respect to the underwater sound produced by rain. The previous optical and acoustical studies have extensively examined the role of drop size and impact velocity as well entrainment formation mechanisms. However, the role of surfactants on the liquid surface has received less attention especially with respect to sound production. One previous study [1] of two different surfactants (Kodak Photoflo and a sulfo detergent) reports that these suppress entrainment resulting in diminished or negligible bubble noise. However, we have found bubble entrainment and acoustic emissions associated with the addition of a heptane layer on the water surface. Using a synchronized hydrophone and a high-speed camera, acoustical and optical data of the bubble drop dynamics were obtained. Particle image velocimetry (PIV) was also utilized to measure the surface velocity produced by the drop. These results show a significant difference in the drop rebound and subsequent fluid column dynamics, which results in a dual acoustic emission for the surfactant case.

INTRODUCTION

A liquid droplet impinging onto either a liquid or solid surface is of fundamental scientific interest and also of practical importance to a variety of industrial processes such as ink-jet printing [2], spray coating [3] and sputtering systems. Studies often incorporate high-speed imaging systems [4–6] for visualization and measurement of this rapid physical phenomena. Research work incorporating complementary acoustic measurements of the drop impact and bubble entrainment have focused on the mechanisms of underwater noise generation from rainfall [7, 8]. The investigation of surface tension in these acoustics studies has been limited to a few surfactant-water cases in which a dominant sound generation mechanism (primary bubble entrainment) was found to be significantly diminished [1]. A recent study [9] has shown enhanced thin film rupture of drops impacting a Heptane layer, with respect to a comparable water layer. The lower surface tension value of Heptane is hypothesized to contribute to the significant secondary drop development. We note the previous acoustic studies concentrated on regular entrainment regimes related to the collapse of the initial cavity. However, surface tension influences the secondary drop formation from the Rayleigh column [10], though its role in sound generation has yet to be rigorously explored. In this study, we investigate the acoustic and morphological differences of a water drop impacting onto a water surface covered by a thin layer of Heptane. Simultaneous acoustic and optical measurements are used to quantify the associated novel fluid dynamics and acoustics.

EXPERIMENTAL SETUP

The drop impact experiments were performed in a glass tank (50 x 32 x 26 cm^3), filled to 10 cm with degassed, filtered water

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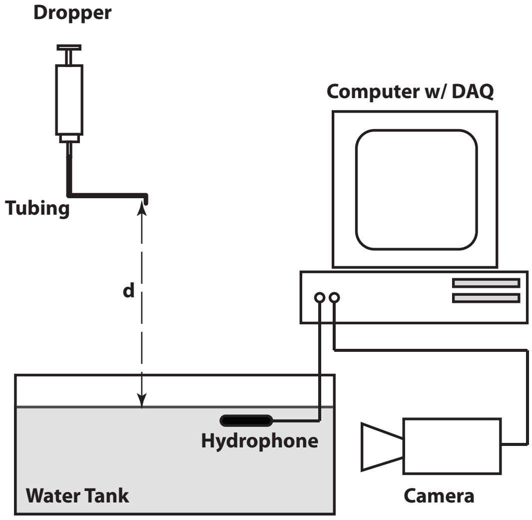

FIGURE 1. *The experimental setup for acoustic and high-speed imaging of water drop impact on water or heptane/water for a drop height d of 68 cm.*

at 22 ^oC (Fig. 1). The drops were formed with a 30 ml plastic syringe supported on a ring stand, connected to a 3.1 mm diameter silicone tube. The end of the tube was positioned 68 cm above the surface of the water. An IDT X-Stream XS-3 (CMOS) high-speed camera was used to record the droplet impact at 730-1000 frames/s. Droplet velocities and diameters were measured with the high-speed camera. The water drops had an average diameter and impact velocity of 3.4 mm and 3.5 m/s, respectively. A Bruell&Kjaer 8103 hydrophone was positioned approximately 3 cm from the impact site and 2 cm below the free surface. Recorded signals were amplified 20 dB (Reson VP 2000 preamplifier) and sampled with a National Instruments 16 bit 6251 USB data acquisition board at 100 kHz controlled with Labview. HPLC grade Heptane (40 ml) was deposited on the water surface to produce a uniform layer of 0.5 mm thickness. Dynamic surface tension measurements of the water and heptane were done using a tensiometer.

RESULTS

The acoustic signatures of oscillating bubbles entrained through a thin layer of heptane is shown in Fig. 2. Two distinct acoustic emissions, due to the oscillations of two separately entrained air bubbles, are produced under these drop conditions. The first emission consist of a temporally short high frequency oscillation, whereas the following emission is temporally extended and at a lower frequency. Figure 3 shows a close up of the two emissions with fitted amplitude envelopes. The decay constants for these two bubble signals where obtain by lease-squares fitting the data to a function of the form ae^{bt}. A ratio of the first sound decay constant b_1 to the second one b_2 of approximately 8

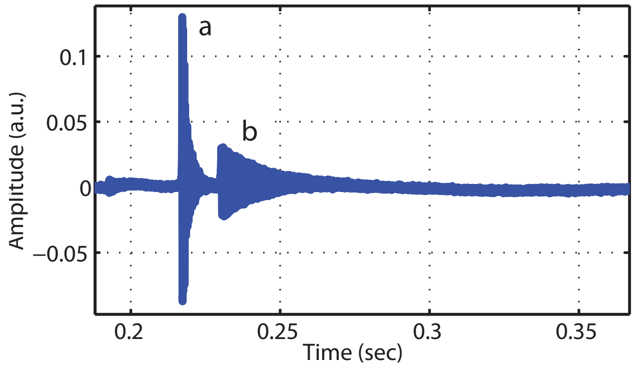

FIGURE 2. *Acoustic signature for water drop onto a water surface with heptane layer showing two entrainment sounds.*

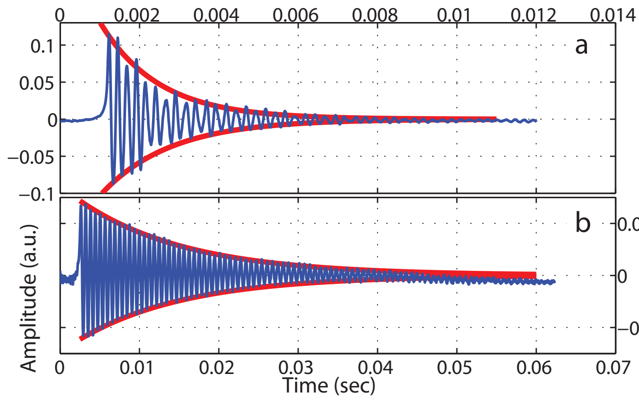

FIGURE 3. *Detail of the two entrainment sounds from figure 2 (note time scale difference.*

was obtained. The amplitude ratio a_1/a_2 was equal to 3.7.

For pure water, only one bubble is entrained for these drop conditions. The acoustic characteristics of this drop are similar the first sound produced from the heptane layer case (image not shown).

The mechanism for these two sounds can be illustrated by examining the images from the high-speed camera, Fig. 4. The crater formed from the initial drop impact retracts up to become the well known Rayleigh column [11]; no acoustic emission during this time. The breakup of the Rayleigh column into two distinct droplets begins when the column reaches its maximum height. The first drop to hit the bottom of the small secondary crater entrains a bubble through a film rupture (Fig. 4a); this produces the higher frequency emission. This is immediately followed by the impact of the second drop, which entrains the second bubble from a pinch off mechanism (Fig. 4b).

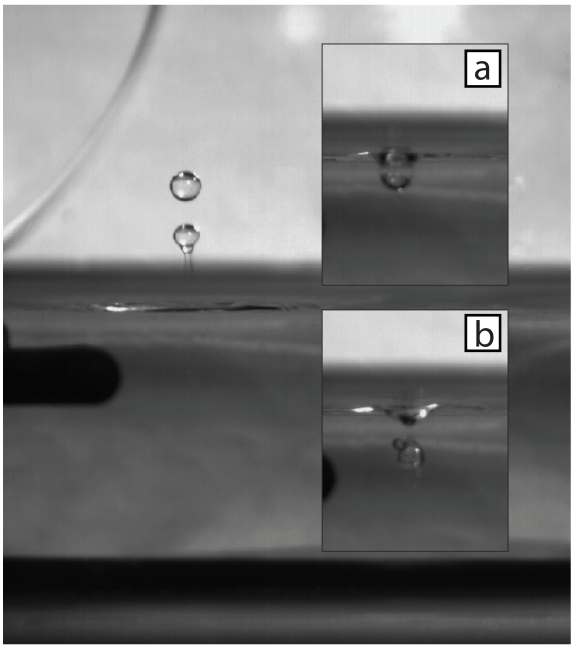

FIGURE 4. *For the heptane case, the break up of the Rayleigh column into two droplets results in the entrainment of two air bubbles.*

CONCLUSIONS

A Heptane layer generates additional air bubble entrainment and novel associated acoustic phenomena.

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