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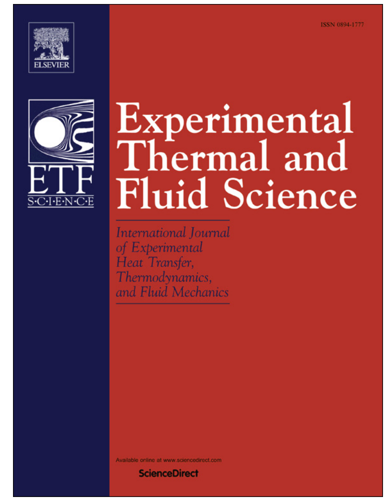

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ABSTRACT

The interactions of two oscillating bubbles beneath a free surface are studied with the help of high-speed photography. The collapse can produce liquid jets both in the bulk water and upon the free surface. Different interaction modes and surface jets are observed, which are significantly affected by the relative bubble-bubble distance and the relative depths below the free surface. The phenomena are summarized in a dimensionless parameter plot, where several regions are divided based on the collapse behavior. Particularly, a transition region is observed where different behaviors occur randomly. Based on the experimental results, the boundary lines between the regions are proposed in a wide range of parameters.

Keywords: Bubbles, Free surface, Interactions, Collapse jet, Surface jet

1. Introduction

The collapse behavior of cavitation bubbles plays an important role in many industrial and clinical applications. In free fields, the dynamics of a single cavitation bubble can be estimated from the Rayleigh-Plesset equation, based on the theoretic work by Rayleigh [1]. In recent decades, the development of high-speed photography allows to capture the bubble dynamics in detail, which greatly promotes the knowledge of cavitation bubbles, especially about their collapse process [2]. Various collapse behaviors were observed, which were greatly affected by the surrounding interfaces and the other bubbles nearby.

On the collapse of a single cavitation bubble, many publications have covered several different boundary conditions, such as in the neighborhood of a rigid wall, a free surface, or an elastic membrane. Based on experimental and numerical results, it was found that the collapse often developed a liquid jet. Ignoring the gravitational effects, the jet can be directed towards a rigid wall [3, 4], or directed away from an air-water surface [5]. The direction of the liquid jet could be predicted by Kelvin impulse theory, as proposed by Blake [6]. The effect of an elastic membrane was also studied for potential biological application, which was observed to induce mushroom shape, elongation and splitting of the bubble [7]. The boundary integral method is widely applied in the area of bubble collapse, in order to provide quantitative details of the bubble deformation and the liquid jet [8, 9]. In recent years, this numerical method was also employed to study the final collapse stage and the rebound [10, 11].

Besides the boundary condition, a second cavitation bubble nearby also affects the collapse process significantly. As demonstrated by Fong et al. [12] and Chew et al. [13], the collapse of a bubble pair in a free field develops two liquid jets in most cases, which could be directed towards each other or away from each other, determined by the phase difference and the bubble size difference. Otherwise, the two bubbles may merge during the expansion phase, or go through a particular “catapult” deformation. Recently, Han [14] numerically studied the speed of the