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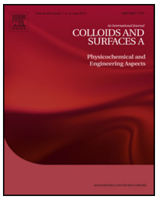

Influence of external vibrations on bubble coalescence time at water and oil surfaces—Experiments and modelling

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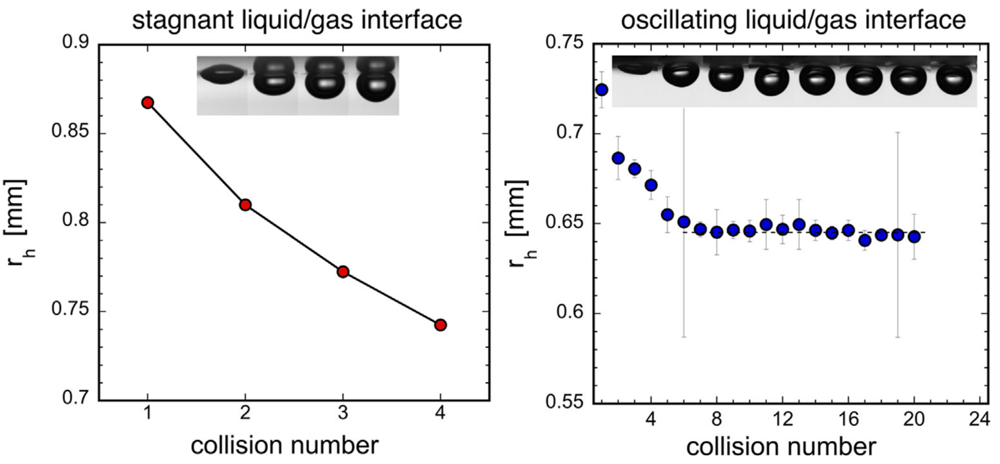
GRAPHICAL ABSTRACT



HIGHLIGHTS

- Bubble collision courses on stagnant and oscillating liquid/air interfaces are compared.
- For stagnant interfaces the coalescence time is bubble radius dependent.
- At oscillating interfaces coalescence time can be prolonged significantly.
- This is related to degree of bubble deformation determining size of liquid film.
- Higher acceleration prevents coalescence of bubbles of higher Laplace pressure.

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ABSTRACT

We report results of the experiments and numerical simulations on kinetics of collision, bouncing and coalescence of air bubbles at free surface of pure liquids of different viscosities. The bubble collision and bouncing courses on the stagnant and vibrating (with controlled acceleration), water/air and silicone oil/air interfaces are compared. For stagnant interfaces the coalescence time (t_c) was found to be the bubble radius (R_b) dependent. For larger bubbles the t_c was longer. This was caused by higher impact velocity resulting in an increased bubble deformation and higher tendency of the bubble to rebound from the liquid/gas interface. At oscillating liquid/gas interfaces with proper vibration frequency and amplitude the bubble coalescence time can be prolonged significantly as a consequence of prolongation of the bubble bouncing time. This was due to the fact that the energy dissipated during the bubble collision

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Coalescence
Kinetic energy

and bouncing was re-supplied via interface vibrations with a properly adjusted acceleration. The analysis of the bubble deformation showed that this effect is related to the degree of the bubble deformation, which determined size of the liquid film formed at the interface. The bubble was bouncing when radius of the liquid film formed was large enough to prevent the draining film to reach a critical thickness of rupture during the collision time. Moreover, it was found that higher acceleration should be applied to prolong the coalescence time (t_c) of the bubbles having higher Laplace pressure. The results obtained prove that mechanism of the bubble bouncing from various interfaces depends on interrelation between rates of two simultaneously going processes: (i) exchange between kinetic and surface energies of the system, and (ii) drainage of the liquid film separating the interacting interfaces.

1. Introduction

The coalescence of air bubbles is the phenomenon occurring always when air is being dispersed in a liquid phase. It can, for example, affect the rate of formation and stability of foams, due to the fact that the foam layer is formed only, if the number of bubble arriving at the solution surface exceeds the number of rupturing ones. Moreover, the coalescence of air bubbles plays an important role in processes carried out in bubble columns, gas strippers, distillation towers, direct-contact evaporators, flotation columns and stirred aerated tanks [1]. In reactors and separation tanks, where the highest degree of dispersion of the air phase is desired, the coalescence phenomenon is unfavourable—due to the coalescence the radius of bubbles increases. As a result, the interfacial area can be drastically reduced as well as the mass transfer rates. For example, during flotation separation process, where the bubbles act as carriers of grains of useful minerals suitable, degree of dispersion is crucial for flotation efficiency. Moreover, the coalescence changes the velocities of the bubbles, affecting simultaneously the flow regimes. The energetic relations during bubble-solid surface collisions can be changed due to such flow regimes variations, what can affect the effectiveness of bubble-grain aggregate formation. Therefore, controlling of degree of dispersion of bubbles is important also from the practical point of view. This is straightforwardly related to mechanism of the coalescence phenomenon, which is complex and whose mechanisms are still not fully understood [2].

Among many methodologies a high-speed video monitoring of collisions of single bubbles with liquid/gas interfaces is a convenient way to study kinetics of the bubble coalescence phenomenon. Here, the coalescence is monitored under dynamic conditions, which are close to that encountered in real processes. Generally, it was postulated theoretically [3] that during the bubble collisions with liquid/gas interface, the kinetic energy associated with its motion is transferred into the surface energy related to increased bubble surface area during the collision. The bubble ruptures if the rate of the energy exchange is slower than rate of the film drainage to its critical rupture thickness. Otherwise, the bubble bounces apart and this spectacular phenomenon can be observed even at the surface of pure liquids. This theoretically postulated mechanism had been confirmed later on the basis of experimental observations [4,7,8] and numerical calculations [5,6]. It was shown experimentally that the bubble bouncing at surface of pure liquid could be prolonged almost indefinitely when the kinetic energy is re-supplied to the system by a controlled induction of the surface waves at the liquid/gas interface.

In this paper we present results of systematic studies documenting importance of size of the liquid films formed in kinetics of coalescence of the bubble colliding with surfaces of pure liquids. We found that prolongation of the bubble bouncing can be obtained in the case of pure liquids only if the induced surface waves, causing the energy supplement to the system, have suitable frequency and amplitude (acceleration) to assure that size of the liquid film formed is large enough. Moreover, this threshold acceleration depends on the liquid surface tension and bubble size, i.e. factors affecting the value of Laplace pressure – parameter determining the bubble shape deformability.

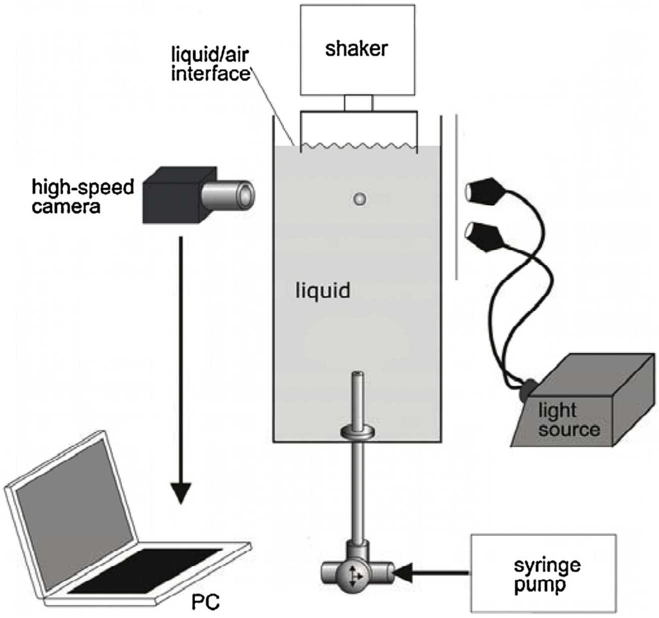

Fig. 1. Experimental set-up.

2. Materials and methods

2.1. Experiments

Fig. 1 presents schematic illustration of the experimental setup used for monitoring the bubble collision with liquid/gas interfaces [8]. A single bubble was formed at the capillary orifices of various inner diameters (cap. ID), ranging between 0.025 and 0.150 mm at the bottom of a square glass column (45 × 45 mm). The experiments were carried out either in Milli-Q® water or silicone oil of kinematic viscosity 0.65 cSt (Xiameter PMX-200 silicone fluid). The liquid/gas interface was located at distance ca. 130 mm from point of the bubble detachment, which was far enough for establishment of the bubble terminal velocity. Precise syringe pump (NE-1000, NewEra Pump Systems) was used to control the bubble formation and release frequency. The motion of the bubble was monitored and recorded using high-speed video cameras (Weinberger, SpeedCam MacroVis and/or IDT NX5) of frequency 1000–5000 fps. Sequences of the recorded frames were analysed frame-by-frame using image analysis software (ImageJ [9], Sigma Scan Pro, Motion Studio) to determine the bubble horizontal (d_h) and vertical (d_v) diameters, its equivalent radius ($R_b = 0.5[d_v \times d_h^2]^{1/3}$), degree of shape defor-

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