Influence of air pressure on bubble entrapment in drop impact onto solid surfaces

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Abstract

An experimental study of the impact of glycerol/water drops onto a dry glass surface at different ambient pressures is presented. During the impact of a high-viscosity liquid drop onto a solid surface, air can be entrapped in the form of bubbles of different sizes. Depending on the impact conditions, the bubbles are distributed forming several patterns. In a previous work on drop impact, we observed, for sufficiently large capillary numbers, the existence of a ring of micro-bubbles, delimiting an outer cloud of bubbles. This outer ring, along with the smaller ring surrounding the entrapped central bubble, were characterized for wide ranges of impact conditions. In the present work, we investigate the influence of the ambient air pressure, which in previous works has been found to be a relevant parameter for splashing inception, on the formation of the bubble patterns. Investigating the dependence of the rings size on liquid viscosity and ambient pressure may help assess different possible scenarios occurring during the impact process. We carried out new experiments of impacts of drops of a glycerol/water mixture in a vacuum chamber that allowed the ambient air pressure to vary between 20 and 100 kPa. A high-speed digital camera was used to capture the images of the impact at a rate of about 63 000 fps, with a shutter speed varying from 1 to 13.75 μm, an image size of 256×128 pixels and a typical resolution of 15 to 25 pixel/mm. The images were captured from below, with back lighting provided by a 575 W metal halide lamp, without a diffuser placed between the lamp and the drop impact area. This method, although not appropriate to visualize the spreading of the lamella and entrapment of bubbles in detail, indirectly reveals some flow features that may shed some light on the phenomena involved in bubble entrapment and help determine the instant at which the lamella separates from the solid surface. Attention is mainly focused on the existence and evolution of the observed rings of micro-bubbles. We propose correlations for the size of the rings of micro-bubbles measured in impacts of drops of three different glycerol/water mixtures at atmospheric pressure and impacts of 3:2 (v/v) glycerol/water drops at different ambient pressures, as a function of the relevant parameters. The dependence on the impact Reynolds number and ambient pressure of the critical Stokes number at which an abrupt jump in the size of the outer ring of micro-bubbles occurs is discussed. Some authors have proposed the hypothesis that the liquid sheet might originate as a result of the interaction of the drop liquid with the intervening gas layer, before the drop contacts the solid surface. However, some findings of the present work do not point to the persistence of a thin air layer beneath the spreading drop at the time a splash is produced. We have observed effects of the liquid viscosity on the location of the micro-bubble rings, which suggests an extensive liquid-solid contact before a liquid sheet is ejected. On the other hand, it has been observed that the size of the inner ring of micro-bubbles increases with the Stokes number, following a dependence law that compares reasonably well with the prediction made by other authors for the radius at which sheet ejection (accompanied by a breakdown in the continuum theory) occurs, which suggests that the model proposed by these authors is adequate at least for the early stages of impact. It has also been found that the size of the outer ring of micro-bubbles increases with decreasing ambient pressure, and that the influence is higher for Stokes numbers smaller than the critical value where the jump in the radius of this outer ring occurs. Another finding is the slight dependence on the ambient pressure of the critical Stokes number, which increases with decreasing ambient pressure (i.e., the jump occurs at smaller velocities when the ambient pressure is reduced). These trends are consistent with the known fact that a reduction in the ambient pressure tends to suppress splashing.

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