Bubble-Object Interactions: Dynamics of the Separating Liquid Film

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Abstract:
Slurry bubble columns, used in environmentally-conscious industries, operate as complex three-phase systems with fluid, gas, and particles. Understanding the interactions between these phases is crucial for sustainable column design. Bubble-object interactions are investigated using a simplified two-dimensional consideration as a cylinder instead of the three-dimensional nature of particles in the fluid domain as a fixed obstacle. It is found that increasing the Weber number reduces the film thickness between the bubble and object, with bubble breakup occurring at a critical Weber number of 0.47. This approach provides insight into particle-bubble dynamics, aiding in column design optimization.

Keywords: Bubble-particle interaction; separation liquid film; multiphase flow; bubble column

Introduction:
In response to growing concerns about climate change, industries have increasingly focused on reducing greenhouse gas emissions and adopting efficient fuels and raw materials. An effective solution in the chemical, biochemical, and petrochemical sectors is the use of slurry bubble column reactors (SBCR) [1]. Due to the complex nature of these three-phase systems (liquid, gas, and particle), various studies have been conducted to investigate the effects of particle porosity, concentration, size, and wettability on the gas holdup, efficiency, and behavior of these columns [2], however, a deeper investigation of bubble-particle interaction remains necessary to enhance our understanding.

In this study, a simplified experimental setup based on the interaction of a fixed cylinder is employed to investigate bubble and particle interactions. Previous studies have reported the existence of a liquid film, ranging from 20 to 700 μm in thickness, between bubbles and cylinder [3, 4]. This film prevents any direct contact between the bubble and the cylinder and therefore manipulate the working condition of the column. To optimize column performance, a thorough study of the interaction's nature is essential.

Methodology:
The experimental setup consists of a Plexiglas square column filled with specific concentration of aqueous glycerol solutions (Morton number is equal to 0.022, $Mo = (\rho_L - \rho_G) g \mu_L^4 / \sigma^3 \rho_L^2$, where the ρ_L and ρ_G are the fluid and gas density, respectively, g is the gravitational acceleration, μ_L is the fluid viscosity, and σ is the surface tension), and bubbles are produced using a syringe, as demonstrated in Figure 1 (a). A stainless steel cylinder (d_c =1.47 mm) is fixed at the height of 5 cm from syringe as the fixed object. A high-speed camera (IDT high-speed camera, OS II – Series 8, Macro Lens 2.8/60 mm) captures bubble motion at 2500 Hz. Raw images are processed using open source software, FIJI, to post-process images and measure the distances.

Results and discussion:
The presence of the separation liquid film thickness is illustrated in Figure 1 (b). The deformation of the bubble interface near the cylinder's surface, observed from the beginning of the collision interaction until the end, demonstrates that this liquid film prevents direct contact. The bubble impact velocity (u_b) and equivalent diameter (D_{eq}) play a crucial role in characterizing impact behavior. To distinguish between different cases, the Weber number ($We = \rho_L u_b^2 D_{eq} / \sigma$) is utilized. Two distinct regimes are identified based on the behavior of the bubbles: cutting and non-cutting.

Figure 1 (c) shows the effect of the Weber number (We) on the behavior of the liquid film thickness (δ) at the normalized time (τ, the time is divided by the maximum time duration). The behavior of δ is fitted by a fourth-order polynomial equation (R^2 > 0.95). All plots start from a distance of 500 μm from the bottom

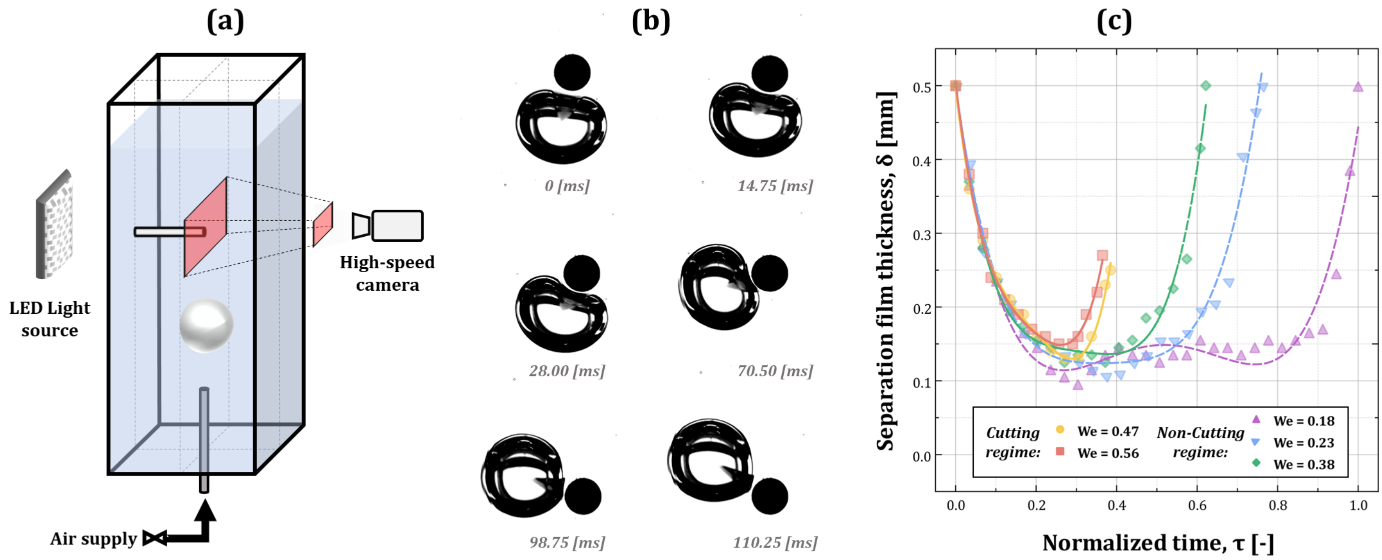

Figure 1: a) The illustration of experimental setup. b) Behavior of the separation liquid film in non-cutting bubble impact . c) Evaluation of the liquid film thickness (δ) during the time.

point of the cylinder. As the bubbles approach, their interfaces deform due to the cylinder and the local flow field. Upon reaching a certain distance from the cylinder surface, known as the minimum film thickness (δ_m), the bubble either attempts to rotate and pass around the cylinder or splits into two daughter bubbles, depending on the regime. Generally, δ_m increases with rising Weber number (We), ranging from 95 to 144 μm. This indicates that during the splitting regime, a film with a thickness of 6-10% of the cylinder diameter prevents direct contact and halts the wetting of the cylinder surface. The time during which the bubble interface is at a distance of δ_m from the cylinder is referred to as the "touch duration". In the non-cutting regime, the touch duration increases as the Weber number (We) decreases while the bubble attempts to pass the cylinder. In the cutting regime, after the touch duration, the thickness δ increases until the interface ruptures and two daughter bubbles form. It is important to note that both cutting scenarios involve asymmetric cutting.

Conclusion:

The behavior of the separation film thickness is investigated for two cutting regimes. The relationship between film thickness and dimensionless parameters as Mo and We number was revealed. A thorough study of the separation film offers better insight into bubble-particle interactions and aids in optimizing SBCR design.

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