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On interactions of stationary particles and rising bubbles

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1. Summary

The attachment of the bubbles onto a collecting surface or sphere (solid, air bubble and liquid droplet) is a ubiquitous natural phenomenon, playing a critical role in numerous practical processes. The goal of this project is to broaden our knowledge about hydrodynamic interactions between bubbles and solids of comparable size that occur in the flotation process. We studied the collision process between a single rising bubble and stationary spherical particle. The experimental research was focused on the description of a bubble trajectory, collision efficiency and the determination of the limit collision angle. A high-speed digital camera was used for the experimental documentation.

Keywords: bubble - particle interaction, collision efficiency, bubble trajectory

2. Extended Abstract

Flotation is one of the examples in which bubble-particle attachment and particle agglomeration play a vital role. Due to its high separation efficiency, cost effectiveness and simplicity in operation and maintenance, flotation has been extended to many industries dealing with solid-solid and solid-liquid separations. In contrast with the previous efforts stemmed from the needs of mineral flotation aimed at particles much smaller than bubbles, our research activities are aimed at the investigation of behaviour of particles greater or comparable in size with bubbles, which has not been satisfactorily covered yet.

The bubble – particle interaction can be described by three independent steps : 1/ collision - approach of the bubble and the particle to the contact distance and the subsequent collision; 2/ attachment - adhesion of the bubble on the particle surface and 3/ stability - detachment of the bubble from the particle surface, if an instability of the bubble – particle aggregate exists. The effectiveness of the whole process is often determined by efficiencies of the particular steps. The total efficiency, collision and attachment efficiencies are defined as the fraction of particles captured by a bubble, the fraction of particles colliding with a bubble, and the fraction of colliding particles which actually attach to the bubble surface, respectively.

Our research activities were target on the investigation of interactions between stationary spherical particle and single rising bubble. The experimental research was focused on the description of a bubble size and trajectory, collision efficiency and determination of the limit collision angle. A high-speed digital camera Redlake Motion Pro was used for the experimental documentation. The NIS-elements software and programme equipment were employed for image analysis. The silanized glass balls with diameters from 5 to 15mm were used as model particles, the bubble diameter ranged between 0,4 to 0,9mm. A solution of frother terpineol was used as a liquid medium. The initial angle φ_0, collision angle φ_c and adhesion angle φ_a were evaluated from the captured images. The initial angle φ_0 characterizes the bubble position in big distance from the solid particle. The collision angle φ_c is higher than φ_0 due to the deviation of the bubble trajectory. Finally, the adhesion angle φ_a is considered for the arrangement when the bubble is adhered on the particle surface and the three-phase contact area has a fixed and stable perimeter. The theoretical maximum initial angle is 90^o that corresponds with the situation when the distance of the bubble and the particle centres equals to the sum of their radii.

According to the obtained experimental results, the trajectory deviation caused by the presence of a stationary solid spherical particle is very small and it is observed only in the immediate vicinity of the surface. These results are in good correspondence with theoretical assumptions. The change of bubble trajectory was not significant, because around stationary particle narrow hydrodynamic zones are considered. In case of small bubbles (d_b < 1mm), only very small stream field could be observed. Therefore, the streamline influences the bubble motion immediately before an interaction with the particle. A linear dependence of the collision angle on the initial angle (proportion constant 1,04) is obvious from the measured experimental data. No collision occurs for initial angles greater than 75°. For such initial angles the streamlines deviate significantly from the linear direction and consequently the distance between the particle and the bubble centres is greater than r_b+r_p during the whole bubble motion. For smaller bubbles (d_b < 0,7 mm) collision efficiency does not change significantly and its average value is 0,91. For bigger bubbles (d_b > 0,7 mm) the collision efficiency slightly decreases with increasing bubble size. No significant influence of particle size was observed.

A good starting point for theoretical study of interaction between a small bubble and a large particle is the study of a bubble collision with an inclined plane, representing a particle of infinite size. The model theory was created for this type of interaction. The model is based on the motion of a single solid sphere. The relationship of the liquid streamlines is given and external forces on the rising sphere are expressed. Finally, the relationships for the liquid film flow in the thin layer and sphere motion are given. The bubble trajectory before and during the interaction with the inclined plane was calculated and compared with the experimental data.

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