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Break-up in formation of small bubbles: Break-up in a confined volume

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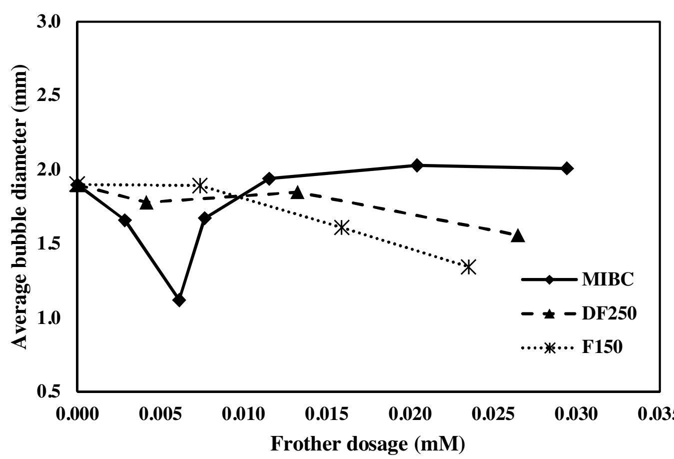
HIGHLIGHTS

- An experimental setup mimicking bubble formation behind an impeller element was developed.
- The break-up of a confined air volume was affected by the presence of frothers.
- Frothers generate surface tension gradients which enhance surface instabilities.

GRAPHICAL ABSTRACT

The presence of frothers generally causes a decrease in bubble size through break-up.



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ABSTRACT

Small bubbles play the critical role in flotation of providing the large interfacial area for collecting and transporting selected (hydrophobic) mineral particles. The generation of these bubbles is a physical process chemically assisted by addition of surfactants (frothers). The prime action of frothers is commonly considered to be coalescence inhibition. In contrast, the possible role of frothers in the initial air break-up has attracted little attention. In this paper, we investigate the effect of frothers on break-up. An experimental setup was designed to isolate break-up from coalescence. Single bubbles were produced through mechanically-induced deformation of a trapped air volume, the design aiming to mimic the break-up of the air cavity behind an impeller blade in a mechanical flotation machine. The results show that the bubble size produced at break-up is strongly affected by the presence of frother, but weakly by the input mechanical energy and the volume of trapped air. The proposed mechanism is that frothers induce surface tension gradients which increase the instabilities along the air/water interface. For a finite air volume, increasing the number of instabilities means that more and smaller bubbles will break away. Frothers of different types and concentrations were tested.

1. Introduction

Froth flotation is a process that separates valuable mineral particles from gangue minerals by attachment to air bubbles, a process

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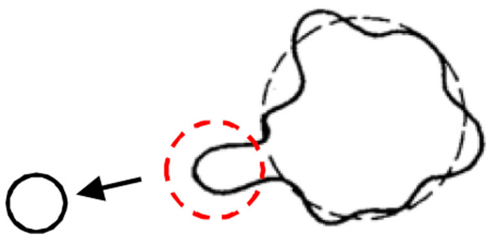

Fig. 1. Disintegration of an air mass: Bulgy mechanism. Adapted from Hinze [17].

that depends on differences in particle hydrophobicity. Small bubbles (*ca.* 1 mm) play a key role as they comprise the bubble swarms that provide the large interfacial area for collecting and transporting the selected mineral particles. The generation of fine bubbles can be viewed as a chemically assisted physical process where surfactants (frothers) are added to modify the bubble formation process. The effect of frothers on reducing bubble size is well known, but their detailed action remains obscure [1].

There are suggestions that frother action is related to surface tension reduction [2], but experiments fail to support such a connection [3–5]. A common explanation is coalescence prevention [6,7]. On this basis, Cho and Laskowski [8], noting that bubble size in a swarm reached a minimum at a particular concentration, argued that this concentration corresponded to complete suppression of coalescence and introduced the term critical coalescence concentration (CCC). By bringing two bubbles into contact it can be readily demonstrated that frother does retard coalescence [8,9]. There are occasional references that frothers also aid in the break-up of the air mass injected into the machine [2,10–12].

Understanding the role of frother in bubble formation is pertinent to flotation theory and practice. The purpose of this paper is to determine the possible effect of frother on the break-up process. To begin, we introduce some background relevant to this break-up hypothesis.

1.1. Frothers

Frothers are a class of surface-active agents or surfactants. They are simple hetero-polar compounds, such as alcohols and polyglycols, that comprise hydrophilic (polar) and hydrophobic (non-polar) groups. The polar groups typically contain hydroxyl (—OH), carbonyl (—C=O) and ether linkages (—O); the non-polar groups are hydrocarbon chains of various lengths both straight chain and branched. Through the polar groups the frother molecule H-bonds with water molecules to become hydrated while there is practically no interaction with the non-polar groups [13]. As a result, the frother molecule tends to accumulate at the air/water interface orientated with hydrophilic groups on the water side and the hydrophobic group on the air side thus satisfying both properties of the molecule.

Frothers lower surface tension. In most industrial flotation systems, frother concentration is about 5–10 ppm (parts per million), which, comparing to the surface tension of water, 72.8 mN/m, would cause a reduction of, at most, about 7% [14]. The presence of frothers also perturbs the air/water interface. Some authors [15,16] observing waves on a bubble surface suggested that the presence of frothers promoted a surface tension gradient driven stress, which interplays with the mechanical stress to de-stabilize the interface.

Reference to surface tension usually implies the 'equilibrium' or 'static' value. However, the conditions in flotation are dynamic, especially around the impeller region where the air mass breaks up and where frother must act to influence bubble formation.

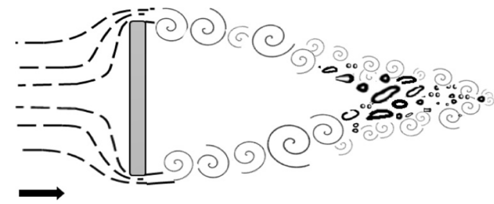

Fig. 2. Break-up of an air loaded cavity behind an impeller object in a mechanical flotation machine. Adapted from Grainger-Allen [21].

1.2. Break-up

The break-up of an air mass in a turbulent environment is a complex phenomenon. Prior to break-up the air/water interface must deform. The deformation can take different forms depending on the hydrodynamic forces associated with the liquid flow patterns around the interface. Hinze [17] suggested that interfacial instability, shown in Fig. 1, is one of ways that can perturb the air/water interface. In this case, the deformation occurs locally resulting in parts of the air mass separating. This process appears to be relevant to air beak-up in mechanical flotation machines.

The rotor-stator device in a mechanical flotation machine is responsible for dispersing air into bubbles [18,19]. The rotation of the impellers induces mechanical suction that draws the incoming air to the downstream side of the impeller blades where air-loaded cavitation occurs. This air cavity deforms rapidly due to shear with the fluid flow around it. At the trailing edge, the air/water interface interacts with local turbulent eddies causing interfacial instabilities. These subsequently grow and eventually break away to form bubbles [20,21]. Fig. 2 shows an example of such a process and mirrors the break-up by interfacial instabilities described in Hinze (Fig. 1). It is suggested that the downstream side of other objects (named as impeller elements), such as the stator wall, bars, fingers, are also regions where air-loaded cavitation might appear [19,22].

Bubble formation is not limited to break-up of an air mass. A minor phenomenon, which is not the interest of this work, is the precipitation of microbubbles. In this case, the small bubbles are produced due to the precipitation of dissolved air, which is caused by the pressure difference across the upstream and downstream sides of an impeller object.

The coalescence prevention argument is that the machine produces the small bubble size and frother preserves it. In mechanical flotation machines, coalescence takes place mostly outside the dispersion zone (*i.e.* outside the vicinity of the rotor-stator). In the next section, we review work that investigates the possible effect of frother on break-up in the dispersion zone.

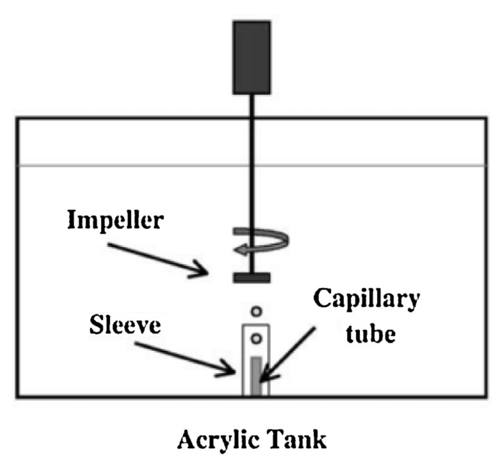

Fig. 3. Experimental setup of Kracht and Finch [23].