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Analysis of attachment process of bubbles to high-density oil: Influence of bubble size and water chemistry

M.W. Lim, E.V. Lau*, P.E. Poh

School of Engineering, Monash University Malaysia, Jalan Lagoon Selatan, 47500 Bandar Sunway, Selangor Darul Ehsan, Malaysia

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ABSTRACT

The interaction studies between high-density oil and bubbles were investigated to understand the bubble attachment behaviour on oil with respect to bubble size, pH and temperature. An increase in the bubble size from 350 µm (microbubbles) to 1000 µm (macrobubbles) demonstrated a decrease in the attachment force due to the reduction in contact angle by 7%. The results were in good agreement with the bubble-strength visualization tests, as the retraction of microbubble attached onto oil demonstrated a significant change in shape from concave to convex, as opposed to constant shape of macrobubble attachment-retraction from the oil layer. This was attributed to a higher cross sectional area to volume ratio (IA:V) of 12.3 for oil-microbubble attachment compared to IA:V of 4.9 for oil-macrobubble attachment. Due to the higher IA:V, microbubble is more firmly attached onto the oil layer compared to macrobubbles. Therefore, microbubbles could help to enhance the flotation process as it would preferentially attach to the oil contaminant as opposed to macrobubbles. The results also indicate that increase in pH is detrimental for oil-bubble attachment due to the production of natural surfactants, while the increase in temperature does not appear to affect the bubble attachment on the oil layer.

1. Introduction

Flotation technology is a combination of chemical, physicochemical and physical method which enables the separation of oil from soil via a gas-liquid-solid system using bubbles [1–3]. As bubbles plays an important role in determining the flotation kinetics, the success of flotation, therefore, depends on the bubble interaction with the contaminant, which includes: (a) collision between particles and bubbles, (b) attachment of particle and bubble to form bubble-particle, (c) flotation of bubble-particle due to difference in buoyancy and (d) detachment of particles from bubble-particle [4,5]. The key mechanism of oil flotation technology lies heavily in the attachment success rate between the generated air bubbles and the hydrophobic oil layer [6,7]. Thus the increase in the probability of bubble-oil attachment would lead to a higher removal of oil contaminant attributed to the buoyancy of the bubbles that could aid the flotation of oil contaminant to the surface of the flotation cell.

One of the parameters that could influence the bitumen-gas bubble attachment process is bubble size, as the decrease in bubble size provides a larger surface area available for contact, which is crucial to enhance the adhesion of bubble to the contaminant particle [8–10]. The impact of bubble size on flotation applications had been well reported especially in wastewater treatment [11–13], paper deinking [14,15] and flotation of minerals such as coals and phosphate [16–18]. In oil remediation, the bubble size was also reported to improve the oil flotation efficiency. Recent oil flotation experiments by Zhou et al. (2010) concluded that the usage of microbubbles with bubble size distribution of 0.3–0.4 µm diameter could improve the oil flotation efficiency from sands. The bubbles were created by saturating deionized water with air under high pressures (7 atm) and temperature (80–95 °C). The bubbles generated (in the microbubble range) increased the bitumen recovery from 42% (without nucleation) to 64% (with bubble nucleation). This phenomenon was attributed to the increase in the probability of bubble collision and adhesion with oil, which leads to a higher oil removal efficiency [19].

Recent studies on the liquid-gas interaction also focused on the attachment process between oil and bubble under a variety of parameters. Flury et al. (2013) studied the corresponding liquid properties that would affect the bubble attachment onto the oil. The authors reported that the application of different caustic types (sodium hydroxide and ammonium hydroxide) for bitumen flotation would affect the induction time between bitumen-bubble attachments. The use of ammonium hydroxide resulted in a shorter

* Corresponding author. Fax: +60 3 5514 6207.
E-mail addresses: lim.mee.wei@monash.edu (M.W. Lim), lau.ee.von@monash.edu, evonne_lau@yahoo.com (E.V. Lau), poh.phaik.eong@monash.edu (P.E. Poh).

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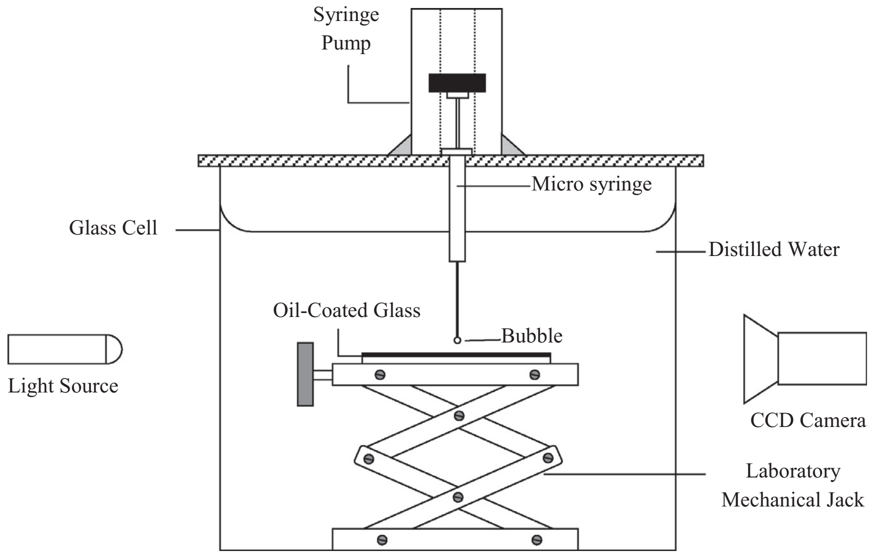

Fig. 1. Schematic diagram for visualization of oil-bubble attachment.

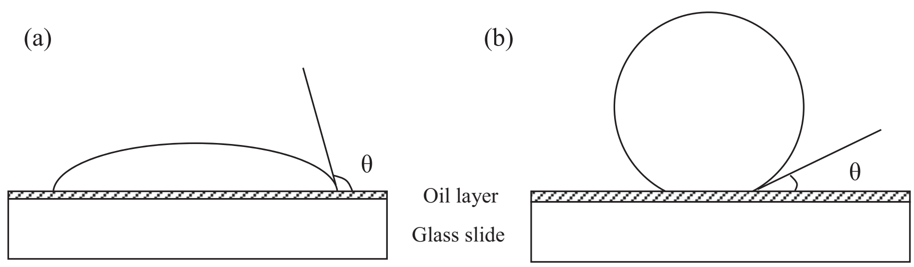

Fig. 2. Attachment of air bubbles on bunker oil layer; (a) Air bubble which is strongly attached on oil layer, (b) Air bubble which is weakly attached on oil layer.

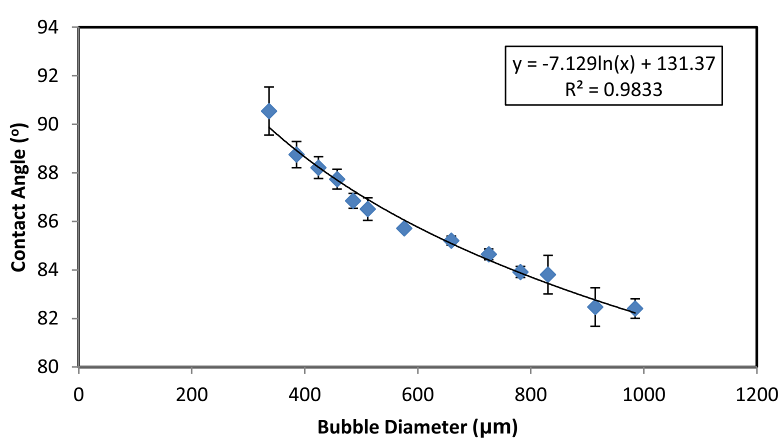

Fig. 3. Contact angle of bubble on oil layer with respect to bubble size in room temperature distilled water (pH 7).

induction time which led to a faster bitumen-bubble attachment [20]. Similar works were also conducted by Eftekhardadkhah and Øye (2013) on the effect of synthetic brine (salts) on the induction and coverage times of a single crude oil droplet on air bubble. The authors found that the addition of salts compressed the electrical double layers and removed the double-layer repulsion, leading to a lower induction time [21].

In recent works, He et al. (2015) investigated the effect of a solvent such as toluene and naphtha addition on the bitumen-air bubble attachment to determine the induction time and bubble-bubble coalescence time, as these parameters play a critical role in bitumen-air bubble attachment. Results from this investigation demonstrated that the minimum induction time under ambient conditions was at a solvent dosage of 10 wt% of the bitumen for both toluene and naphtha. Further increase in solvent dosage to more than 20 wt%, however, showed a decrease in the bubble attachment probability onto the bitumen. This suggests that the addition of solvents could facilitate the accumulation and adsorption of surfactants and ions such as Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+} on the bitumen surface which was beneficial for bubble attachment. However, the thickening of surfactant film on water-bitumen interface with an increase in solvent dosage would be detrimental for bubble attachment process [22].

From literature, the oil-bubble attachment is a complex process, and is highly affected not only by the bubble size, but also the chemical and physical water properties. In addition, the oil removal

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