



Original Research Paper

Flotation of coarse composite particles: Effect of mineral liberation and phase distribution

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ABSTRACT

The objective of this study is to relate the flotation of coarse composite particles with their mineral composition. For this purpose, composites of quartz particles in lead borate matrix were fabricated in different size fractions. The quartz in the composite particles was selectively hydrophobised. The composite particles were floated and backscattered scanning electron microscopy was used to measure the number of particles in each flotation product, their size and liberation class. Results showed that the flotation of these composite particles decreased with increasing particle size, and decreasing the quartz (the hydrophobic phase) liberation class. Furthermore, it was also found that diesel oil addition improves the adhesion of composite particles with bubbles, and consequently enhances their flotation recovery.

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1. Introduction

It is well known that froth flotation is a size dependent process, i.e. fine, intermediate and coarse particles exhibit different flotation behaviour [1–3]. Extending the upper particle size limit of flotation is of interest to the mining industry, particularly for the base metals mineral processing plants where low grade ores are common [4]. It should be highlighted that grinding is the highest energy consuming stage in mineral processing [5,6]. However, valuable minerals in the coarse size fractions are the single largest contribution to the overall loss in the recovery in many ores [7,8].

The flotation of coarse mineral particles is always low due to their detachment from bubbles in the high turbulent regions of flotation cells [2,9]. Particle-bubble detachment increases with decreasing surface hydrophobicity resulting from low collector coverage, sulphide mineral oxidation or the presence of composite particles. With the ongoing depletion of high grade, coarse-grained mineral deposits, composite particles are always present in the feed, and therefore a perfect mineral liberation cannot be achieved. Composite particles occur generally in coarser size fractions where there is incomplete liberation of the valuable minerals from the gangue minerals [10]. It is known that a large part of the non-floating particles are coarse particles where the valuable minerals are locked in composite particles with gangue minerals and can

only be liberated with appropriate finer grinding. It is therefore essential to understand the flotation behaviour of these composite particles as this can help to design proper procedures to improve the recovery of valuable minerals.

Sutherland [10] used a natural ore to study the flotation behaviour of composite particles made of chalcopyrite, pyrite and quartz. The disadvantage of using natural ores to study composite particles is that they may only contain a very small amount of composite particles with a variety of mineral phases, which makes it difficult to interpret the results. With synthetic composite particles, the percentage of each mineral phase and their distribution can be to some extent controlled [11,12]. For example, composite particles of silica and lead borate were fabricated by Lin and Finch [13].

Wang and Fornasiero [14] prepared composite of quartz particles in lead borate matrix at different size fractions between 75 to 600 μm . They produced simple locking and complex locking textures by changing the size of the quartz particles (Fig. 1). The quartz phase was selectively hydrophobised using trimethylchlorosilane (TMCS). They observed that the flotation recovery and flotation rate of composite particles increase with quartz liberation class, while they decrease with the particle size. Furthermore, the flotation recovery of composite particles with the complex locking texture was higher than that with simple locking texture in the same liberation class and particle size fraction, especially for particles with a lower liberation class and coarser size. They found that composite particles with complex locking

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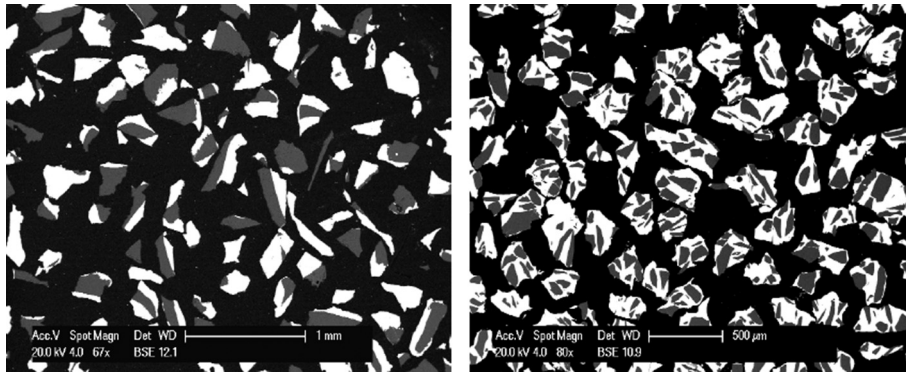


Fig. 1. BSE-SEM images of composite particles of lead borate and quartz between 210 and 250 μm with simple locking texture (left) and complex locking texture (right) reported by Wang and Fornasiero [14]. The dark and light areas inside the particles represent quartz and lead borate, respectively.

texture were on average more strongly attached to bubbles than those with the simple locking texture, although their contact angles were similar. This was attributed to the different distributions and sizes of the hydrophobic quartz patches in the composite particles as bubble had a higher probability of contacting a hydrophobic quartz patch on the surface of composite particles with complex locking texture than with simple locking texture [14].

The aim of the current study is to investigate the effect of fine hydrophobic particles (phases) in the flotation of composite particles. Composite particles similar to those prepared by Wang and Fornasiero [14] were fabricated. However the size of the quartz particles used in the current study is much smaller than those used by Wang and Fornasiero [14] (i.e. $<10\ \mu\text{m}$ compared to $>75\ \mu\text{m}$). The flotation of these composite particles as a function of particle size and quartz liberation class was investigated to determine the effects of phase distribution and size of each phase on the particle hydrophobicity and flotation recovery. It is known that longer hydrocarbon chain collectors (such as amyl xanthate) adsorb more strongly on minerals and produces more hydrophobic surface than shorter chain collectors (such as isopropyl xanthate) [15,16]. Therefore, the effect of oily collector (i.e. diesel oil) on the detachment of coarse composite particles from bubbles and on the flotation of these particles was also studied.

2. Experimental methods

2.1. Fabrication of composite particles

Lead borate (Merck KGaA, Germany) and pure quartz particles (Sigma, $<10\ \mu\text{m}$) were used to fabricate composite particles. The procedure of fabrication of the composite particles and selective hydrophobisation of the quartz phase follows that of Wang and Fornasiero [14]. For this purpose, 200 g of lead borate and 100 g of quartz were mixed and placed in a 200 mL porcelain crucible. The quartz particles were cleaned with strong acid (HCl, 35%) and then washed with water to natural pH before mixing with lead borate. The mixture of lead borate and quartz was placed in an induction furnace for one hour at $600\ ^\circ\text{C}$. As the melting point of lead borate is approximately $500\ ^\circ\text{C}$, the lead borate melts and embeds the quartz particles to form a block. The crucible was taken out of the furnace and allowed to cool down to room temperature. The block of lead borate and quartz was removed from the crucible, crushed, ground and sieved to six different size fractions using Tyler screens (i.e. 75–150, 150–210, 210–250, 250–300, 300–350 and 350–600 μm). Pure lead borate and quartz particles in the same size fractions were prepared using the same method as for the preparation of composite particles to insure that they have

the same properties and characteristics as the lead borate and quartz phases in the composite particles.

High purity trimethylchlorosilane (TMCS) ($>99.95\%$, Merck) was used to selectively hydrophobise the quartz phase [17–19]. Composite particles were dried in a clean oven at $110\ ^\circ\text{C}$ for 12 h to remove any physisorbed water on the surface before hydrophobisation with TMCS since TMCS reacts with water [18,19]. The hydrophobisation reaction was performed in a glove box under a dry nitrogen atmosphere for one hour and involved mixing the particles with a solution of TMCS in cyclohexane (99.95%, HPLC grade) at a concentration of 0.01 mol/L. According to Blake and Ralston [18] the quartz surface should be fully covered by TMCS after one hour at this concentration. After hydrophobisation, the particles were rinsed with cyclohexane to remove any non-reacted TMCS, and they were transferred to a clean oven and dried at $110\ ^\circ\text{C}$ for 12 h and stored in a vacuum desiccator with silica gel. The contact angle of the dry particles was measured with a Wilhelmy balance (DCAT 11/DCAT 11EC, DataPhysics Instruments GmbH, Germany) using the Washburn technique. The procedure has been described previously by Wang and Fornasiero [14]. The contact angles of the pure quartz and lead borate particles, prepared in exactly the same way as the composite particles (including heating at $600\ ^\circ\text{C}$ for 1 h), were 25° and 10° ($\pm 2^\circ$), respectively, before TMCS treatment, and 90° and 28° ($\pm 2^\circ$), respectively, after TMCS treatment. These results show that TMCS mainly reacts with the quartz surface. The contact angle of the pure quartz particles decreased to $\theta = 48^\circ$ ($\pm 2^\circ$) when the TMCS concentration in cyclohexane was reduced.

2.2. Flotation

After hydrophobisation, 4.5 g of particles (of each size fractions) in 250 mL tap water were floated at natural pH value in a small scale flotation cell (300 mL). Dowfroth250 was used as a frother (150 mg/L) and was added 1 min before flotation. As only coarse particles were present in the samples, a relatively high frother concentration was necessary to produce a stable froth. Gas superficial velocity (J_g) of 0.47 cm/s and agitation rate of 2200 rpm (the minimum speed to suspend the coarser particles in the flotation cell) were used during flotation. Four concentrates were collected at flotation times of 0.5, 2, 4 and 8 min (cumulative). The flotation products were dried in an oven and weighted.

2.3. SEM analysis for liberation class

The liberation class of flotation products was measured using Backscattered Electron-Scanning Electron Microscopy (BSE-SEM) and image analysis. The particles in each of the flotation products

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