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Stability and flotation behaviour of silica in the presence of a non-polar oil and cationic surfactant

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Abstract

This present work deals with the stability and flotation efficiency of silica in the presence of a cationic surfactant, dodecylamine (DDA) and a non-polar oil, dodecane. Dispersion stability was defined by turbidity measures and the flotation tests were carried out in a laboratory scale flotation cell. Results from stability measurements indicated that DDA caused extensive aggregation at concentrations of 600–12,000 g/t (DDA/silica) (0.17–3.34 mM). Increasing the dodecane concentration from 0–2730 g/t (0–0.81 mM) in a DDA-silica system was found to have no effect on the stability of the silica particles. Flotation data showed that the addition of dodecane with DDA in combination increased the removal rate of silica particles. The effect of dodecane addition rate on the bubble size and bubble clustering in the flotation cell was also investigated. A specifically designed cell was used to view bubbles in the cell and their images were recorded using a high speed camera. By using an image analyzer the cluster size, the average size of bubbles in the clusters and independent bubbles, i.e. those had not aggregated were investigated as a function of dodecane concentration. The average bubble size was found to be affected by dodecane dosage.

Keywords: Flotation; Surfactant aggregation; Bubble size; Non-polar oil; Dodecylamine

1. Introduction

The processing of silicate minerals from ore deposits is of great importance because they represent one of the most common gangue minerals in ores to be treated by flotation. Amines are widely used in the flotation of silicate minerals primarily because of their relatively high solubility. Under the usual basic pH conditions however, when using amines, the particles become flocculated through intermolecular forces, unless steps are taken to control their surface charges [1,2]. The silica particles thus float as aggregates rather than individually, so that it is difficult to recover particles selectively from other fine minerals. When aggregation occurs, it is obviously impossible to study flotation on size-by-size basis when the aim is to investigate the particle size effect on the flotation rate.

Many authors have investigated the various stages of surfactant adsorption onto oppositely charged solid surfaces [3,4]. In this work the suspension particles must be kept in a stable, dispersed state due to previously mentioned reasons. To retain stability a repulsive barrier between the silica particles is required, in this case the barrier is a result of the negative charge on the silica particles. However, for flotation, the particles should be hydrophobic. Thus, a delicate situation is created in which the need for hydrophobicity is balanced by the destabilisation effect of the surface active agent. Therefore, it is important that we know how the stability of the particles changes with addition of surfactant and hydrophobic agents.

In order to float dispersed silica a long chain non-ionic substance can be added to the system at a low pH as suggested by the work of Smith [5] who added dodecanol to an amine–quartz system. Under such conditions, contact angles were observed at low pH values (about 1.5–2 pH units). The contact angles were determined on quartz plates and flotation experiments were carried out in a Hallimond tube. No steps were taken to investigate the aggregation of silica as a function of oil concentration. Apart from increasing the hydrophobicity of partially hydrophobic particles, non-ionic oils are also known to promote particle–particle aggregation (or agglomeration) by forming oil bridges between particles [6]. Non-ionic substances are commonly used as a collector in the flotation of naturally hydrophobic solids such as coal, graphite, sulphur, molybdenite and talc. They are also used

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as an extender whereby the oil is first emulsified to form finely dispersed oil droplets before adding to the system. The oil drops interact with the particles previously hydrophobised with a collector and then spreads over the surface of the minerals as oil layer following the formation of agglomerates. In that way, the adhesion forces between particles increases tremendously due to oil bridges, making the aggregates stronger, and enabling them to withstand greater shear forces [6,7].

In most work dealing with oil-assisted flotation processes, much emphasis has been given to the characterization of the suspension through zeta potential, contact angle and stability measurements with little attention paid to the flotation step. The effect of aggregation or non-ionic oil on the bubble–particle attachment and on the froth phase of the flotation has also been neglected. This paper not only investigates the stability of fine silica particles in the presence of a cationic reagent (dodecylamine), and a non-ionic long-chain oil (dodecane), but also the effect of dodecane concentration on the bubble–particle attachment in the flotation cell. The behaviour of bubble size in the cell was studied and its influence on the flotation efficiency was discussed.

2. Experimental

2.1. Materials

Washed quartz purchased from Unimin, Australia under the brand name Silica 400G was used in the experiments. The average particle size of the sample (d_{50}), was 7 μm as determined using a Malvern MasterSizer.

2.2. Reagent

Dodecylamine (DDA) of >99% purity was supplied by Aldrich Chemicals. Reagent grade dodecane was obtained from Sigma. Methylisobutyl carbinol (MIBC; 4-methyl-2-pentanol) was used as a frother without further purification and the pH adjusted with sodium hydroxide and nitric acid. Millipore water was used throughout the work.

2.3. Optical characterization of the stability

The stability of silica suspensions was performed using a TURBISCAN (TurbiScan MA2000). The apparatus has an optical detection head composed of a pulsed near-infrared light source and two synchronous detectors. The transmission detector receives the light which goes across the sample, while the back scattering detector receives the light scattered backward by the sample. The sample to be analyzed is contained in a cylindrical glass measurement cell and the optical head scans the entire length of the sample, recording the transmitted and back-scattered intensities as a function of the sample height.

Before preparing the suspension, the pH of solution was adjusted to pH 8 by stirring the solution in a beaker with a magnetic stirrer for approximately 60 s. The required amount of silica (5%, w/w) and reagents (DDA, dodecane and frother) were then added into the mixture and conditioned for 90 s. Meanwhile the pH was readjusted to pH 8. The suspension was then slowly transferred to a cylindrical glass measurement cell in a near-horizontal position in order to prevent aggregates from being destroyed. After homogeneous filling, the glass cell was turned to the upright position and the Turbiscan started. Height values of the suspension–supernatant interface were measured throughout the experiment.

In all experiments, the total volume of liquid including reagents was 40 mL and frother (MIBC) was present at 30 ppm concentration. Dodecane was dispersed with the aid of ultrasonication for 60 s (Misonix Inc.) before adding to the solution. The effect of DDA and dodecane on the stability of silica was studied in the 0–12,000 g/t and 0–2730 g/t concentration range, respectively.

During the Turbiscan tests, it was observed that particles attached to the glass wall, resulting in incorrect readings. With experiments using only dodecylamine this was overcome by rinsing the glass cell with Millipore liquid of pH less than 2, while with dodecylamine and dodecane mixture the glass cell was cleaned using a non-ionic surfactant solution and then rinsed with Millipore water several times.

2.4. Flotation experiments

Experiments were carried out in a 1.2 L mechanically-agitated cell. The impeller speed remained constant at 450 revolutions per minute. The air flow rate was controlled using a rotameter and was set at 5 L/min. A known amount of silica was transferred to the cell and was conditioned with reagents (collector and frother) for 15 min. The pH was adjusted to pH 8 using either sodium hydroxide or nitric acid. Then air was introduced and the solids allowed to float for 2 min. Make-up water at the same pH and frother concentration was added to the cell during the flotation to keep the water level in the cell constant. The concentrate and tailings samples were filtered, dried and then weighed to determine overall flotation and water recoveries. In all tests the initial solids concentration and the frother concentration were 5% (w/w) and 30 ppm, respectively. DDA concentration was varied from 50–800 g/t and dodecane concentration was in the range of 0–2730 g/t.

In flotation tests with dodecane, dodecane was ultrasonicated for 1 min, then added to the cell together with DDA and MIBC and the usual procedure was followed.

2.5. Bubble size measurement

The bubble size in the presence of increased dodecane concentration was measured using a specifically designed viewing cell in which bubbles from the flotation cell can rise. The motion of bubbles was recorded using a high speed camera and the images were analysed using an image analyzer. Substantial bubble clustering was observed. The cluster size and average bubble size in the clusters were determined at different oil concentrations. The details of the experimental procedure for analyzing bubbles and bubble clusters were given elsewhere and will not be repeated here [8]. It should be noted that this series of tests were carried out in a bigger flotation cell (12 L), because more