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Effect of particles on the electrical charge of gas bubbles in flotation

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ABSTRACT

Direct bubble–particle interactions are followed by measuring bubble sedimentation potential (BSP) and by visualization at a pendant bubble. Alumina and silica were selected as examples of positive and negative charge particles, respectively, at the test pH 6–7 along with a serpentine sample isolated from an ultramafic Ni-ore. Provided particle concentration was not too high, BSP could be measured and interactions followed. Alumina and serpentine hydrophobized by anionic surfactant made the bubble charge less negative and with silica made hydrophobic by cationic surfactant the bubble became less positive. With non-ionic surfactant (frother) and electrolyte, BSP increased with alumina suggesting an electrostatic (non-hydrophobic) interaction. The visualization experiments confirmed attachment of hydrophobic particles and revealed attachment of non-hydrophobic alumina, silica and serpentine. Non-hydrophobic interactions were explored by introducing ionic surfactant to give the bubble the same sign charge as the particles which diminished pick-up. Under these same conditions the BSP could not be measured attributed to particles being well dispersed from the bubbles and giving competing particle sedimentation potential signals. The possibility of manipulating bubble charge to depress minerals is discussed.

1. Introduction

Flotation, first developed in the mining industry is now used in a variety of industries, e.g. water treatment, petrochemical, paper manufacturing, food processing (Rousseau, 1987). Attachment of hydrophobic particles to bubbles is the dominant recovery process but other mechanisms lead to some recovery of non-hydrophobic (hydrophilic) particles. An electrostatic interaction mechanism dependent on relative surface charge of bubbles and particles is sometimes suspected (Myers, 1991). Given the usually large amount of hydrophilic gangue to be rejected even minor recovery levels due to non-hydrophobic interactions could lead to downgrading of concentrate. This possibility was raised in the case of an ultramafic Ni-ore when it was observed that the dominant gangue serpentine mineral was positively charged and bubbles negatively charged at flotation pH which stimulated the present enquiry.

The recovery of hydrophilic particles is usually attributed to entrainment (Trahar, 1981). The mechanism can be identified, for example, by correlating with water recovery. Attempting to isolate an electrostatic interaction contribution to hydrophilic particle recovery by flotation experiments would likely be overwhelmed by the mass recovered by entrainment. A direct investigation of bubble–particle interaction is required.

The purpose of this paper is adapt a previously developed bubble sedimentation potential apparatus (Uddin, 2011) to include particles as one means to directly study bubble–particle interactions and to augment by visualizing interaction at a pendant bubble exposed to agitated particle suspensions.

2. Background

2.1. Bubble charge

For bubbles in water alone the iso-electric point is ca. pH 1.5–4 (Li and Somasundaran, 1991; Yang et al., 2001; Takahashi, 2005) hence over most of the pH range the charge is negative. This has led to two hypothesized charging mechanisms: preferential orientation of water dipoles with hydrogen towards the water, which attracts OH^- to the interface (Alty, 1926); and adsorption of OH^- ions to satisfy hydration energy requirements (Yoon and Yordan, 1986; Kim et al., 2000). Measurement of bubble charge reveals interaction with ionic collectors and inorganic ions (Usui and Sasaki, 1978; Li and Somasundaran, 1991; Uddin, 2011).

2.2. Bubble–particle electrostatic interactions

The possibility of an electrostatic origin of bubble–particle attachment in flotation systems has been entertained periodically. Dibbs et al. (1974) measured the streaming current of gas bubbles with the cationic surfactant (collector) dodecylamine hydrochloride. Flotation recovery of quartz was found to increase as streaming current was increased to more positive values by changing pH which was interpreted as evidence of increased electrostatic interaction

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with negatively-charged quartz particles. Cichos (1973) used the rotating tube method (McTaggart, 1922) to try to correlate flotation with the zeta potential of bubbles and particles. Collins and Jameson (1977) related flotation recovery of polystyrene particles in presence of cetyltrimethylammonium bromide to electrophoretic mobility of the bubbles and particles. The flotation rate constant was found to decrease significantly as the positive charge on both bubbles and particles was increased, explained by double-layer repulsion. Similar findings were made by Fukui and Yuu (1980). Okada et al. (1990) reported that flotation efficiency of latex particles was strongly influenced by the charge on bubbles and particles. Fan et al. (2004) observed that quartz particles in de-ionized water attached to air bubbles and attachment increased with increasing pH even though both bubbles and particles were negatively charged. The proffered explanation was hydrogen bonding between OH^- on bubbles and either the oxygen atoms of the quartz or adsorbed OH on the quartz. Johnson et al. (2009) using AFM (atomic force microscopy) measurements, showed a long range repulsive force between a silica glass bead and micro-bubble in presence of anionic sodium dodecyl sulphate (SDS) and an attractive force in presence of cationic dodecyltrimethylammonium bromide (DTAB). Bubble charge reversal was observed with the DTAB which correlated with the much higher bead recovery than with SDS.

There is no literature apparent describing measurement of bubble electrical charge with particles present. In this study, a previously developed bubble sedimentation (swarm) potential (BSP) apparatus (Uddin, 2011) is modified to measure BSP in the presence of particles.

3. Experimental

3.1. Materials

The reagents and particles used are summarized in Tables 1 and 2, respectively. The reagents included two commercial frothers (non-ionic surfactants), two ionic surfactant collectors (note HTAB is same as CTAB), and KCl as background electrolyte. Alumina and silica were selected as model solids providing, respectively, positive and negative surface charge at the test (natural) pH. The clinochrysotile (a form of serpentine) was derived from a sample of ultramafic Ni-ore (provided by Vale) by a series of physical processes and identified by X-ray diffraction (Fig. 1).

3.2. Apparatus

3.2.1. Bubble sedimentation potential

The setup (Fig. 2) comprised a glass column 2.6 cm inner diameter and 1 m in length. Two pairs of Ag/AgCl electrodes (Warner Instruments Inc.) were mounted through stopcocks with electrodes set 50 cm apart and connected to an Agilent 34901A 20-Channel Multiplexer embedded in an Agilent 34970A data acquisition/switch unit (multimeter). One pair was used for potential difference measurement and the other for resistance (conductivity) measurement. For the latter, a flip switch was included to reverse polarity to avoid charge build-up on the electrodes. The pH electrode (Cole-Parmer) inserted into the column via a CG-350-03 glass joint was connected to another channel on the multimeter through an Oakton 510 benchtop pH meter. A porous plate sparger at the base of the column dispersed air into bubbles with air controlled via a calibrated flowmeter. A Masterflex pump was used to circulate the overflow to the cell.

The measurement was validated in absence of particles by showing the iso-electric point (iep) given by pH when BSP is zero compared well with range (pH 3.2–4) determined by other techniques (Table 3). The iep with air is generally higher than for inert gases which Tabor et al. (2011) attributed to CO_2 producing some surface species.

3.2.2. Visualization

The setup consisted of a 300 mL beaker placed in a rectangular water-filled Plexiglas tank perched on a magnetic stirrer (Fig. 3). Using a graduated syringe equal volume air bubbles (0.015 mL) were introduced into an agitated suspension of particles. Imaging was by digital camera (Cannon EOS 500D, EF 100 mm f/2.8 USM Macro Lens).

3.3. Procedure

3.3.1. Bubble sedimentation potential

Suspensions of $-25\ \mu m$ particles were prepared using de-ionized water with 10^{-2} M–10^{-3} M KCl as background electrolyte. All tests were performed at natural pH which remained between 6 and 7. The suspension was agitated over a magnetic stirrer for 30 min and transferred to the column. Bubbles were introduced at air rate of 50 mL/min. Ten minutes was sufficient for the system to reach steady-state (i.e., signals to become steady). Potential

Table 1
Description of reagents used (RG – reagent grade).

Reagents	Chemical formula	F.W.	Status	Purity	Source
Nonionic surfactants					
MIBC	$(CH_3)_2CHCH_2CHOHCH_3$	264.37	Liquid	RG	Sigma–Aldrich
DF250	$CH_3(C3H_6O)_4OH$	102.18	Liquid	RG	Dow chemical
Ionic surfactants					
SHS	$Ci_6H_{33}Na0_4S$	344.49	Solid	RG	Alfa Aesar
HTAB	$Ci_6H_{33}(CH_3)_3NBr$	364.44	Solid	RG	Fisher scientific
Salts					
Potassium chloride	KC1	74.55	Solid	RG	MP biomedicals

Table 2
Description of particles used.

Particle	Source	IEP	IEP Reference
Alumina	Sigma–Aldrich (CAS No. 1344-28-1)	~9.0	Uddin et al. (2010)
Silica	Opta Minerals (BARCO 32)	~2.0	Uddin et al. (2010)
Clinochrysotile	Vale's Thompson ultramafic deposit	~10.0	Alvarez-Silva et al. (2010)