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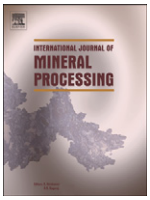

Effect of frothers on bubble coalescence and foaming in electrolyte solutions and seawater

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ABSTRACT

Inhibition of bubble coalescence is of fundamental importance in a flotation process because it determines the size of bubbles and foam stability. For this work commercial frothers have been selected, MIBC, DF-250, DF-400 and DF-1012; and NaCl as inorganic electrolyte. Surface tension measurements used to characterize the tested frothers revealed that these frothers have quite different properties. Polypropylene glycols are much more surface active than MIBC. The differences between these two are further augmented in concentrated NaCl electrolyte solutions. The concept of the *surface tension switch point* (s.t.s.p.) is introduced to characterize the effect of electrolyte concentration on frother properties. The s.t.s.p. values for MIBC and DF-250 were determined to be around 120 ppm and 1.2 ppm, respectively. The effect of MIBC and DF-250 frothers on bubble coalescence was not very different, although finer bubbles were generated in the presence of MIBC than of DF-250 in seawater. Only dynamics foamability measurements (DFI) confirmed the differences, the foams produced in the presence of DF-250 were much more stable, also in electrolyte solutions. This fact confirms the importance of dynamic effects in foam formation and stabilization.

1. Introduction

The sizes of bubbles, which are determined by bubble coalescence, play a very important role in the flotation process. Flotation frothers – weakly surface active compounds – are employed to facilitate air dispersion into fine bubbles and to stabilize the froth. Bubble coalescence is a particularly complex phenomenon especially when it takes place in saline water or seawater, since both surface active compound (frother) and surface-inactive compound (inorganic salt) are able to stabilize bubbles against coalescence and thus reduce bubble size.

The mechanism of bubble coalescence in solutions of frothers has been extensively studied. The coalescence of bubbles can be completely prevented at frother concentration exceeding a particular concentration, referred to as critical coalescence concentration (CCC) (Cho and Laskowski, 2002; Laskowski et al., 2003; Grau et al., 2005; Grau and Laskowski, 2006).

Inorganic electrolytes also inhibit bubble coalescence (Laskowski et al., 2003) and increase gas holdup in flotation systems (Quinn et al., 2007; Kracht and Finch, 2010). Smaller bubbles rise at lower velocities and thus gas residence time increases.

Most of common inorganic electrolytes show positive coalescence inhibition, some salts do not affect it suggesting that specific-ion effects and ion–water interactions play a role (Marrucci and Nicodemo, 1967; Zieminski and Whittemore, 1971; Lessard and Zieminski, 1971; Keitel and Onken, 1982; Craig et al., 1993a,b; Weissenborn and Pugh, 1995 and 1996; Deschenes et al., 1998; Craig, 2004).

In a number of applications, e.g., froth flotation in brines and in seawater, frothers are used in concentrated electrolyte solutions. Flotation of potash ores is carried out in a NaCl–KCl saturated brine, which is a solution of 6–7 mol of NaCl–KCl/L. The surface tension measurements carried out with MIBC under such conditions (Laskowski et al., 2003) revealed an interesting relationship between surface tension, MIBC concentration and electrolyte concentration. This relationship is shown in Fig. 1 as we decided to explore it further in this work. As it is seen, the three experimental surface tension isotherms intersect at one MIBC concentration and it seems that this intersection point could be used to depict the effect of ionic strength of the solution on the surface properties of tested frothers.

The aim of the present work is to study bubble coalescence in the presence of common flotation frothers in electrolyte solutions and in seawater. A better understanding of the mechanism of bubble coalescence in flotation cells, when seawater or saline water is used, is needed if seawater flotation is to be commercialized. The bubble coalescence in this work is studied using bubble size measuring technique and dynamic foamability tests.

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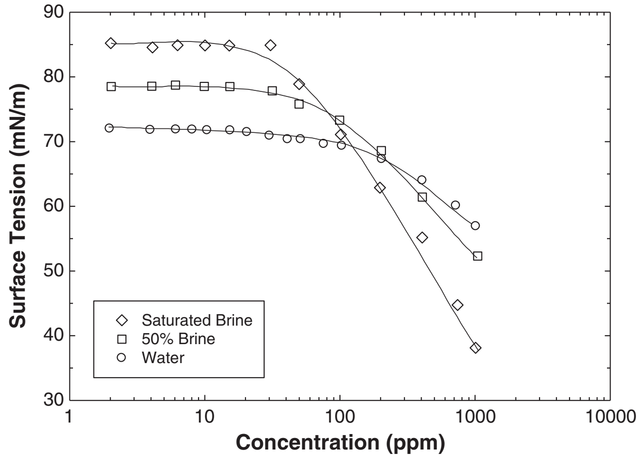

Fig. 1. The effect of MIBC and electrolyte concentration on surface tension of aqueous solutions (Laskowski et al., 2003). Saturated brine stands for NaCl–KCl saturated brine of 6–7 mol/L.

2. Experimental

2.1. Materials

MIBC (methyl isobutyl carbinol) was provided by Cytec-Chile, and the polyglycol frothers DF-200, DF-250, DF-400 and DF-1012 were commercial products obtained from Moly-Cop Chile S.A.

Sodium chloride used in this study was of reagent grade (Merck).

A local sample of seawater from Concepcion city (Bellavista-Tome) with a salinity of 33.5‰ was employed.

2.2. Apparatus

2.2.1. Surface tension measurements

KSV Sigma 700 tensiometer, with a Pt Du Noüy ring, was used in the surface tension measurements. Bi-distilled water was used for preparation of solutions. The Wilhelmy plate method was used in a few cases to cross-check results. No differences were found. Low frother concentration solutions were prepared by successive dilution of a 5 ppm frother solution. All the measurements were carried out at ambient temperature and resulting pH.

2.2.2. Bubble size measurements

The bubble size analyzer (BSA) developed by the Cape Town University (UCT) was employed. This comprises a glass capillary and two pairs of photo-transistor-LED detectors. Bubbles are drawn up through the capillary tube under vacuum and collected in a modified burette. The suction rate is controlled by a peristaltic pump. The bubbles are transformed into cylinders inside of the glass capillary, and their velocities and length measured using the optical detectors. The total volume of gas collected in the burette is utilized in order to estimate the absolute size of the bubbles. A detailed description of the instrument has been published by Randall et al. (1989).

The size of bubbles was measured in a 4.5 cm inner diameter column (the same column was employed in the DFI measurements) in which nitrogen gas was bubbled through the sinter glass frit either in water or in electrolyte solutions and the bubbles could freely collide with each other. The gas flow rate was 275 cm^3/min.

2.2.3. Dynamic foamability index

The DFI method (Malysa et al., 1981; Czarnecki et al., 1982) requires determination of gas retention time in a column (in which gas is bubbled through sintered disc) as a function of gas flow rate and frother concentration. What is measured is the total height of the solution plus the foam phase. These tests were carried out in a glass column of 101 cm height and 4.5 cm inner diameter, with the pore size range being from 40 to 100 μm; and 500 mL of solution was used in each experiment.

The equations used to express the DFI as a function of gas flow rate and frother concentration are:

$$rt = \frac{\Delta V}{\Delta Q}. \tag{1}$$

where,

rt is the retention time
V is the total gas volume in the system (solution + foam)
Q is the volumetric gas flow rate.

Then, the dynamic foamability index (DFI) is calculated from:

$$\mathrm{DFI} = \left(\frac{\partial rt}{\partial C}\right)_{C \to 0}. \tag{2}$$

Finally, it can be graphically determined from the slope of the initial part of the rt vs. C curve.

3. Results and discussion

3.1. Surface tension of frothers in aqueous NaCl solutions

As Fig. 1 demonstrates, for MIBC aqueous solutions there is a characteristic concentration point, which splits the whole range into two concentration ranges. This is confirmed in Fig. 2. At MIBC concentration of about 120 ppm there is a critical point. Over the MIBC concentration range exceeding this point (we will call it the *surface tension switch point*, s.t.s.p.) the surface tension of the MIBC solutions containing NaCl is lower than the surface tension of MIBC aqueous solutions. This agrees very well with Fig. 1. The same results re-plotted in Fig. 3 as a function of NaCl concentration clearly indicate that up to about 120 ppm of MIBC curves are dominated by the surface-inactive compound (NaCl). Only at the MIBC concentrations higher than the s.t.s.p., the plot starts resembling the situation in which a surface-active compound is present in the system.

This behavior is contrasted with another commercial frother, DF-250. As Fig. 4 demonstrates, the *surface tension switch point* for DF-250 is situated around DF-250 concentration of 1.2 ppm. This is very different from MIBC for which s.t.s.p. is around 120 ppm.

The results when re-plotted (Fig. 5) reveal quite a different relationship between DF-250, NaCl concentration, and surface tension from

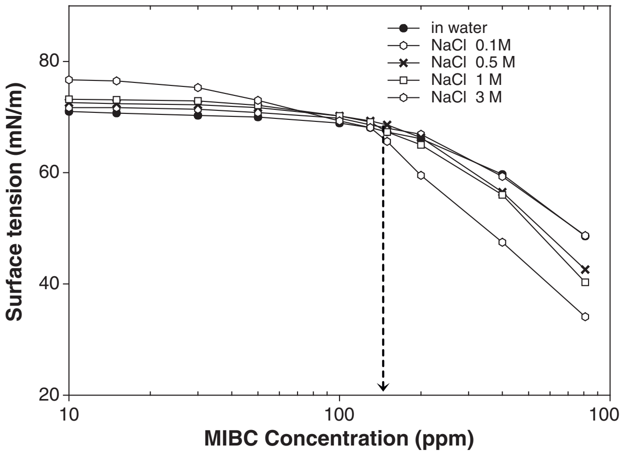

Fig. 2. Effect of MIBC concentration on surface tension of aqueous solutions in the presence of NaCl (Castro et al., 2012a).