



## Characterisation of frother properties in coal preparation process water



Ghislain Bournival<sup>a</sup>, Syeda R. Muin<sup>a</sup>, Noel Lambert<sup>b</sup>, Seher Ata<sup>a,\*</sup>

<sup>a</sup> The School of Mining Engineering, The University of New South Wales, Sydney, NSW 2052, Australia

<sup>b</sup> Clean Process Technologies Pty Ltd, 700 Standen Drive, Lower Belford, NSW 2335, Australia

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### ABSTRACT

From an environmental and economic perspective coal handling and preparation plants are under increasing pressure to reduce their consumption of fresh water and to strictly follow tight standards and specifications to release process water. Many coal washeries use recycled water as part of their water management strategy, which contains a higher content of inorganic electrolytes. In this study, five water samples from four coal washeries were analysed. The effect of methyl isobutyl carbinol (MIBC) frother was tested to evaluate the influence of water composition on the persistence of bubble pairs and the effectiveness of MIBC in preventing coalescence in a quiescent and dynamic environment, respectively. It was shown that the coalescence time was longer for bubbles in water samples of higher ionic strengths. However the effectiveness of an addition of MIBC was weakened in these solutions. It was also established that the water samples with higher ion content produced smaller bubbles in a laboratory flotation cell. In contrast to the binary coalescence experiment, the addition of MIBC appeared to be more effective in reducing the bubble size whilst a higher electrolyte concentration is present. The sensitivity of the effects of inorganic electrolytes on the bubble-bubble interactions suggests that coal washeries may benefit in monitoring the quality of the water employed in the flotation circuit.

### 1. Introduction

The coal industry is facing major challenges (Klima et al., 2012). Two of these challenges that are worth noting are the processing of increasingly poorly liberated coals and plant water shortages. The necessity to process an increasing amount of poorly liberated coals is resulting in a decrease in the crushing top size. Although only the oversize fraction of coal is crushed, it may be expected that a larger amount of fine coal particles will be produced as the particle top size is reduced. A large volume of fine material is also produced due to increased mechanization in the coal mining industry. It may consequently mean that coal washeries will rely more heavily on flotation to recover a larger amount of fine particles. Moreover, it is not uncommon for coal-producing areas to struggle with water supply. Coal handling and preparation plants (CHPPs) need to put in place strategies to preserve their water supplies and insure the viability of their operations. Among those schemes is closed water circuits or recycling of process water. This strategy, which is not limited to coal operations, results in water containing residual organic compounds such as collector or frother and inorganic electrolytes or species leaching from

coal, which may affect the flotation process in various ways (Rao and Finch, 1989; Liu et al., 2013).

In the 1930s Russian scientists already recognised the benefit of using a slurry containing a high concentration of inorganic electrolytes to recover naturally hydrophobic minerals by flotation (Klassen et al., 1963). However, it is only over the past few decades that targeted research efforts on the effect of non-fresh water sources on the process of flotation has taken place (Pugh and Manev, 1992; Weissenborn and Pugh, 1996; Quinn et al., 2007; Kurniawan et al., 2011; Castro et al., 2013; Wang and Peng, 2013) mostly driven by increasingly stringent environmental measures on the mining industry especially in the consumption of fresh water and disposal of used water. In its simplest description the process of flotation consists in the selective attachment of valuable particles onto air bubbles. The particle-laden bubbles rise to the surface due to density difference and form a froth layer, which is recovered along with the valuable particles separating them from the non-valuable particles. The gangue particles do not attach to air bubbles and remained in the flotation cell. The flotation process can generally be viewed in terms of particle-bubble interaction and bubble-bubble interactions. Both types of interactions are affected by

\* Corresponding author.

E-mail address: [s.ata@unsw.edu.au](mailto:s.ata@unsw.edu.au) (S. Ata).

the presence of inorganic electrolytes, the focus here being on the latter.

Numerous studies (Pugh and Manev, 1992; Castro et al., 2013; Bournival et al., 2014b) suggested that inorganic electrolytes affect bubble-bubble interactions as well as the effectiveness of frothing agents on these bubble-bubble interactions. Kurniawan et al. (2011) found an improved recovery of coal whilst performing flotation in the presence of inorganic electrolytes, which prevented the coalescence of bubbles. They attributed the increase in the recovery only in terms of the anti-coalescing properties of the salts. The effect of inorganic electrolyte on bubble size in the liquid zone in the presence of non-ionic surfactants was found to be important at concentrations sufficient to prevent bubble coalescence (Bournival et al., 2014b). The adsorption of ionic surfactants is well known to be influenced by inorganic electrolytes as the surface excess of molecules increases due to smaller electrostatic interaction forces between the molecules. Interestingly the adsorption of non-ionic surfactants has also been found to be influenced by inorganic electrolytes (Ozdemir et al., 2009; Castro et al., 2013). Although the surface tension is generally higher at low surfactant concentrations, it decreases more rapidly resulting in a more surface active compound. It was theorised (Ozdemir et al., 2009) that a large number of water molecules are required to hydrate the dissolved inorganic electrolyte ions at high concentrations. Since the surfactant molecules have less water molecules to form a structured hydration shell around the surfactant molecules, the solubility of the compound is decreased whilst its surface activity is increased.

In the foam phase, a study by Pugh and Manev (1992) showed that a small amount of salt resulted in an increase in the life time of ethylene glycol surfactants, C<sub>10</sub>(EO)<sub>5</sub> and C<sub>12</sub>(EO)<sub>5</sub>, whilst further additions caused a decrease in foam stability. Another investigation demonstrated that the addition of salt caused an increase and a decrease in the foaming of an alcohol and polyglycol solutions at low and high surfactant concentrations, respectively (Bournival et al., 2014b). These works highlight the relative effect of the addition of salt, which can be either detrimental or beneficial to foam stability. However, in the flotation of coal, solutions of higher ionic strength showed improved froth stability (Kurniawan et al., 2011; Farrokhpay and Zanin, 2012; Wei et al., 2014).

Due to the sensitivity of the flotation process caused by the composition of the water it is important to understand how the recycling of water may affect the usage of flotation reagents such as the frother and to know how it may impact the recovery of coal particles. Beside the metallurgical reasons (i.e. flotation recovery and yield) there is also an operational incentive for the study of the impact of salts on bubble stability. For instance, it is reported that overly-stable froths cause frothing in pump boxes, tanks, and thickeners, which commonly disrupt plan operation in Australian CHPPs (Wei et al., 2014).

Therefore the objective of this study is to investigate the effect of water quality on the persistence of bubbles. The evaluation of the stability of bubbles was twofold. Firstly the coalescence time of capillary-held bubble pairs was used to characterise bubble stability, which represents a quiescent environment such as may be found in foams or froths. Secondly, the Sauter mean bubble diameter was measured to determine the tendency of bubbles to resist coalescence in a turbulent environment produced by a laboratory flotation cell. To this end, five water samples were taken from four different Australian CHPPs. The composition of the water samples was determined and the estimated ionic strength of the samples was used for comparing the samples. The persistence of bubbles in the process water was tested at different frother concentrations. The frother employed in this study was methyl isobutyl carbinol (MIBC) since it is still readily found in CHPPs (Parekh and Miller, 1999) and can easily be obtained at a high purity

**Table 1**

Water samples from different CHPPs with the sampling dates and pH and conductivity,  $\lambda$ , values reported at 25 °C.

Properties	Plant A	Plant B	Plant C	Plant D (Nov)	Plant D (Dec)
Date sampled	22 Jan 2016	12 Nov 2015	6 Aug 2013	11 Nov 2015	17 Dec 2015
pH	8.12	8.76	7.62	7.09	2.59
$\lambda$ , m S cm <sup>-1</sup>	3.797	4.154	7.329	8.002	10.95
Reagent	Nalco 9830	Nalco 9830	MIBC	Nalco 9830	Nalco 9830

grade although substitutes are being investigated (Cappuccitti and Finch, 2008; Park et al., 2016).

## 2. Experimental procedure

### 2.1. Materials

The frother used for the experiments was MIBC (Aldrich,  $\geq 98\%$ ), also designated 4-methyl-2-pentanol. Sodium hydroxide (NaOH) (Sigma-Aldrich,  $\geq 97\%$ ) and ethanol (Chem-Supply,  $\geq 99.8\%$ ) were used for cleaning. Throughout, concentrations of MIBC expressed in ppm are on a volume basis i.e. v/v. Milli-Q water dispensed from a Milli-Q Pure water system with a resistivity of 18.2 M $\Omega$  cm was used for all experiments unless otherwise specified.

All glassware were soaked in a cleaning solution for at least 15 min. The cleaning solution consisted of a mixture made of 120 g of sodium hydroxide dissolved in 120 g of water and diluted with 1 L of ethanol. The glassware were then rinsed with water. The flotation cell and the bubble viewer were cleaned by circulating a 0.1 M sodium hydroxide solution made up with distilled water for 20 min. The system was then rinsed with distilled water until the pH returns to that of distilled water. Other laboratory equipment such as stainless steel capillaries were sonicated in ethanol and water.

### 2.2. Water samples

Water samples were collected from CHPPs from 4 locations in New South Wales and Queensland, Australia. The clarified water samples were designated Plant A through Plant D with the latter sampled in November (Nov) and again in December (Dec) as presented in Table 1. The table also includes the pH values of the water, their electrical conductivity and the frothing reagent used.

It is worth noting that Plant C used MIBC as a frother and Plants A, B, and D used Nalco 9830 (a mixture mainly containing 2-ethylhexanol and some primary alcohols) both of which are alcohol-based and relatively volatile. It is expected that residual amount of frother may be present in the water albeit at very low concentrations. As an example, Gélinas and Finch (2007) reported a residual concentration of MIBC of approximately 0.3 ppm in Rio Tinto's Copperton Concentrator. Moreover, the MIBC tended to deplete after sampling through probable evaporation (Finch et al., 2006) or is likely to adsorb on surfaces (Bournival et al., 2015).

Samples were semi-quantitatively analysed by ICP-MS in order to get the main elements present in the water samples for the quantitative analysis. The quantitative analysis was performed by ICP-OES and Ion Chromatography. These analyses yielded the quantity of inorganic ions present in the clarified water samples. The alkalinity/acidity of the samples was determined by titration following a standard procedure (Clesceri et al., 1998).

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