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ScienceDirect
Trans. Nonferrous Met. Soc. China 24(2014) 2964−2968
Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

Evaluation of effect of viscosity changes on bubble size in a mechanical flotation cell

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Received 9 September 2013; accepted 20 January 2014

Abstract: In operating flotation plants, the viscosity of the pulp can vary significantly. Consequently, the resulting impact on bubble size is of interest as many plants experience seasonal changes in water temperature, or particle size changes as ore hardness, mineralogy and throughput fluctuate. However, given its importance in flotation, there existed no mathematical relationship linking bubble size created in flotation machines to the key process variable of fluid viscosity. In this study, a program of investigation to develop such a model was utilizing a pilot-scale mechanical flotation machine, to investigate the effect of water viscosity due to temperature on bubble size distribution. The bubble sizes were determined using a specific bubble viewer and imaging technology. The temperature itself was varied as a method for introducing significant viscosity change. The viscosity−temperature effect introduced a correspondingly significant change in the water viscosity (1619 to 641 μPa·s). It is suggested that a considerably stronger relationship may exist, yielding D_{32} versus $(\mu/\mu_{20})^{0.776}$, and hence viscosity becomes an important design consideration for plants operating where pulp temperature fluctuations, very small particles or high solid fractions are present.
Key words: flotation; bubble size; viscosity; surface tension; frother

1 Introduction

Froth flotation widely utilises differences in physicochemical surface properties of various minerals to achieve specific separation [1]. The efficiency of this separation process is dependent on the size of the bubbles [1−5]. Therefore, the ability to control the generation of bubbles in order to produce an optimum size range in flotation cells is attractive. Towards this purpose, bubble size measurements and modelling in flotation cells are clearly required. There has been some work on bubble size measurements and modelling in flotation [6,7]; however, neither of them have been adequate in accounting for the effect of the key variables such as fluid viscosity affecting the flotation process.

Plants also operate in conditions where the pulp temperatures can vary from near 0 °C to near 70 °C, and particle size and solid content are in a wide range, which will impact pulp viscosity. As a result, the effective viscosity of the liquid/solid phase can vary greatly. Testing for the effect of viscosity change is not straightforward, and early experiments are focused on finding a suitable additive to alter the water viscosity without impacting the other properties [8]. Two materials were tried: sucrose (sugar) solution and polyacrylamide (PAM), a well-know thickening and flocculating agent [9−11]. The sucrose was proved to have some frothing properties and so was rejected on the basis that it could impact bubble size apart from viscosity effects. The PAM seemed to promise initially having a wide range in viscosity possible ($(1-5)\times10^3$ μPa·s), until at higher concentrations (0.15% in mass fraction and above) its impact on the D_{32} was proved to be inversely dependent on time and concentration [5]. It is speculated that the long, cross-linked acrylamide chains were broken apart by the high shear in the impeller region of the Denver cell where the initial testing occurred. An attempt was therefore made to include the effect of viscosity on bubble size, by varying water temperature between 3 °C and 40 °C. The plan of work did not involve solids so the reference here to the effect of viscosity must be strictly

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DOI: 10.1016/S1003-6326(14)63432-4

that resulting from changes in water temperature. The ranges selected for all the variables can be considered representative of industrial practice, with some extension above and below typical operating range for frother concentration, and below normal for gas rate (J_g), in order to more fully define relationships. The initial work reported here was performed using the two phase water−gas (air) system in the laboratory environment. Once developed, the approach calls for an additional stage of experimentation by introducing solids as well.

2 Apparatus and method

2.1 Viscosity measurement

The viscosity measurement involved measuring liquid viscosity at different temperatures, as described in Fig. 1, in order to provide practical viscosity ranges (viscosity – temperature curve) for testing in the flotation machines. The setup consisted of a Canon-Fenske Routine (CFR) viscometer (size 100), a 6 L beaker, a thermometer, a magnetic stirrer, and a heating element connected to a thermocouple with a temperature sensor.

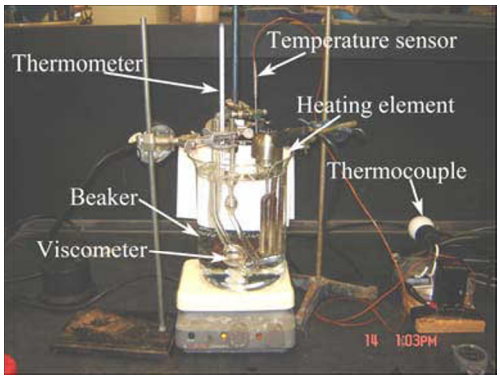

Fig. 1 Setup of viscosity measurement apparatus

The heating element was connected to the thermocouple which was set at the desired temperature. Based on the signal from the temperature sensor, the thermocouple regulates the heating of the element. If the set temperature is reached, the thermocouple will turn the heater off. The magnetic stirrer served to distribute the heat from the element evenly throughout the bath.

2.2 Bubble size determination

An AutoCAD sketch of the set-up to measure bubble size is shown in Fig. 2. The nominal volume of the Metso RCS^{TM} 0.8 m^3 mechanical flotation cell is 800 L, with a standard test volume of 700 L employed. The impeller diameter is 21 cm and that of the outside diffuser is 33 cm. A feature of the design is the baffle ring at 40 cm from the bottom of the tank (32 cm below water surface) which divides the turbulent zone around the impeller from the quiescent zone above where bubble size is determined. The cell was forced-air and air supply was from a compressed air system and manipulated via a 400 LPM KMS^{TM} mass flow meter. The sampling tube of the MBSA was positioned 33 cm from the central shaft (19 cm from the wall) and 52 cm from the bottom of the tank (20 cm below the water surface). This location inside the quiescent zone had been established previously as both being representative of the average air rate in the cell and giving reproducible data [5,12,13]. All experiments were run under the following conditions: air superficial velocity (J_g, i.e., volumetric air rate divided by cell cross-sectional area) 1 cm/s and impeller speed 1500 r/min (equivalent to 5.73 m/s tip speed). The cell was filled with Montreal tap water and frother DF250 was added at 5×10^{-6} (CCCx of 59%). The CCCx was set at a level where changes to D_{32} would be evident [14].

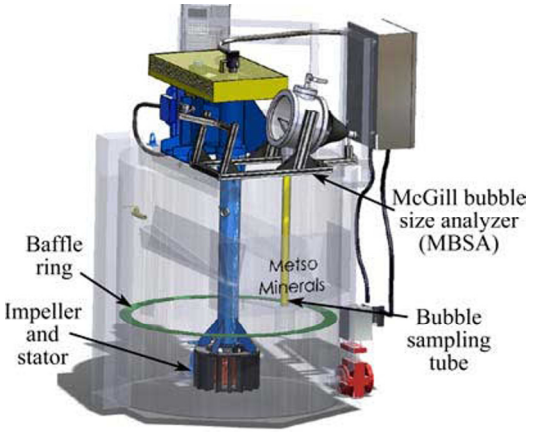

Fig. 2 Side view of Metso RCS^{TM} 0.8 m^3 mechanical cell and MBSA (CAD drawing)

In order to vary water temperature in the Metso cell as a mean of altering viscosity, the testing period was in winter and a test range of 3 °C to 40 °C was possible by varying proportions of cold and warmer water and by running the cell at the highest possible speed to generate additional heating. A total of five test series (i.e. 32 tests) were run to cover the full temperature range. Bubble sizes were determined using a specific bubble viewing chamber and sampling-for-imaging technique [15,16]. Further details were given in Refs. [13,17].

3 Results and discussion

Varying only viscosity without significantly affecting the many other factors that could influence bubble size is not straightforward. The point could be argued that other properties of water that are temperature-dependent could impacting the bubble size distribution, such as surface tension, density or contained enthalpy. The trends in Fig. 3 suggest that water temperature was selected as the first situational variable