Minerals Engineering 22 (2009) 1209–1217

Contents lists available at ScienceDirect

Minerals Engineering

journal homepage: www.elsevier.com/locate/mineng

Effect of ultrasound on separation selectivity and efficiency of flotation

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ARTICLE INFO

Article history:
Received 19 January 2009
Accepted 25 June 2009
Available online 22 July 2009

Keywords:
Flotation froths
Flotation kinetics
Sulphide ores

ABSTRACT

The effect of the use of ultrasound in the froth phase on the flotation performance has been investigated in relation to the flotation rate of a complex sulphide ore. A series of kinetic flotation tests with and without ultrasound were conducted in a flotation machine with a 2-L cell, in which an ultrasonic probe is located in the froth zone. The results indicate that there is a considerable effect of ultrasound on separation selectivity and efficiency in the flotation of a complex sulphide ore at intermediate and high level airflow rates whereas, no significant differences in the separation performance were obtained from the flotation with and without ultrasound at low airflow rates. In addition, the results of the size-by-size analysis show that a much better cleaning action in the froth was promoted for coarse particles rather than fine particles as a result of the use of ultrasound. As a result of increase in the bubble coalescence, it was found that the use of ultrasound in the froth is more effective at shallow froths. Therefore, either effective pulp volume can be increased with a negligible loss of flotation performance or the pulp density can be decreased to obtain better product quality with the use of ultrasound in shallow froths.

1. Introduction

Ultrasonic wave, or ultrasound, can be used to improve efficiency and/or selectivity of the flotation process. Most studies have examined the effect of the use ultrasound before flotation, e.g., removal of adsorbed layer of reagents from minerals, emulsification of flotation reagents, while other recent studies have revealed the effect of ultrasonic treatment during and after flotation processes (Nicol et al., 1986; Slaczka, 1987; Celik, 1989; Djendova and Mehandj, 1992; Farmer et al., 2000; Ozkan, 2002; Gurpinar et al., 2004). Various investigators have shown that intensive acoustic fields can modify the state of a material, leading to chemical or dispersive effects. Generally, the effect of ultrasonic vibration depends upon the nature of the mineral and also the way ultrasonic wave is applied (Celik, 1989; Ozkan, 2002). The effect of ultrasonic treatment is characterized by cavitation. When an ultrasonic wave is projected in liquid negative pressure is created and causes the liquid to "fracture", a process known as cavitation, which creates bubbles that oscillate in the projected ultrasonic waves. Cavitation takes place primarily on the phase boundary, since solid/liquid interactions are weaker than liquid cohesion forces. The occurrence of ultrasonic cavitation depends on a number of factors (temperature, surface tension, medium viscosity, hydrostatic pressure, the degree of gas saturation, gas type and others), therefore they are different for different mediums and experimental conditions (Celik, 1989; Chen and Simpson, 1992; Brennen, 1995; Farmer et al., 2000; Sorys and Zielewicz-Madej, 2007). Several investigators suggested that ultrasonic energy can improve the flotation performance (Slaczka, 1987; Celik, 1989; Djendova and Mehandj, 1992; Aldrich and Feng, 1999; Ozkan and Kuyumcu, 2007). Their findings suggest that ultrasonication improves the effectiveness of the reagent due to its more uniform distribution in the suspension and also in enhancement of the activity of the chemicals used. In addition, the damage of the mineral surface should cause changes in its adsorption properties in relation with flotation collectors and thus change its flotation properties.

It is known that evaluation of the effects of altering flotation variables is easily accomplished by fitting batch data to first-order rate equations. Many parameters used in the modelling of the overall flotation performance have been derived from tests conducted in batch flotation cells (Fichera and Chudacek, 1992; Wills, 1997; Mathe et al., 2000; Polat and Chander, 2000; Nguyen and Schulze, 2004; Zheng et al., 2006). However, the froth zone contributes considerably to the overall flotation performance. The role of the froth zone in determining flotation performance has been explicitly recognised by many investigators (Feteris et al., 1987; Gorain et al., 1998; Mathe et al., 1998, 2000; Vera et al., 1999, 2002; Ata et al., 2002; Alexander et al., 2003; Zheng and Knopjes, 2004; Zheng et al., 2006).

Most of the research conducted on ultrasonic flotation with a modified cell so far to understand the reagent-valuable mineral interaction mechanisms from the overall flotation performance point of view. However, a review of the literature indicates that

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doi:10.1016/j.mineng.2009.06.007

no work has been done with regard to effect of the use of ultrasound in the froth zone on the efficiency and selectivity of flotation. The objective of the present study is therefore to investigate the effect of the use of ultrasound in the froth on performances of the pulp phase and froth phase in flotation of a complex sulphide ore. In other words, the present study was developed to determine and interpret potential improvement in the overall flotation performance as well as the separation selectivity regarding the use of ultrasound in the froth.

2. Experimental

2.1. Material

A copper–iron sulphide ore sample containing 1.2–1.8% Cu and 19.5–23.8% Fe was used in the experiments. Minerals of the ore sample are chalcopyrite associated with pyrite in a non-sulphide gangue (mainly quartz). The liberation size of the minerals is minus 0.038 mm.

2.2. Method

Ultrasound may be applied during the different stages of flotation, such as prior to, or during flotation (Celik, 1989; Djendova and Mehandj, 1992; Aldrich and Feng, 1999; Ozkan, 2002). Flotation tests were performed in Denver laboratory flotation machine with a 2-L cell constructed from Plexiglas, in which an ultrasonic probe (Bandelin Sonoplus HD 2200, 20 kHz, 0.2 kW) is located in the froth phase. A schematic illustration of the experimental setup used is given in Fig. 1. The flotation reagents used in this study were supplied by Cytec Industries, USA. In the light of previous works on this subject and the results of the preliminary tests conducted, a face-centred cubic (cube plus star) experimental design was used to statistically define the effects of airflow rate, froth depth and impeller speed on selectivity and efficiency of the flotation with and without ultrasound (Montgomery, 1991; Myers and Montgomery, 1995; Sheridan et al., 2002). Range of the operating parameters and the chemical conditions used in flotation tests are given in Table 1.

In order to elucidate the effect of ultrasound on performances of the froth phase and the pulp (collection) phase, kinetic flotation tests were conducted with and without ultrasound. The froth was removed at preset time intervals for all flotation tests. For each test, predetermined froth depth (F_D ±2 mm) was kept constant by the addition of make-up water into the cell by using a variable speed peristaltic pump. The froth was scrapped every five seconds. Each froth product (water and solids) was weighed, filtered, dried and weighed again to determine water recovered in the incremental concentrates. The products were analysed for copper and iron by atomic absorption spectrophotometry. Size-by-size analysis was also performed in order to determine relationship between ultrasound and the particle size distribution of the products of some flotation tests. Furthermore, to compare the bubble size distributions with and without ultrasound, some photographs were taken at various positions within the froth phase and, were analysed using a commercial image analysis software. The bubble size distribution was determined from measuring at least 300 bubbles in each case.

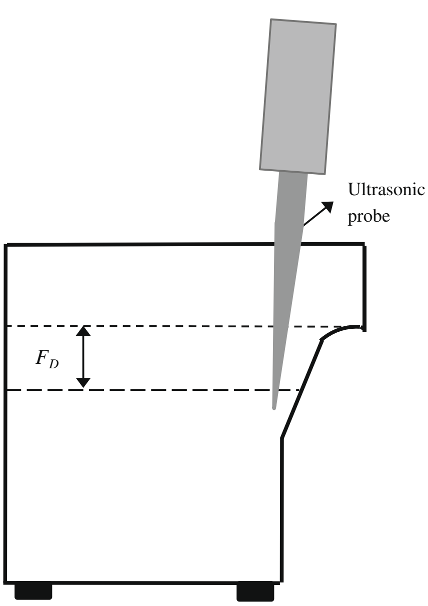

Fig. 1. The schematic illustration of the experimental setup.

Table 1
Flotation conditions used in the tests.

Parameters	Ranges	The conditioning time (min)
pH of pulp (with CaO)	11	10
Collector (Aerophine 3418 A)	80 g/t	5
Frother (Oreprep F-507)	50 g/t	1
Pulp density	18 (% solids)	
Airflow rate (L/min)	4, 6, 8	
Froth depth (mm)	5, 15, 25 ± 2	
Flotation time (min)	0.5, 1, 2, 3	
Impeller speed (rpm)	1000, 1250, 1500	

It is assumed that the recoveries of valuable mineral, gangue minerals and water can be described by a first-order rate equation (Lynch et al., 1981; Agar, 1987; Wills, 1997; Agar et al., 1998; Polat and Chander, 2000; Nguyen and Schulze, 2004; Angadi and Suresh, 2005). The experimental results were fitted to following first-order rate model:

$$R_{oi} = RI_i\{1 - exp[-k_{oi}(t + b_i)]\} \quad (1)$$

where R_{oi} is the overall recovery (%) of a pulp component (i) at time t (min), b_i is the time correction factor, RI_i and k_{oi} are the ultimate recovery (%) and the rate constant (min^{-1}), respectively. In addition, the separation selectivity of flotation can be evaluated by the selectivity index, which defines as the ratio of the modified rate constant ($k_{\mathrm{mod}i} = RI_i k_{oi}$) of mineral I to the modified rate constant of mineral II (Xu, 1998). The selectivity index was used as the measure of separation selectivity of chalcopyrite (C) over pyrite (P) or gangue (G).

3. Results and discussion

3.1. Effect of ultrasound on flotation efficiency

The recovery of each pulp component (chalcopyrite, pyrite, gangue and water) obtained from the tests with and without ultrasound is given in Table 2 which also contains the factor levels used in the experimental design. As can be seen, the overall recoveries of the mineral species are decreased in all cases as froth depth increased in flotation without ultrasound. In some cases, increase in the airflow rate and/or impeller speed compensates for the detrimental effect of the froth depth on the chalcopyrite recovery. The results in Table 2 show that the use of ultrasound has an effect in a certain extent on all chalcopyrite recoveries. These results were as expected. The existence of such a relationship between the valuable mineral recovery and ultrasound has also been observed by Celik (1989), Djendova and Mehandj (1992), Aldrich and Feng (1999), Ozkan (2002), Gurpinar et al. (2004).

In order to assess the net effect of ultrasound on the responses, a decent data set was generated by calculating the differences