Effect of ultrasound on flotation kinetics in the reactor-separator

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Abstract. Effect of the ultrasound on flotation kinetics in reactor-separator has been studied for chalcopyrite/quartz mix mineral system. Under ultrasound treatment, recovery of chalcopyrite into bulk concentrate is higher than that at reagent-only treatment. It can be explained by increased of flotation rate for slow fraction as defined by Kelsall model. The slow fraction flotation rate increase multiplied by 6 vs. ultrasound treatment. Additional effect of the ultrasound treatment has been noticed under conditions when gangue minerals detachment from bubbles can be controlled. Reactor-separator has advantages over other types of flotation cells for this purpose providing a special zone for the ultrasound treatment that can be easily designed in this impeller less machine. The ultrasound influence on particles collision probability is able to explain of chalcopyrite recovery increase in the concentrate and activation chalcopyrite particles flotation.

1. Introduction

The use of the ultrasound conditioning in flotation has been expanding in the recent years. Application of the ultrasound at 20 kHz frequency and approximately 0.3 W/cm² power causes cavitation in water or slurry. The cavities collapse obtained under ultrasound treatment results in very high energy densities [1]. Ultrasound treatment at these characteristics has been used for pre-conditioning of low solubility reagents [2, 3], for froth destruction as well as during the flotation [4, 5, 6].

The ultrasound effect at slurry conditioning on sulphide ores flotation results has been investigated by Aldrich and Feng [4]. Among all the parameters (temperature, solids content, conditioning time), the duration of ultrasound treatment has been the most significant. It has been demonstrated that ultrasound treatment allows reducing the depressant consumption.

Jordan [7] has demonstrated that in an impeller less flotation machine ultrasound affects collision and attachment of particles to bubbles, bubble coalescence, and other flotation sub processes in the mixing chamber. The drawback of this design is the direct location of the vibrator in the slurry, which reduces operation reliability.

The literature review [8] show that in the most of studies carried out, whole cell volume has been exposed to the ultrasound. In fact the intensity of the oscillations drops rapidly in the pulp from the wave source. Indeed, only a weak proportion of the slurry was subjected to US treatment even in a laboratory cell as was shown by Vargas-Hernandez et al. [9].
The goal of the present research is to study the role of ultrasound treatment on the bubble-particle attachment in a cell of reactor-separator type. Reactor-separator has distinct zones for air flow dispersion into bubbles in the sparger, bubbles-particles attachment/detachment in the reactor, bubble-mineral aggregates removal into froth in the separator [10]. Thus, it is possible to chose only a unique stage of flotation process to be affected by US treatment.

In other types of flotation cells, all these processes occur simultaneously in the same zone, which makes problematic the application of ultrasound treatment at a large scale. The setup used in this work allows application of ultrasound to a selected reactor zone in continuous slurry stream. It is important to note that in this case bubbles with maximum mineral load enter the ultrasound treatment.

2. Experimental

2.1. Experimental Set-up

The experimental set-up included a separation cell, a bubble-sparger and an ultrasonic emitter placed on the reactor. The principles of experimental set-up operation can be described in Figure 1. Pulp prepared after ore grinding was poured into sump (1) for reagent conditioning. At the end of conditioning step, feed pulp is pumped into the reactor (4) through bubble generator (3), creating a high-pressure jet, which disperses the forced air feed in fine bubbles. Due to high mixing velocity and a high gas/liquid interfacial area, rapid collision between bubbles and particles occurred.

![Figure 1. Set-up of the laboratory scale reactor-separator.](image)

The bubble-particles attachment was provided in the reactor (4) that directs the aerated slurry into separation cell (5). Bubbles-particles attachment in the sparger or/and in the reactor zone (4) occurs in terms of particle surface hydrophobicity. The aerated mixture exits from the reactor and enters the separation cell (5). Bubbles/particles aggregates disengage from the pulp in this low turbulent zone producing two flows: floated products (sulfide concentrate) and non-floated products (tailings).
When the slurry level reaches the steady state, froth is removed and tails are recirculated to sump (1). Air flow was measured and regulated by air flowmeter (9). Pressure level at the centrifugal pump discharge was controlled by the manometer (10).

System capacity was 4.2 L/min of slurry.

An ultrasound emitter (6) is attached in the external side of reactor. Ultrasound frequency was regulated from 0 to 27 kHz.

2.2. Materials and research methods

In this work the effects of US on the flotation of a chalcopyrite/quartz mixture was studied. Sample of 1 kg of ore has been ground in a ball mill. Solid content in the flotation slurry was 25 %.

Potassium butyl xanthate was used as collector for sulfide mineral flotation. The collector and pin oil type frother were added in the sump. Reagents dosage and particle size distribution after grinding are provided in the Table 1. The pH of slurry during conditioning and flotation steps were maintained between 8 and 8.5.

Flotation kinetics curves (mineral recovery vs flotation time) and a model to evaluate the experimental results were used. To obtain the flotation kinetics curves froth product has been removed in fractions for 15.5 minutes.

| Table 1. Experiment conditions. |
|-------------------------------|
| Ore type | Size (µm) | Cu content (%) | Butyl xanthate | Frother |
| Chalcopyrite /Quartz = 1/3 | 86 % | -0.074 | 8.6 | 150 | 180 | 100 | 120 |

Three parameters fast/slow floating particles model was used [11]:

\[ R = (1 - \Phi)[1 - \exp(-K_f t)] + \Phi[1 - \exp(-K_s t)] \]  

(1)

\( R \) is recovery at time \((t)\), \( K_f, K_s \) are the rate constants for fast and slow components \((\text{min}^{-1})\), \( \Phi \) is the fraction of flotation components with slow rate constant.

This equation (1) incorporates two rate terms instead of one rate constant. The model does not include an ultimate recovery parameter but rather the ultimate fractional recovery is assumed to be 1.0. When \( K_s \) parameter approaches 0, the parameter \((\Phi)\) will then represent the fraction not recovered and the term \((1 - \Phi)\) becomes analogous to ultimate recovery and the model reduces to two-parameter model.

Mineral contents in products have been measured by the method of densities (this was possible due to the difference of chalcopyrite and quartz densities):

\[ \rho = \frac{m_2}{m_1 - (m_3 - m_2)} \cdot \rho_c \]  

(2)

\( \rho \) = density of sample; \( \rho_c \) = density of water; \( m_1 \) = weight of water for a volume \( V_{\text{const}} \); \( m_2 \) is the weight of sample; \( m_3 \) is the weight of initial suspension \((V_{\text{Sample}} + V_{\text{Water}} = V_{\text{const}})\).

The recovery of chalcopyrite in the floated product was calculated from measured yield and mineral content obtained by formula 2.
3. Results and discussion

Flotation kinetics of chalcopyrite recovery is shown in Figure 2. Chalcopyrite recovery with ultrasound increased by 15-20 %, but change slightly with ultrasound frequency variation.

![Figure 2. Kinetics of chalcopyrite recovery with ultrasound.](image)

At the same time, yield of concentrate increased from 19.1 % (without ultrasound) to 24.8 % (with ultrasound frequency of 27 kHz). Chalcopyrite content decreased at the end of flotation: without US from 89.3 to 82.5 %, and with US 27 kHz from 93.6 to 83.5 %. Increase of chalcopyrite recovery occurred due to increase of the yield, rather than of the chalcopyrite content in concentrate.

The rate constants of flotation for fast and slow components with ultrasound frequency were calculated using Kelsall’s flotation model (figure 3).

![Figure 3. Rate constant of chalcopyrite flotation for fast Kf and slow Ks components vs. ultrasound frequency.](image)

The rate constants increase with using of ultrasound treatment. Activation of the floatability of two considered components is noticed. The flotation rate constant of slow fraction $K_s$ was multiplied by 6 with US treatment. The flotation rate of fast fraction changed slowly (by 8 %) with ultrasound: at ultrasound frequency variations, considerable changes didn't occur.

The obtained results show clearly that US treatment can activate the floatability of slow fraction.

Increased kinetics can be explained by three hypotheses:

- the ultrasound allows a selective particle detachment from bubble [12];
• the ultrasound cavitation can modify the surface of mineral particles by micro or nano bubbles formation and facilitate the bubble-particle attachment [13].
• the ultrasound can influence on particle collisions probability.

During the passage of the ultrasonic processing zone (Figure 4), a selective quartz particles detachment from bubble is possible, that allows to clean air bubbles surface and additional chalcopyrite particles can be fixed on the cleaned bubbles surface. Increase of chalcopyrite content in the concentrate can be explained by this effect.

Increase of the concentrate yield (from 19.1 % without US to 24.8 % with US=27 kHz) and the chalcopyrite recovery in the concentrate (Figure 2) can be explained by ultrasonic cavitation. Cavitation bubbles occur mainly on hydrophobic surfaces. Therefore chalcopyrite particles can be activated by the cavitation (Figure 3).

Figure 4. Scheme of flow reactor for ultrasonic activation of particle attachment/detachment sub-processes.
A selective particle detachment from bubble with ultrasound processing occurs. Flow reactors are more efficient than classical cells because of the lower energy dissipation i.e. the whole flow is subjected to the ultrasonic activation.

The ultrasound influence on particles collision probability is able to explain the increase of chalcopyrite recovery in the concentrate but this hypothesis needs a direct experimental confirmation.

4. Conclusions
Results show an increase of the flotation efficiency in the presence of ultrasonic processing:
• chalcopyrite recovery increases by 5-20 % with ultrasound treatment.
• an increase in flotation rate constant is obtained when ultrasound frequency varies from 0 to 27 kHz. The significant contribution to this augmentation is related with the “acceleration” of slow component flotation: the rate constant of slow component as defined in Kelsall model, increases 6 times for the ultrasound frequency of 27 kHz.
• it should be noted that the retention time in the ultrasound pan was approximately 0.1 s. Therefore, ultrasound exposure was of the pulse type and its mechanism needs to be studied in more details.
• ultrasound treatment can influence the particle detachment process exclusively. Special zone should be provided for the ultrasound treatment that can be easily designed in impeller less machine as in reactor-separator.

References
[1] Gogate P R, Taayal R K and Pandit A B 2006 Curr. Sci. 91 (1), 35
[2] Mitome H 2003 Action of ultrasound on particles and cavitation bubbles Proc. World Congress on Ultrasonics (Paris), 2342-2346
[3] Ozkan S G and Kuyumcu H Z 2006 Int. J. Miner. Proces. 81 201
[4] Aldrich C and Feng D 1999 Miner. Eng. 12 701
[5] Zaidi S A H 1997 Fuel Process. Technol. 53 31-39
[6] Wenze K, Haixin X and Jun H 2008 coal Fuel Process. Technol. 89 1337
[7] Jordan C E 1991 Ultrasonic flotation system US Patent 5.059.309., Oct 22
[8] Ozkan SG and Kuyumcu H Z 2007 Ultrason. Sonochem. 14 (5) 639
[9] Vargas-Hernandez Y, Gaete-Garreton L and Magne-Ortega L 2002 High Power Ultrasound to Recover Fine Particles in Flotation Process Revista de Acústica 33, Special issue
[10] Samyguin V D, Panin V V, Filippov L O and Stenin N Yu 2010 Metallurgist, 54, 394-400
[11] Kelsall D F 1961 Application of probability in the assessment of flotation systems Bull. Instrn. Min. Metall. 650, 191-204
[12] Kondratiev S A 2005 Flotation method Russian Patent 2243824
[13] Zhou Z A, Zhenghe Xu, Finch J A, Masliyah J H and Chow R S 2008 Miner. Eng. 22 419