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Ultrasound treatment on tailings to enhance copper flotation recovery

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ABSTRACT

As ore grades fall, the amount of tailings production for the same copper production is expected to rise. Flotation recovery of copper sulfide from the El Teniente plant has deteriorated in recent years, in this regard ultrasound treatment of tailings for enhanced copper recovery was evaluated in laboratory experiments. The impact of the ultrasound wave was examined under different conditions, with the conclusion that improved recovery occurs when ultrasound is applied during conditioning and flotation. The results can be explained by the effect of acoustic cavitation that cleans particle surfaces and minimizes slime coatings, facilitating the action of the reagents. In this way, improvement in copper recovery of up to 3.5% were obtained.

1. Introduction

One of the biggest challenges facing the mining industry is the deterioration of mineral grades. This problem makes it necessary to improve the recovery of current operations to offset the steady decline of Cu grades. Such a decline of average saturation grade has meant a fall of 1.0% Cu to 0.86% of global average grade during the last decade (Chile, Ministerio de Minería, Corporación Chilena del Cobre, 2015). It is estimated that in Chile the amount of tailings generated only as products of copper sulfide concentration reaches 481 M ton annually, a figure that will continue to rise as mineral grades fall. That is why it is interesting to explore the use of new technologies to improve overall recovery and reduce tailings.

Ultrasound treatment is used in various industries for surface cleaning (Farmer et al., 2000; Gallego-Juarez, 1994; Zhao et al., 2007). Ultrasound treatment has lead to interesting research in the mineral processing industry to improve coal processing (Ozkan and Kuyumcu, 2006, 2007; Ozkan, 2012; Ambedkar et al., 2011), fluid-solid particle separation (Riera-Franco de Sarabia et al., 2000) and flotation of oil shale cleaning (Altun et al., 2009). Moreover, various studies to optimize the flotation process by using ultrasound treatment have been conducted (Aldrich and Feng, 1999; Ishak and Rowson, 2009; Kang et al., 2009; Ozkan and Gungoren, 2012; Schlesinger and Muter, 1989; Vargas et al., 2006), but none of the studies contemplated the re-treatment of the poorest tailings in order to recover bornite, chalcopyrite, cuprite or molybdenite.

Following this line of research, Ozkan (2002) has shown that pre-treatment of magnesite by ultrasound increases magnetite recovery. In his analysis, he assumed a cleaning effect on the surface of the mineral. Similarly, Kang et al. (2009) have shown that the application of ultrasound radiation in coal flotation improves the efficiency of the process, reducing ash recovery. Also, sulfides were oxidized due to the ultrasound effect.

Aldrich and Feng (1999) observed an improvement in the ultimate recovery of sulfur from Merensky Reef, Africa, using ultrasound treatment, despite the negative effects of the concentration of solids, temperature, conditioning time and gas flow. Meanwhile, Vargas et al. (2006) found that conditioning by means of ultrasonic radiation could preserve the concentration of copper sulfides, but decrease the recovery of iron sulfides, resulting in improved selectivity in the flotation, reducing the recovery of pyrite and increasing the concentrate grade.

Previous work (Stoev et al., 1992) have shown the significant positive impact that may have the application of mechanical vibration and the acoustic wave excited by them in several mineral processing units, particularly in flotation. Their results were promising and show applications of vibroacoustic excitation at low frequencies to promote attachment of mineral particles to air bubbles, increment of recovery, increment of flotation rate, increment of selectivity, control bubbles size, emulsification of reagents, desorption of reagents, and froth control among others. The principle that justifies the use of ultrasound relates to the same phenomena

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described in this seminal work, a process based on the wave spreading in the aqueous medium. Additionally, as the wave frequency increases reaching high intensities such in ultrasound, the vibroacoustic waves can lead to acoustic cavitation, a phenomenon that causes bubble generation due to progressive pressure drop in each wave cycle. The bubbles begin to oscillate along the sound field in the first stage; after a few cycles the bubbles reach a critical size at which they resonate in a nonlinear regime. This regime makes it difficult for the bubbles to expand to larger sizes, making the medium's response increasingly important, due to the inertial forces that cause shrinkage of the bubble in the compression cycle (Gaete et al., 1997). Eventually the bubbles collapse under considerable elevated pressure emanating from the medium (Mitome, 2003). This implosion generates a supersonic *microjet* of fluid in the area where the bubble collapses. It has been shown that this microjet possesses great capacity to erode a surface which would remove contaminants on the surfaces of the particles, thus improving the efficiency of the concentration process.

This study suggests that the cavitation phenomenon caused by ultrasound could improve the flotation tailings of copper sulfides. The tailings consist of fine and ultra-fine particles of gangue, and a percentage of particles containing copper that were not floated due to lack of release and surface contamination. Copper sulfides inside the tailings might have been oxidized and ultrasound treatment may have removed the oxidized layer from the particles surfaces as well as helping the desliming. This would mean an improvement in the overall recovery of the system before sending the tailings to their final deposition.

Subsequently, the methodology of the development and evaluation of laboratory flotation tests for processing the tailings of copper sulfide is presented. For this evaluation a 'Denver' flotation cell has been changed to be able to control the ultrasound field applied to the particles. The results are analyzed via obtaining the kinetic curve flotation, its parameters and the resulting Cu grade.

2. Materials and methods

2.1. Materials

To develop this study, copper sulfide tailings, provided by Valle Central Mine, were used. The tailings have an average copper grade of 0.12%, with most in the form of chalcopyrite, and with a specific gravity of 2.7 [g/cm^3]. The tailings consist of fine and ultra-fine particles under 70 mesh, which have previously passed through a stage of grinding and flotation in the mine of 'El Teniente', a branch of the national copper company CODELCO Chile, a mill plant located in central Chile.

Three tailings samples of 500 ml out of the 100 L sample were analysed to characterize the particle size of the supplied material. After tailings were homogenized, increments of 50 ml were taken from different parts of the container to complete one sample. The samples were extracted and analysed via laser diffraction technology with a Mastersizer 2000. Table 1 and Fig. 1 display the results of the analyses and distributions of the size for each sample, respectively. As can be seen, the results show that the tailings is mostly composed of particles of about 10 μm, with 50% of the particles under 14 μm and 90% of the particles under 220 μm. Sample one is coarser than sample two and three. This difference may due to the fact that the upstream classification process is not operating perfectly and few coarse particles may have end in the final sample. In average though, the product size is below the limit. No agglomeration was observed in the sample. Samples were sonicated 20 min before the particle size analysis.

2.2. Ultrasound treatment

In this study we evaluated the use of ultrasound to improve the recovery of copper sulfides by applying three different conditions, derived from experience gained from evaluating heavy minerals in previous research (Celik, 1989; Cilek and Ozgen, 2009; Djendova and Mehandjiski, 1992; Aldrich and Feng, 1999; Ozkan, 2002; Vargas et al., 2006). The three ultrasound conditions applied are: Ultrasound Conditioning (UC) where ultrasound is applied only during conditioning; Ultrasound Flotation (UF) which applies ultrasound only in flotation; Flotation and Conditioning with Ultrasound (FCU), in which ultrasound is applied throughout the process of conditioning and during flotation. These tests were compared with the results of a basic test called Standard Flotation (SF) that considers the same operating conditions but without applying ultrasound during any of the processess. All tests were run in random order and in duplicate to control the variability of

Table 1
Characterization of collected samples.

Characteristic	Sample 1	Sample 2	Sample 3	Average	Standard deviation
Uniformity	7,48	3,32	5,07	5,29	2,09
Specific surface [m^2/g]	0,86	1,15	1,11	1,04	0,16
Average particle size D[3,2] [μm]	7,00	5,20	5,43	5,88	0,98
Average particle size D[4,3] [μm]	158,02	40,76	59,73	86,17	62,94
10% Under diameter [μm]	2,76	2,12	2,27	2,39	0,34
50% Under diameter [μm]	20,12	10,82	10,79	13,91	5,38
90% Under diameter [μm]	402,70	118,53	130,01	217,08	160,86

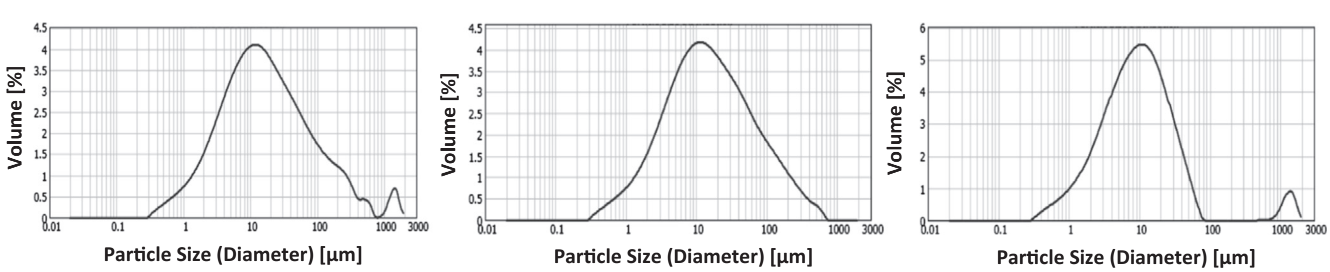

Fig. 1. Particle size distribution in three samples collected from Minera Valle Central feed. Sample 1, 2 and 3 are shown from left to right.