HIGH-POWER ULTRASOUND AS AN ALTERNATIVE TO HIGH-INTENSITY CONDITIONING IN FLOTATION

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Abstract
The effect of high power ultrasound on the recovering of useful minerals from fine and ultra-fine particles in metallurgic pulp is being studied. The ultrasound effect was compared with the high-intensity conditioning, the most promising technique to the recovering of metals from fine and ultra-fine particles. The results are very interesting showing that with ultrasound it is possible a significant increasing in the recovering with an important gain in the law of the obtained concentrate. In addition, the ultrasonic technique produces an interesting saving of energy with consumption's less than half of the spent in the High Intensity Conditioning.

Introduction
In the mining process a very important system, should we say, the most significant, is flotation. It consists in separating useful substances from the useless ones that pertain to the mineral. The flotation consists of making a pulp formed with water and the mineral ground to a size of about 100 microns. Adding some surfactants that make the useful substances hydrophobic, the particles are caught in tiny bubbles that are introduced in the flotation chamber. The particle-bubble system goes up in the flotation tank and it is recovered as a concentrate. However, the problem of recovering the fine (6-50 μm) and ultra-fine (< 6 μm) mineral particles continues to be a challenge for researchers. Important improvements in the treatment of the problem were reached in a laboratory scale using the "high intensity" conditioning method. The method consists of introducing a high turbulence in the flotation pulp, the effect of such a treatment seems to be the aggregation of tiny particles reaching sizes suitable for flotation. The shear stress was identified as one of the physical mechanisms to produce the desired flocculation of the fine and ultra-fine particles [1], [2].
In this paper the effect of acoustic cavitation in the flotation was investigated. The main hypothesis for this research was that it is possible to introduce a high energy content in the metallurgic pulp if it is radiated for a high-intensity acoustic field. Two effects can be produced; the first one is an agglomeration of particles reaching a size that is appropriate for flotation. The second one is the production of very tiny bubbles that can be efficient in the catching of fine and ultra-fine particles.
Experiments of flotation with high-intensity conditioning treatment (HIC) in full-controlled situations were done, afterwards the results will be compared with experiments carried out with similar metallurgic pulp in the same flotation cell but insonated with a high intensity acoustic field. The main aim of this treatment is to produce tiny cavitation bubbles and to promote the collision between particles and bubbles in special conditions created by the acoustic field inside the chamber.

Materials and Methods

A. High-Intensity Conditioning (HIC)

A representative sample of Chilean copper ore was ground in a laboratory ball mill, 17.5 cm in diameter and 22.5 cm in length until a size 100% below 10 Tyler Mesh. Homogeneous samples of approximately 1200 g were obtained from this powder. The influence of HIC in the recovery of fine and ultra-fine particles was evaluated undergoing the sample to different mill grades. The mill grade refers to the percent in weight of the fraction under 325 Tyler mesh in this way samples with different fine and ultra fine content were produced allowing the assessment recovering this kind of particles.
The flotation conditions and grinding process were defined in a protocol to make the tests. A pulp concentration of 68% in weight of solids in grinding and 36% in flotation was employed. An Isopropyl Sodium Xanthate, 25 g/t dosage, and Isopropyl-butyl Sodium Mercaptotiophosphate, 8 g/t, was added as a collector just before the beginning of HIC. To make the flotation foaming agents, at a rate of 20 g/t, a mix of Dow Froth 250, MIBC and Pine Oil, volume proportion of 4:2:1, was added. The agitation speed in cell was 1100 rpm. The pH of the pulp in flotation was 10.5. The method includes the foam removal every 5 seconds and a total flotation time of 9 minutes, water was added to the cell to keep the water level constant.
The HIC was carried out in a 4 litre-capacity Denver flotation Cell. The inferior part of the stator was removed to obtain a higher shear grade. The Denver cell was equipped with four removable acrylic baffles, producing high turbulence. The energy transferred to the pulp during the HIC was monitored using a true power meter. To produce the turbulence, the impeller was driven constantly at 1500 rpm, this way the

energy transferred to the pulp was proportional to the duration of the experiment. The amount of pulp treated in this experiment was 2.5 litres and the energy supplied ran from 2 to 12 kWh/m^3, this conditioning was equivalent to a HIC duration time run of 40 to 240 s.
Immediately after HIC, flotation was made in a 2.7 l Denver flotation Cell (Fig. 1), adding the necessary amount of water to complete the cell volume.

B. Ultrasonic Flotation Tests

For the ultrasonic flotation tests a special protocol was developed to investigate the effects of ultrasound on interaction between particles and bubbles were looking for. The question is, if it is possible to improve the flotation performance in a process of metallurgic pulp ultrasonically irradiated. For this task the Denver cell used in the HIC was equipped with two specially designed transducers. The transducers were driven by an electronic system that kept constant the emission levels [3] (Fig. 2). In figure 1 the transducers embedded in the cell flanks can be observed. The modification of the Denver Cell has been done in such a way that it keeps the same geometrical measurements that those used in the HIC cell. The transducers were situated in the lateral tubes embedded to the cell and to the coupling with the metallurgic pulp and immersed in distilled water. A fine flush mounted membrane on either side of the lateral wall cell covered the radiant heads of the transducers. With this device it is possible to transmit the acoustic radiation of metallurgic pulp to the same geometrical measures used in the HIC.
The radiating head of the transducers have a special profile to improve the impedance matching, this can be appreciated in the block diagram of the experimental set-up showing in figure 2.
The grinding system was the same used in the HIC. However, the mineral was treated with other kinds of surfactants because the mineral came from different mining companies. During the grinding step, two (AP3758 +AP8809) collectors were added at a rate of 27 g/ton. In the flotation process two (AF76A+DF1012) foaming agents were added at a rate of 15 g/ton and a AX343 collector at a rate of 13 g/ton.
The frequency of the transducers was at a 17.5 kHz rate and a power capability reach of 500 W.

Fig. 1 Denver Cell for flotation experiments

The experimental set-up for the ultrasonic flotation experiments shown in the Fig.2.

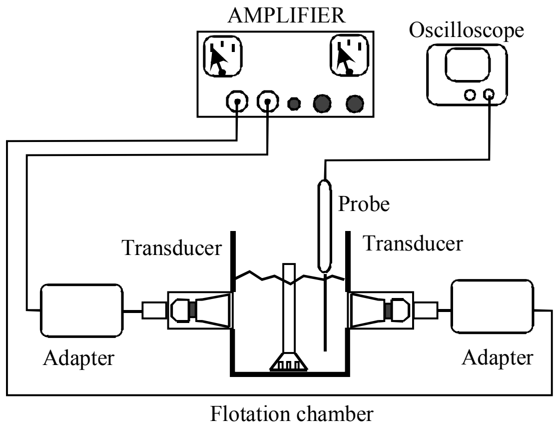

Fig. 2 Bock diagram of experimental set-up for ultrasonic flotation experiments.

The flotation carried out in the Denver Cell of Fig.1 consists of an application of ultrasonic energy at different power and irradiation times.
The agitation speed in the cell was of 1400 rpm. The pH of the pulp in flotation was 11. The method included the foam removal every 10 seconds and a total flotation time of 12 minutes. Water was added to the cell to keep the level constant. To keep the air content inside the cell constant, air was added in the following sequence: from 0 to 4 minutes of flotation, a flow rate of 4 l/min; from 4 to 8 minutes a rate of 5 l/min; and from 8 to 12 minutes of flotation a rate of 6 l/min.

Results

A. High Intensity Conditioning

From the data obtained in the experiments, the most representative and interesting curve is the plotting of the recovering curve vs. the energy supplied to the system, this curve is shown in figure 3.

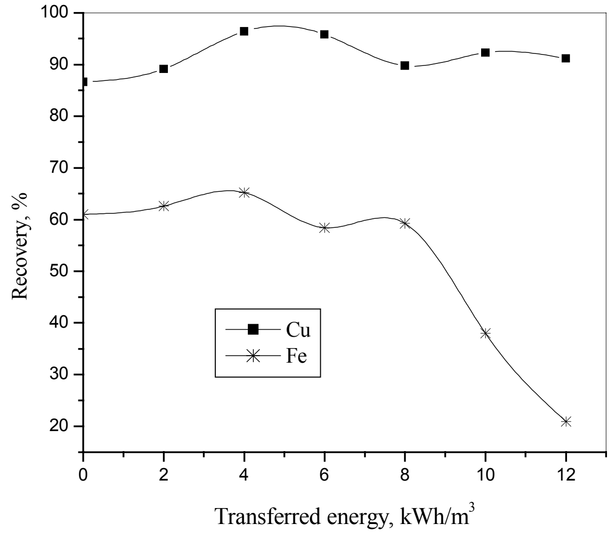

Fig. 3 Recovering curves for Cu and Fe vs. the applied energy in a HIC.

The experiment shown in figure 3 is very significant. From this figure it is easy to appreciate that when greater the energy supplied to the system greater the recovering of copper from fine and ultra-fine particles. It is interesting to point out that the content of Fe, product that contaminates the Cu, is diminished with the increasing of the energy supplied. The recovered substance has a maximum of approximately 5 kWh/m^3, afterwards the efficiency of the system falls. However, the Fe content continues diminishing and probably the concentrate law will increase again. The key for this method is to find the best working point that optimizes the whole efficiency of the process.

B. Ultrasonic Flotation Experiments.

The results for ultrasonic experiments with different applied powers are shown in the fig. 4.
The curves presented in the figure 4 are very interesting. In this case, on the contrary to the situation shown in figure 3, the best result is not the one obtained with the greater energy spent. The best results are obtained when the ultrasonic power of 40 W that were applied during 8 minutes. This suggests an interesting and unknown interaction mechanism between the cavitation, natural bubbles and particles during the flotation experiments.
Also the behaviour of the Fe content is very interesting, as the minor content of this contaminant substance is produced when the applied power is of 40 W during the first 8 minutes of flotation. The curve is presented in the figure 5. It is to be noted that for 0 W of applied power the Fe content is at its highest, producing the worst law in the concentrate.

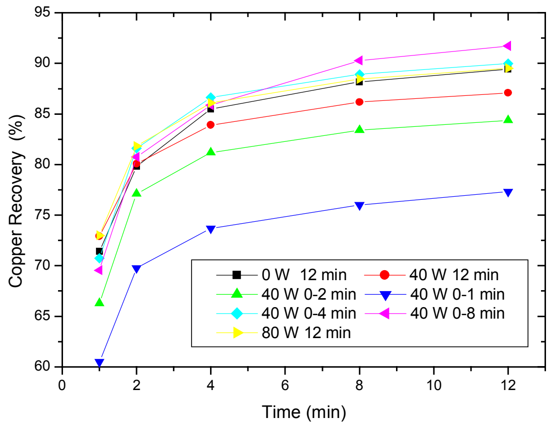

Fig 4 Ultrasonic flotation experiments. For different applied powers and treatmen time.

The best performance in the diminishing of Fe content is obtained from an applied power of 40 W during 1 minute. However for this application time the copper recovering is really low. This is an experimental fact suggesting that an optimum value of both the application power and time to optimize the process can be found. In other words one can expect that there is an acoustic pressure level and treatment time that optimizes the process. This fact can lead to an optimized camber design.
To explain this interesting behaviour it is necessary to design and carry out new experiments. At this point, when the ultrasound was applied during the flotation tests, a thicker layer of foam was observed. May be this thicker foam layer is responsible of the selective filtration of Fe particles.

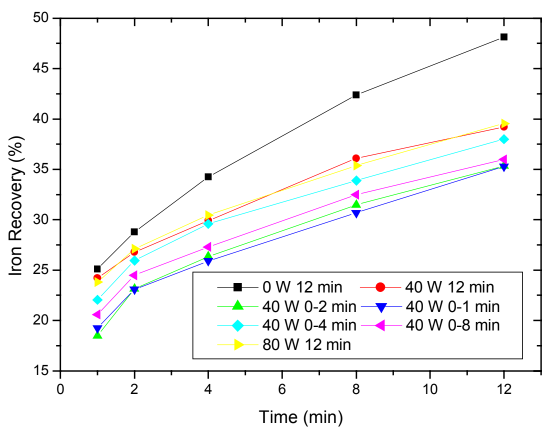

Fig. 5 The Fe content in the ultrasonic recovered concentrate vs the applied power and treatment time.

In figure 5 the percentage of the Iron recovered is shown. The iron content in the final concentrate represents an undesired contamination of the final product. The process was looking for the recovering of copper, and this product less abundant than the iron, shown in table I.

	Cu	Fe	Mo
Over 325	1,2	4,6	0,13
Under 325	11,5	38,0	0,47
	12,7	42,6	0,60

TABLE I The main products in the ore for the ultrasonic flotation experiments. Ore from El Teniente. Codelco Chile.

In table I the total amount of minerals present in the ores are shown. The ore treated has a mass of 1050 grams and it was grounded according to the protocol described ahead. The ground ore was divided into two classes according to the size of the particles. The fine and ultra-fine particles were under 325 Tyler mesh. The sieving was the most used method for particle size analysis. The 325 Tyler mesh corresponds to a particle of 45 microns in size. The particles that are larger are the ones that remain in the upper part of the sieve once the classification is over. When the particles are being sieved a flow of water is added to prevent problems in the manipulation of the particles.
The table shows that for an ore of 1050 grams only 12.7 grams corresponds to copper mineral. The iron present in the same mineral has a mass of 24,6 grams (almost twice the copper content). Another interesting product is the Molybdenum, but as it can be observed in table I, the Mo content is only marginal. This fact illustrates the importance that the diminishing of the iron percentage has in the final product, and as shown in the curve of figure 5 the ultrasound treatment produces a beneficial effect in this sense.
The best performance in the experiments with ultrasound done in this research were of 1.57 kWh/t which is approximately the third part of the energy spent in the HIC.

Discussion

The main effect of high-intensity conditioning has been identified as the promotion of interaction particle-particle. What can be appreciated in figure 3 is that an important improvement in the copper recovering can be reached for high-energy conditioning. The improvement is interpreted as an effect of the growing of tiny particles by aggregation during the HIC. The new particle size is enough to produce one or more effects, these being that the particle acquires a kinetic energy enough to catch a bubble and to float with it to the foaming region in the top of cell; the particle has a cross section big enough to collide with the bubbles; or the particles surface is big enough to produce a suitable level of interaction with the surfactants to make it hydrophobic. For ultrasonic effect the same arguments can be mentioned. And in addition the production of tiny cavitation bubbles supply a population of bubbles with adequate size to float tiny particles. Also the cross section of the particles can be increased due to the oscillatory movement of bubbles and particles. This could be a very interesting effect, similar to the orthokinetics effect in aerosol acoustic field interaction.

Conclusions

- In conclusion, an ultrasonic flotation experiment has been carried out.
- The results show that the ultrasound technology could offer an alternative competitive with the HIC in recovering useful substances from fine and ultra-fine particles in flotation.
- The energy spent with the new technology is one third part of the HIC.
- The law of the recovered concentrate is higher than that obtained by HIC in the same conditions.
- The influence of additives in the process; the ultrasonic frequency and the ore quality ought to be studied in future work.
- The results seems to suggest that the main effect of ultrasound is produced after the first 2 minutes of flotation.
- The results obtained in these flotation experiments have opened an interesting field of research looking for the basic phenomena involved in it.

Acknowledgment

This work was supported by CONICYT-CHILE Grant FONDECYT 1010243.

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