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SEPARATION OF MINERALS BY ELECTROFLOTATION

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Bench scale experiments were conducted to study the flotation response of chalcopyrite fines. Three different electroflotation cells were designed and tests were conducted on the beneficiation of chalcopyrite. Electrolytic oxygen bubbles were found to have significant effect on the floatability of chalcopyrite concentrate. As an applied part of the above technique, experiments were extended to beneficiate chalcopyrite ore without collector. Though the results show possible separation the grade and recovery were found to be poor. The addition of sodium diethyl dithiocarbamate as collector has shown substantial improvement on both recovery and grade. High enrichment ratio of chalcopyrite was observed with column cum electroflotation method. Variables like current density, pulp density and collector concentration were studied and optimised.

Key words: Electroflotation, chalcopyrite, beneficiation

INTRODUCTION

Electroflotation - "Flotation by electrically generated bubbles as a means of separating solid from liquid phases or one liquid phase from another" - has been discussed in earlier publications [1-2]. Initially this technique was adopted in the field of waste water treatment competing with the established processes like dissolved gas flotation. The application of electroflotation in the field of mineral processing was considered after the thorough analysis of hydrodynamics in the flotation system. Collision probability, the main criteria of the fine particles flotation, was shown to be effectively improved by the fine bubbles generated electrolytically [3]. Particularly the minerals which are prone to electrochemical changes, react more positively for the effective separation. For example, flotation of pyrite with xanthate has shown that, with bubbles of oxygen 98% recovery could be achieved whereas with hydrogen bubbles there was practically no flotation. The activating effect of oxygen is so great that pyrite floated even in alkaline medium. Electrolytic oxygen makes the surface of pyrite and other sulphides so strongly hydrophobic that there is no need to use a flotation reagent [4]. In a short span of their existence in atomic state these bubbles cause significant changes on the surface properties. This unique property of electroflotation can be advantageously utilized by the separate use of oxygen and hydrogen bubbles. Since the electrochemical changes are more in the case of sulphides, in the present investigation, chalcopyrite was chosen as an experimental material to study the beneficiation response by electroflotation.

Though the commercial success in mineral beneficiation is a subject of speculation, the success of this process in the field of effluent treatment can't be compared for the reason that the percentage of solids are usually high in mineral beneficiation compared to that in waste water treatment. But this technique can be applied reasonably in the case of low grade, finely disseminated values, where the conventional methods fail to enrich.

EXPERIMENTAL

Materials

The chalcopyrite sample used in the present investigation was obtained from Chitradurga Copper Co., Karnataka. To concentrate the sample further, a fraction of -72 +100 B.S.S. was taken and subjected to heavy media separation and isodynamic separation. The chalcopyrite obtained from the above procedure was thoroughly cleaned with acetone to remove the surface contamination and dried. The dried sample was ground in a pebble mill (dry grinding) and the material that passed through 325 B.S.S. was taken for the experimental work. The chemical analysis of the sample is shown in Table I.

Table I: Chemical analysis of the chalcopyrite samples

S.No.	Element	Analysis	
		Concentrate	Run of mine ore
1	Copper	32.20%	0.99%
2	Iron	30.86%	8.36%
3	Sulphur	33.85%	Not analysed
4	Silicates	0.56%	38.01%

Sodium diethyl dithio carbamate (D.T.C.) 99.5% pure was used as a collector. All other chemicals used in this investigation are of Analar quality.

Methods

Based on the earlier research work on modified Hallimond tube for electroflotaion, three different types of cells with the capacity of 3.0 litres each were developed to carry out bench scale trials. Nickel coated S.S. gauze was used as an electrode. The leads of the electrodes were connected to the output of a rectifier. A mechanical stirrer was used to agitate the pulp during conditioning and flotation.

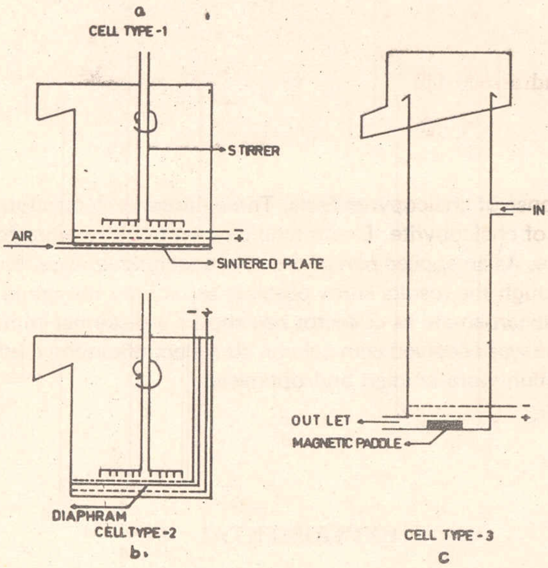

Fig 1: Schematic diagrams of electroflotation cells

ELECTROFLOTATION CELLS

Type 1 (Fig. 1a) is a simple electroflotation cell designed to use the mixed bubbles of O_2 and H_2 generated by electrolysis of water. Separate provision was made to pass the compressed air besides the electrolytic bubbles.

Type 2 (Fig. 1b) was designed for the separate use of electrolytic oxygen and hydrogen bubbles. The anode and cathode were separated by a diaphragm which serves the dual purpose of confining the fines in the upper region and preventing the bubbles of lower electrode from entering the flotation zone.

Type 3 (Fig. 1c) is a continuous type of electroflotation cell. Electrodes were fitted at the bottom of 1 metre long cylindrical column. Pulp was introduced into the cell from a conditioning tank through an inlet provided at a height of 0.7 metre. Pulp can be drained from the bottom outlet to a settling tank. Magnetic stirrer was used to agitate the pulp.

In all the experiments sodium sulphate was used as an electrolyte, just before the start of flotation. Immediately after the completion of the experiment the froth was separated, washed, filtered and dried under I.R. lamp.

Chemical analysis was done with Atomic Absorption Spectrophotometer (A.A. 575, Varian Techtron). All the experiments were carried in duplicate and the average values are incorporated in the text.

RESULTS AND DISCUSSION

In the preliminary tests conducted using pine oil and methyl isobutyl carbinol as frothers, it was noticed that the froth is too loose and unstable affecting the recovery. Among various frothers tried naphthenic acid and teepol (a laboratory detergent) were found to be effective in producing fine cohesive foam with better stability. Based on this observation, naphthenic acid was tried as frother in all the experiments.

In the first part of the investigation the flotation response of chalcopyrite concentrate without collector was studied.

Effect of electrolytic gas bubbles on the floatability of chalcopyrite

In order to understand the effect of electrolytic gases flotation experiments were conducted in type 2 electroflotation cell at various current densities. Comparison of these results shown in Fig. 2 clearly indicates the superior role of oxygen bubbles on the recovery of chalcopyrite fines.

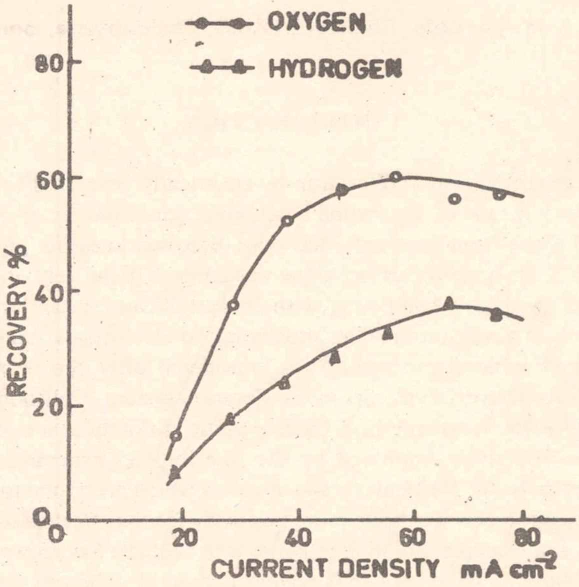

Fig. 2: Effect of electrolytic gases on the flotability of chalcopyrite concentrate (without collector): Pulp density = 10%; frother = 2 drops; flotation = 300 sec

The floatability of sulphide minerals mainly depends on availability of oxygen/ oxidising environment and anodic potential. These factors contribute for the final hydrophobicity in different pathways. The above conditions are fully met in this particular test. During the agitation of the pulp, mineral particles in the cell may undergo anodic oxidation and form elemental sulphur on the surface of the particles.

$$CuFeS_2 \longrightarrow CuS + Fe^{2+} + S + 2e$$

The possibility of above anodic oxidation was established by electrochemical investigation [5]. Thus the sulphur formed by superficial oxidation is one of the definite hydrophobic entity which causes the floatability of chalcopyrite. As discussed earlier, electrolytic oxygen also renders the mineral more floatable. Though the electrolytic oxygen has shown definite positive effect on the floatability excess oxidation and continuous release of H^+ ions into the pulp causes other adverse effects. So the controlled operation is necessary to reduce other side effects. The low floatability with hydrogen bubbles may be due to the reducing environment enforced on the system [6] and the OH^- ions released during flotation. The electrical nature of the surface may change due to the adsorption of these ions.

Effect of current density

This variable determines the rate of bubble evolution and bubble size [1]. Fig. 2 indicates tht the recovery increased with the current density upto 57 mA/cm^2. This value would therefore appear to be most suitable for the system. Excess current densities lead to overoxidation/reduction of the mineral which affects the overall flotation.

Based on the optimum conditions obtained on concentrate, a few experiments were conducted to beneficiate chalcopyrite from the run of mine ore without collector. Results of the same were plotted in Fig. 4. It was found that the selectivity varies very little with the current density, whereas recovery increased with current density.

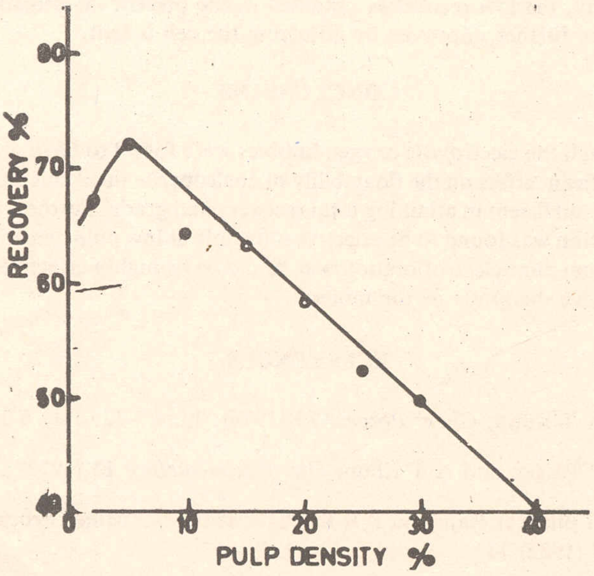

Fig 3: Effect of pulp density on the recovery of chalcopyrite concentrate
Current density = 57 mAcm^{-2}; Frother = 2 drops; Flotation = 300 sec; Carrier gas = oxygen

Effect of pulp density

Figs. 3 and 5 show the effect of the pulp density on the recovery and grade of chalcopyrite. It was found that low pulp densities are favourable in obtaining good enrichment ratio. But this pulp density is too low to compare the pulp densities in mineral processing industry, where they are normally around 30%.

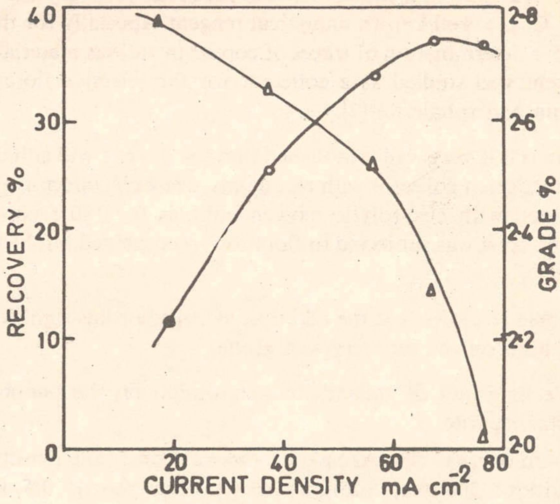

Fig 4 : Effect of electrolytic oxygen on the floatability of chalcopyrite (R.O.M.) without collector Pulp density = 10%; Frother = 2 drops; Flotation = 300 sec;
-o-o-Recovery ; -△ - △- Grade

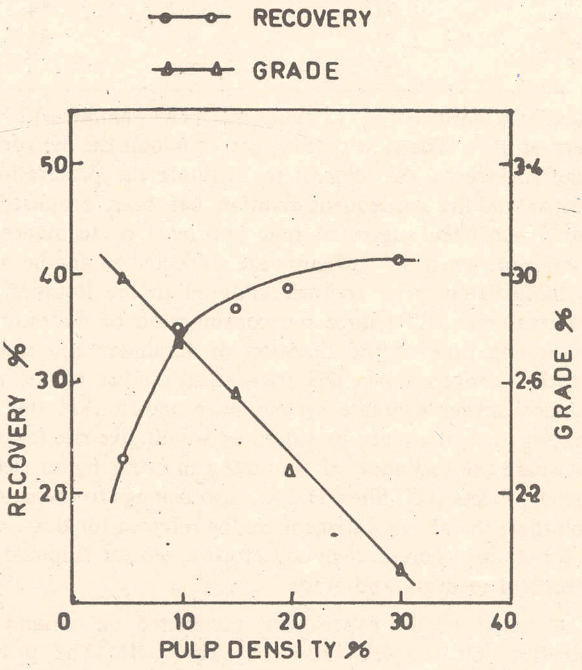

Fig 5 : Effect of pulp density on the recovery and grade of chalcopyrite (R.O.M.): Current density = 57 mA cm^{-2}; Frother = 2 drops; Flotation = 300 sec; Carrier gas = oxygen
-o-o-Recovery; - △ - △ - Grade

Effect of collector on the floatability

DTC was used as a collector to obtain better recovery and grade. D.T.C. is a well known analytical reagent especially for the quntitative determination of traces of copper in various materials. This reagent was studied as a collector for the selective flotation of galena and sphalerite [7].

Since it is very well established that the oxygen will enhance the interaction of collector with metal ions, ore with collector was conditioned with electrolytic oxygen bubbles for 120 seconds and thereafter it was subjected to flotation by combined bubbles in cell type 1.

Table II shows that the addition of collector has significant effect both on the recovery and grade.

Table II: Effect of collector concentration on the beneficiation of chalcopyrite

Current density: 57 mA/cm^2; Frother: 2 drops; Pulp density: 10% Flotation: 300 sec; Sodium silicate (depressent): 0.5 kg/ton; pH of the pulp during conditioning : 9.0

S.No.	Collector concentration (kg/t)	Grade (%)	Recovery (%)
1	0.01	12.2	68.9
2	0.02	12.0	68.2
3	0.04	11.8	73.1
4	0.06	10.2	77.2
5	0.08	10.2	84.2
6	0.10	9.2	85.9
7	0.20	8.9	83.4

It has been enriched by 12 times the head sample with a recovery of 85%. The view that oxygen promotes the dehydration of the surface of the mineral to facilitate the penetration of collector and its consequent fixation has been proposed [8]. Also it has been suggested that improved performance will be obtained, when the collectors are subjected to anodic oxidation immediately prior to their addition to the flotation cell. Such treatment will reduce the consumption of collector and conditioning time of the flotation of sulphides and leads to enhanced recoveries [9]. Electrochemical studies of the metal sulphide- oxygen-xanthate system have shown that the catalytic reduction of oxygen by sulphides would give rise to anodic sites where the oxidation of xanthate can occur by an electron transfer process [10]. Since D.T.C. also belongs to the category of xanthate the above statement can be referred for this system. The simultaneous presence of collector-oxygen and sulphide leads to excellent recovery and grade.

The results of the experiments conducted on column cum electroflotation cell are shown in Table III. The principle of counter current flow was utilized to improve the separation process. The results show that the grade of the mineral was improved to the extent of 25% at the pulp densities of 5%. Since the bubbles rise continuously through a downward flowing slurry there is considerable opportunity for the mineralized bubble to be washed free of entrapped gangue particles. There is some controversy regarding suitable cell height for electroflotation. Since cell height is dependent on pulp density, the low recoveries obtained in the present investigation can be further improved by adjusting the cell height.

Table III: Effect of column cum electroflotation on the beneficiation of chalcopyrite

Collector concentration : 0.06kg/t; Current density : 57mA/cm^2; Frother : 2 drops; Flotation : 300 secs; pH of pulp during conditioning : 9.0; Sodium silicate : 0.5 kg/t

Sl.No.	Pulp density (%)	Recovery (%)	Grade (%)
1	5.0	18.9	28.2
2	10.0	27.8	25.4
3	15.0	26.5	23.8
4	20.0	32.2	20.5
5	25.0	35.8	18.8

CONCLUSIONS

Though the electrolytic oxygen bubbles were found to have some significant effect on the floatability of chalcopyrite fines, this alone is not sufficient in attaining total recovery and grade. Further, the flotation was found to be selective only only at low pulp densities. Column-cum-electroflotation was found to be highly effective to improve the grade of the mineral.

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