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PILOT SCALE STUDIES ON THE BENEFICIATION OF COMPLEX SULPHIDES BY FLOTATION COLUMN

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Experiments using pilot size flotation column as cleaner were conducted to evolve a suitable flow sheet for the production of bulk sulphide concentrates of Cu-Pb-Zn. The flotation circuit consisting of roughing, scavenging, and two stage cleaning by conventional flotation machines was compared with the circuit where two stage cleaning operation was replaced with single stage cleaning by flotation column. It is clearly demonstrated that a single stage cleaning by flotation column is more efficient and sufficient to obtain bulk concentrate suitable for further processing. Of the two types of sparger systems used viz, TURBO and MICROCEL , the former was found to be better to achieve high quality concentrate.

INTRODUCTION

In recent years, column flotation has been receiving an increased attention both for plant improvemments and new installations [1-2]. Industrial use of flotation columns has witnessed a remarkable growth since the beginning of the eighties. The column has outperformed mechanical cells especially for difficult separations involving fines [3-6]. Based on the spectacular performance of column, over 2000 columns were installed all over the world for the beneficiation of different minerals. In India, Kudremukh Iron Ore Company Limited (KIOCL) and Tamilnadu Minerals Limited have successfully implemented column technology for the beneficiation of iron ores and graphite respectively.

By considering the advantages of flotation columns, it has been decided to investigate the amenability of column technology for the beneficiation of Cu, Pb and Zn complex sulphide ores. This paper incorporates extensive R & D work conducted to evolve a suitable flow-sheet for the production of bulk concentrate of Cu-Pb-Zn suitable for smelting operation.

MATERIALS AND METHODS

Mineralogy

Ambaji multimetal deposit owned by M/s GMDC Ahmedabad contains 7 million tonnes of demonstrated ore reserves at an average of 8.5% of Cu-Pb-Zn. In addition there is approximately 1 million tonnes of inferred reserves. Mineralogical characteristics of this ore body is complex compared to the other deposits of similar nature. Sulphides of copper, lead and zinc are valuable minerals along with siliceous gangue, talc and mica. The appropriate mineral suite is shown in Table.I. The mineralogical analysis suggests that the ore is highly oxidised in nature and the gangue is fully liberated at a d_{80} value of 75 μm.

Table I. Approximate mineral suite of Ambaji multimetal deposit

Valuable Minerals		Gangue Minerals	
Mineral	Weight%	Mineral	Weight%
Chalcopyrite	1.15	Muscovite	
Galena	3.25	Biotite	
Sphalerite	7.45	Chlorite	
Pyrite	10.25	Amphibole	≈ 70.00
Magnetite	1.72	Talc	
Pyrrhotite	0.50	Quartz	
Chalcocite	0.10	Dolomite	

EXPERIMENTAL

Pilot Column: The pilot column with the dia of 30 cm and a height of 10 m was installed in the premises of the existing pilot plant test facility at Ambaji. The column shell is made out of three flanged sections which are connected together with proper gaskets and bolts. The legs of the column shell were bolted to the ground after checking the verticality. The dimensions of different zones of column viz, collection, cleaning and froth zones are shown in Fig 1.

Sparger: The pilot column incorporates two alternative technologies for bubble generation, namely, Turbo type and Microcel type. Turbo type is high pressure and low shear external bubble generator originally developed at the U S Bureau of Mines (Fig. 2). A mixture of air and water is injected under high pressure (5-6 bars) through injection tubes with distributed nozzles. Bubble size is controlled by manipulating air and water pressure, air and water ratio and frother addition in the water line if necessary. The Microcel type is a low pressure and high shear bubble generator developed at Virginia Polytechnic Institute (U S A). The sparger consists of one static on-line mixer and a centrifugal pump as illustrated in Fig 3. Slurry from the column (tailings) is sucked and pumped again to the column through the in-line static mixture where air and slurry are mixed under high shear conditions to create the bubble dispersion. The bubble slurry mixer is introduced at the column base and the bubbles rise through the column collection zone. A frother pump allows the addition of frother to control the average bubble size.

Level Control: Differential pressure cell was used to control the level of the pulp/froth interface by manipulating the tailings flow. Depending on the level of the interface with reference to set point, DP cell delivers an input signal (4-20mA) to a PID controller. The controller sends out an output signal (4-20 mA) to a proportional electropneumatic control valve which changes the tailings flow in order to keep a constant pulp level in the column. The desired pulp level is directly entered in the PID controller as the set point. By changing the set point of the pulp/froth interface, froth depth can be varied between 20 cm to 120 cm.

Wash Water: The purpose of wash water is to remove entrained gangue minerals from the froth and improve the concentrate grade. It also enhances the froth stability. A flowmeter indicating flow rate and totallizer was installed for measurement purpose.

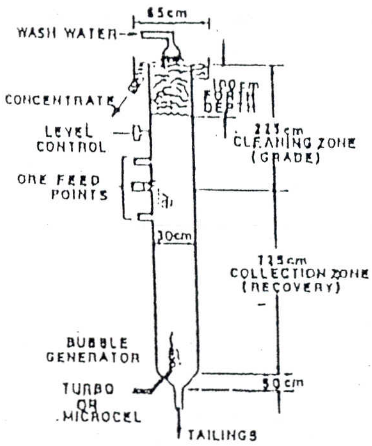

Fig.1. Pilot column dimensions

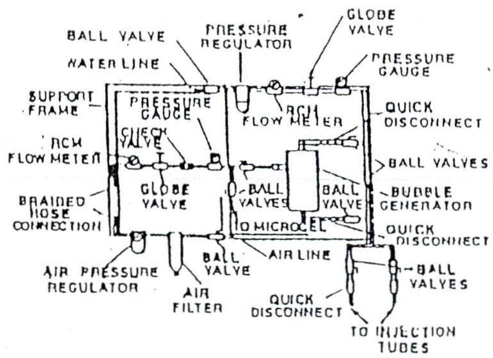

Fig.2. Schematic arrangement for the Turbo air^{TM} system

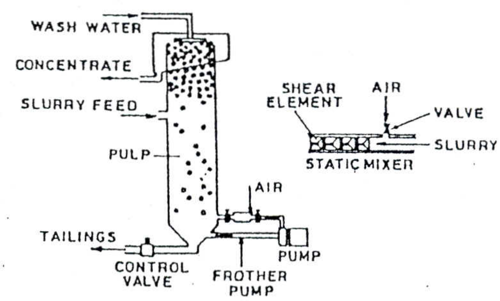

Fig 3. Principle of Microcel^{TM} bubble generation system

Slurry flow: Slurry flow rates were measured by installing magnetic flow meters in the pipe lines of feed, tails and concentrate.

Procedure: Pilot plant test runs were conducted over a period of one month. Before starting the plant, column was filled with water and stabilised at required froth depth and wash water addition. Rougher concentrate generated from the rougher circuit was pumped directly to the column. Necessary reagents for cleaning were added in rougher concentrate launder itself. Column tailings were directed to an appropriate location of the circuit for recirculation. All the parameters were noted just before collecting the sample. Due to limitations of ball mill capacity, R O M was varied between 1.3 - 2.0 TPH. The percentage of solids of rougher concentrate was maintained by adjusting the launder water. Samples were collected at every half-an-hour interval, after allowing the circuit to run continously for a period of four hours. The collected samples are processed to determine % solids prior to chemical analysis. Analyses of Cu, Pb, Zn, Fe and Mg were conducted by atomic absorption spectrophotometer. Standard gravimetric methods were adopted for the estimation of silica and insoluble material.

Gas Hold up measurement : Volumetric fraction of the slurry displaced by gas is called "Gas holdup". Water manometers were connected to the column, at different points. The actual gas holdup was evaluated by using the following equation

$$\varepsilon_g = 1 - \frac{\Delta P}{\rho_{sl} g \Delta L}$$

where ρ_{sl} = density of slurry, g = gravitational acceleration, Δ L = distance between two pressure taps on the column and Δ P = pressure difference between the two points.

Pilot plant : Multi purpose pilot plant comprising ore bin, crusher, grinding mill classifier, conditioning and flotation units with the capacity of 2 tonnes per hour is available at Ambaji project site. It has attained an unique status in India by installing flotation column. The entire test work has been conducted at Ambaji multi metal project site.

RESULTS AND DISCUSSION

Preliminary tests were conducted both on laboratory and pilot plant scale to study the effect of various reagents and to optimise reagent schedule to obtain the final concentrate with required grade and recovery. Sodium silicate, NaCN and starch were used as depressants for silica, pyrite, mica minerals and talc respectively. $CuSO_4$ was used to activate sphalerite and isopropylxanthate as collector. Since the ore is highly oxidised in nature, sulphidization prior to flotation was found to be essential to obtain better recoveries. Na_2S was used for this purpose. Reagent schedule thus optimised (Table II) was adopted during the pilot plan runs.

Systematic experiments were conducted for the individual separation of Cu, Pb and Zn by differential flotation and found to be not encouraging. Attempts made to separate talc by using MIBC has resulted in 30% loss of galena. Thus the contamination of talc with lead and considerable loss of lead makes the process not attractive. Further set of experiments were conducted to separate sphalerite from chalcopyrite and galena.

Table II. Pilot Plant : Reagent Schedule

Reagent	Soln %	Ball Mill	Rougher	Scaven-ger	Cleaner -1	Cleaner -2	Total	(kg/l)
Lime	8.75	1600	-	400	Nil	Nil	2000	5.25
$CuSo_4$	3.75	Nil	540	450	Nil	Nil	990	1.11
Na_2S	1.25	1300	Nil	Nil	Nil	Nil	1300	0.50
Starch	2.00	Nil	340	340	170	170	1020	0.60
NaCN	0.50	Nil	270	270	135	70	745	0.11
Xanth	0.50	Nil	450	270	135	Nil	855	0.13
MIBC	Conc	Nil	1.50	1.30	Nil	Nil	2.80	0.068

Generally, the floatability of sphalerite is very weak in the absence of an activator. Quite contrary to its usual behaviour, floatability of sphalerite was found to be very high inspite of high dosages of depressants like $ZnSO_4$ and NaCN (Table III). This unintentional activation of sphalerite is attributed to weathering action. $CuSO_4$ is formed in solution as a result of oxidation and dissolution of the chalcopyrite and pyrite in the upper regions of the deposit. These solutions percolate down to the water table, where they react with chalcopyrite to form the rims of the secondary copper sulphides namely covelite and chalcocite. The copper sulphate also reacts with sphalerite, depositing copper ions on the grain surfaces [7].

$$Cu^{2+}_{(aq)} + ZnS_{(Surf)} = CuS_{(Surf)} + Zn^{2+}_{(aq)}$$
$$2\,Cu^{2+} + 2\,ZnS_{(Surf)} = Cu_2S + 2\,Zn^{2+} + S^0_{(Surf)}$$

Table.III. Activation of sphalerite by dissolved metal ions.
Conditions : Sod. silicate : 1 kg/t; Starch:0.2 Kg/t Xanthate:0.15 Kg/t MIBC : 0.05 Kg/t;: pH of slurry 9

Depressants	(Kg/t)	Float (wt%)	Assay %			Recovery %		
$ZnSO_4$	NaCN		Cu	Pb	Zn	Cu	Pb	Zn
1.00	0.05	17.9	1.50	4.19	11.20	60.2	55.8	67.5
2.00	0.05	18.1	1.51	4.99	12.60	63.7	59.8	70.6
3.50	0.10	18.2	1.48	5.30	12.10	69.6	62.1	69.6

Because of oxidation, the concentration of metal ions in slurry increases beyond the solubility product of individual minerals. Metal ions released into the pulp due to oxidation in turn absorb on sphalerite and activate the same according to the following mechanism.

$$ZnS_{(Surf)} + Cu^{2+}_{(aq)} + 2H_2O = ZnS\ Cu(OH)_{2\,(surf)} + 2H^+$$
$$Cu(OH)_{2(ads)} + ZnS_{(surf)} = CuS_{(surf)} = Zn(OH)_{2\,(ads)}$$
$$2Cu(OH)_{2\,(ads)} + 2\,ZnS_{(surf)} = Cu_2S_{(surf)} + 2Zn(OH)_{2\,(ads)} + S^0_{(surf)}$$

Thus, oxidation appears to have an important bearing on the beneficiation. Secondary copper sulfides rims of covellite and chalcocite thus formed on the surface of sphalerite particle activate its flotation. Under such circumstances it is extremely difficult to produce clean and separate concentrates of chalcopyrite, galena and sphalerite. Hence, attention was paid to produce bulk concentrate of Cu-Pb-Zn.

Two types of bubble generation systems viz, TURBO and MICROCEL were studied and the results of the same are shown in Table IV. It is evident that the overall recovery is better in Microcel where as Turbo type yields better quality concentrate. Higher recovery in Microcel could be attributed to high air holdup values.

Table.IV Difference in performance of Turbo and Microcel spargers

Type of	Conc Assay(%)			Column Recovery		
Sparger	Cu	Pb	Zn	Cu	Pb	Zn
Turbo	2.56	16.40	32.00	65.78	55.24	62.00
Microcel	1.64	13.10	32.10	48.34	68.39	73.75

Microcel system produces much finer bubbles than the Turbo system. Consequently, the air bubble surface area available in the collection zone is greater with Microcel. Furthermore, while the slurry is recycled through static mixture (for bubble generation) where the air is introduced cocurrently,it enhances the collection process in the sparging zone. During this process, unattached hydrophobic particles make contact with air bubbles.

Thus the overall recovery is enhanced by adopting microcel sparger system. However, if the hydrophobic particles are gangue minerals the quality of the concentrate is drastically affected. Microcel sparger may cause adverse effect especially in the case of Ambaji deposit where the gangue is dominated by naturally hydrophobic minerals like talc and mica. Comparatively high recoveries of lead and zinc in Microcel are due to fine bubbles suitable to the fine particles of lead and zinc.

The performance of conventional flotation cells with column is compared in Table V. In the 1st case, flotation circuit consisting of roughing, scavenging and two stage cleaning by conventional flotation cells (Fig 4) was run on three different ore samples. In the 2nd case, two stage cleaning by conventional cells was replaced by single stage column operation as depicted in Fig 5.

Table V Performance of conventional machines and column cell

Type of ore	Conventional						Column					
	Grade (%)			Recovery (%)			Grade (%)			Recovery (%)		
	Cu	Pb	Zn	Cu	Pb	Zn	Cu	Pb	Zn	Cu	Pb	Zn
Lean	2.53	10.4	16.4	84.2	69.9	86.1	1.98	11.20	34.42	88.4	76.9	61.2
Deri	2.12	16.6	35.5	92.9	73.1	88.8	2.50	17.25	36.20	89.4	93.3	96.6
Mix	2.37	17.2	29.6	80.5	79.8	87.0	2.96	25.10	25.00	82.5	80.8	82.4

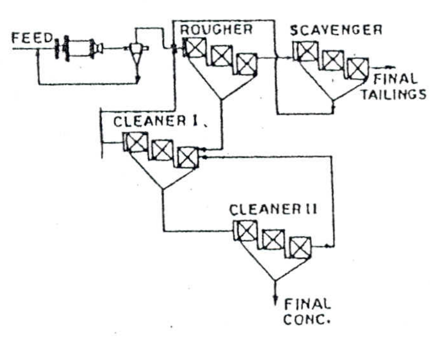

Fig.4 Bulk flotation circuit of Cu-Pb-Zn

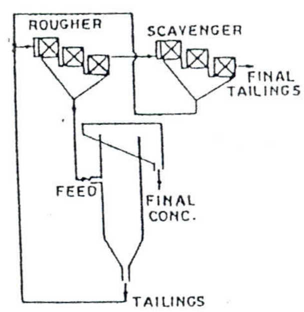

Fig.5 Bulk flotation circuit of Cu-Pb-Zn concentrate column as cleaner

It is apparent from Table.V that the quality of the concentrate obtained by column operation is superior compared to that of the conventional cells. A single stage cleaning by column was found to be enough to obtain much cleaner concentrate. The entrainment of fine gangue material in the froth product is a serious drawback with conventional machines. Due to high turbulent conditions prevailing in the conventional cells, fine gangue particles could be easily carried into the froth by getting either entrained in the liquid or mechanically entrapped with the particles being floated affecting the quality of the concentrate. The absence of turbulence at the interface of the column minimises the chances of physical entrapment of unwanted gangue minerals. As the mineralized froth enters the cleaning zone, it immediately encounters a blanket of water spray which washes down the entrapped gangue. Finch and Dobby [8] reported that less than 1% of process water reaches the concentrate product during the steady state column flotation operation. The net effect is an improved selectivity resulting in a high grade concentrate product. This inherent cleaning action is a main reason that the flotation column finds its application mostly in cleaning operations.

Thus, irrespective of the fluctuations in feed grade, the quality of the concentrate could be maintained uniformly by introducing flotation column in the circuit. Also, recirculation loads, circuit complexity could be minimised by replacing two stage cleaning by conventional cells with single stage cleaning by column. Other attendant benefits like low maintenance, less power consumption etc can be reaped.

CONCLUSIONS

Pilot scale test was conducted to evolve a suitable flow sheet for the beneficiation of complex sulphides multimetal deposit at Ambaji. The possibility of obtaining individual concentrates of copper, lead and zinc was found to be a difficult task due to the weathering action. However, production of bulk concentrate of Cu-Pb-Zn suitable for smelting can be achieved by adopting simple flotation circuit consisting of roughing, scavenging (conventional machines) and single stage cleaning by flotation column. Flotation circuit consisting of roughing, scavenging and two stage cleaning by conventional cells was compared with the circuit where two stage cleaning operation was replaced with single stage cleaning by flotation column. It was proved beyond doubt that the flotation circuit involving column is more efficient to derive better metallurgical benefits. Of the two types of sparger systems tried, Turbo type was found more suitable to obtain high quality concentrates.

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