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Circuit Simplification by Flotation Columns – A Pilot Scale Study

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Abstract

Pilot scale studies on the beneficiation of low-grade fluorspar and copper-lead-zinc ore were investigated using flotation columns. Acidspar concentrates suitable for HF production can be produced by adopting two-stage column cleaning in place of multi-stage cleaning by conventional flotation cells. A three-column configuration in the place of four-stage cleaning in acidspar circuit and four in metspar circuit was suggested. Similarly, it was demonstrated that a single stage cleaning by flotation column was found to be sufficient in the place of two-stage cleaning by conventional flotation cells to obtain bulk concentrates of Cu-Pb-Zn.

INTRODUCTION

The fast depletion of high-grade mineral reserves has necessitated the effective utilization of low-grade finely disseminated ores. The input costs are invariably high in the case of these low-grade ores. Further more fines generated during mining, milling and other metallurgical operations are to be processed not only to recover the values but also on environmental considerations. In most of the cases large amount of such mineral values are discarded as fines and ultra fines due to lack of suitable technology. The problems associated with processing of fine particles were identified and discussed in detail [1-2]. The process of flotation is mainly affected by a small mass of the particle. Low momentum, slime coating and high reagent consumption are the most frequently discussed difficulties. Models based on interception theories and hydrodynamics highlighted the importance of bubble size for the effective flotation of fine particles. The probability of particle-bubble collision and collection efficiency was found to depend on the ratio of particle to bubble size [3-4]. As the size of the bubble plays a vital role in flotation process, extensive research was focused on controlling the bubble size. Since conventional mechanical flotation cells have limitations in producing fine bubbles, spargers that can produce fine bubbles were developed for columns. Concurrently attempts also were made to improve the collision probability. Column flotation technology was developed to achieve better collision and collection efficiencies. The concept of counter current contact between the downward flowing slurry with rising air bubbles forms the essential basis of column flotation. Though the above concept of column flotation has been conceived by Boutin and Wheeler [5] in 1967, it was implemented in various industries only during 1990. Since the phenomena of entrainment are low in flotation column, the high quality concentrate can be easily achieved with minimum cleaning stages. An increase in concentrate grade and product recovery with minimum circuit complexity has been reported in many instances [6-10]. The other advantages of column flotation include energy efficiency and precise control of critical parameters such as bubble size, air content, froth depth and froth cleaning. Flotation columns were found to be amenable for the recovery of high grade CaF_2 from the Fish Creek deposit of Nivada [11].

EXPERIMENTAL

Flotation Columns

Pilot size flotation columns were shifted to the respective sites of Ambaji multi metal deposit and Kadipani fluorspar project and installed at a suitable location to conduct the experimental work. Three different spargers viz-simple ceramic tubes, Turbo Air^{TM} type and Microcel ^{TM} type were tried for bubble generation. The turbo type is a high pressure, low shear external bubble generator originally developed at the US Bureau of Mines. A mixture of air and water is injected under high pressure (5-6 bar) through injection tubes with distributed nozzles. The bubble size is controlled by manipulating air and water pressure, air to water ratio and frother addition in water line if necessary. The gas holdup was measured and found to vary between 11-16%. The schematic arrangement of the Turbo Air^{TM} system was shown in Fig.1. The microcel type is a low pressure and high shear, which is developed at Virginia Polytechnic Institute (USA). The sparger consists of one static on-line mixture and a centrifugal pump as shown in Fig.2.

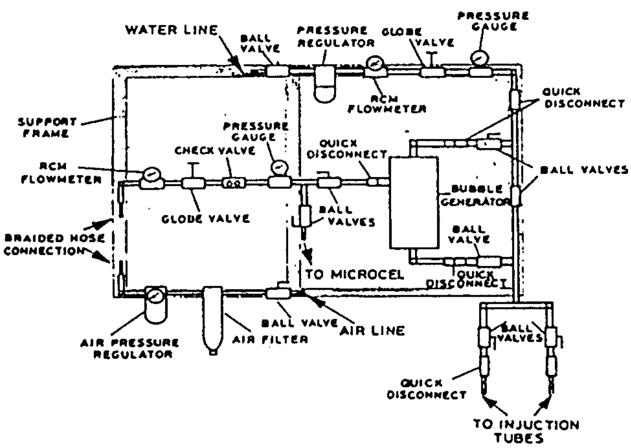

Figure 1 Schematic arrangement of Turbo Air^{TM} system

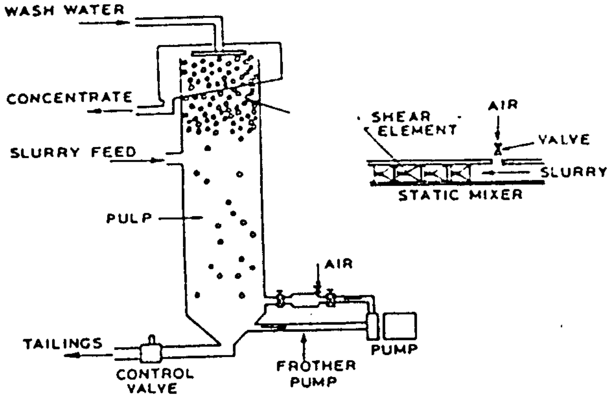

Figure 2 Schematic arrangement of Microcel™ system

Slurry from the bottom of the column (tailings) is sucked and pumped again to the column through the static mixture where air and slurry are mixed under high shear conditions to disperse the bubbles. The bubble slurry mixture is introduced in to the column so that bubbles rise through the column collection zone. A frother pump whose discharge end is connected to the static mixture allows the addition of frother to control the average bubble size. In microcel system much higher gas holdup values ranging from 15-20% were noticed. Differential pressure (DP) cell looped to tailing control valve was used to control the level of the slurry/froth interface. Depending on the level of the interface with reference to set point, the DP cell delivers an input signal in the range of 4-20 mA to a control valve through a PID controller. Based on the input signal, the control valve is actuated and slurry from the column is discharged. The slurry flow rates both feed to the column and discharge from the column were continuously monitored by online magnetic flow meters. Similarly wash water addition was monitored throughout the experiment.

Experimental Procedure

Samples from process circuit were tapped directly to the conditioner and the slurry was conditioned with appropriate reagents. Series of conditioners were used to condition the slurry with different reagents. The conditioned slurry was fed to the flotation column at desired flow rate. The column was initially filled with water at constant airflow rate, wash water and froth depth. After stabilization with water, slurry conditioned with necessary reagents was fed to the column through the feed pump. The column was allowed to run for at least three nominal residence times before sample collection. In order to check the steady state, tailing samples were collected at different time intervals and pulp densities were measured. After ascertaining that the steady state conditions of the experiment, timed samples of feed, concentrate and tailings were collected with the help of automatic sampling valves. All the column parameters were simultaneously recorded. The collected samples were filtered, dried and weighed after measuring the percentage of solids. In continuous operation, representative samples were taken from the samples collected over the entire day. Standard column test procedure suggested by Finch [12] was followed. Results obtained at optimum values of reagent dosages and column parameters were presented. All the flotation reagents used in the investigation are of commercial type.

RESULTS AND DISCUSSION

Fluorspar

The fluorspar beneficiation plant established by M/s. Gujarat Mineral Development Corporation (GMDC) Limited is the only plant in India which produces fluorspar concentrate suitable for the manufacture of hydrofluoric acid. The detailed flowchart is shown in Fig.3.

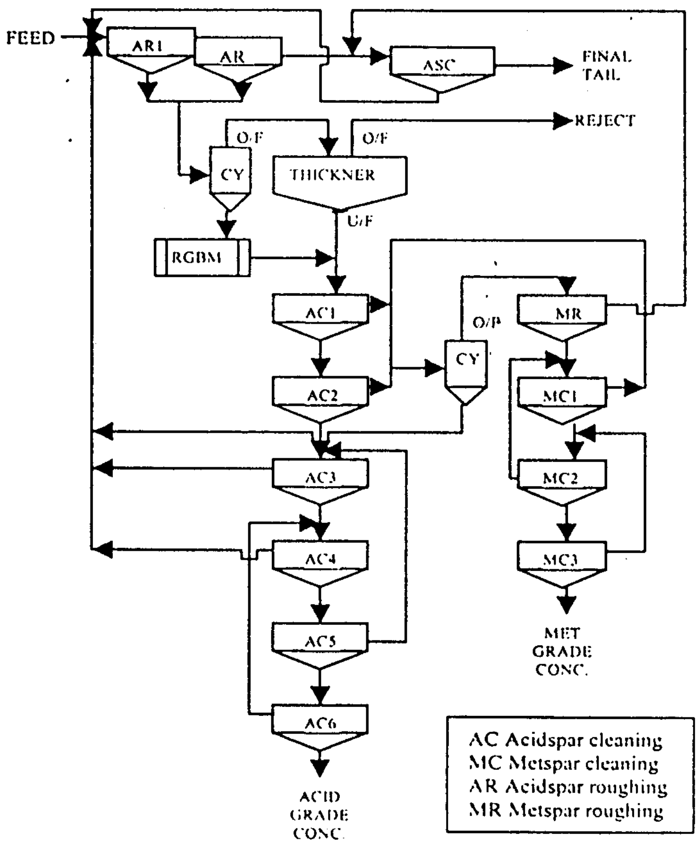

Figure 3 Schematic flowchart of fluorspar flotation circuit at Kadipani

The acidspar flotation circuit of the existing plant consists of roughing, scavenging and six stages of cleaning. Sodium oleate is being used, as collector while starch and tannin are used to depress calcite and apatite. Sodium silicate is used as a modifier for silica. Presently, in spite of several cleaning stages, the quality of the acidspar concentrates are seriously affected due to gradual depletion of high-grade ore over the years and large fluctuations in run of mine ore. The present cost of production is also high compared to the open market price. The separation of fluorite from calcite and apatite minerals is difficult due to similar surface properties. In the present investigation, the possibility of minimizing the cleaning stages by using flotation columns was explored. 0.5 m diameter flotation column with ceramic spargers was used in series with 0.3 m diameter flotation column with Microcel ™ sparger (second stage column cleaning).

Table1: Results of single stage cleaning using flotation column

Conditions:

Superficial feed velocity	: 0.8 cm/s,	Superficial air velocity	: 1.05 cm/s
Wash water bias	: 0.07 cm/s,	Froth depth	: 65-75cm
Solids	: 15-17%		

Assay of ROM : CaF_2: 29.5, $CaCO_3$: 7.40, P_2O_5: 1.45, SiO_2: 51.14

Sl. no	Feed CaF_2 (%)	Assay of column concentrate (%)				Tails (%)	Rec. (%)	Plant concentrate Assay (%)			
		CaF_2	$CaCO_3$	P_2O_5	SiO_2	CaF_2		CaF_2	$CaCO_3$	P_2O_5	SiO_2
1	76.31	94.22	3.02	0.43	0.19	67.00	42.20	94.62	2.50	0.25	0.78
2	86.28	94.63	3.26	0.43	0.15	80.41	37.73	93.79	2.53	0.32	1.30
3	88.23	94.83	2.96	0.55	0.20	80.00	25.00	94.62	2.40	0.28	0.95
4	77.73	95.84	2.16	0.17	0.42	73.26	24.40	92.70	2.93	0.37	1.10
5	80.38	94.62	3.40	0.22	0.15	66.34	58.44	93.40	2.90	0.43	1.40
6	84.45	95.85	1.83	0.32	0.40	73.26	56.22	-	-	-	-
7	79.36	93.00	3.76	0.89	0.21	71.22	43.80	94.60	2.41	0.29	0.96
8	76.52	92.60	3.82	0.86	0.35	65.12	50.20	94.51	2.43	0.30	1.00

The fluorspar concentrate from the second stage cleaning of the acidspar circuit was fed to the flotation column without further addition of reagents. In the existing flotation circuit, 3.0 kg/t of sodium silicate is added in the ball mill and 0.16 kg/t of sodium oleate and each 0.075 kg/t of tannin and starch is added in roughing stage. During the 1st stage cleaning, 1.0 kg/t of sodium silicate, 0.35 kg/t of oleate, 0.17 kg/t of tannin and 0.075 kg/t of starch are added. In the 2nd stage cleaning, 0.75 kg/t of sodium silicate, 0.11 kg/t of tannin and 0.2 kg/t of starch are added to achieve optimum results. Samples of feed, concentrate and tailings were collected and the chemical assay of the samples was estimated. The results of the same were compiled in Table1.

Simultaneously, the final concentrate obtained by the conventional flotation cells of the plant were also collected and analyzed. From the results it is apparent that the concentrates obtained by single stage cleaning by flotation column are almost similar to the quality of the concentrates that are obtained after four cleanings by conventional cells. It may be noted that in spite of heavy fluctuations (77-88%) in CaF_2 content in the feed to the flotation column, the quality of the fluorspar concentrate has been improved to around 95% in a single stage column cleaning. However the quality of the concentrate especially in terms of P_2O_5 content is inferior and as such not suitable for HF production. Hence, two stage cleaning by flotation columns was attempted. The concentrate from the first column was fed to the second column for further cleaning. The results of the two stage cleaning by flotation columns are presented in Table 2. It is evident that the concentrates suitable to HF grade could be achieved using two stage column cleaning.

Table 2: Results of two stage cleaning by flotation columns

Set No	Cleaning stage	Feed CaF_2 (%)	Assay of column concentrate (%)				Rec. (%)
			CaF_2	$CaCO_3$	P_2O_5	SiO_2	
1	1st stage	77.04	95.84	1.68	0.25	0.75	30.2
	2nd stage	95.84	97.27	0.88	0.12	0.30	30.3
2	1st stage	75.70	93.61	2.00	0.35	1.20	30.6
	2nd stage	93.61	96.46	1.04	0.15	0.70	-
3	1st stage	64.92	93.20	2.12	0.81	1.20	33.3
	2nd stage	93.20	97.27	1.01	0.17	0.25	43.0
4	1st stage	62.67	95.44	1.50	0.46	0.84	27.2
	2nd stage	95.44	95.80	0.92	0.16	0.46	83.2
5	1st stage	70.00	95.80	1.76	0.22	0.57	55.1
	2nd stage	95.80	95.80	0.93	0.16	0.64	83.9
6	1st stage	69.00	93.20	2.50	0.93	1.44	27.6
	2nd stage	93.20	97.20	0.96	0.16	0.42	-
7	1st stage	68.80	95.60	1.83	0.27	0.70	60.0
	2nd stage	95.60	96.60	1.14	0.21	0.65	92.8
8	1st stage	74.80	93.40	3.20	0.40	1.30	61.8
	2nd stage	93.40	96.40	1.42	0.25	0.38	62.5

Based on the test work conducted, flotation circuit involving three-column configuration as shown in Fig.4 was proposed to obtain both metallurgical grade and HF grade concentrates. Acidspar concentrates assaying 97% CaF_2 could be achieved by adopting two-stage column cleaning in the place of six stage cleaning by conventional cells. Concentrates suitable for metallurgical grade could be achieved in a single stage column cleaning by replacing roughing and three stage cleaning by conventional flotation cells. Thus the number of stages (four in acidspar circuit and four in metspar circuit) could be eliminated and the complexity of flotation circuit can be simplified by using flotation columns.

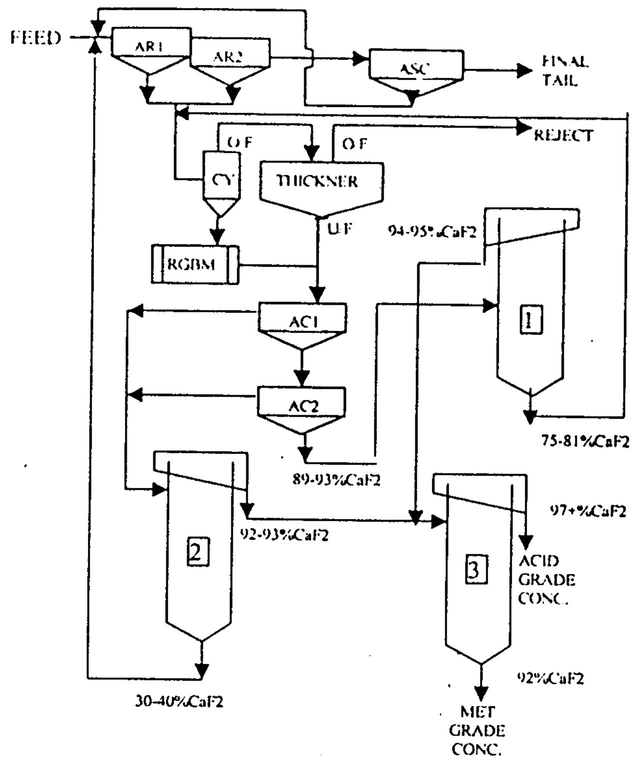

Figure 4 Proposed flotation circuit involving flotation columns

Copper, lead and zinc

The ore body of Ambaji multi metal deposit owned by M/s GMDC, Ahmedabad is complex compared to the other deposits of Cu-Pb-Zn. The ore consist of sulphides of copper, lead and zinc as valuable minerals and talc and mica as gangue minerals. The mineralogical analysis suggests that the ore is highly oxidized in nature. Different reagents are used in the bulk flotation of Cu-Pb-Zn. Sodium silicate as modifier for silica, copper sulphate to activate sphalerite, starch and sodium cyanide to depress mica and pyrite, isopropylxanthate as collector, methyl isobutyl carbinol as frother are used. Since the ore was highly oxidized, sulphidization was carried using sodium sulphide. Flotation column with a diameter of 30 cm supplied by M/s BRGM, France was used in the study. As mentioned earlier, two types of spargers viz, Turbo Air™ and Microcel™ were tried.

The conventional flotation circuit shown in Fig 5 consists of banks of flotation cells for roughing, scavenging and two-stage cleaning. The circuit was optimized to produce bulk concentrate of Cu-Pb-Zn with a total metal content of 50%. In the present study, flotation column was tried in the cleaning stage. The rougher concentrate generated from conventional cells was fed to the flotation column and the effectiveness of the different spargers was tested. The results of the same are shown in Table 3. From the results it is evident that the quality of the overall concentrate is more or less same in both the cases.

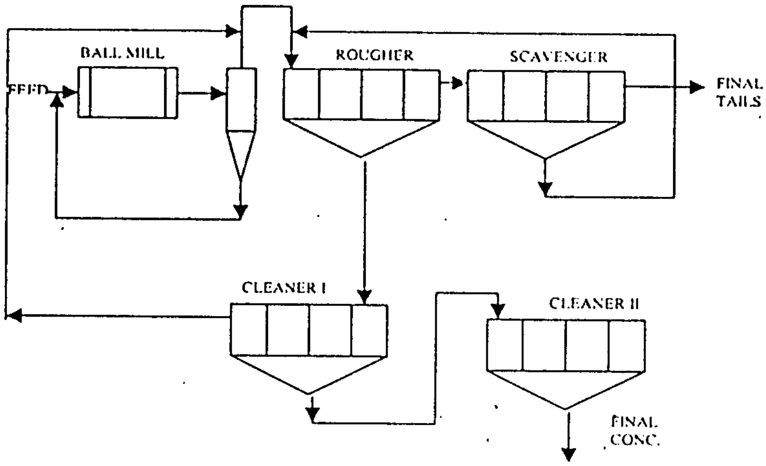

Figure 5 Schematic diagram of conventional flotation circuit for the beneficiation of copper-lead-zinc at Ambaji

Table 3: Comparison of Turbo Air™ and Microcel ™ spargers

Reagent Conditions:

Reagents	Dosage (kg/t)	
	Rougher stage	Cleaner stage
Sod.silicate	2.06	0.19
$CuSO_4$	1.00	nil
NaCN	0.04	0.03
Starch	0.40	0.20
Xanthate	0.15	0.01
MIBC	0.045	nil

Column parameters:

Air velocity	1.2 cm/s
Feed velocity	0.7 cm/s
Wash water bias	0.05 cm/s
Froth depth	70 cm

Sparger	Sample	Assay (%)				TMC
		Cu	Pb	Zn	Fe	(%)
Microcel ™	Col.Feed	1.40	11.10	18.40	21.20	30.90
	Col.Conc	1.69	14.20	31.00	12.90	46.89
	Col.Tails	1.21	5.50	12.70	25.30	19.41
	Plant Tails	0.10	1.20	0.56	-	1.86
	Col. Recovery	47.78	82.34	52.48	-	63.45
	Plant Recovery	75.92	62.42	89.44	-	79.14
Turbo Air™	Col.Feed	1.05	9.20	12.80	28.60	23.05
	Col.Conc	2.01	12.60	34.20	12.20	48.81
	Col.Tails	0.87	4.10	8.30	31.20	13.27
	Plant Tails	0.15	1.27	0.86	7.45	2.28
	Col. Recovery	30.23	82.17	46.42	-	58.27
	Plant Recovery	64.26	57.30	80.05		74.04

However the recoveries are better by using Microcel ™ type sparger. This could be attributed to more gas holdup and fine bubbles. It was also observed that the negative bias conditions are very frequently encountered while using Microcel™ type sparger. It is generally known that the negative bias affects the quality of the concentrates. The operation of the flotation column was affected even under minimum frother dosage. Hence further tests were conducted using Turbo Air™ sparger. Continuous tests were conducted by incorporating flotation column as cleaner (Fig.6). Since quality of the concentrates was affected with mica minerals, the froth depth was increased to 100 cm. By introducing column in the place of two stage cleaning, the flotation circuit was compressed and as a result, the points of reagents addition were readjusted for proper conditioning.

By re-circulating the column tails to rougher conditioner where xanthate also was added, more pyrite was found to report to the final concentrate. Hence the addition of sodium silicate, soda ash and sodium cyanide was shifted from rougher conditioner to ball mill. The column tailings also were diverted to rougher flotation cells via a junction box. With these modifications, continuous experiments were conducted and the results of the tests were compiled in Table 4. The results indicate that the bulk concentrate of Cu-Pb-Zn with total metal content of 50% could be achieved by introducing flotation column in the place of two-stage cleaning by conventional flotation cells.

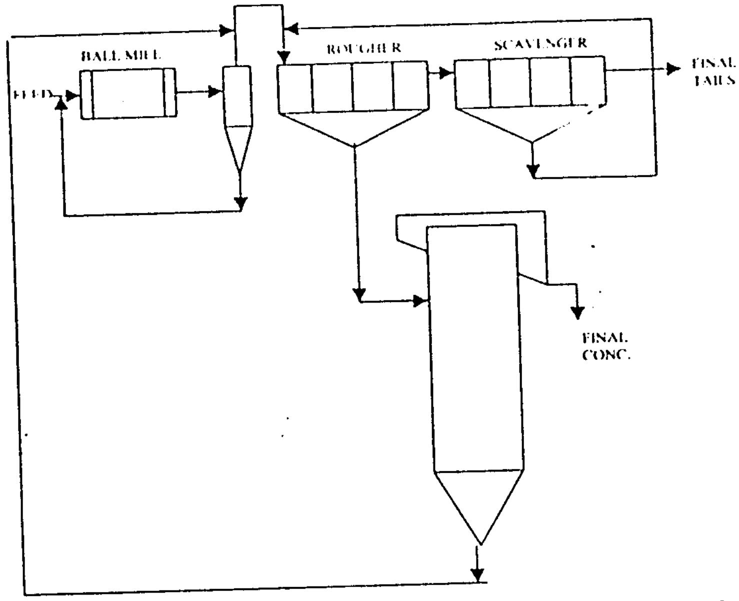

Figure 6 Proposed flowsheet incorporating column in cleaning circuit

Table 4: Comparison of Column and conventional flotation cells

Reagent Conditions:

Reagents	Dosage (kg/t)	
	Rougher stage	Cleaner stage
Sod.silicate	2.06	0.19
$CuSO_4$	1.00	nil
NaCN	0.04	0.03
Starch	0.40	0.20
Xanthate	0.15	0.01
MIBC	0.045	nil

Column parameters:

Air velocity	1.965 cm/s
Feed velocity	0.7 cm/s
Washwater bias	0.05 cm/s
Froth depth	110 cm

Test No	Sample	Assay (%)				TMC
		Cu	Pb	Zn	Fe	(%)
1	Cyclone overflow	0.40	2.79	5.28	7.99	8.47
	Feed to column	1.02	6.75	12.30	25.30	20.07
	Column Conc.	2.28	17.60	29.40	10.40	49.29
	Plant Recovery	80.69	72.72	88.04	-	83.00
2	Cyclone overflow	0.40	2.82	5.18	8.65	8.40
	Feed to column	1.19	6.69	16.00	24.50	23.88
	Column Conc.	2.33	15.20	35.10	8.10	52.63
	Plant Recovery	80.61	75.29	87.39		83.00
3	Cyclone overflow	0.39	2.76	5.27	8.48	8.42
	Feed to column	1.09	6.86	17.10	27.20	25.05
	Column Conc.	1.83	13.20	34.80	11.20	49.83
	Plant Recovery	76.39	67.65	87.49		80.00
4	Cyclone overflow	0.41	3.00	6.32	9.20	9.73
	Feed to column	1.52	7.60	24.10	22.80	33.22
	Column Conc.	2.10	12.20	39.70	11.76	54.00
	Plant Recovery	79.39	73.21	94.08		87.00
5	Cyclone overflow	0.36	2.80	5.31	8.84	8.47
	Feed to column	1.30	7.75	16.40	22.90	25.45
	Column Conc.	2.00	15.40	32.00	11.00	49.40
	Plant Recovery	78.54	77.30	90.72		85.80
6	Cyclone overflow	0.37	3.01	5.27	9.19	8.65
	Feed to column	1.60	8.49	21.60	16.90	31.69
	Column Conc.	2.12	15.50	35.40		53.02
	Plant Recovery	74.12	72.30	86.78		81.14

CONCLUSIONS

Beneficiation of fluorspar and complex sulphides of Cu-Pb-Zn was investigated by installing pilot size flotation columns at respective plant sites. Based on the test work conducted, it was established that improved grades and recoveries could be achieved by adopting column flotation technology. Acidspar concentrates assaying 97% CaF_2, suitable for HF production, can be produced by adopting two-stage column cleaning in the place of multi-stage cleaning by conventional flotation cells. Similarly metspar concentrates assaying 90% CaF_2, suitable for metallurgical applications can be achieved in single stage cleaning by flotation column. Number of cleaning stages, i.e., four in acidspar circuit and four in metspar circuit can be eliminated by adopting a three column configuration. The studies on the beneficiation of complex sulphides of Cu-Pb-Zn indicate that the existing two-stage cleaning by conventional flotation can be replaced by a single stage column cleaning. Thus the cost of production, the complexity of the circuit and the power consumption can be effectively reduced with other attendant benefits.

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