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Semi-Commercial Scale Studies Using Flotation Column And Dual Extraction Column On Iron Ores Of Goa, India

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Abstract:

Goa state in India is endowed with large deposits of low-grade iron ores, geologically formed from the lower Dharwar super group of Archaean rocks. Petrological studies have revealed that silica and alumina are the main gangue minerals, where alumina exists as fine clay and adherent material interspersed in ore body and in some cases both silica and alumina are interlocked with iron ore particles. The amenability of Column flotation and Dual Extraction Column to remove such gangue was studied by installing test units at the Greater Ferromet beneficiation plant of M/s. Sociedade De Fomento Industrial Ltd., Goa. A reverse flotation process was adopted wherein gangue minerals containing silica and alumina are floated using cationic collector. Sodium hydroxide and starch were used to regulate the slurry pH and depress the iron ore, respectively. Iron ores of different mines and their mixtures were studied using different cationic collectors. The effect of both process and column parameters on grade and recovery were established. The results clearly suggest that iron ore concentrate assaying 67% Fe and 2% SiO_2 and Al_2O_3 could be obtained with a recovery of 85-90% by single stage column operation. The better performance of flotation column over Dual Extraction Column in terms of reduction of gangue was also brought out in these studies.

INTRODUCTION AND BACKGROUND

Iron ore continues to remain the major feedstock for steel making in the foreseeable future. According to the International Iron and Steel Institute (IISI), among the major iron ore producing countries, the Fe content in South African ore is 68%, 65% in Norway, Australia and Mexico, and 66% in Brazil. Canadian and Swedish ore have 63% Fe content, Venezuela 64%, India 61% and USA 60%. The world has over 233 billion tonnes of estimated reserves of iron ore (Fasihuddin, 1997). The recoverable reserves of iron ore in India are about 12,400 million tonnes, of which only about 950 million tonnes are of high grade (>65%). Beneficiation is required to upgrade the remaining ore and for the utilization of the large quantities of fines generated during mining. Also, there has lately been a marked shift from lumps to fines in iron making.

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The processes, which permit the use of ore fines, have a cheaper cost of production than those using lump ore, pellets and sinter.

The state of Goa in India is endowed with 300 million tonnes of proven hematite iron ores, geologically formed from the lower Dharwar Super Group of Archaean rocks. These deposits were basically formed by enrichment of banded ferruginous horizons of magnetite and hematite and covered with thick laterite caps. Since alumina exists as fine clay and adherent material interspersed in the ore body and, in some cases, both silica and alumina are interlocked with iron ore particles, their removal by conventional methods is difficult. It has also been conclusively established that the adverse high alumina to silica ratio (ideally it should be <1) is detrimental to blast furnace as well as sinter plant productivity.

Iron ores of Goan origin are currently being beneficiated by washing, scrubbing, hydrocycloning and magnetic separation. Since magnetite is a ferromagnetic mineral, Wet Low Intensity Magnetic Separators are used to recover magnetite. Matrix type magnetic separation equipment such as High Gradient Magnetic Separator (HGMS) from SALA and Ferrous Wheel from Eriez are being used for recovery of paramagnetic hematite possessing low magnetic susceptibility. The above physical methods were found to be inadequate for processing fine sized valuable minerals. Under such circumstances, froth flotation is highly useful. Beneficiation of pre-concentrated iron ore fines using collectors such as oleates, sulfonates, sulphates, amines and hydroxamates is a well-established industrial process. In the present investigation, reverse flotation of gangue minerals using amines was adopted, as the gangue content is relatively low.

Among various flotation techniques, column flotation has shown to be promising in obtaining high grade concentrates with less circuit complexity and power consumption (Bhaskar Raju et al., 1993, 1994; Bhaskar Raju and Prabhakar, 2000). Column flotation has been developed utilizing the principle of counter-current contact between downward flowing slurry with rising air bubbles (Boutin and Wheeler, 1967). In many cases it was proved that the concentrates produced in a three-stage operation by conventional flotation could be achieved in a single-stage operation by using flotation column (Prabhakar and Bhaskar Raju, 1998; Coffin and Miszczak, 1982). Iron ores are being beneficiated using larger diameter flotation columns both in India and Brazil (Michael and Ian, 1989; Donald and Harold, 1991). The Dual Extraction Flotation Cell (DEC) is a new advanced column flotation cell. Some of the advantages advocated in its favor are better recovery than mechanical cells and other columns, cost effective installation, higher capacity per square foot, clean concentrates with excellent scavenging capabilities, low power consumption-as low as 13% of other column flotation cells for the same capacity, lower water usage than eductors and capability of recycle water being used on the infuser bubble generator.

M/s Sociedade De Fomento Industrial Limited, Goa, India was able to produce concentrates of 65-66% Fe from their non-magnetic circuit after installing HGMS at their Greater Ferromet beneficiation plant. Different products generated in their beneficiation circuit are given in Table 1. Comparative studies were conducted on a semi-commercial flotation column, designed and developed by National Metallurgical Laboratory Madras Centre, India, and a Dual Extraction Column supplied by McNally Bharat Ltd., Bangalore, India for further enrichment of concentrate obtained from HGMS.

Table 1: Different products generated in the processing of iron ore at Greater Ferromet beneficiation plant

Description	Weight % Rec.	%Fe	% Al_2O_3	% SiO_2
Concentrate	46.0	62.3	1.84	3.57
-60 + 10 mm	11.8	61.5	1.88	2.80
-10 + 6 mm	2.1	60.3	2.19	3.28
Para magnetics	12.2	65.3	1.34	2.85
O/S	3.2	59.0	2.50	3.20
Tailing	24.7	46.4	6.24	11.68
Feed	100.0	58.5	2.90	5.38

EXPERIMENTAL

Flotation Column:

A 0.5m diameter flotation column designed and developed by NML Madras Centre was shifted to the plant site and erected at a suitable location so that the concentrate product of HGMS is directly fed to the column. The details of the flotation column set-up are shown in Figure 1. The flotation column is an assembly of flanged sections consisting of the air injection zone, collection zone, feed point and cleaning zone/froth zone. The slurry / froth interface was maintained using a Differential Pressure Transmitter (DPT) mounted to the column shell. The output signal

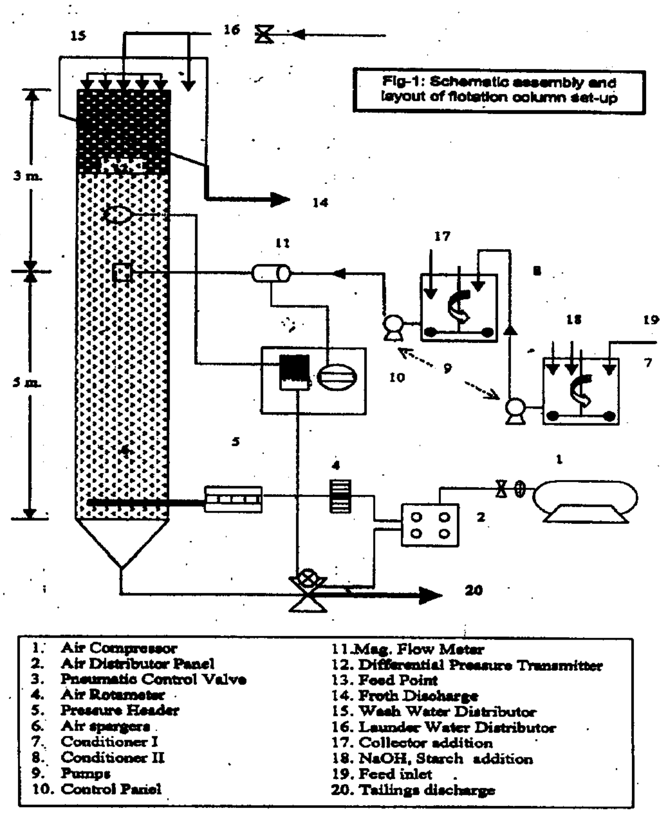

Figure 1:

of the DP cell was looped to an electro-pneumatic tailing valve through a controller. Based on the signal (4-20 mA) generated by the DP cell, the concentrate discharge valve is automatically actuated and, accordingly, the slurry discharge is maintained. The froth depth could be altered between 50 to 150 cm by changing the set point in the controller. Internal spargers and wash water spray arrangement, designed by NML Madras Centre, were used in the studies. Airflow was monitored by a purge rotameter while slurry flow rate was measured using magnetic flow meters.

Experimental procedure:

The air from the compressor was let into the column through spargers at a desired flow rate. The column was filled with water and stabilized at the required froth depth at a constant wash water addition. Then, the conditioned iron ore slurry was pumped into the column at the desired flow rate. Concentrate from HGMS was tapped to the first conditioner, in which sodium hydroxide and starch were added. Slurry residence time of 180 seconds was maintained in the first conditioner. This slurry was next pumped to the second conditioner where it was conditioned with the amine collector. Minimum residence time of 180 seconds was maintained in the second conditioner also. Dosing pumps were used to deliver the reagents to the respective conditioners. The conditioned slurry was pumped into the column through a flow meter and feed distribution box. The column was allowed to run for a minimum of 3-4 residence times. Samples were drawn under near-steady state conditions. Both the process parameters and column operating conditions were recorded before collecting the samples. Samples were analyzed for Fe, Al_2O_3 and SiO_2 by adopting standard methods of analyses.

A picture/schematic of this unit would be very helpful. I'm not sure I understand how it operates – so I didn't edit this paragraph because I'm not sure how the flow moves through this unit and I didn't want to change things incorrectly.

Dual Extraction Column:

This column has two chambers, one upper and the other lower one where the separation is accomplished. The feed is introduced as slurry after conditioning with reagents into a feed well. It is then equally distributed through a bottom plate, thus entering the upper chamber where initial separation takes place. Air bubbles are created by introducing fresh water into two header pipes with hose attachments leading into multi- infusers specially designed to create a high volume of finely divided air bubbles. Low-pressure air is provided by a blower to combine in the infusers. As the rising air bubbles move upward in the chamber, separation of values from the gangue takes place and the tailings reports to a launder for removal. The concentrate exits the upper chamber via a discharge throat at a controlled rate by means of a dart or plug valve positioned in the opening and connected to a movable shaft capable of up or down movement through a thread bar and adjusting wheel arrangement. The non-separated gangue still present in the concentrate now has sufficient residence time in the lower chamber where an identical separation as described for the upper chamber takes place. The tailings from this lower chamber overflow into the launder and combines with concentrate from the upper chamber for further dewatering. The concentrate exits the lower chamber via a concentrate discharge pipe. See note at beginning of paragraph

RESULTS AND DISCUSSION

Characterization:

The color of lump iron ore samples varied from reddish brown to yellow. Occasionally, the iron ore was found to be associated with argillaceous/arenaceous material, which could be from the host rocks and dykes / intrusions into the ore body. This extraneous material was found to contribute extra silica and alumina to the finer fractions of ore during processing. Microscopic studies of all the iron ore samples revealed the presence of hematite, goethite, martite, and magnetite, while quartz and clay constituted the silicates. In many samples, the presence of limonite was also noticed. Hematite / martite and magnetite were found to be granular while goethite showed oolitic, pisolitic and colloform texture. The size of hematite / martite grains ranged from 30-40 μm to 180 μm while that of silicate ranged from 5-10μm to 70-80 μm. Silicate grains were present as inclusions within goethite and hematite and *vice-versa* (Figures 2 & 3).

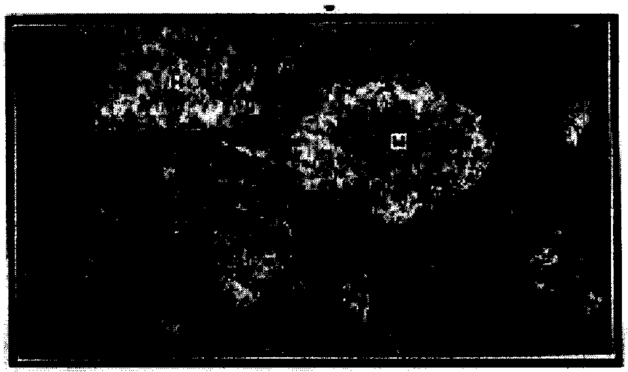

Fig. 2: Hematite (H) grains within a matrix of clay and goethite. Patches of clay are seen as black. Reflected Light x150

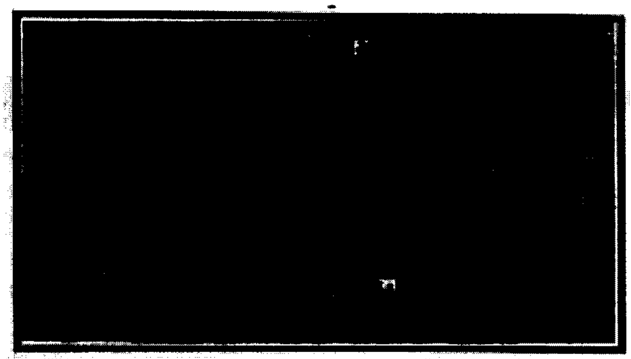

Fig. 3: Silicate matrix within goethite (G). *Fine inclusions of hematite (white grains) within the silicates (S). Reflected light, x 150*

Sieve and chemical analyses of feed to the column and column concentrate were conducted and the results are shown in Tables 2 and 3 respectively. It is evident that gangue particles are interlocked with iron minerals above 150 μm. Though this fraction is very small, the contribution of gangue is very high. Most of the free gangue is in the finer fraction i.e., below 45 μm. However, both alumina and silica were uniformly eliminated by flotation in all the sieve fractions except the –300+150 μm size.

Table 2: Sieve and Chemical analysis of feed to column (HGMS Conc.)

Sl. No.	Sieve fraction (μm)	Wt. (g)	Wt. %	Assay % Fe	Assay % Al_2O_3	Assay % SiO_2
1	300+150	1.0	0.36	59.6	NA	NA
2	-150+75	61.0	21.96	66.5	1.07	1.43
3	-75+45	79.2	28.51	67.0	0.90	1.45
4	-45	136.2	49.03	64.7	1.47	2.83
	Calculated			65.7	1.21	2.12
	As per analysis			65.9	1.22	2.59

Table 3: Sieve and Chemical analysis of Column Concentrate

Sl. No.	Sieve fraction (μm)	Wt. (g)	Wt. %	Assay % Fe	Assay % Al_2O_3	Assay % SiO_2
1	300+150	2.62	0.17	58.7	2.64	5.39
2	-150+75	311.4	20.08	67.3	0.60	1.10
3	-75+45	554.2	35.74	68.0	0.74	1.00
4	-45	682.6	44.01	66.3	1.10	1.44
	Calculated			67.1	0.87	1.22
	As per analysis			67.4	0.71	1.16

Preliminary tests on laboratory size flotation column:

Preliminary tests were conducted using a 3.0" diameter Laboratory size flotation column at NML Madras Centre. The sample marked SGO-C / HGMS was beneficiated by reverse flotation using commercially available Chem-540F and Chem-550F cationic collectors supplied by Ideal Speciality Chemicals, Mumbai, India. Experimental conditions and the results obtained are presented in Tables 4 and 5 respectively. Though both the reagents are suitable, Chem-550F was found to be more selective towards Al_2O_3 whereas Chem-540F was better for SiO_2 elimination. It was also observed that reagent consumption of 0.2 kg/t is required to reduce the combined Al_2O_3 and SiO_2 content to less than 2%. By increasing the collector dosage further, reduction in gangue was achieved at the cost of recovery. Experiments were also conducted to optimize the slurry pH by maintaining the collector dosage at 0.2 kg/t, the results are shown in Table 6. The slurry pH was adjusted using commercial grade NaOH (0.05-0.1 kg/t). It was observed that the optimum results were achieved by maintaining the slurry pH in the range of 8.0 – 9.0. It may also be noted that these results were in conformity with the solution chemistry of amines and surface properties of iron minerals, Al_2O_3 and SiO_2.

Table 4: Lab scale Flotation column results using Chem-550F as collector

Sl. No.	Collector dosage (kg/t)	Weight (%)		Concentrate Assay (%)			Tailings Assay (%)			Fe %Rec
		Conc.	Tails	Fe	Al_2O_3	SiO_2	Fe	Al_2O_3	SiO_2	
1	0.25	87.2	12.8	66.6	1.01	1.38	56.7	3.95	9.16	88.9
2	0.40	78.3	21.7	67.1	0.87	1.11	58.6	2.40	7.83	80.6
3	0.50	74.6	25.4	67.3	0.82	0.91	60.0	2.68	6.33	76.6
4	0.75	69.3	30.7	67.4	0.79	0.83	60.7	2.17	5.68	71.5

Column Parameters:		*Process Parameters:*	
Air velocity	*: 1.00 cm/s*	*Slurry pH:*	*8.50*
Wash water velocity	*: 0.08 cm/s*	*Starch:*	*1.0 kg/t*
Froth depth	*: 50 cm*	*NaOH:*	*0.05kg/t*
Slurry residence time	*: 600 sec.*		

Feed: Fe: 64.8%; Al_2O_3: 1.57%; SiO_2: 2.76%

Table 5: Lab scale Flotation column results using Chem-540F as collector

Sl. No.	Collector dosage (kg/t)	Weight (%)		Concentrate Assay (%)			Tailings Assay (%)			Fe %Rec.
		Conc.	Tails	Fe	Al_2O_3	SiO_2	Fe	Al_2O_3	SiO_2	
1	0.20	88.0	12.0	66.7	0.85	0.67	56.5	4.87	7.87	90.3
2	0.30	77.9	22.1	66.9	0.99	0.64	59.7	3.04	6.49	80.2
3	0.40	70.5	29.5	67.1	0.79	0.62	61.6	2.57	5.04	72.4
4	0.50	60.7	39.3	67.3	1.00	0.57	62.7	2.02	4.02	72.4

Table 6: Effect of slurry pH on grade and recovery

Sl.No.	Slurry pH	Wt (%)		Assay (%)		Fe %Rec.
		Conc.	Tails	Conc.	Tails	
1	7.00	79.7	20.3	66.4	57.8	81.9
2	8.30	83.1	16.9	66.5	57.1	85.2
3	9.00	88.6	11.4	66.3	57.0	90.1
4	9.80	91.1	8.9	66.1	51.3	92.2
5	10.50	92.6	7.4	65.3	56.5	92.7

Feed: Fe: 64.8%; Al_2O_3: 1.57%; SiO_2: 2.76%

Results on semi-commercial scale flotation column

Effect of collector dosage:

Experiments were conducted with a semi-commercial flotation column to fine tune the collector dosage, these results are presented in Table 7. From the results it is apparent that 0.15 to 0.20 kg/t collector dosage was sufficient to obtain concentrates assaying 67% of Fe with a recovery of around 90%. Gangue (Al_2O_3 and SiO_2) content in the concentrates was reduced to approximately 2%.

Table 7: Effect of collector dosage (Chem- 540F) on grade & recovery

Sl. No.	Dosage (kg/t)	Weight (%)		Conc. Assay (%)			Tailings Assay (%)			Fe %Rec.
		Conc.	Tails.	Fe	Al_2O_3	SiO_2	Fe	Al_2O_3	SiO_2	
1	0.09	88.1	11.9	66.9	1.10	1.21	56.1	5.88	8.05	-
2	0.14	89.0	11.0	67.0	0.95	1.14	54.9	5.03	11.69	90.8
3	0.16	89.4	10.6	67.4	0.71	1.16	48.1	3.25	15.60	92.2
4	0.21	88.0	12.0	66.9	0.92	1.21	57.1	4.10	10.12	89.6
5	0.26	82.5	17.5	67.0	0.95	1.33	58.8	4.04	7.11	82.5
6	0.44	89.2	10.8	66.8	1.05	1.04	54.7	3.16	15.88	91.0
7	0.74	86.8	13.2	66.6	1.13	1.14	57.8	2.72	10.62	88.3

Column Parameters
Wash water velocity : 0.085 cm/s
Froth depth : 75cm
Air velocity : 1.02 cm/s
Feed velocity : 0.71cm/s

Process Parameters
Solids: 20%
Slurry pH: 8.0 - 8.5
Starch: 1.0 Kg/t

Feed grade: Fe: 65.5%; Al_2O_3: 1.3%; SiO_2: 3.1%

Effect of airflow rate:

Air rate is an important variable, which affect both grade and recovery. Generally air velocity should be as large as possible to ensure a high throughput. At the same time, if it is too high, the flow pattern will be disturbed and there is every possibility to lose the bubble swarm. In order to achieve better results, a bubbly flow regime, where gas hold up varies linearly with air rate should be maintained. Furthermore, at low air rates of < 1.5 cm/s, the feed water concentration that enters into the froth zone should be minimized. Frother dosage (in this case collector dosage) is an additional factor controlling feed water penetration into the froth. By increasing the collector concentration, the bubbles will become smaller and the penetration of these smaller bubbles into the froth zone will increase and consequently negative bias, i.e., loss of interface, will occur. Tests were conducted at different airflow rates and the results are presented in Table 8. It was observed that the superficial air velocity of 1.02 cm/s was found to be optimum to obtain better grade and recovery. However, air velocities of above 1.5 cm/s are being used in many industrial scale operations. It was also observed that the penetration of wash water was reduced beyond the air velocity of 1.1 cm/s. In this particular case, though the amine concentration was increased to 0.50 kg/t, the negative bias problems were not encountered.

Effect of Froth Depth:

Froth depth was adjusted to the required value by a controller looped to a pressure transmitter. Experiments were conducted at different froth depths ranging from 0.5m to 1.5m and the results are presented in Table 9. The rejection of entrained iron ore particles depends on froth depth. Due to high air velocities, some fraction of iron ore will be entrained into the froth phase. If there is not enough froth depth, these particles will be carried along with the gangue and thus the recoveries will be affected. In the froth zone, particles are subjected to repeated detachment/reattachment events due to coalescence. During this process, particles with sufficient hydrophobicity only will float. Particles with less hydrophobicity will ultimately report to the slurry phase. In industrial operation, typical froth depths of 1m were adopted to reduce entrained particles. In the present case, though there is no significant variation in grade and recovery, a froth depth of 0.75m to 1.0m appears to be optimum to obtain good quality concentrates.

Table 8: Effect of Air-rate on grade and recovery

Sl. No.	Air velocity (cm/s)	Feed Assay (%)			Conc. Assay (%)			Tails Assay (%)			Fe %Rec.
		Fe	Al_2O_3	SiO_2	Fe	Al_2O_3	SiO_2	Fe	Al_2O_3	SiO_2	
1	0.51	65.5	1.37	2.22	66.3	1.11	1.97	45.5	10.9	13.9	96.6
2	0.68	65.5	1.44	2.10	66.5	1.28	2.02	45.1	11.3	13.8	96.8
3	1.02	65.6	1.95	1.83	67.5	1.16	1.18	47.6	10.8	11.2	93.1
4	1.19	66.0	1.46	1.78	66.1	1.36	1.70	52.7	8.0	9.9	99.4
5	1.36	65.5	1.49	2.07	67.1	0.99	1.32	57.4	4.4	6.6	85.6

Column Parameters:
Wash water velocity : 0.034 cm/s
Feed velocity : 0.66 cm/s
Froth depth : 50 cm

Process Parameters:
Chem-540F: 0.14 Kg/t
Starch: 1.0 Kg/t
Slurry pH: 8.0- 9.0

Table 9: Effect of Froth Depth on grade and recovery

Sl. No.	Froth Depth (cm)	Feed Assay (%)			Conc. Assay (%)			Tails Assay (%)			Fe %Rec.
		Fe	Al_2O_3	SiO_2	Fe	Al_2O_3	SiO_2	Fe	Al_2O_3	SiO_2	
1	50	65.0	1.43	2.66	66.8	0.96	1.50	53.6	-	-	89.0
2	75	65.6	1.40	2.24	67.0	0.90	1.26	46.4	6.76	13.8	88.0
3	100	65.6	1.43	1.97	67.2	1.07	1.43	58.9	5.79	7.22	93.0
4	125	65.7	1.25	1.80	67.0	0.95	1.21	54.2	5.25	9.90	87.0

Column Parameters:
Wash water velocity: 0.085 cm/s
Feed velocity: 0.75 cm/s
Solids: 20%
Air velocity: 1.02 cm/s

Process Parameters:
Chem 540-F: 0.14 Kg/t
Starch: 1.0 Kg/t
Slurry pH: 8.0 -9.0

Effect of wash water:

Wash water was introduced through a distributor across the column cross section. The wash water device was fixed at a height of 10 cm above the froth lip. Results obtained at different wash water rates are presented in Table 10. In column flotation, wash water provides the bias water and the water necessary to transfer the collected solids into the launder. The bias water replaces the water draining naturally from the froth and promotes froth stability. Thus the wash water rate controls the recovery by replacing feed water in the froth and thereby removing hydrophilic iron ore particles. Usually, wash water rates are kept as low as possible to minimize unnecessary dilution of reagents. Since the collector adsorption is physical in nature, excess wash water may desorb the reagent from the surfaces of silica and alumina. Consequently, both gangue minerals would report to the slurry phase, affecting the grade. In this particular case though there is not much variation in metallurgy, wash water velocity of 0.06 cm/s appears to be optimum.

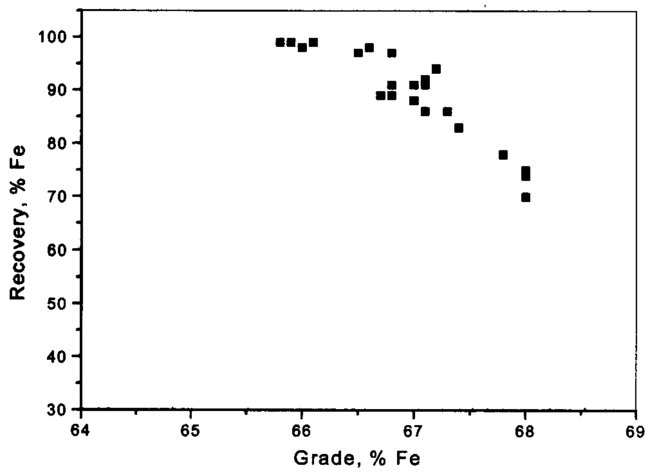

Fig. 4. Grade – Recovery Profile

Table 10: Effect of wash water on grade and recovery

Sl. No.	Wash Water (cm/s)	Feed Assay (%)			Conc. Assay (%)			Tails Assay (%)			Fe %Rec.
		Fe	Al_2O_3	SiO_2	Fe	Al_2O_3	SiO_2	Fe	Al_2O_3	SiO_2	
1	0.04	65.5	1.24	1.79	66.9	0.87	1.51	54.9	5.78	10.4	90.2
2	0.06	67.0	1.14	1.18	68.1	0.86	0.59	61.2	2.67	-	85.5
3	0.07	66.4	1.25	1.67	67.2	1.10	0.71	55.7	3.65	7.22	94.0
4	0.09	65.6	1.43	1.97	66.2	1.07	1.43	58.9	3.79	7.22	93.0

Column Parameters:		*Process Parameters:*	
Air velocity:	*1.0 cm/s*	*Chem 540-F:*	*0.15 Kg/t*
Feed velocity:	*0.75 cm/s*	*Starch:*	*1.00 Kg/t*
Froth depth:	*75 cm*	*pH of slurry:*	*9.0*
% solids:	*20*		

Continuous semi-commercial scale tests on Flotation Column:

At optimum conditions, continuous tests were conducted on different samples and the results of the same are presented in Table 11. Results clearly suggest that column flotation is amenable for the beneficiation of iron ore of Goan origin. Concentrate assaying 67% Fe could be achieved in a single stage column flotation operation. Gangue (Al_2O_3 and SiO_2) content in the final concentrate was reduced to below 2%. Selected values were considered to obtain a grade – recovery profile and the results are shown in Figure 4. It is apparent that an average Fe grade of 67% could be achieved with recoveries of around 85-90%.

Table 11: Results of continuous test runs on Flotation Column

Sample Code	Feed Assay (%)			Conc. Assay (%)			Tails	Fe %Rec.
	Fe	Al_2O_3	SiO_2	Fe	Al_2O_3	SiO_2	Fe (%)	
CGL-B	65.5	1.24	1.79	66.9	0.87	1.50	54.9	90.2
CGL-C	64.8	1.51	2.82	66.7	1.15	0.62	59.5	75.8
SGO-C	66.7	1.36	1.99	67.4	1.04	0.90	56.7	94.4
SGO-C	67.0	1.14	1.18	68.1	0.86	0.59	61.2	84.5
CBN-C	66.1	1.51	3.03	66.8	1.16	1.68	42.4	98.2
CBN-C	63.6	1.49	5.26	67.0	1.16	1.48	-	96.3
SGO-B&C	64.9	1.38	3.36	66.4	1.49	1.29	31.6	97.9
SGO-B&C	66.0	1.24	2.21	67.2	1.09	0.86	58.6	87.6
SGO-B&CBN-C	65.7	0.93	2.73	67.6	0.77	0.91	58.6	81.1
SGO-B&CBN-C	66.4	1.28	1.67	67.2	1.10	0.71	55.7	94.2
SGO-B&CGL-B	65.0	1.44	3.03	66.7	1.22	1.49	54.8	88.0

Table 12: Results of continuous test runs on Dual Extraction Column

Sample Code	Feed Assay (%)			Conc. Assay (%)			Tails	Fe %Rec.
	Fe	Al_2O_3	SiO_2	Fe	Al_2O_3	SiO_2	Fe (%)	
SG/CB-C	64.5	1.06	4.14	66.3	0.76	2.15	47.1	90.6
SG/CB-C	64.4	1.31	4.54	66.4	1.20	1.72	44.0	91.1
SG/CB-C	64.8	1.75	4.03	66.4	1.20	2.17	45.0	92.5
SG/CB-C	64.8	1.75	4.03	67.0	1.20	1.38	51.0	86.3
SGO-C	64.3	1.44	3.91	66.1	1.17	1.86	42.9	92.2
SGO-C*	67.4	0.83	2.06	67.8	0.70	1.39	54.0	97.1
SGB/NSN	65.2	1.17	2.64	65.9	1.03	1.75	53.0	94.6
SGB/MST	64.8	1.46	2.67	66.2	1.20	1.55	53.0	89.4
SGB/MST	64.8	1.46	2.67	65.7	1.17	1.55	55.0	91.6
SGB/MST♦	66.0	1.28	2.06	66.7	1.02	1.26	54.8	94.1
SGB/MST♦	65.0	1.71	2.67	66.3	1.24	1.49	53.9	89.5

** Feed is the concentrate from Medium Intensity Magnetic Separator*

♦ Secondary tails re-circulated to the first conditioner

Continuous semi-commercial scale tests on Dual Extraction Column:

Continuous tests were carried out on samples drawn from different mines and some of the salient results are presented in Table 12. It is evident that the gangue (Al_2O_3 and SiO_2) content in the final concentrate could not be brought down to below 2%.

CONCLUSIONS

Microscopic examination of the sample indicated the presence of hematite, goethite, martite, and magnetite as iron minerals, and quartz and clay as silicate gangue.

Limonite was found associated with both opaque minerals and gangue. The presence of silicate grains within goethite and hematite and vice versa was also observed. Gangue was interlocked with iron minerals in the plus 150 µm fraction. Two commercially available cationic collectors, viz., Chem-540F and Chem-550F, were tested. It was observed that Chem-550F is selective towards Al_2O_3 and Chem-540F for both alumina and silica. Though Chem-550F is selective, its solubility was found to be very poor. Tests conducted using a semi-commercial flotation column on samples derived from different mines clearly indicate its amenability. Iron ore concentrate of 67% Fe and $\leq 2\%$ SiO_2 and Al_2O_3 could be obtained with a recovery of 85-90% by single stage column flotation. Comparative studies on the Dual Extraction Column indicate its limitation in reduction of gangue to the same extent as in flotation column.

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REFERENCES:

1. Bhaskar Raju, G., Prabhakar, S and Sankaran, C., 1993. Beneficiation of iron ores by column flotation. Transactions of the Institute of Mining and Metallurgy, Sect. C132-135.
2. Bhaskar Raju, G and Prabhakar, S., 2000. Beneficiation of fluorspar by column flotation. Minerals & Metallurgical Processing, 17(3), 167-172.
3. Boutin, P and Wheeler, D.A., 1967. Column flotation development using an 18 inch pilot unit. Canadian Mining Journal, 3, 94-101.
4. Coffin, V.L and Miszczak, J.,1982. Column flotation at Mines Gaspe. In: Proceedings of XIV International Mineral Processing Congress, Toronto, Canada, pp-21.
5. Donald, J.M. and Harold, E.W, 1991. Large diameter column flotation cells takes hold. Engineering and Mining Journal, 8, pp. 40-42.
6. Fasihuddin, M., 1997. Review of developments in Iron ore beneficiation. In: Amit Chatterjee (Ed.), Multi-Facets of Metallurgy: Emerging Trends, Proceedings of Annual Technical Meeting of Indian Institute of Mineral Engineers, Jamshedpur, India, pp 1-20.
7. Prabhakar, S., Bhaskar Raju, G and Sankaran, C.,1994. Quality improvement of copper concentrates by column flotation. Transactions of the Indian Institute of Metals, 47, 89-101.
8. Prabhakar, S and Bhaskar Raju, G., 1998. Amenability of column flotation for lead-zinc beneficiation. Metals Materials and Processes, 10, 109-117.
9. Michael, J.B. and Ian,T.R.F. 1989. Modernization of the Nchanga Flotation plant: A Comparison of flotation cells and columns. Mining Magazine, 7, pp. 34-39.