Value Addition of Indian Iron Ore Fines by Column Flotation – Few Case Studies

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Abstract

The Government of India highlighted Processing and utilization of iron ore fines as a pre-requisite to meet the domestic raw material requirements for the projected 110 million tonnes of domestic steel production by the year 2019-20 in the National Steel Policy announced in November 2005. This would require 190 million tonnes of iron ore. The depletion of high grade iron ore and increased generation of fines during mining and handling and demand for high grade iron ore fines for export has necessitated the processing of low to medium grade fines. The R&D efforts undertaken at NML-Madras Centre, India in this direction have been highlighted. Flotation in general and Column Flotation in particular appear to be promising in addressing this problem. This would also mitigate the environmental problem created by the dumping of huge quantities of low and medium grade iron ore fines. Three case studies involving iron ore fines of varying silica and alumina content from Goa and Bellary-Hospet regions of India were discussed. The results clearly indicate the feasibility and significance of flotation process in treating the fines to obtain marketable concentrates.

Keywords: *Iron ore fines, flotation, Column Flotation, silica reduction.*

INTRODUCTION

National Steel Policy, a Vision Statement, unveiled by the Government of India in November 2005 envisages achieving a long-term target of 110 million tonnes of domestic steel production by the year 2019-20 (Sharma, 2005). The Steel Policy discusses the major issues concerned with this projected growth: most critically, the domestic raw material availability situation – which has already become a source of concern for domestic steel producers. Government of India would encourage iron ore trading in order to make this essential raw material available to the iron and steel industry throughout the country. It further lays emphasis in encouraging investments in adding value to iron ore fines. On the basis of the anticipated 110 million tonnes production by 2019-20, the Steel Policy envisages an iron ore consumption of 190 million tonnes. The policy says "Government would encourage investments in creation of an additional modern mining and beneficiation capacity of 200 million tonnes" to meet the raw material requirement.

The Indian resources of iron ore have been made compatible with United Nations Framework Classification (UNFC), which is more scientific and adopted in most countries of the world. Iron ore reserves and resources estimated on the UNFC basis as on 1.4.2000 are about 12,906 million tonnes of hematite ore and about 10,628 million tonnes of magnetite ores. For the first time, Indian Bureau of Mines (IBM) has given the lumps and fines break up of the hematite iron ore reserves (Table 1). There are four types of classification, lumps, fines, lumps and fines and others. Others include blue dust etc. About 42% of the total reserves are lumps - 5403 million tonnes, that of fines of about 34% - 4326 million tonnes and lumps and fines together, constitute 10% of the total reserves - 1287 million

tonnes, and 11% are the prospective resources. The remaining 3% are blue dust etc. 11% of the total reserves are of high grade (7% lumps + 1% fines + 3% lumps and fines). Major chunk of the reserves, around 45% are of medium grade quality (22% lumps + 20% fines + 3% lumps and fines). This grade of the ore, particularly the fines, is the feed for the Indian iron ore export market. Besides these hematite ore reserves, India also has a substantial magnetite resource base. Of the total 1068 million tonnes of magnetite reserves, Karnataka with a reserve of 7883 million tonnes has a major chunk of about 74% magnetite iron ore resources of the country. Another point that should be noted here is that the hematite resources are estimated at 55% cut off. It is, therefore, quite obvious that as and when the mining activity intensifies, concomitantly, exploration will also increase leading to the discovery of more resources. The resource position will increase further if the cut-off is brought down to 45% Fe. With the modern technology it should be possible to utilize iron ore of 45% Fe and above.

Table 1: Iron Ore (Hematite) Reserves in India As on 1.4.2000

Source: Ibm Year Book, 2005

GRADE	Total Resources 000 tonnes	Per cent to Total Hematite %
A. Lumps		
High Grade	915276	7
Medium Grade	2822917	22
Low Grade	1131915	9
Unspecified Grade	533225	4
Sub Total A	5403333	42
B. Fines		
High Grade	139221	1
Medium Grade	2506868	20
Low Grade	1325515	10
Unspecified Grade	354187	3
Sub Total B	4325791	34
C. Lumps & Fines		
High Grade	409095	3
Medium Grade	421225	3
Low Grade	331754	3
Unspecified Grade	116650	1
Sub Total C	1278724	10
D. Prospective Resources	1480005	11
E. Others	417940	3
Total Hematite (A+B+C+D+E)	12905793	
Magnetite Ore	10682207	
Grand Total	23588000	

Table 2: Iron Ore Production: Product-Wise, Quantity: '000 Tonnes

Source: Indian Bureau of Mines, Nagpur

Grade	2000 – 01	2001 – 02	2002 – 03	2003 – 04	2004 – 05(p)
Lumps	33567 (42)	34572 (40)	39581 (40)	48960 (40)	57590 (40)
Fines	41189 (51)	45224 (53)	52994 (53)	67679 (55)	79976 (56)
Concentrates	6006(7)	6430(7)	6497(7)	6199(5)	5145(4)
Total	80762	86226	99072	120601	142711
% Growth		7	15	21	18

Note: Figures in parenthesis are percent to total

Data in Table 2 indicates that 60% of iron ore production comes in the form of fines (including concentrates) during the course of mining operations itself. Further, 10-12% lumps become fines while handling, loading / unloading (particularly in Bellary – Hospet where the ore is friable) and while converting them into calibrated lump ore (CLO) for sponge / pig iron plants / exports. On an average 2.5 tonnes of run of mines (ROM) are required to get one tonne of CLO. Thus about 70 - 75% of the total production, of the country's iron ore is fines either at the time of mining or handling of ore. In addition, there is already a stockpile of about 40-45 million tonnes of fines in IISCO and SAIL mines, which is creating environmental hazards. As can be seen from Table 3, significantly high part of the exports is fines (83%) in 2004 – 05. For that matter during the past three years about 75% and above Indian iron ore exports are fines. Table 4 indicates the nature of exports is gradually transforming from +64% Fe to lower grades. In 2002 – 03, the exports of +64% Fe grade of iron ore constituted more than 50% of the total quantity. This came down to just 26% in 2004 - 05 and are mostly covered under long-term contracts with Japan and South Korea. On the other hand 62-64% Fe grade constituted about 44% of the total exports and 62%

Table 3: India's Iron Ore Export – Lumps / Fines, Qty. Million Tonnes

	2002 – 03			2003 – 04			2004 – 05 (p)		
	Qty. Fines	Qty. Lumps	Qty. Total	Qty. Fines	Qty. Lumps	Qty. Total	Qty. Fines	Qty. Lumps	Qty. Total
Total	35.72 (74.39)	12.30 (25.61)	48.02 (100)	49.12 (78.50)	13.45 (21.50)	62.57 (100)	64.60 (82.67)	13.54 (17.33)	78.14 (100)

Note : *Figures in parenthesis indicate the percentage to the total exports.*

Source : *GMOEA, KIOCL, NMDC, MMTC ROS / PRIVATE MINE OWNERS Pellets included in lumps and concentrates in fines Information compiled on the basis of data as available / collected from above sources. E & OE. Data for Financial Year 2004 – 05 is on provisional basis.*

Table 4: India's Iron Ore Exports: Grade-Wise, Qty: Million Tonnes

Year	+64% Fe	62 – 64% Fe	62% Fe & below	Total
2002 – 03	24.11 (50.21)	5.44 (11.33)	18.47 (38.46)	48.02 (100)
2003 – 04	21.87 (34.95)	15.61 (24.95)	25.09 (40.10)	62.57 (100)
2004 – 05 (p)	20.15 (25.79)	34.22 (43.79)	23.77 (30.42)	78.14 (100)

Note : *Figures in parenthesis are the percentages to the total exports. Pellets included in lumps and concentrates in fines*

Sources : *GMOEA, KIOCL, NMDC, MMTC ROS / PRIVATE MINE OWNERS Information compiled on the basis of data as available / collected from above sources. E & OE. Data for financial year 2004 – 05 is on provisional basis.*

Fe and below another 30%. In other words, exports of lower than 64% Fe grade were more than 74% of the total exports currently. There is a need to use up all the fines, both low and medium grades and beneficiate them since there is a market for them in the world.

Since alumina exists in iron ores as fine clay and adherent material interspersed in ore body and in some cases both silica and alumina interlocked with iron ore particles, their removal by conventional physical separation methods is difficult. It has also been 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. Indian iron ores are being beneficiated by washing, scrubbing, hydrocycloning, gravity separation and magnetic separation. These physical separation methods were found to be inadequate to process fine

sized ores. Under such circumstances, froth flotation is highly useful. Beneficiation of pre-concentrated iron ores using collectors such as oleates, sulfonates, sulfates, amines and hydroxamates is a well-established process.

Depending on the nature of iron ore, either iron minerals or gangue minerals can be floated using suitable collectors. If the ore is of very low grade (i.e., Al_2O_3 & SiO_2 content is very high) iron minerals are floated directly using oleic acid or other collectors (Direct flotation). On the other hand, (if the gangue Al_2O_3 & SiO_2 content is relatively low) gangue minerals are made to float using fatty amines as collectors (Reverse flotation). Choice of direct or reverse flotation is mainly dictated by the overall economics of the process. In this particular case, since gangue content is comparatively less, reverse flotation using cationic collector was adopted.

Generally, fatty amines with hydrocarbon chain length 12-18 carbon atoms are used as collectors for the flotation of silica and alumina. In order to enhance the solubility of amines, they are usually converted to their chloride salts and/or acetates. Fatty amines with better solubility and surface activity are ideally suitable.

It is well known that amines are positively charged molecules up to pH 10.0

$$R\text{-}NH_2 + H^+ \rightleftarrows R\text{-}NH_3^+ \tag{1}$$

Positively charged molecules are easily attracted towards negatively charged particles by electrostatic interaction. Thus negatively charged particles are made hydrophobic by adsorbing collector molecules. Since the iso electric point of SiO_2 is around 2.5, silica particles are negatively charged above pH 2.5.

$$SiOH_2^+ \xrightarrow{-H^+} SiOH \xrightarrow{-H^+} SiO^- \tag{2}$$

Though pH 3.0 to 10.0 is an ideal range for adsorption of amine molecules on silica particles, alumina and iron minerals are positively charged up to pH 7.5 – 8.0. In order to achieve better selectivity, the particles should be thoroughly dispersed. This could be achieved by adjusting the pH to above 8.0 where iron minerals, silica and alumina are negatively charged. At this stage, surface of the iron particles is masked to avoid amine adsorption by conditioning with starch. Thus iron minerals could be depressed and, silica and alumina could be selectively floated using cationic collectors.

Among various flotation techniques, column flotation was proved to be promising to obtain high-grade concentrates with good recoveries. Column flotation has been developed utilizing the principle of counter-current contact between downward flowing slurry with rising air bubbles. From the hydrodynamic considerations, the collision probability of fine particles can be improved by introducing fine bubbles in a turbulent free zone. The merits of column flotation include improved metallurgical performance in terms of grade and recovery, effective cleaning action with a blanket of fresh water, less floor space due to vertical configuration, less capital, operational and maintenance costs due to absence of moving parts and easily amenable for automation. In many cases it was proved that the high quality concentrate that was produced in three-stage operation by conventional flotation was achieved in a single-stage operation by using flotation column.

NML Madras Centre has been engaged in the activity of beneficiating low, medium and high grade iron ore fines of Goa and Bellary-Hospet regions by conventional flotation as well as by flotation column in order to produce concentrates of marketable quality and for pellets making. In this paper three samples of varying alumina and silica content supplied by three leading mining companies in the above-mentioned region were investigated for their amenability to flotation using variety of cationic collectors commercially produced by different manufacturers.

EXPERIMENTAL PROCEDURE

Laboratory scale Flotation tests: Conventional flotation tests were conducted in Denver Sala D12 laboratory flotation cell to test the selectivity of different collectors and to optimize their dosage.

Laboratory scale Flotation Column: The automated flotation column with an internal diameter of 74 mm, designed and developed by NML Madras Centre was used in the present study. The column shells are made up of flanged sections consisting of air injection zone, collection zone, feed point, cleaning zone/froth zone. Electronically controlled metering pumps were used to feed and discharge the slurry. The pumps were designed to deliver an accurately measured volume of slurry with an error of +/- 2%. Slurry/froth interface was maintained using Differential Pressure Transmitter (DPT). The output signal of the DP cell was looped with the stroke controller of the tailing pump so that the pumping rate could be automatically varied to maintain the interface level at a fixed froth depth. Under steady state conditions, the interface level could be maintained at a constant height to within +/- 1cm. Purge rotameter with a differential pressure regulator were used to control the flow of air and water.

The air from the compressor was let into the column at a desired flow rate. The column was filled with water and stabilized at required froth depth. After stabilization with water, the conditioned iron ore slurry was pumped into the column at desired flow rate. Iron ore slurry at 20% solids was conditioned with sodium hydroxide in a conditioner with a conditioning time of 180 seconds. In the second stage, starch was added and conditioned for further 180 seconds. This slurry was further conditioned with amine collector. Minimum residence time of 180 seconds was maintained. The column was allowed to run for a minimum period 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.

The following formula was adopted to calculate the recoveries:

By assays f, c and t,

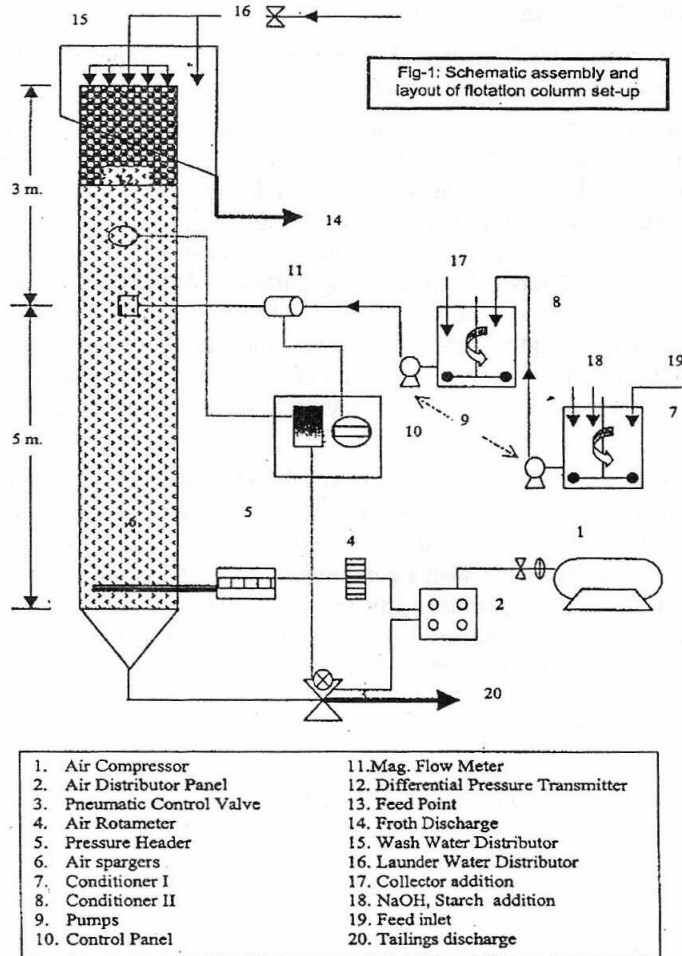$$\% R = c(f-t) / f(c-t) \times 100$$

Where

R is recovery
'f' is the assay of Fe in feed (%),
'c' is the assay of Fe in concentrate (%) and
't' is the assay of Fe in tails (%) .

Pilot scale Flotation Column: 0.5m diameter flotation column designed and developed by NML Madras Centre was shifted to the plant site and it was 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 were shown in Figure 1. The flotation column is an assembly of flanged sections consisting of air injection zone, collection zone, feed point and cleaning zone/froth zone. Slurry / froth interface was maintained using Differential Pressure Transmitter (DPT) mounted to column shell. The output signal of the DP cell was looped to an electro-pneumatic tailing valve through a controller. Based on the signal (4-20 mA) generated by DP cell, the concentrate discharge valve will be automatically actuated and accordingly the slurry discharge is maintained. The froth depth could be altered between 50-150 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 purge rotameter while slurry flow rate was measured using magnetic flow meters.

Fig-1: Schematic assembly and layout of flotation column set-up

1. Air Compressor	11. Mag. Flow Meter
2. Air Distributor Panel	12. Differential Pressure Transmitter
3. Pneumatic Control Valve	13. Feed Point
4. Air Rotameter	14. Froth Discharge
5. Pressure Header	15. Wash Water Distributor
6. Air spargers	16. Launder Water Distributor
7. Conditioner I	17. Collector addition
8. Conditioner II	18. NaOH, Starch addition
9. Pumps	19. Feed inlet
10. Control Panel	20. Tailings discharge

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 required froth depth at a constant wash water addition. After stabilization with water, the conditioned iron ore slurry was pumped into the column at 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 further pumped to the second conditioner where it was conditioned with 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 flow meter and feed distributor 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.

RESULTS AND DISCUSSIONS

Reduction of silica and alumina from HGMS pre-concentrate (M/s. Sociedade De Fomento Industrial Ltd., Goa): Microscopic studies of all the iron ore samples revealed the presence of hematite, goethite, martite, magnetite while quartz and clay constituted the silicates. In many samples, presence of limonite was also noticed. Hematite / martite and magnetite was 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*. Sieve and chemical analyses of feed to column and its concentrate were conducted and the results (Tables 5 & 6) indicate that gangue particles are interlocked with iron minerals above 150 μm fraction. Though this fraction is very less, contribution of gangue is very high in this fraction. Most of the free gangue is in finer fraction i.e., below 45 μm. Preliminary tests were conducted in Denver Sala D12 laboratory flotation cell to test the selectivity of Chem-540F and Chem-550F cationic collectors supplied by Ideal Speciality Chemicals, Mumbai, India. Though both the reagents are suitable, Chem-550F was found to be more selective towards Al_2O_3 whereas Chem-540F for SiO_2 elimination. It was also observed that reagent consumption of 0.2 kg/t is required to reduce Al_2O_3 and SiO_2 content to the extent of below 2%. By increasing the collector dosage further, reduction in gangue was achieved at the cost of recoveries. Similarly other process parameters such as pH of the slurry and starch dosage were studied and optimized. Thus, after establishing the process parameters of reverse flotation of iron ore fines in the conventional laboratory flotation cell, a series of tests were conducted in the 74 mm diameter laboratory size flotation column to optimize the column parameters. The overall optimum conditions obtained for target grade of 66 to 67% Fe is given in Table 7.

At optimum conditions, continuous tests were conducted using 0.5m-diameter pilot scale flotation column and the results are presented in Table 8. In a related study to compare the performance of Conventional Flotation, Column Flotation and Dual Extraction Column at pilot plant scale, it was established that quality of the concentrate obtained in case of flotation column was found to be better in terms of lower silica and alumina (Vijaya Kumar et al., 2005). This could be attributed to relatively higher froth bed and wash water addition at a positive bias that result in qualitative change in the froth of the flotation column. The wash water addition improves the froth rheology and product discharge. It also replaces the draining inter-film liquid, thus promoting froth stability. Furthermore, secondary cleaning resulting from the displacement of less hydrophobic particles (iron ore) by more hydrophobic particles (alumina and silica), is typical for the upper portion of the froth with high gas hold up and insufficient bubble surface area.

Table 5: Sieve and Chemical Analysis of Feed to Column (HGMS Conc.)

Sl. No.	Sieve fraction (μm)	Wt. (g)	%Wt.	Assay %		
				Fe	Al_2O_3	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 6: Sieve and Chemical Analysis of Column Concentrate

Sl. No.	Sieve fraction (μm)	Wt. (g)	%Wt.	Assay %		
				Fe	Al_2O_3	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

Table 7: Optimized Column Flotation Parameters

Parameter	Value
(a) Process parameters	
Chem 540 (Collector)	0.2 kg/t
Slurry pH	8.5 – 9.0
Starch	0.5 kg/t
NaOH	0.07 kg/t
(b) Operating parameters	
Superficial velocity of air	1.02 cm/s
Superficial velocity of wash water	0.06 cm/s
Superficial velocity of slurry feed	1.1 cm/s
Froth depth	75 – 100 cm
Percent solids	20
Pulp density of feed	1.19

Table 8: Results of Continuous Test Runs on Flotation Column

Sample Code	Feed Assay (%)			Conc. Assay (%)			Tails	Fe
	Fe	Al_2O_3	SiO_2	Fe	Al_2O_3	SiO_2	Fe (%)	%Rec.
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
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

Laboratory scale Column Flotation studies on highly siliceous iron ore from M/s. Chowgule and Company Limited, Goa: The mineralogy of the three samples received was found to be more or less similar to the one in the previous investigation. Fraction-wise sieve and chemical analysis of the samples are presented in Tables 9 - 11. From the data it could be inferred that the gangue (SiO_2 and Al_2O_3) are present in the finer fractions. It may also be noted that sample 1 is more siliceous compared to the other two samples. Three different cationic collectors viz., Liquid B-50, Flotamine and Chem 510 from three different manufacturers were tried. Preliminary experiments were conducted to optimize the dosage and know the selectivity of the collectors on a D12 Denver Sala laboratory conventional flotation cell. The results indicated that all the three collectors tested were found to be selective for the separation of silica and alumina from iron in these samples. The flotation response of sample 3 was poor. The collector consumption was relatively higher (0.3 kg/t) in the case of sample 1 which is more siliceous as compared to that in case of sample 2 (0.15 to 0.2 kg/t). Iron ore concentrates assaying 63.5% Fe with recoveries of around 90% could be obtained by flotation. Typical results obtained on a laboratory flotation column on samples 1&2 are presented in Tables 12 - 14. The recoveries were found to be slightly higher by column flotation. Further grinding could help in achieving higher-grade concentrates with silica less than 2%.

Table 9: Fraction Wise Sieve and Chemical Analysis of Sample 1

Size(μm)	%Wt	%Fe	%FeO	%Al$_2$O$_3$	%SiO$_2$	%LOI
+150	7.40	59.90	1.54	1.16	9.40	3.02
+75	21.20	60.50	1.15	1.13	8.46	3.00
+45	17.60	48.00	0.90	1.11	26.40	2.84
-45	53.80	39.80	0.26	1.80	37.42	2.80
Total	100.00	47.20	0.77	1.48	26.98	2.89

Table 10: Fraction Wise Sieve and Chemical Analysis of Sample 2

Size(μm)	%Wt	%Fe	%FeO	%Al$_2$O$_3$	%SiO$_2$	%LOI
+150	5.40	60.20	1.02	1.27	8.76	3.05
+75	20.30	60.90	1.28	0.95	8.60	2.60
+45	15.20	52.50	0.77	1.05	20.20	2.80
-45	59.10	44.20	0.26	1.53	31.70	2.55
Total	100.00	49.80	0.64	1.38	23.72	2.55

Table 11: Fraction Wise Sieve and Chemical Analysis of Sample 3

Size(μm)	%Wt	%Fe	%FeO	%Al$_2$O$_3$	%SiO$_2$	%LOI
+150	10.80	50.60	1.54	1.76	18.46	5.64
+75	16.90	51.80	1.54	2.27	18.22	4.63
+45	11.50	49.80	1.79	2.00	20.20	4.90
-45	60.80	41.90	0.51	4.05	28.14	6.03
Total	100.00	45.40	0.77	3.08	24.41	5.70

Test conditions

Slurry residence time	:	12 minutes
Superficial air velocity	:	1.09 cm/s
Slurry pH	:	9.0
Froth Depth	:	75 cm
Wash water	:	no addition
Sample 1 feed grade	:	47.20% Fe, 1.48% Al$_2$O$_3$, 26.98% SiO$_2$, 2.89% LOI
Sample 2 feed grade	:	49.80% Fe, 1.38% Al$_2$O$_3$, 23.72% SiO$_2$, 2.55% LOI

Table 12: Column Flotation Test Results on Sample1&2 with LIQUID B-50

Sample	Reagent dosage (kg/ton)	Assay %					% Fe recovery
		Non-float (Concentrate)				Float	
		Fe	SiO$_2$	Al$_2$O$_3$	LOI	Fe	
1	0.05	55.00	15.80	1.19	3.25	5.80	98.05
1	0.30	63.50	3.47	-	-	16.23	88.14
2	0.05	61.80	6.91	0.67	3.25	11.80	94.31
2	0.15	64.20	3.50	-	-	16.00	90.40

Test conditions

Slurry residence time	:	12 minutes
Superficial air velocity	:	1.09 cm/s
Slurry pH	:	9.0
Froth Depth	:	75 cm
Wash water	:	no addition
Sample 1 feed grade	:	47.20% Fe, 1.48% Al2O3, 26.98% SiO2, 2.89% LOI
Sample 2 feed grade	:	49.80% Fe, 1.38% Al2O3, 23.72% SiO2, 2.55% LOI

Table 13: Column Flotation Test Results on Sample1&2 with FLOTAMINE

Sample	Reagent dosage (kg/ton)	Assay %					% Fe recovery
		Non-float (Concentrate)				Float	
		Fe	SiO₂	Al₂O₃	LOI	Fe	
1	0.10	58.40	10.67	0.69	3.55	7.60	96.45
1	0.20	61.00	5.76	-	-	8.11	95.51
2	0.10	61.40	6.55	0.67	3.26	9.20	95.89
2	0.15	62.28	6.79	-	-	11.75	94.17

Test conditions

Slurry residence time   :   12 minutes
Superficial air velocity   :   1.09 cm/s
Slurry pH   :   9.0
Froth Depth   :   75 cm
Wash water   :   no addition
Sample 1 feed grade   :   47.20% Fe, 1.48% Al2O3, 26.98% SiO2, 2.89% LOI
Sample 2 feed grade   :   49.80% Fe, 1.38% Al2O3, 23.72% SiO2, 2.55% LOI

Table 14: Column Flotation Test Results on Sample1&2 with CHEM 510

Sample	Reagent dosage (kg/ton)	Assay %					% Fe recovery
		Non-float (Concentrate)				Float	
		Fe	SiO₂	Al₂O₃	LOI	Fe	
1	0.15	58.80	10.90	0.67	3.65	10.60	94.60
1	0.30	65.11	4.37	-	-	10.34	92.84
2	0.10	61.80	7.11	0.69	3.39	11.20	94.66
2	0.20	64.68	4.38	-	-	12.85	92.59
2*	0.20	62.90	6.94	-	-	6.44	97.00

* wash water addition at the rate of 30lph.

Table 15: Size-Wise Chemical Analysis of Sample I

Size in microns	Wt %	% Fe	%Al₂O₃	%SiO₂	%LOI
+150	0.85	59.98	3.37	7.17	3.37
+75	10.29	63.14	2.55	3.99	2.86
+45	23.46	63.33	2.37	4.53	2.04
+25	12.47	64.82	1.94	3.24	1.73
-25	52.93	54.91	6.41	9.81	4.12
Head	100.00	59.01	4.48	7.13	3.19

Table 16: Size-Wise Chemical Analysis of Sample II

Size in microns	Wt %	%Fe	%Al₂O₃	%SiO₂	%LOI
+150	17.07	62.96	2.52	5.15	1.79
+75	40.6	65.93	1.85	2.18	1.19
+45	7.47	66.02	1.80	2.07	1.22
+25	9.2	62.85	2.62	4.20	2.80
-25	25.66	58.63	4.83	7.82	3.01
Head	100.00	63.27	4.31	2.80	1.91

Laboratory scale flotation tests on iron ore fines from M/s. JSW Steel Limited, Toranagallu,

Karnataka: The mineralogy of the three samples received indicated the presence of hematite in major proportion with goethite and magnetite in minor proportions and limonite in traces. Alumina and silica formed the gangue. The objective of the studies has been to reduce alumina content to below 2%. The size-wise chemical analysis of these samples was shown in Tables 15 - 17. It implies the presence of relatively higher amounts of fines

Table 17: Size-Wise Chemical Analysis of Sample III

Size in microns	Wt %	%Fe	%Al$_2$O$_3$	%SiO$_2$	%LOI
+150	15.08	65.54	1.64	2.12	2.12
+75	22.26	65.94	1.60	1.86	1.84
+45	13.88	66.02	1.58	1.71	1.90
+25	9.42	65.97	1.59	1.65	2.02
-25	39.36	60.93	2.89	4.52	5.06
Head	100.00	63.92	2.91	2.11	3.17

Table 18: Desliming of Sample – III on 2" Hydroyclone Followed by Flotation on Cyclone Underflow Using Reagent - B

Product		% Wt.	Assay			% Distribution		
			%Fe	% SiO$_2$	%Al$_2$O$_3$	Fe	SiO$_2$	Al$_2$O$_3$
Cyclone O/F		40.8	62.17	3.78	2.38	39.3	71.0	51.9
Cyclone U/F	Tailings	3.6	52.33	4.07	2.52	2.9	6.9	8.0
	Conc.	55.6	67.25	0.87	1.35	57.8	22.1	40.1
Head (Calc.)		100.0	64.64	2.17	1.87	100.0	100.0	100.0
Head (Assay)			63.92	2.91	2.11			

(52.93%, 25.66% and 39.36% by weight of –25µm size fraction in samples I, II and III respectively) coupled with relatively lower %Fe, higher %SiO$_2$, higher %Al$_2$O$_3$ and higher %LOI in this size fraction as compared with the corresponding values in other size fractions. Flotation tests on sample I using reagent-A at 0.33 kg/t showed that it could be upgraded to 64.78% Fe, 2.84% SiO$_2$ and 1.91% Al$_2$O$_3$ from a feed value of 62.94% Fe, 4.64% SiO$_2$ and 2.47% Al$_2$O$_3$ with 43.4% Fe recovery. Under the identical experimental conditions, reagent-B proved to be better with a concentrate of 64.33% Fe, 3.27% SiO$_2$ and 1.91% Al$_2$O$_3$ with 67.5% Fe recovery into the concentrate. Flotation tests on sample II with the same set of reagents indicated that reagent-A at 0.08 kg/t can upgrade the iron ore fines of 63.61% Fe, 4.24% SiO$_2$ and 2.73% Al$_2$O$_3$ to a concentrate of 65.69% Fe, 2.64%

SiO$_2$ and 1.86% Al$_2$O$_3$ with 64.8% Fe recovery. Reagent-B at 0.164 kg/t could reduce the % Al$_2$O$_3$ from 3.14 to 1.97 with %Fe recovery into the concentrate being 82.7. Sample-III responded better as compared to the other two samples with % Al$_2$O$_3$ varying from 1.55 to 1.84 in the concentrate as against the feed value of 2.10% Al$_2$O$_3$ with %Fe recovery in the concentrate being in the range of 64.2 to 88.7. Desliming of the same sample in a hydrocyclone followed by flotation of cyclone underflow using reagent-B yielded a concentrate of 67.25%Fe, 0.87% SiO$_2$ and 1.35% Al$_2$O$_3$ with %Fe recovery of 57.8 (Table 18). In most of the cases, it was noticed that as the reagent dosage was increased, the recoveries decreased with marginal increase in grade, probably due to poor selectivity at such fine size of the feed material. However, there is scope for further improvement when these samples are subjected for flotation column test work, the studies of which are to be undertaken.

The above case studies bring out the importance and role of flotation in general and flotation column in particular in processing of low to medium grade iron ore fines to make them marketable value-added products of required specifications.

CONCLUSIONS

Iron ore fines of Goa and Bellary-Hospet regions of varying alumina and silica content can be processed by flotation to produce marketable concentrates of required specifications. Selection of suitable collector plays a critical role, which needs to be determined by experimentation. Highly siliceous ores of 47.20% Fe, 26.98% SiO_2 and 1.48% Al_2O_3 could be upgraded to 63.20% Fe, 3.77% SiO_2 and 0.59% Al_2O_3 at %Fe recovery of 91.72. Similarly high alumina iron ore fines of around 2.5% Al_2O_3 respond well for its reduction to the levels of 1.5% with respectable recoveries. Column flotation was found to be more apt to process these iron ore fines.

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REFERENCES

[1] Sharma, R. K., 2005, JPC Bulletin on Iron and Steel, Vol. V,(11), 7 – 18.
[2] Vijaya Kumar, T. V., Rao, D. S., Subba Rao, S., More, P., Reddy, Y. S., Prabhakar, S., and Bhaskar Raju, G., 2005, Powder handling and Processing, 17(2), 88 – 93.
[3] Vijaya Kumar, T. V., Rao, D. S., Subba Rao, S., Prabhakar, S., More, P., and Bhaskar Raju, G., 2005, Journal of Minerals and Materials Characterization & Engineering, 4(2), 113 – 124.