BENEFICIATION OF LOW-GRADE IRON ORES

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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. Beneficiation of iron ores in general and column flotation in particular are highlighted in this paper. 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 Kudremukh regions of India have been discussed. The results clearly indicate the feasibility and significance of flotation process in treating the fines to obtain marketable concentrates.

INTRODUCTION

Minerals and metals have been so intimately associated with human civilization. Hence some periods are christened after important metals that gained prominence during the evolution of civilization. Minerals are non-renewable resource and hence call for judicious and rational methods for their exploitation. The mineral endowments of a country are exploited to accelerate the industrial growth and to improve the quality of life. Minerals in both raw and processed forms contribute significantly to India's export trade. Iron is the most indispensable metal and the growth of modern industry is largely dependent on its availability and sustained supply. It plays a dominant role in building the country's economy. The per capita consumption of steel in India is mere 26.2 kg per year as compared to 60 kg in China, 410 kg in USA and 801 kg in Japan.

India is bestowed with rich mineral resources and occupies 6th position in the world. A rapid increase in consumption rate of metals especially iron over the last few decades and consequent depletion of mineral resources have necessitated the effective utilization' of low-grade finely disseminated ores that are abundantly available. The utilization of such reserves may help to. Maintain an adequate supply of minerals to meet economic and strategic needs of our country. Since the yield of low-grade ores is low, escalation in input cost is inevitable. In order to process such reserves in an economically viable fashion, efficient technologies are essential. To cope with the situation, new equipment is constantly being developed all over the world. National Metallurgical Laboratory has developed column flotation technology to process fine particles. It has been extensively field tested for the beneficiation of complex Cu-Pb-Zn sulfide ores of Ambaji multimetal deposit, fluorspar, limestone, sillimanite, gold ores of Kolar Gold Fields and iron ores of Goa and Karnataka. In the present paper, various techniques adopted for the beneficiation of iron ores and utilization of natural fines by flotation column are discussed.

Indian Iron ore resources:

Indian iron ores generally contain hematite, magnetite, limonite and siderite minerals. In the total iron ore reserves of about 17.712 billion tonnes, hematite is about 12.3 billion tonnes and magnetite is 5.4 billion tonnes. From the estimated resources of 12745 million tonnes in 1990, the same has now increased to 17712 million tonnes and it is likely to increase with further exploration. State wise iron ore resources, production details and exports are presented in Tables 1 -3. Hematite represents 75 % of the total iron ore resources in which 12% of hematite deposits are high grade (Fe: +65%), 44% are medium grade (Fe: 6365%), 28.% are low-grade (Fe: less than 62%). Blue dust is over 1% of the total ore. Iron ore reserves of Tamilnadu and Kerla are mostly magnetitic in nature. Lowgrade magnetites are distributed in Salem, North Arcot, Dharmapuri, Coimbatore and Nilgiris districts of Tamilnadu. Similar ore bodies are reported from the districts of Kozhikode, Kottayam, Malappuram and Pidghat of Kerala.

The Tidco has re-launched the iron ore mining and beneficiation project at Kanjamalai (2 million tonnes per annum) in Salem district and Kavuthimalai (1 million tonnes per annum) of Thiruvannamalai district. M/s. Jindal Vijayanagar Steel Limited was selected as promoters and developers to implement the project with 1 % -equity participation by Tidco. The joint venture company was formed by name Tamilnadu iron Ore Mining Corporation Limited to implement the project In Salem, iron

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Table. 1 : Indian Iron ore resources (In million tonnes)

Province	Proven	Probable	Possible	Total
Hematite				
Orissa	1824.1	762.9	1590.2	4177.2
Jharkhand	2560.2	334.8	386.0	3281.0
Chattisgarh	993.1	537.5	747.5	2278.1
Karnataka	765.7	208.7	311.1	1315.5
Goa	461.0	149.3	119.4	729.7
Redi	106.9	76.9	89.2	273.0
Total	6741.0	2070.1	3243.4	12054.5
Magnetite				
Karnataka	1653.4	503.8	1686.6	3943.8
Andhra Pradesh	43.0	1266.6	-	1309.6
Goa	67.3	5.42	115.2	187.92
Tamilnadu	107.39	62.0	332.31	501.7
Kerala	-	63.64	24.65	88.29
Total	1763.7	1774.82	1808.8	5341.32

Source : Indian Bureau of Mines

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 parenthisis are percent to total

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 : Sharma (2005)

ore is present as banded iron ore formations with Fe content of 30-40%. Beneficiation and pelletization plant with a capacity of 1.0 million tonnes per year is being planned at Salem. Detailed techno – economic feasibility report for development of iron ore deposits at Kanjamalai was prepared by M.N Dastur & Co Pvt. Ltd. Nearly 500 crores is being planned to invest and Tidco is taking steps to obtain various clearances required from MoEF. Kerala State Mineral Development Corporation and state Geology department are planning to tap minor iron ore deposits of Kerala, which translates into the least minimum risk to environment. These low- grade ores have gained importance mainly due to sharp increase in price and demand out placing supply. In 2000-01 the iron ore prices were at $17/t and presently it is being sold at $ 68/t, which is nearly 4-fdd increase. The production costs are hardly Rs 100/t.

Table 4 : Specifications of iron ores for blast furnace & sponge iron

Iron or type	Chemical Constituent	Assay (%)
Lumps	Fe	62-65
	Al_2O_3	2.0 Max
	SiO_2	2.5 Max
Sinter fines	Fe	63.5
	Al_2O_3	2.0 Max
	SiO_2	2.5 Max
Pellet fines	Fe	67 - 68
	Al_2O_3	1.0 Max
	SiO_2	2.0 Max
	P	<0.05
Sponge iron	Fe	65.0
	$AL_2O_3 + SiO_2$	5.0
	Abrasion Index	5.0 Max
	Thermal degradation Index	5.0 Max

India has emerged, as the largest producer of sponge iron in the world in 2001. The growth of sponge iron especially during the last five years in terms of capacity and production has been substantial. The installed capacity of sponge iron increased from 1.52 million tonnes per annum in 1990-91 -to around 7.0 million tonnes per annum 2001-02. There are 53 sponge iron plants installed in the country having a capacity of 7.0 million tonnes per annum.

Challenges of Indian Iron ores

The problems of Indian iron ores are a) highly friable in nature, b) high alumina and silica, c) poor liberation of alumina even at finer size, d) alumina to silica ratio, e) low utilization of low-grade ores and dumps and f) difficulties in dewatering of slimes for water re-circulation. The quality of iron ore plays an important role in the production of iron and steel and the cost of steel in the market. Indian iron ores suffers two basic problems viz the softness of the ore and high amount of silica and alumina. Large quantity of fines and slimes are generated during mining and milling operations due to softness of the ore. Some times it will be as high as 45%. Appreciable quantity of fine-grained silicates are inter grown with iron ores. The alumina to silica ratio that is typically greater than one in certain ores, pose serious operational problems during sintering and subsequent smelting in blast furnace. High alumina leads to viscous slag during smelting that in turn requires a high coke rate. Thus the high amount of silica and alumina adversely affect the productivity and operation of blast furnace. Micro porosity of porous iron ores reduce the dewatering effect and also increase the loss of heavy media. The extent of oxidation of magnetite to martite/hematite will have an effect on magnetic separation. The aluminous (gibbsite, boehmite) and alumino silicates (kaolinite and illite) gangue frequently occurs in fine cavities and fractures in the iron ore. Contaminants such as phosphorous, silica and alumina occur in the lattice, network and adsorbed state in goethites. These complex textural intergrowths cause serious problems in separation process. It was also demonstrated that it is difficult to depress speculartite particles during reverse flotation.

Beneficiation:

Washing :

The alumina content in the iron ore used in sinter making in all over the world is around 1 %. However in indian iron ore fines it is as high as 4-6%. During rainy season, operational difficulties are encountered in crushing and sizing due to sticking of wet fines. Alumina exists as fine clay and adherent material. Hence washing is essential to remove the adherent clay. While the clay can be washed, the lateritic material may pose greater problems as it may be interspersed in the ore body. However it can be used only as a pre-concentration technique.

Gravity concentration:

In iron ore beneficiation, equipments such as jigs, spirals and cyclones are widely used. Jigging is a gravity separation and cost effective technique where bulk materials are separated in to light fraction, medium density fraction or heavy density fraction. The Barsua iron ore mines in India have adopted Remco Jigs to up-grade their iron ore fines. Other jig manufacturers are Bateman, BAT AG, Denver and Harz. RRL Bhubaneswar conducted systematic study on the beneficiation of iron ores using jigging. It was established that iron ore concentrates assaying 66% Fe with the recoveries of above 90% can be achieved from the iron ores containing initial Fe content of 63% with a feed size of -5mm+ 1 mm. However the yield of iron concentrates was drastically reduced to 60% when the feed size was decreased to -1 mm+0.21 mm (Table 5).

Table. 5 Typical Results of Jigging

Sl. No.	Particle size, mm	Products	Fe%	Feed Fe, %
1.	-5+1 mm	Concentrate Tailings	65.90 51.52	64.5 -
2.	-5+1 mm	Concentrate Tailings	66.32 47.33	65.0 -
3.	-5+1 mm	Concentrate Tailings	66.46 51.94	64.8 -
4.	-1+0.21 mm	Concentrate Tailings	66.18 55.01	60.67 -
5.	-1+0.21 mm	Concentrate Tailings	66.22 53.22	60.72 -
6.	-1+0.21 mm	Concentrate Tailings	66.00 54.28	60.32 60.32

(Ref: B. Das et al RRL Bhubaneswar, Personal Communication)

Spiral is an energy saving gravity equipment where large quantity of sample can be fed for pre-concentration. It is possible to achieve required grade by subj6cting to cleaning and re-cleaning by spirals. However the recoveries will be affected.

Magnetic Separation:

Magnetic separation techniques exploit the difference in magnetic properties between the ore and gangue minerals. Depending on the nature of the ore body, variety of magnetic separators like Low Intensity Magnetic Separators (LIMS) Medium Intensity Magnetic Separators (MIMS) and High Gradient Magnetic Separators (HGMS) can be utilized to separate iron values from gangue minerals. In order to separate paramagnetic minerals of extremely low magnetic susceptibility, HGMS and Ferrous Wheel are extensively used. The advantages of HGMS are High separation efficiency, Low maintenance, low specific power consumption and large process capability. However problems like matrix clogging and mechanical entrainment of non-magnetic particles in the matrix are frequently encountered. To solve these problems, Pulsating High Gradient Magnetic Separators (PHGMS) are developed. Jones High Intensity Magnetic Separators are al~o extensively used to process very fine and strongly inter grown ores.

Column Flotation:

The concept of counter current contact between the downward flowing slurry with rising air bubbles forms the essential basis of column flotation. Conditioned mineral slurry is fed through a side inlet, which is located at a height of 2/3 from the bottom. The mineral particles encounter rising air bubbles while settling down by gravity. Fine air bubbles are generated through the sparger unit located at the bottom of flotation column. The continuous head-on collision between air bubbles and mineral particles ensures the flotation of hydrophobic minerals. When the mineralized bubbles reach the upper portion of the flotation column i.e cleaning zone where the continuous phase is froth,

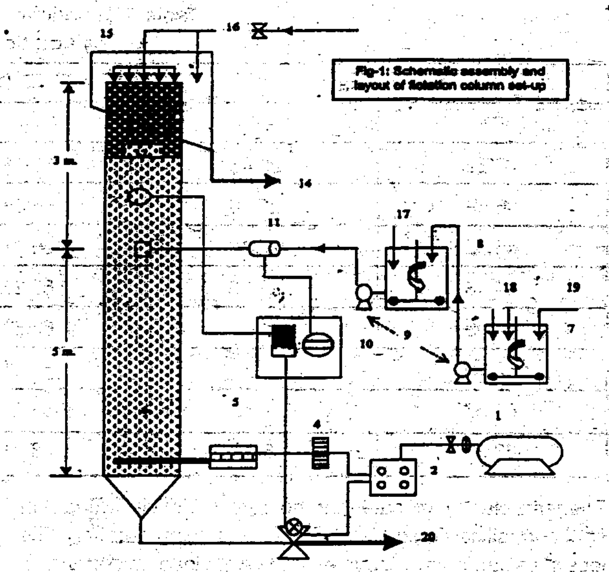

Fig-1: Schematic assembly and layout of flotation column set-up

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

they encounter a blanket of cleaning water, so that no process water enter the froth product. The over flow of the cleaned froth product is discharged through a launder system. The cross sectional area of flotation column mainly determines the throughput of the circuit, while the length of recovery and cleaning zones determines the recovery and grade of froth product respectively. Since there is no mechanical mixing, a quiescent condition always prevails in the flotation column that allows the flotation of even weakly hydrophobic minerals. The size of the bubbles is much finer in flotation column that results in higher gas hold-up than in mechanical flotation cells.

Case studies:

Kudremukh Iron ore:

The SiO_2 content of iron ore concentrates obtained from magnetic and gravity separation methods are rather high. The concentrates from primary magnetic separator analyses 63-

65% Fe and 5.5-6.4% of SiO2. After passing through the secondary magnetic separator the Fe content increases to 67-68%. However the silica reduction is only marginal. In order to reduce the silica to below 2%, concentrates obtained from secondary magnetic separator are further subjected to tertiary magnetic separation. The rejects of the magnetic circuit that is non-magnetic portion contain mostly hematite. The non-magnetic portion is upgraded to 63-65% Fe by spirals. The recovery of iron values by spirals (roughing, cleaning and re-cleaning) was observed to be hardly 35%. To increase both recovery and grade, column flotation tests were conducted. Reverse flotation that is flotation of silica using cationic collector were conducted and results are shown in Table.6.

Table.6 Beneficiation of iron ore fines by flotation column

Feed assay		Concentrate assay		Fe Recovery
Fe	SiO2	Fe	SiO2	
46.32	28.46	65.87	2.84	87.90
46.52	27.80	66.08	2.38	80.92
46.32	28.46	66.11	2.40	75.34
51.48	22.26	65.23	2.97	97.28
52.09	-	65.69	2.07	96.33
52.09	-	65.61	1.90	95.45
61.57	7.52	68.16	1.65	96.72
63.31	6.85	68.31	2.05	92.14

The tests clearly indicate that the iron ore concentrates with minimum silica could be obtained by column flotation. The loss of valuable iron resources can be avoided and the circuit can simplify.

Iron ores of Goa:

M/s. Sociedade De Fomento Industrial Ltd is one of the leading exporters of iron ores of Goa. Iron ores of goan region contain clay as adherent material interspersed in ore body in addition to usual silica. The ore also contain some amount of limonite. The final concentrates obtained from high gradient magnetic separator are of inferior quality for pellet making. NML Madras Centre has conducted detailed column flotation studies to improve the quality of the iron ore concentrates. Iron ore concentrates of different mines of M/s.Fomento were fed to the flotation column and salient results of the tests are shown in Table.7.

Table.7 Beneficiation of iron ore fines by flotation column

Sample	Feed Assay %			Concentrate Assay %			Fe Recovery
	Fe	Al_2O_3	SiO_2	Fe	AL_2O_3	SiO_2	
1	65.5	1.24	1.79	66.9	0.87	1.50	90.2
2	64.8	1.51	2.82	66.7	1.15	0.62	85.8
3	64.9	1.38	3.36	66.4	1.49	1.29	97.9
4	65.7	0.93	2.73	67.6	0.77	0.91	81.8
5	65.0	1.44	3.03	66.7	1.22	1.39	88.0
6	63.92	2.11	2.91	67.3	1.35	0.87	-

From the above results it is evident that the iron ore concentrates suitable to direct reduction process can be produced by column flotation.

Low grade siliceous ores:

Low grade iron ore samples from Mls Chowgule and company limited, Goa were also studied by flotation column. The silica content was very high and is liberated in fine size. It was observed that these ores could be beneficiated by flotation column. The results are shown in Table 7.

Table. 8 Beneficiation of low-grade iron ore fines by flotation column

Sample	Feed Assay %			Concentrate Assay %			Fe Recovery
	Fe	Al_2O_3	SiO_2	Fe	AL_2O_3	SiO_2	
1	47.20	1.48	26.98	63.50	1.09	3.47	88.14
2	49.80	1.38	23.72	64.20	-	3.50	90.40
3	47.20	1.48	26.98	65.11	0.69	4.37	92.84
4	49.80	1.38	23.72	64.68	0.76	4.38	92.59

Limestone Beneficiation:

The limestone deposits of Tamilnadu occur either in the form of crystalline or amorphous. Most of the limestone deposits especially southern districts of the state are crystalline in nature and are found south of Moyar-Bhavani-Attur lineament. The total reserves of crystalline limestone are around 200 million tones of proved categories out of which 50 million tones account for Salem and Namakkal districts. Due to recent suspension of production at neighboring cement factories in that area, the limestone mining companies are trying alternate market for their limestone. Due to demand for high quality product that meet the specifications of paper and rubber industry, some mine owners has decided to beneficiate their limestone. NML Madras Centre has tried column flotation technology for the beneficiation of limestone. Accordingly semi-commercial flotation column was shifted to one of the limestone mines and systematic studies were conducted at mine site itself. Instead of calcite, gangue minerals were floated to enrich calcite (Reverse flotation). The results are presented in Table9.

Table. 9 Beneficiation of low-grade Limestone by flotation column

Feed Assay		Concentrate Assay		$CaCO_3$ recovery
$CaCO_3$	SiO_2	$CaCO_3$	SiO_2	
82.47	10.74	97.69	0.98	74.7
79.70	12.43	97.69	0.37	80.8
79.70	12.43	97.19	0.63	80.7
82.46	13.53	97.44	0.64	73.3
82.44	9.06	96.44	0.97	87.2
79.95	10.51	96.4	0.83	76.5

It is evident that the limestone concentrates assaying 96-97% CaCOa with less than 1% Si02couid be achieved by column flotation technology. NML is presently assisting one of the mine owners in setting up beneficiation plant at Salem.

Conclusion:

Beneficiation of different iron ores especially by column flotation technology was studied and the results were presented. The results clearly illustrate that lowgrade iron ores can be beneficiated to a marketable iron ore concentrates by column flotation technology. Column flotation technology is especially useful to produce high-grade iron ore concentrates suitable for pellet making. Low-grade limestone of Salem can be enriched to super grade limestone concentrate useful for high- end application.

CORRIGENDUM

Reference - MEJ - Feb. 2008 (Vol. 9, No. 7) Page 27 - Readers Write.

1st Line : Please read 31-12-2005 for 31-01-2005

13th Line : Please read 25-07-2001 for 25-07-2007

Inconvenience is regretted.