

COLUMN FLOTATION FOR THE BENEFICIATION OF IRON ORE FINES

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1. INTRODUCTION

"Iron ore is more integral to the global economy than any other commodity" perhaps except oil. Indian iron ore industry is one of the world's largest and growing at a rapid pace. Optimum utilization of iron ore resources have become a national priority. As per the recent national steel policy, our country will be producing about 110 million tons of steel per annum by 2020 requiring around 42 million tons of iron ore. The iron ore exports are projected to a level of 114 million tones and it amounts to total production of 300 million tons by 2020. In the present steel boom, many global steel producers have projects in states of Chattisgarh, Jharkhand, Karnataka and Orissa. Research on utilization of low grade iron ore to produce quality raw material would play a key role in future which is a fact acknowledged by the iron and steel industry. [1,2]

India is bestowed with rich iron ore reserves in the form of hematite and magnetite. Most of the iron ore mines produce hematite ores and have washing plants to produce lumps as well as fines. During the washing process, around 8-10 million tons of slimes containing around 48-60% of Fe are discarded every year. Further, hematite ores can contain significantly higher concentrations of penalty elements, such as water content and aluminum. The challenge facing the iron ore industry is to deal with the problem of processing alumina rich iron ore fines and slimes. Apart from these available fines, low and off grade ores such as banded hematite quartz (BHQ) and Banded Hematite Jasper (BHJ) are invariably ground finer sizes for liberation there by generates slimes which need suitable processing technology.

The depletion of high grade reserves coupled with increasing market pressure for improved product quality has forced iron ore producers to re-examine their process flow sheets and evaluate alternate or supplemental processing routes. The requirement for higher quality iron ore demands that the silica and alumina contents be lowered for effective use in the steel making. Reverse flotation (silica & alumina is floated away from the concentrate) has proven to be an economical and effective method for reducing silica & alumina content to acceptable levels. [3,4]

Iron ore is being beneficiated all around the world to meet the quality requirement of Iron and Steel industries. However, each source of iron ore has its own peculiar mineralogical characteristics and requires specific beneficiation and metallurgical treatment to get the best product out of it. The choice of the beneficiation treatment depends on the nature of the gangue present and its association with the ore structure. Beneficiation studies using various techniques such as washing, jigging, hydrocyclone, spiral, advanced gravity separations, magnetic separation, flotation etc. were carried out to develop a suitable process flowsheet as a step towards the upgradation of iron values and to reduce gangue content. The required separation technique was selected based on particle size and the properties for effective separation.

When the particles are finer in size (< 100 microns) gravity and magnetic separations are not effective. The best alternative is flotation, which is a physio-chemical operation and was proven to be the main unit operation in the mineral industry for treatment of fines for recovering values from gangue. The process of flotation is mainly affected by the small mass of the particle. Low momentum, slime coating and high reagent consumption are the most frequently discussed difficulties. As the size of the bubble plays a vital role in flotation process, extensive research was focused on controlling the bubble size. Conventional flotation cell has its own limitations in producing fine bubbles below 800 microns. Keeping in view of the above aspects, the technology of column flotation has been developed.

In recent years, flotation columns are being used for improving the grade-recovery performance of froth flotation due to their inherent selectivity would make it possible for reducing multistage conventional flotation circuits to only one or two stage column flotation. Many iron-ore producers worldwide are considering columns as a viable alternative to conventional flotation machine for the reduction of silica in fine pellet feed. The technology has been used with great success at many iron ore processing plants worldwide. NML over the years have done laboratory and pilot scale test work and has demonstrated some significant metallurgical and economic advantages at various iron ore beneficiation plants, which include M/s KIOCL, Kudremukh, M/s FOMENTO, Goa, M/s JSW Ltd., Tornagallu, Karnataka, M/s Tata Steel, Joda Mines, Orissa and M/s RBSSN Ltd., Hospet, Karnataka. Some of the salient results of the test works are discussed in the present paper highlighting the application of column flotation technology in beneficiation of iron ore fines. [5]

2. COLUMN FLOTATION TECHNOLOGY AND APPLICATIONS

Column flotation offers mineral processors several opportunities to significantly improve process economics. Properly designed and operated columns can deliver high recoveries and concentrate grades, reduce reagent consumption, cut energy costs and lower capital expense. High recoveries are possible because of the column's ideal hydrodynamic environment and its ability to operate at relatively high volume fractions of air. Grade performance is enhanced because a deep froth layer can be maintained and rinsed with a water wash to remove gangue material. Because feed conditioning and flotation are carried out separately, flotation takes place in a quiescent environment that encourages bubble/particle attachment.

Improved metallurgical performance is assured by column flotation as a result of:

- Less entrainment and entrapment through froth washing
- Independent control of operating variables
- Flotation of coarse and slimes particles
- Can also be used as roughers and scavengers

Reduced running costs as a result of:

- No moving parts
- Lower reagent consumption
- Lower energy consumption (40 - 50% lower than an equivalent mechanical flotation circuit)
- Reduced downtime

Low maintenance and low inventory requirements.

Reduced capital costs as a result of:

- Lower residence time
- Higher gas holdup
- Substantial reduction in floor area
- One stage of column flotation is equivalent to 3 stage conventional flotation
- Simplification of circuit configuration

A comparison between column flotation and conventional flotation cells is presented below for better understanding.

Conventional Flotation Cell	Column Flotation Cell
1. Relatively large air bubble generation at the impeller zone	1. Positive air pressure generates fine air bubbles through air bubbler at the bottom
2. Recovery: Very low for fine and coarse particle	2. Recovery: High for fine and coarse particles
3. Turbulent pulp body (i) Not favorable for the flotation of the large, less floatable particles (ii) Contamination of the froth bed by non-floatable particles	3. Quiescent pulp body (i) Good for flotation of large, less floatable particles (ii) Less contamination of the froth bed by the non-floatable materials
4. Mineral particle air bubble attachment in the active impeller zone (i) Effective residence time and mineral particles and air bubbles at the active zone is very short (ii) Small relative velocity between air bubble mineral in the ideally mixed pulp body	4. Counter current flow of the gravity induced settling mineral particles and rising air bubbles (i) Effective residence time is 100% of the residence time for the mineral particle and air bubbles in the recovery zone (ii) Mineral particles & air bubbles move air opposite directions for head on collision
5. Limitation in froth depths	5. Long cleaning zone
6. High operating costs (i) High power consumption (ii) High maintenance costs (iii) Low recovery	6. Low operating costs (i) Low power consumption (ii) Low maintenance costs (iii) Loser control points, low manpower
7. Long floor space (i) Flat configuration (ii) Low capacity	7. Small floor space (i) Vertical configuration (ii) Large capacity
8. High costs for instrumentation and auxiliary unit	8. Low costs for instrumentation and auxiliary units
9. Unit operation capability of small capacity	9. Unit operation capability at large capacity (i) Improved metallurgical performance (ii) Process simplification

3. NML'S EXPERTISE IN COLUMN FLOTATION TECHNOLOGY

NML Madras Centre by its extensive R&D efforts had developed indigenous automated laboratory and pilot flotation column units. The Centre made a pioneering effort in demonstrating the technology by installing and conducting feasibility studies at the plant premises of various mineral beneficiation industries both in public and private sector covering base metals, iron ore, industrial minerals, gold etc.

3.a Design and Development

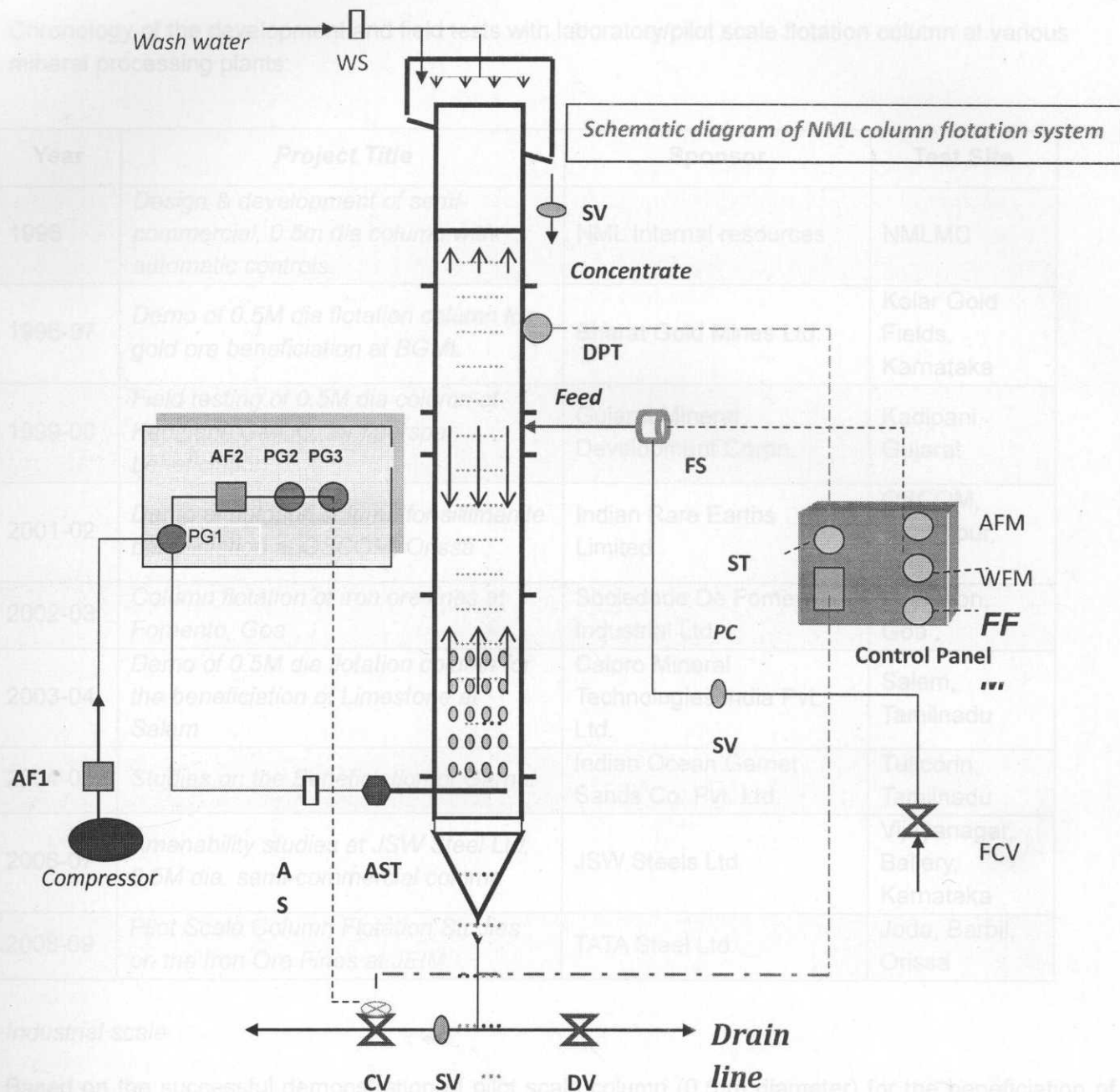
Fully automated laboratory model and pilot size flotation columns were designed, fabricated and extensively field tested by the Centre. Spargers, both internal and external types were developed to suit different applications. Special attention was paid in sparger design to generate required bubble size and bubble flux to suit a wide range of applications. The overall column design facilitates the variation of column height, feed injection point, froth depth etc.

Laboratory scale

A 75mm. laboratory column was designed, developed and installed at NML Madras Centre during 1990 that has several unique features. The sparger is of internal type fitted with sintered bronze disc of desired porosity. Differential Pressure Transmitter (DPT) coupled with a micro processor based dual-loop controller was adopted to maintain the interface between slurry and froth. The interface can be monitored from display on the LCD screen of the controller. At the steady state, the interface level could be maintained within ± 2 cm. Various instruments were incorporated to monitor variables like airflow, slurry flow, wash water flow etc. The system was extensively field tested and standardized. Similar systems were supplied to the R&D Centre of NMDC to study the beneficiation of iron ore fines and Golden Valley Institute of Technology for academic purposed.

Pilot scale

The experience gained in design and development of laboratory and the successful execution of in plant trials at different mineral processing plants with a wide range of ores, culminated in the development of a pilot scale model to treat part of the plant stream (50-100 tpd). Accordingly, a 500 mm dia. column (maximum height 14 metres with flanged sections) was fabricated equipped with suitable pumps, electronic level controls, magnetic flow meters, automatic sampling valves etc. Different types of bubble generators (spargers) have been designed, suitable to process various minerals in plant conditions.



AS	Air flow Sensor	DPT..	Differential Pressure Transmitter	
AF1&AF2	Air filters		FCV	Feed Control Valve
AST	Air sparger tank	FFM*	Feed Flow Meter	
PC	Column Controller		PG1	Line Pressure gauge
CV	Control Valve		PG2	Valve Pressure gauge
DV	Drain Valve		PG3	Transducer Pressure gauge
FS	Feed Flow Sensor		SV	Auto sampling valve
WS	Wash Water Flow Sensor	***	WFM	Washwater flow meter
AFM	Air flow meter		ST	Sampling timer

Chronology of the development and field tests with laboratory/pilot scale flotation column at various mineral processing plants:

Year	Project Title	Sponsor	Test Site
1996	<i>Design & development of semi-commercial, 0.5m dia column with automatic controls.</i>	NML Internal resources	NMLMC
1996-97	<i>Demo of 0.5M dia flotation column for gold ore beneficiation at BGML</i>	Bharat Gold Mines Ltd.	Kolar Gold Fields, Karnataka
1999-00	<i>Field testing of 0.5M dia column at Kadipani, GMDC, for fluorspar beneficiation</i>	Gujarat Mineral Development Corpn.	Kadipani, Gujarat
2001-02	<i>Demo of flotation column for sillimanite beneficiation at OSCOM, Orissa</i>	Indian Rare Earths Limited	OSCOM, Chatrapur, Orissa
2002-03	<i>Column flotation of iron ore fines at Fomento, Goa</i>	Sociedade De Fomento Industrial Ltd.	Madgaon, Goa
2003-04	<i>Demo of 0.5M dia flotation column for the beneficiation of Limestone at Salem</i>	Calpro Mineral Technologies India Pvt. Ltd.	Salem, Tamilnadu
2004-05	<i>Studies on the Beneficiation of Garnet</i>	Indian Ocean Garnet Sands Co. Pvt. Ltd.	Tuticorin, Tamilnadu
2006-07	<i>Amenability studies at JSW Steel Ltd. 0.5M dia. semi-commercial column</i>	JSW Steels Ltd.	Vijayanagar, Ballery, Karnataka
2008-09	<i>Pilot Scale Column Flotation Studies on the Iron Ore Fines at JEIM</i>	TATA Steel Ltd.	Joda, Barbil, Orissa

Industrial scale

Based on the successful demonstration of pilot scale column (0.5 m diameter) for the beneficiation of sillimanite and limestone, industrial size columns were designed and commissioned for the following industries:

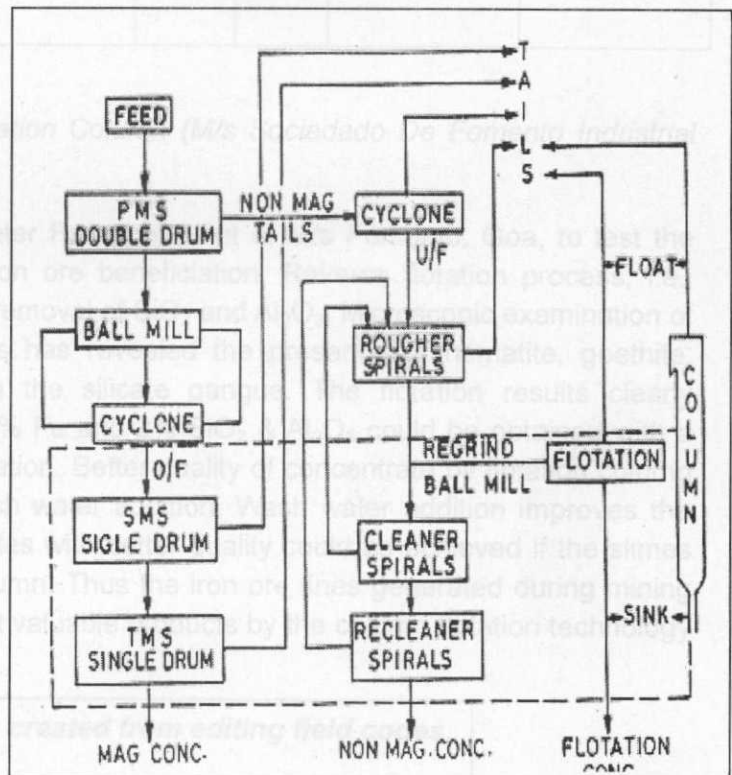
- Beneficiation of sillimanite (150 tons/day), Indian Rare Earths Ltd., Chatrapur, Orissa
- Beneficiation of sillimanite (150 tons/day), Indian Rare Earths Ltd., Chavara, Kerala
- Beneficiation of limestone (100 tons/day), Calpro Mineral Technologies Ltd., Salem, Tamilnadu

3.b Studies conducted by NML on iron ore beneficiation by flotation columns:

Gangue minerals in iron ores generally comprise of quartz or silicates such as alumino-silicates and their proportion is relatively less. This type of ores are generally beneficiated by flotation using cationic reagents like amines as collectors and the process is called „reverse flotation“. The cationic flotation (reverse flotation) is advantageous in plant practice because the cationic collectors need less induction time and provides high contact angles facilitating tenacious bond with the minerals to be separated out. Hence, they are being widely used world over in iron ore flotation practice. NML-Madras Centre has been carrying out pioneering work in this area on iron ores of different regions of the country for the past few decades. Few case studies are discussed below.

1. Feasibility Studies of Column Flotation to Improve the Quality of Iron Ore Concentrate at Kudremukh (M/s Kudremukh Iron Ore Company Ltd., July 1992) [6]

The objective was to reduce the silica content in the concentrate while improving the iron recovery using a lab model flotation column (74mm dia) at the plant site. Reverse flotation tests were conducted on four different samples viz., spiral rougher concentrate (ground), feed to secondary magnetic separator, mixed feed of spiral rougher concentrate and feed to secondary magnetic separator in the ratio 1:2 and another mixed feed consisting of secondary and tertiary magnetic tail in the ratio 4:1. Among these, the first three have shown excellent improvement in both grade and recovery. It was possible to obtain a concentrate with silica content of 2.0% and iron recovery of over 90% from existing 80% apart from circuit configuration simplification. The results of the column tests given in Table indicate clearly that the performance of the column compared with that of the conventional mechanical cells was excellent and capable of improving the recovery of both magnetic and non-magnetic iron minerals.



Salient results of column flotation tests:

Sample No.	Feed Wt%	Con. Wt. %		Tailings Wt%	Recovery, %
	Fe	Fe	SiO ₂		
1	Rougher spiral concentrate				
2	51.48	65.23	2.97	6.03	97.28
3	52.09	65.69	2.07	8.09	96.33
3	54.98	65.81	2.71		98.44
1	Feed to secondary magnetic separator	68.16	1.65	15.98	96.72
2	61.57	68.31	2.05	34.08	92.14
	63.31				

2. Beneficiation of Iron Ores by pilot scale Flotation Column (M/s Sociedad De Fomento Industrial Ltd., Goa, June 2002) [7]

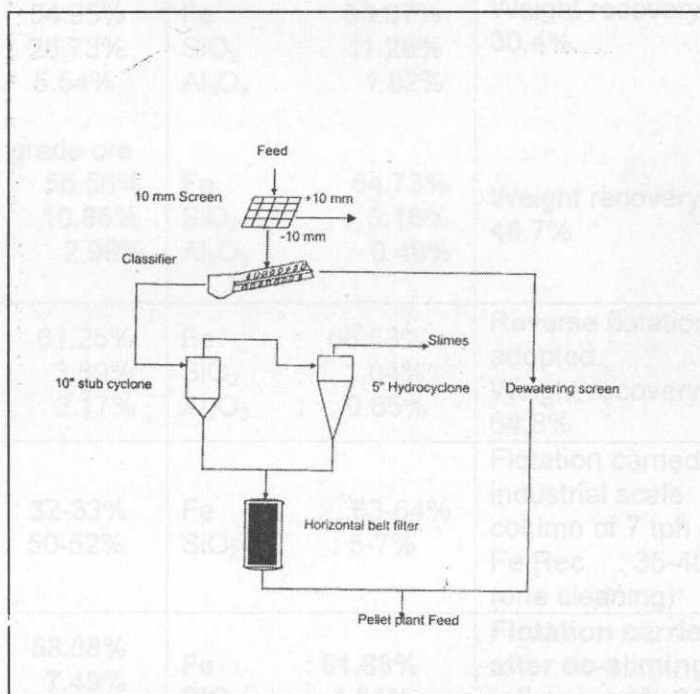
0.5 m dia flotation column was installed at Greater Ferromet plant of M/s Fomento, Goa, to test the application of column flotation technology for iron ore beneficiation. Reverse flotation process, i.e., flotation of gangue minerals was adopted for the removal of SiO₂ and Al₂O₃. Microscopic examination of the samples collected from four different mines has revealed the presence of hematite, goethite, martite, magnetite while quartz and clay form the silicate gangue. The flotation results clearly suggested that iron ore concentrate assaying 67% Fe and 2% SiO₂ & Al₂O₃ could be obtained with a recovery of 85-90% by single stage column operation. Better quality of concentrate by flotation column could be attributed to deeper froth bed and wash water addition. Wash water addition improves the froth rheology and product discharge. Concentrates with better quality could be achieved if the slimes are removed before feeding into the flotation column. Thus the iron ore fines generated during mining and milling operations could be converted to most valuable products by the column flotation technology besides resolving the environmental issues.

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S.No.	Feed assay%			Conc. Assay			Fe% Rec.
	Fe	Al ₂ O ₃	SiO ₂	Fe	Al ₂ O ₃	SiO ₂	
1	66.7	1.36	1.99	67.4	1.04	0.90	94.4
2	66.0	1.24	2.21	67.2	1.09	0.86	87.6
3	65.4	1.28	2.67	67.2	1.10	0.71	94.2

3. Pilot Scale Column Flotation Studies on the Iron Ore Fines (M/s JSW Steel Ltd., Toranagallu, Karnataka, June 2007) [4]

The aim of the work was to reduce alumina and improve upon present weight recovery (45%) of iron values from screw classifier overflow ($d_{80} = 40.5\mu\text{m}$) in the beneficiation plant by adopting reverse and column flotation so as to increase the quality of the product and productivity of the beneficiation plant. A typical feed of 60.54% Fe, 5.95% SiO₂ and 3.67% Al₂O₃ could be improved to 64.21% Fe, 2.64% SiO₂ and 2.20% Al₂O₃ at concentrate weight recovery of 82.7% and Fe recovery of 84.7%, a significant gain in the weight recovery. This in turn leads to increasing the feed availability to the pellet plant. The process developed is being implemented on commercial scale columns to be installed shortly.



4. Pilot Scale Column Flotation Studies on the Iron Ore Fines at Joda East Iron Mines (M/s Tata Steel Limited, March 2009)

Extensive test work was done at laboratory tests level and at the beneficiation plant site to improve the quality of screw classifier overflow ($d_{80} = 45.6\mu\text{m}$) by reduction of alumina and silica by direct, reverse and column flotation. By reverse flotation at laboratory level tests, feed of 58.70% Fe, 5.30% SiO₂ and 5.79% Al₂O₃ could be improved to 63.16% Fe, 3.04% SiO₂ and 4.51% Al₂O₃ at concentrate weight recovery of 54.26%, which is not significant in terms of reduction of alumina to less than 2.5%. Direct flotation tests at laboratory level and on-site plant trials met with little success and are insignificant from industrial practice point of view. The reasons attributed are the predominant form of alumina (gibbsite) and its intricate and interlocked association with hydrated iron oxides and silica bearing minerals.

Apart from the above case studies exploratory work was done on different ore samples received from various companies and the salient results are given in the following Table.

Exploratory studies on iron ore beneficiation:

Sponsor	Aim	Feed to column	Conc. produced	Remark
M/s Chowgule, Goa	To reduce SiO_2 from iron ore ultra fines / slimes ($60\% < 45\mu\text{m}$)	Fe : 47-50% SiO_2 : 23-27%	Fe : 63-65% SiO_2 : 3.5-4.5%	Fe Rec. >90%
M/s RBSSN, Hospet, Karnataka	Reduction of silica and alumina from iron ore	A low grade ore Fe 34.95% SiO_2 26.73% Al_2O_3 5.54% Medium grade ore Fe 55.56% SiO_2 10.86% Al_2O_3 2.98%	Fe 53.87% SiO_2 11.26% Al_2O_3 1.82% Fe 64.73% SiO_2 3.16% Al_2O_3 0.49%	Weight recovery 30.4% Weight recovery 46.7%
M/s Jagannath Steels, Orissa	Reduction of silica and alumina from iron ore	Fe : 61.25% SiO_2 : 3.89% Al_2O_3 : 2.17%	Fe : 66.53% SiO_2 : 1.04% Al_2O_3 : 0.85%	Reverse flotation adopted. Weight recovery 64.8%
M/s MSPL, Hospet, Karnataka	To reduce SiO_2 from Banded Hematite Quartzite (BHQ)	Fe : 32-33% SiO_2 : 50-52%	Fe : 63-64% SiO_2 : 5-7%	Flotation carried in industrial scale column of 7 tph plant Fe Rec. : 35-40% (one cleaning)
M/s JSW, Tornagallu, Karnataka	To recover values from plant tailings dam	Fe : 58.08% SiO_2 : 7.49% Al_2O_3 : 3.65% LOI : 4.38%	Fe : 61.88% SiO_2 : 4.81% Al_2O_3 : 2.52% LOI : 3.30%	Flotation carried out after de-sliming (slimes wt% 32.16 Fe: 51.16%, SiO_2 : 11.89% Al_2O_3 : 5.80%)

NML as an integral solution provider

NML has collaboration with M/s Somu Organo Chem. Ltd.(SOCPL), Bangalore, since 2008, for developing tailor made reagents for the beneficiation of various ores, minerals and coal. The reagents developed by SOCPL were successful evaluated by NML to reduce silica and alumina content in different types of iron ores from variety of sources in our country.

Considering the success of NML flotation column in the beneficiation of various minerals M/s McNally Bharat Engineering Co. Ltd.(MBE), Bangalore, a leading mineral processing equipment manufacturer

and marketing organization showed interest in providing engineering support and marketing the NML flotation column technology. In year 2008 both the organizations signed an MOU to promote and market column flotation technology.

The above collaborations enabled NML to provide a holistic solution for the beneficiation problems of low grade ores which involve developing a viable reagent scheme followed by an industrial scale processing plant on a turnkey basis involving design, installation and commissioning.

Following projects were taken up under the above collaborations:

1. Fully automatic laboratory flotation column (74 mm diameter) with advanced controls – NEIST (CSIR), Jorhat, Assam. Successfully commissioned and working satisfactorily at NEIST laboratory.
2. Pilot scale column (0.5m dia.) for the beneficiation of low grade iron ores with fully automatic controls – M/s RBSSN, Hospet, Karnataka. Supplied, erected and commissioned.
3. Industrial scale column of 35 tph capacity for the beneficiation of barites – M/ s Andhra Barites Corporation Ltd., Kadapa, AP. Work is in progress. The reagent to be used in this plant is developed by NML-SOCPL.

SUMMARY

Over two decades of R&D work NML has gained experience in beneficiating various minerals by flotation columns on laboratory, pilot and industrial scale.

Based on test results obtained by NML on continuous operation, flotation columns were found to be beneficial to achieve high grade concentrates from all types of iron ores.

Three industrial scale columns based on NML technology are in operation for beneficiation of sillimanite and limestone in our country.

Reverse flotation of iron ore places different demands on a flotation column than do other flotation applications. High froth grade is less important than complete recovery of all floatable material from the non-floatable product. Columns perform best in this application in an arrangement that maximizes recovery, rather than one that maximizes froth grade.

Column cells are slowly gaining acceptance for use in roughing applications. With each new successful installation, the degree of confidence in this technology is increases.

References:

1. Mishra, B.K., Reddy, P.S.R., Das, B., Biswal, S.K., Prakash, S., Das, S.K., *Issues relating to characterization and beneficiation of low grade iron ore fines*, Steel World, Nov., 2007, 34-36.
2. Pradip, *Processing of alumina-rich Indian iron ore slimes*, Journal of Minerals, Metals and Materials Engineering, 59 (5), 2006, 551-568.
3. Eisele, T.C. and Kawatra, S.K., *Reverse column flotation of iron ore*, Minerals & Metallurgical Processing, Vol. 24, No., May, 2007, 61-66.
4. Vijayakumar, T.V., Rao, D.S., Subba Rao, S., Prabhakar, S., Bhaskar Raju, G., *Reverse flotation studies on an Indian low grade iron ore slimes*, International Journal of Engineering Science and Technology, Vol. 2(4), 2010, 637-648.
5. Prabhakar, S., Bhaskar Raju, G., Subba Rao, S., Vijayakumar, T.V., *Column flotation technology – NML Experience*, MPT 2010, NML, Jamshedur, Dec., 2010.
6. Bhaskar Raju, G., Prabhakar, S., Sankaran, C., *Beneficiation of iron ores by column flotation*, Trans. Of Institution of Mining and Metallurgy: Sec. C Mineral Processing and Extractive Metallurgy, Vol. 102, 1993, C132.
7. Vijayakumar, T.V., Rao, D.S., Subba Rao, S., More, P., Reddy, Y.S., Prabhakar, S., Bhaskar Raju, G., *Beneficiation of iron ore fines by conventional flotation, flotation column and dual extraction column – A pilot scale study*, Power Handling & Processing, Vol. 17, No.2, March/April, 2005, 88-93.