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Recovery of Values from Tailing Ponds of Iron Ore Washing Plants

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ABSTRACT

Most of the Iron ore washing plants set up in India in the earlier days consist of sizing of the ore by dry / wet screening, washing and classification by screw classifiers. In this classical approach, iron values were lost in the form of fines and utrafines into the tailing ponds as they had little commercial value in those days and accumulated in huge quantities over the years. As the high grade deposits are getting exhausted and the demand for high grade finer material for pellet making is ever increasing, focus is shifting towards recovering the values from the erstwhile tailing ponds by column flotation. This is also supposed to mitigate to certain extent the environmental problems caused by the ever expanding and unmanageable tailing dams.

A case study is presented wherein a composite sample is prepared from samples drawn systematically from multi - locations in a sprawling tailing dam. Laboratory scale column flotation tests on this composite tailings sample, basically originating from two operating iron ore beneficiation plants of JSW Steel Ltd., one of the leading producers of steel in India, are found to be encouraging. De-sliming followed by reverse and cationic flotation tests using flotation column resulted in the concentrate of 61.88% Fe, 4.81% SiO_2, 2.52% Al_2O_3 and 3.30% loss on ignition (LOI) from the tailings analysing 57.86% Fe, 7.10% SiO_2, 3.52% Al_2O_3 and 6.14% LOI with 52% weight recovery. The causes for the quality improvement could be attributed to de-sliming of unliberated ultra fines of kaoline and hydrated iron oxides and their further reduction by efficient flotation process. The process and the cationic collector developed for this purpose are adopted in the new flotation plant created to treat these tailings.

Keywords: Iron ore, washing, ultra fines, tailings pond, column flotation

INTRODUCTION

Reserves of high-grade iron ores are diminishing all over the world at an alarming rate. As a result, alternative ways of augmenting and conserving precious and non - renewable natural resources are being seriously looked into. One such attractive option is the recovery of metal values from slimes / tailings. Iron ore tailings containing around 48 - 60% Fe are generated from the iron ore washing plants and are disposed into tailing ponds without any further utility. These tailings in the form of slimes are not suitable in iron and steel making due to the presence of higher amount of gangue constituents. Several beneficiation techniques have been tried from time to time to reduce the gangue so that the beneficiated products could be effectively used.

Most of the iron ore mines in India produce hematite ores and have washing plants to produce lumps as well as fines. In this process, a part of the fine gangue material is removed from the product. Around 8-10 million tonnes of slimes containing around 48-60% of Fe are discarded every year (Prakash et al., 2000). These slimes can not be used in iron making as they contain higher amount of gangue (Sengupta and Prasad, 1990). Several beneficiation techniques have been tried from time to time to reduce the gangue so that the beneficiated products could be effectively used for iron making (Das et al., 1995; Prakash et al., 2000; Pradip, 2006;). Efforts have been made (Das et al., 1992) to reduce alumina in the slime by using classification followed by separation in a hydrocyclone wherein it is possible to obtain a product containing 64% Fe, 1.4% silica, and 3.5% alumina from a feed assaying 57% Fe, 4% silica, and 8.3% alumina. Several researchers (Gujraj et al. 1983; Mahiuddin et al. 1989; Hanumantha Rao and Narasimhan 1985) worked on the reduction of alumina from iron ores, focusing on flocculation techniques that resulted in success of varying degrees. The beneficiation of iron ore slimes produced from washing plants and tailing ponds of Kiriburu mines was studied (Prasad et al. 1988) using wet high-intensity magnetic separators (WHIMS) followed by classification in hydrocyclone whereby a concentrate assaying 63% Fe and 3.3% alumina was produced with an overall iron recovery of 56%. Though multi-gravity separation is a useful technique (Pradip 1994) for treating iron ore slimes in general and for reducing alumina in particular, it is not very successful commercially due to its low capacity. Separation of Barsua, Bolani, and Kiriburu iron ore slimes was studied (Das et al. 1995) using classification by hydrocyclone followed by high-intensity magnetic separation. Their results show that it is possible to obtain a concentrate assaying 60-65% Fe with 60-80% recovery. Another study (Srivastava et al. 2001) used classification in a hydrocyclone followed by spiral concentration for iron ore slimes obtained from washing plants and tailing ponds of Kiriburu mines. The experimental results show that it is possible to raise the iron content up to 64.17% at a yield of 37.3% with simultaneous decrease in the alumina content, down to 1.17%. Roy and Das (2008) also tried separating the gangue (viz. quartz and kaolinite from iron-bearing minerals, mostly hematite and goethite), to produce a suitable concentrate for downstream processing. Earlier studies (Vijaya Kumar et al., 2005a and b, Vijaya Kumar et al., 2010) indicated that silica and alumina could be reduced by reverse cationic column flotation of a pre-concentrate as a value addition step and also from screw classifier over flow obtained from two different operating beneficiation plants. In another study (Rocha L, Cancado, R Z I and Peres, A E C, 2010) involving flotation column and reverse flotation process, high depressant dosage was suggested to achieve high grade concentrates with low impurity content. They could achieve approximately 60% mass recovery and 80% metal recovery in the flotation stage.

M/s JSW Steel Limited, one of the leading producers of Steel in India operates two beneficiation plants with the twin objectives of reducing alumina and silica from the iron ore fines. The unit operations comprise of wet screening, scrubbing, spirals, magnetic separation, and classification by screw classifiers and hydrocyclones. Recently, flotation was added to one of their beneficiation plants (Beneficiation Plant - 1) washing circuit to maximise the recovery of ultra fine iron values from the hydrocyclones. Another flotation plant is established to process the tailings from both the beneficiation plants that are accumulated at Sultanpura. Table 1 shows the amount of tailings accumulated over the years at JSW tailings dam. A case study is presented here to highlight the recovery of iron values from these tailings by emerging technologies like column flotation.

MATERIALS AND METHODS

Materials

Samples collected from different locations in the tailings pond analysed 52 - 57% Fe, 8 - 9% SiO_2, 5 - 6% Al_2O_3 and 4 - 9% loss on ignition (LOI). The particle size of the composite sample prepared for test work purpose is given in Table 2 and its d_{80} is found to be 16.64 microns. Mineralogical analysis indicated that it is mainly composed of hematite, goethite and limonite as the iron bearing minerals whereas quartz and kaolinite (clay) formed the gangue. Microscopic studies reveal that iron bearing minerals are in intimate association with each other as well as with gangue in the size range below 5 microns. A comprehensive study on the mineralogical, geochemical and separation characteristics of the iron ore fines of this region with special reference to their implications on beneficiation in general and flotation in particular can be found elsewhere (Rao et al., 2009; Vijaya Kumar, Rao and Gopalkrishna, 2011).

Cationic amine collectors which are generically same but compositionally different from each other were developed by M/s Somu Organo-Chem Pvt. Ltd., Bengaluru, India in collaboration with CSIR-National Metallurgical Laboratory - Madras Centre (NML - MC). Their performance was evaluated and the best among them, Sokem 524C, was chosen for lowering alumina content and optimizing process parameters. The causticised maize starch supplied by M/s Riddhi Siddhi Gluco Biols Ltd., Ahmedabad, India was used as depressant for iron bearing minerals. Commercial grade sodium hydroxide was used as pH regulator.

Laboratory flotation column tests

The automated flotation column with an internal diameter of 74 mm designed and developed by NML - MC is used in the present study. The details of the flotation column are shown in Figure 1. The column shells are made up of flanged sections consisting of air injection zone, collection zone, feed point and cleaning zone/froth zone. Electronically controlled metering pumps are used to feed and discharge the slurry. The pumps are designed to deliver an accurately measured volume of slurry with an error of +/- 2%. Slurry/froth interface is maintained using Differential Pressure Transmitter (DPT). The output signal of the DPT is 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 rotameters with differential pressure regulators are used to control the flow of air and water.

Experimental procedure

The air from the compressor is let into the column at a desired flow rate. The column is filled with water and stabilized at required froth depth. After stabilization with water, the reagents' conditioned tailings slurry is pumped into the column at desired flow rate. The slurry at 15% solids is conditioned initially with sodium hydroxide in a conditioner with the conditioning time of 180 seconds. In the second stage, starch is added and conditioned for further 180 seconds. This slurry is further conditioned with amine collector. The reagentized slurry is fed to the column and allowed to run for a minimum period of 3 - 4 residence times. Samples are drawn under near-steady state conditions. Both the process parameters and column operating conditions are recorded before collecting the samples. Samples are analyzed for Fe, SiO_2, Al_2O_3 and loss on ignition (LOI) by adopting standard methods of analyses.

RESULTS AND DISCUSSION

Depending on the nature of iron ore, either iron minerals or gangue minerals can be floated using suitable collectors. If the ore is of low grade, 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 floated 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 less, reverse flotation using cationic collector is adopted.

Generally, fatty amines with hydrocarbon chain length of 12-18 carbon atoms are used as collectors for the flotation of silica and alumina bearing minerals. 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

$$R\text{-}NH_2 + H^+ \rightleftarrows R\text{-}NH_3^+ \qquad \text{.........} \qquad (1)$$

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.

$$SiOH_2^+ \xrightarrow{-H^+} SiOH \xrightarrow{-H^+} SiO^- \qquad \text{.........} \qquad (2)$$

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 - 9.0. In order to achieve better selectivity, the particles are thoroughly dispersed by adjusting the pH to above 9.0 where iron minerals, silica and alumina bearing minerals are negatively charged. At this stage, surface of the iron minerals is masked to avoid amine adsorption by conditioning with starch. Thus iron minerals could be depressed and, silica and alumina bearing minerals could be selectively floated using cationic collectors.

Preliminary experiments are conducted in Denver D12 flotation cell to optimize the dosage of collector (Sokem 524C) and depressant (starch) for iron bearing minerals at pH 10.0. These optimized process parameters (Sokem 524C: 0.3 kg/t and starch: 1.0 kg/t) are utilized during the operation of flotation column. The optimum result that could be obtained when tailings is subjected to column flotation without desliming is shown in Table 3. The experimental conditions maintained are pH: 9.5 - 10.0; starch: 1.0 kg/t; Sokem 524C: 0.3 kg/t; feed to flotation column: 15% solids by weight; superficial air velocity: 1.15 cm/s; slurry residence time: 15 minutes; froth depth: 25 cm. Under the test conditions, alumina could be reduced to 2.90% only from 3.52% with 62.30% weight recovery of the concentrate. To improve the removal of alumina, it is thought prudent to de-slime the sample. The tailings slurry is de-slimed at 10% solids by weight at pH 10.0. All experimental conditions remained the same, except the collector’s dosage which is reduced to 0.2 kg/t. Table 4 shows the results of the test conducted on flotation column after de-sliming the tailings slurry. Figure 2 shows the granulometry of slimes, de-slimed feed to the flotation column, tailings and concentrate generated thereof. It is evident that de-sliming helped not only in elimination but also in avoiding the interference of extreme ultra fines (below 5 microns) with flotation process. They are also undesirable in the process from unfavourable liberation characteristics point of view as borne out by the earlier microscopic studies. This also favoured in reducing the collector’s consumption in the process. The quality improvement could be attributed to de-sliming which removed ultrafine sized kaoline and hydrated iron oxides that were evident from relatively higher values of alumina, silica and loss on ignition in slimes (Table 4). This was further enhanced by their efficient reduction in the form of tailings discharge during flotation process. Thus, a concentrate of 61.88% Fe, 4.81% SiO_2, 2.52% Al_2O_3 and 3.30% LOI could be generated with weight recovery of 52.11% from the feed analysing 57.86% Fe, 7.10% SiO_2, 3.52% Al_2O_3 and 6.14% LOI. The process and the cationic collector reagent developed for this purpose were accepted and adopted by the management of M/s JSW Steel Limited. New facilities involving dredging the accumulated tailings and treating them by flotation are being created near the tailings dam to recover the iron values from it.

CONCLUSIONS

With the increased awareness and importance of recovering ultrafine iron values from slimes / tailings from erstwhile as well as existing tailing dams, industry is looking for suitable and viable technology. Reverse flotation involving cationic collector and flotation column was found to offer the best solution from industrial point of view. A case study is presented on the utilization of tailings sample, drawn from the tailings dam of the operating beneficiation plants of JSW Steel Limited, India. A concentrate of 61.88% Fe, 4.81% SiO_2, 2.52% Al_2O_3 and 3.30% LOI could be generated with weight recovery of 52.11% from the tailings analysing 57.86% Fe, 7.10% SiO_2, 3.52% Al_2O_3 and 6.14% LOI. The concentrate so generated is attractive for pellet making in terms of its granulometry and acceptable levels of alumina content in it. Based on the process and cationic collector developed for alumina reduction in the tailings, new facilities involving dredging and flotation based processing plant are being set up at the tailings dam of M/s JSW Steel Limited, India.

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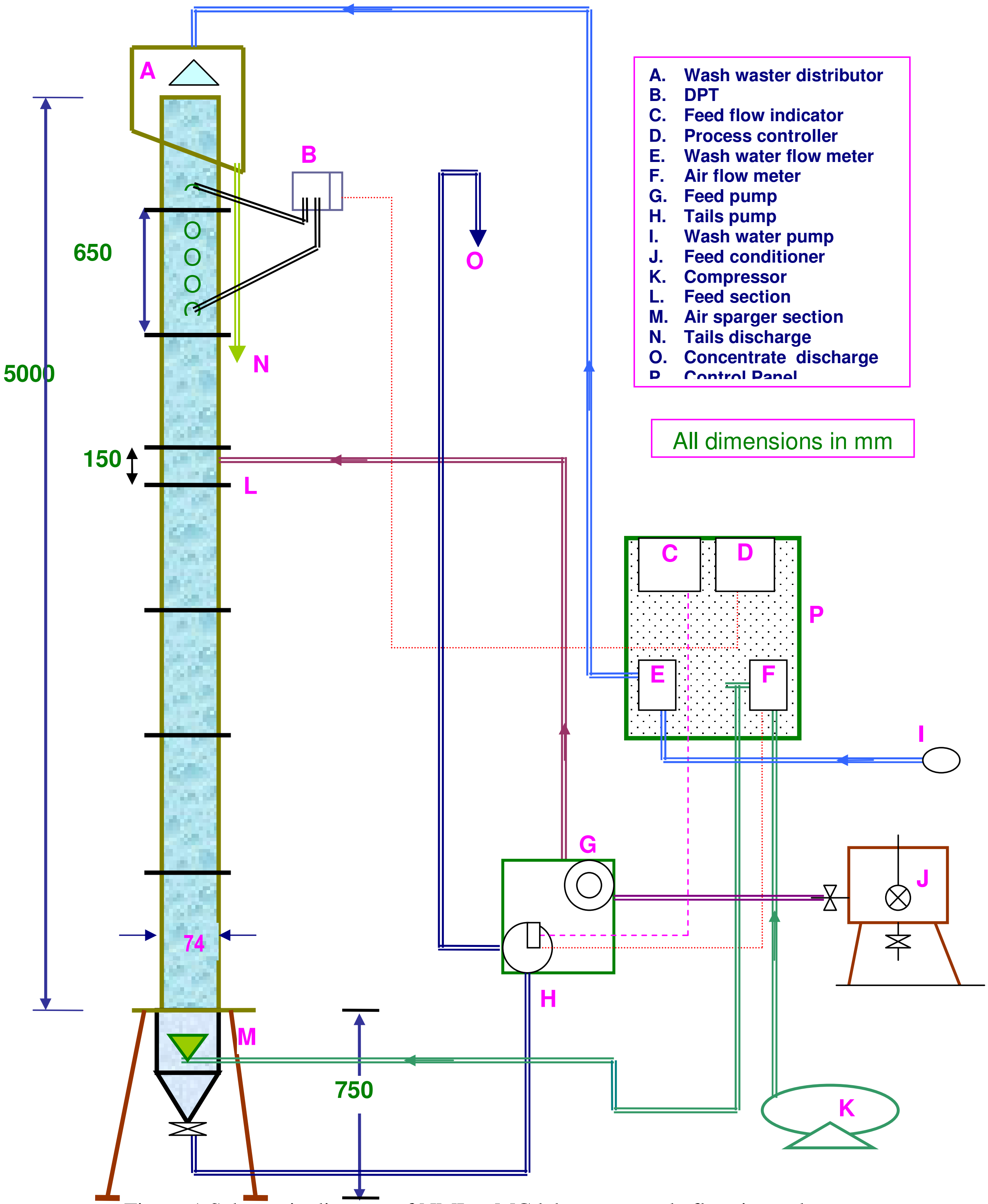

Figure 1 Schematic diagram of NML – MC laboratory scale flotation column

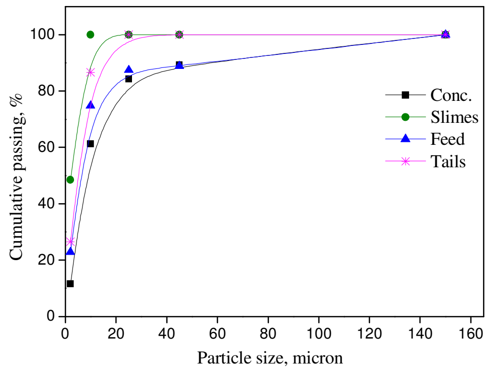

Figure 2 Granulometry of slimes, de-slimed feed to column, concentrate & tailings

TABLES

Table 1

Details of tailings accumulated over the years at JSW tailings dam

Period	Tailings, tonnes
2003 - 04	199929
2004 - 05	235584
2005 - 06	255797
2006 - 07	335674
2007 - 08	462097
2008 - 09	432094
2009 - 10	261410

Table 2

Particle size analysis of the composite tailings sample (feed to flotation column)

Particle size, microns	Cumulative passing, %
2	22.89
10	74.79
25	87.44
45	88.85
150	100.00

Table 3

Column flotation test results on JSW tailings (without de-sliming)

Product	Weight, %	Assay, %				Distribution, %			
		Fe	SiO_2	Al_2O_3	LOI	Fe	SiO_2	Al_2O_3	LOI
Tailings	37.70	54.29	9.51	4.75	5.77	35.39	48.79	49.78	47.89
Concentrate	62.30	59.98	6.04	2.90	3.80	64.61	51.21	50.22	52.11
Head (calculated)		57.84	7.35	3.60	4.54				
Head (assay)		57.86	7.10	3.52	6.14				

Table 4

Column flotation test results on JSW tailings (after de-sliming)

Product	**Weight, %**	**Assay, %**				**Distribution, %**			
		Fe	SiO_2	Al_2O_3	LOI	Fe	SiO_2	Al_2O_3	LOI
Slimes	32.16	51.16	11.89	5.80	6.60	28.33	51.06	51.08	48.48
Tailings	15.73	59.65	7.37	3.01	3.41	16.15	15.48	12.97	12.25
Concentrate	52.11	61.88	4.81	2.52	3.30	55.52	33.47	35.96	39.27
Head (calculated)		58.08	7.49	3.65	4.38				
Head (assay)		57.86	7.10	3.52	6.14				