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Beneficiation of iron ore fines from large deposits of waste dumps

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ABSTRACT

About 20 million tonnes of low grade iron ore fines have been accumulated and stacked over the years as 'Dump Rejects' in the Gua iron ore mine of Bihar and about 8 million tonnes of generated fines are stacked in the Dalli Iron Ore Mine, M.P., under operation by Steel Authority of India Ltd., (SAIL). In order to conserve and utilise these valuable iron ore fines, the authorities of the RDCIS, SAIL, Ranchi have sponsored two samples for pilot plant scale beneficiation studies in order to evaluate the possibility of upgrading these fines to be used as sinter feed. The ore dressing division of the Indian Bureau of Mines (IBM), Nagpur has carried out mineral characterisation of these fines and evolved suitable process flowsheets based on continuous scale testing to yield iron ore concentrates in the size range of all minus 6 mm and assaying over 63% Fe which would suit as sinter feed. The process of beneficiation, comprised scrubbing, trommel washing, classification, jigging and hydrocycloning/spiralling. The iron ore fines of Dalli Mine assayed 57.97% Fe, 5.23% Al_2O_3, 7.52% SiO_2 and 3.73% LOI. The composite concentrate obtained in the pilot plant studies assayed 63.75% Fe, 2.1% Al_2O_3, 2.65% SiO_2 with weight percent yield of 66.7 and iron recovery of 73.2%. The iron ore fines from the reject dumps of Gua iron ore mine assayed 61.5% Fe(T), 0.54% FeO, 3% SiO_2, 3.26% Al_2O_3 and 6.5% LOI. The composite concentrate obtained assayed 63.44% Fe,, 2.17% SiO_2, 2.76% Al_2O_3 and 5.47% LOI with weight percent yield of 79.2 and iron recovery of 81.3%. The occurrence of higher percentage of goethite and limonite as well as the complex textural association of hematite with goethite/limonite and silicates precluded the production of high grade (+65% Fe) iron concentrate with high recovery. However, the above concentrates produced fully meet the size and chemical specification stipulated for sinter feed and allow commercial utilisation of these waste rejects.

INTRODUCTION

Iron ore is a basic raw material used for pig iron production in the blast furnace. The ore burden preparation plays a very vital role in the improvement of the blast furnace productivity. Ore processing has been employed to the ore burden preparation by way of sizing the ore and beneficiation. For better blast furnace productivity, the ratio of maximum to minimum size of lump ore charged in the furnace is approximately 3:1 with the top size of about 30 mm. Almost all the iron ore processing plants producing calibrated ore both for domestic as well as export oriented market employ two stages of crushing except in case of few where they employ three to four stages. Most of the Indian ores owing to their softer nature and high clay admixture generate more fines (–10 mm size) during preparation of the calibrated or sized ore.

About 8 million tonnes of generated fines are stacked in the Dalli iron Ore Mine and generation is on increase because of the regular production of the lumpy size ore. Similarly, about 20 million tonnes of iron ore fines have been accumulated and stacked over the years as 'Dump Rejects' in the Gua iron ore mine of M/s. SAIL.

These fines being of low grade, cannot be used in the blast furnace directly. The low iron content and high gangue content of these fines attributes to high alumina which is present mostly in the fine size range and lowers the blast furnace productivity as well as increases the fuel consumption.

All such low grade fines need beneficiation. The objective of the iron ore beneficiation therefore, is to improve the iron content and decrease the alumina-iron ratio.

Beneficiation and utilization of these fines would thus not only help in reducing the waste dump volumes for disposal as an environmental measure but also lead to conservation of mineral wealth by recovering additional values of iron.

Research and Development Centre for Iron and Steel, Ranchi has recognised the importance of this issue and in the first place sponsored two samples to IBM for pilot scale studies – one sample from Dalli, Durg Dist. M.P., and another from Gua mine, Bihar. The objective of these studies was to evolve a suitable process for beneficiation of these fines to produce iron ore concentrates in the size range of all –6 mm, and assaying over 63% Fe, to be used as sinter feed. The studies are also contemplated to generate other processing parameters/data which could be utilized for the sizing/selection of equipment required for establishment of a commercial beneficiation plant at Dalli to produce about 0.5 million tonnes of iron ore concentrate per year.

PROCESS DEVELOPMENT FOR IRON ORE FINES FROM DALLI MINES

The generated fines from Dalli Iron Ore Mine consisting of mostly –10 mm size material with few lumps upto 75 mm size assayed 58% Fe, 5.23% Al_2O_3, 7.52% SiO_2 and 3.73% LOI. It contained hematite as the main iron bearing mineral with minor amounts of goethite/limonite and martitised magnetite. Among the silicate gangue, clay and mica were the main minerals whereas shale, quartz and gibbsite were present in minor to very minor amounts. The iron oxide minerals were coated and finely interrelated with limonite and laterite material.

Selection of Beneficiation Process Route

On the basis of mineralogical composition and size distribution of sample, a few preliminary test runs were carried out. After completing some tests, a final flowsheet was developed for Dalli fines. The process comprised the following steps.

1. Scrubbing of the as received sample
2. Wet screening of the scrubbed material to separate –6 mm fines which form the feed to the spiral classifier
3. Crushing the +6 mm fraction to all –6 mm and rescrubbing
4. Jigging of the classifier U/F
5. Desliming of classifier O/F
6. Spiralling of cyclone U/F.

Scrubbing – Classification Test :

The scrubbing was carrying out in a 800 mm x 1500 mm rotary scrubber (Make – Sayaji). The feed was continuously drawn from the fine ore bin through belt weigh feeders and fed to the scrubber. Feed water was added through a water rotameter. The scrubbed material was washed over the trommel attached to the scrubber with a known quantity of water sprays. The trommel has 10 mm circular punched openings to separate 6 mm under size which formed the feed to the 300 mm dia Akin's Spiral Classifier. The +6 mm fraction was separately collected as a trommel oversize product and crushed to all –6 mm and reefed to the scrubber alongwith fresh feed in the ratio of 1:3. The classifier is set to overflow all –100 mesh fines.

The metallurgical results of the closed circuit scrubbing – classification test are given in Table 1.

Table 1 : Scrubbing – classification test

Product	Wt (%)	Assay (%) Fe	Al_2O_3	SiO_2	Recovery Fe (%)
Classifier sand (–6+100 mesh)	71.6	62.4	2.8	3.8	76.9
Classifier fines (–100 mesh)	28.4	47.27	9.9	15.2	23.1
Head (Calculated)	100.0	58.1	4.8	7.0	100.0

It is seen from Table 1, that the classifier sand assayed only 62.4% Fe and in order to further upgrade it to +63% Fe, this was subjected to jigging.

Jigging of Classifier Sand :

The jigging tests were carried out in a Duplex type Harz jig having compartment size of 360 x 490 mm. Each compartment has an adjustable side opening (window) through which the required amount of the stratified concentrates (Bed material) can be continuously withdrawn. The classifier underflow was continuously fed to the jig under gravity alongwith measured amount of water. Jig water was continuously added through the flowrator to the first plunger compartment. The stroke length and frequency of the plunger was adjusted to obtain the best possible results. The screens with 5 mm opening were fitted in the jig compartments and iron balls of +5 mm size were used as ragging material. The metallurgical results of the jigging test are given in Table 2.

Table 2 : Metallurgical results of jigging tests

Product	Wt (%)	Assay (%) Fe	Al_2O_3	SiO_2	Recovery Fe (%)
Composite Jig Conc.	61.6	63.9	2.04	2.53	67.8
Jig tails	10.0	53.01	7.01	11.78	9.1
Head (Calculated)	71.6	62.4	2.73	3.82	76.9

It is seen that the jigging test produced the desired grade of concentrate. The classifier overflow fines assayed 47.27% Fe and carried about 23.1% Fe values. An attempt was therefore made to recover additional iron values from these fines.

Desliming of Classifier Overflow by Hydrocycloning:

The classifier overflow was subjected to desliming employing a 50 mm Mozley hydrocyclone. The results are presented in Table 3.

Table 3 : Desliming of classifier overflow

Product	Wt (%)	Assay (%)		
		Fe	Al_2O_3	SiO_2
Cyclone U/F	16.9	55.16	6.36	9.6
Cyclone O/F	11.5	35.69	15.06	23.4
Head (Calculated)	28.4	47.28	9.9	15.2

Since the cyclone underflow assayd only 55.16% Fe and carried lot of gangue minerals, the majority of them being free, it was subjected to spiralling for further upgradation.

Spiralling of Cyclone Under Flow :

The cyclone underflow was subjected to spiralling on a 7 turn spiral from M/s. Mineral Deposits Ltd., Australia. The metallurgical test results are given in Table 4.

Table 4 : Spiralling of cyclone under flow

Product	Wt (%)	Assay (%)		
		Fe	Al_2O_3	SiO_2
Spiral Concentrates	5.1	62.0	2.92	4.04
Spiral tails	11.8	52.21	7.85	12.0
Head (Calculated)	16.9	55.2	6.4	9.6

The spiralling test produced a fine concentrate assaying 62% Fe. The overall metallurgical results of the complete test is presented in Table 5.

Table 5 : Overall metallurgical results

Product	Wt (%)	Assay (%)			Recovery Fe (%)
		Fe	Al_2O_3	SiO_2	
Jig Conc.	61.6	63.9	2.04	2.53	67.8
Jig Tails	10.0	53.01	7.01	11.78	9.1
Spiral Conc.	5.1	62.0	2.92	4.04	5.4
Spiral Tails	11.8	52.21	7.85	12.0	10.6
Cyclone O/F	11.5	35.69	15.06	23.4	7.1
Head (Calc.)	100.0	58.09	4.76	7.05	100.0
Composite Conc. (1+3) (Jig conc. + spiral conc.)	66.7	63.7	2.1	2.65	73.2

It is seen from Table 5 that by employing a combination of unit operations like scrubbing, classification, jigging, hydrocyclonig and spiralling, a composite iron concentrate could be obtained assaying 63.7% Fe, 2.1% Al_2O_3, 2.65 SiO_2 with Wt% yield of 66.7 and iron recovery of 73.2%.

PROCESS DEVELOPMENT FOR IRON ORE FINES FROM GUA MINES OF M/s. SAIL

The iron ore fines from the reject dumps of Gua iron ore mines assayed 61.5% Fe, 3% SiO_2, 3.26% Al_2O_3 and 6.5% LOI. The sample consisted mostly of hematite and goethite/limonite with minor amounts of quartz, and very minor to trace amounts of mica, talc, clay and gibbsite. The hematite was thickly coated with goethite/limonite material. This sort of coating and the clayey portion of the gangue minerals could be removed by scrubbing. Hence, the first step in the beneficiation route was scrubbing.

Experimental Work

Scrubbing – Classification Test :

The scrubbing followed by classification test was carried out in the same machine and in the similar fashion as described for Dalli ore fines. The trommel oversize +6 mm lumps were collected separately. The –6 mm trommel undersize was fed to Akin's classifier. The metallurgical results are presented in Table 6.

Table 6 : Metallurgical results of scrubbing – classification test

Product	Wt (%)	Assay (%)				Recovery
		Fe	Al_2O_3	SiO_2	LOI	Fe (%)
Trammel over size (+6mm)	11.7	62.0	3.39	2.99	6.57	11.8
Classifier over flow (–100 mesh)	16.3	57.67	5.7	5.97	6.59	15.2
Classifier under flow (–6 mm + 100 mesh)	72.0	62.45	3.2	2.42	6.46	73.0
Head (calc.)	100.0	61.62	3.63	3.06	6.49	100.0

It is seen from the above table that the classifier underflow assayed only 62.45% Fe with a very high content of LOI. This needed to be upgraded further by jigging. Since the classifier underflow contained very little fine silicate gangue minerals, the concentration process viz., jigging involved rejection of lighter weight, low iron bearing minerals like goethite/limonite as jig tailings.

Jigging Test :

A large number of jigging tests were carried out to optimise the test conditions and it was observed that the grade of the jig concentrate increased with higher wt% rejection of the jig tails. A relationship was established between the wt% of jig tailing rejected and the grade (% Fe) of the composite jig concentrate. This is graphically presented in Fig. 1.

It is seen from the graph that if the jig tailing rejects are in the range of 16-20%, a good grade (~64% Fe) jig concentrate could be obtained. Hence, the jigging of the classifier underflow was carried out under the conditions which yielded the above products. The metallurgical results of the jigging test are presented in Table 7.

Table 7 : Results of jigging test

Product	Wt (%)	Assay (%)			
		Fe	Al_2O_3	SiO_2	LOI
Composite jig conc.	83.1	63.81	2.54	1.94	5.27
Jig tails	16.9	57.29	7.16	3.6	9.47
Head (calc.)	100.0	62.71	2.22	3.32	5.98

It may be noted that crushing of trommel oversize +6 mm to all –6 mm and rescrubbing was employed for Dalli fines, but in case of Gua Fines, the lumps were kept as such and then after crushing to all –6 mm blended with jig concentrate, thereby avoiding rescrubbing.

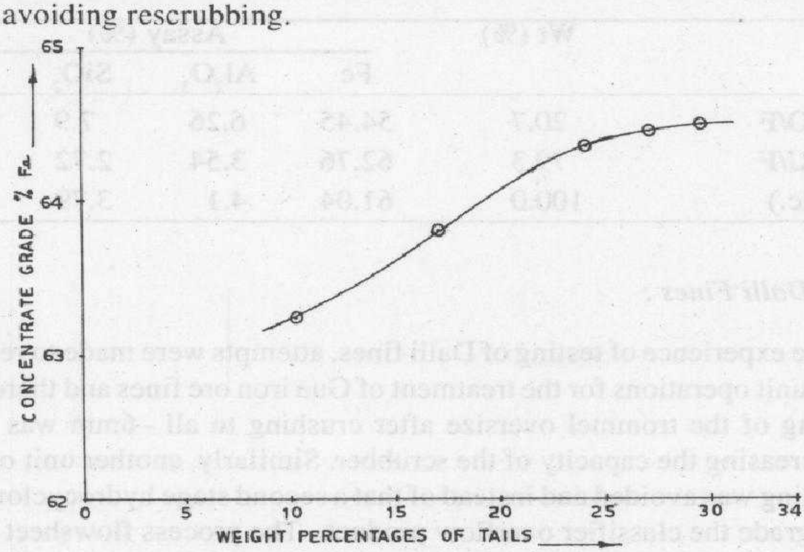

Fig. 1 : Graphical relationship between the weight percentage of tails rejected and the jig concentrate grade (% Fe).

Single stage hydrocycloning of classifier overflow :

It is seen from Table 6 that the classifier overflow assayed 57.67% Fe and carried lot of iron values. Attempts were made to recover additional iron values from the same by hydrocycloning.

The calssifier overflowwas subjected to hydrocycloning on a 50 mm Mozley Hydrocyclone. The test results are presented in Table 8.

Table 8 : Single stage hydrocycloning of classifier O/F

Product	Wt (%)	Assay (%)			
		Fe	Al_2O_3	SiO_2	LOI
Cyclone O/F	40.9	52.44	7.73	10.06	7.71
Cyclone U/F	59.1	60.93	4.17	3.85	5.79
Head (calc.)	100.0	57.46	5.63	6.39	6.57

Two Stage Hydrocycloning :

The single stage cyclone U/F assayed 60.93% Fe. Instead of spiralling, this product was subjected to IInd stage of hydrocycloning for further upgradation. The metallurgical results are given in Table 9.

Table 9 : Results of two stage hydrocycloning test

Product	Wt (%)	Assay (%)			
		Fe	Al_2O_3	SiO_2	LOI
Cyclone O/F	20.7	54.45	6.26	7.9	7.39
Cyclone U/F	79.3	62.76	3.54	2.72	5.41
Head (calc.)	100.0	61.04	4.1	3.79	5.82

Testing of Dalli Fines :

With the experience of testing of Dalli fines, attempts were made to reduce the number of unit operations for the treatment of Gua iron ore fines and therefore the re-scrubbing of the trommel oversize after crushing to all –6mm was avoided thereby increasing the capacity of the scrubber. Similarly, another unit operation viz., spiralling was avoided and instead of that a second stage hydrocycloning was tried to upgrade the classifier overflow product. The process flowsheet thus developed is presented in Fig. 2. The overall metallurgical results of the tests on Gua iron ore fines is presented in Table 10.

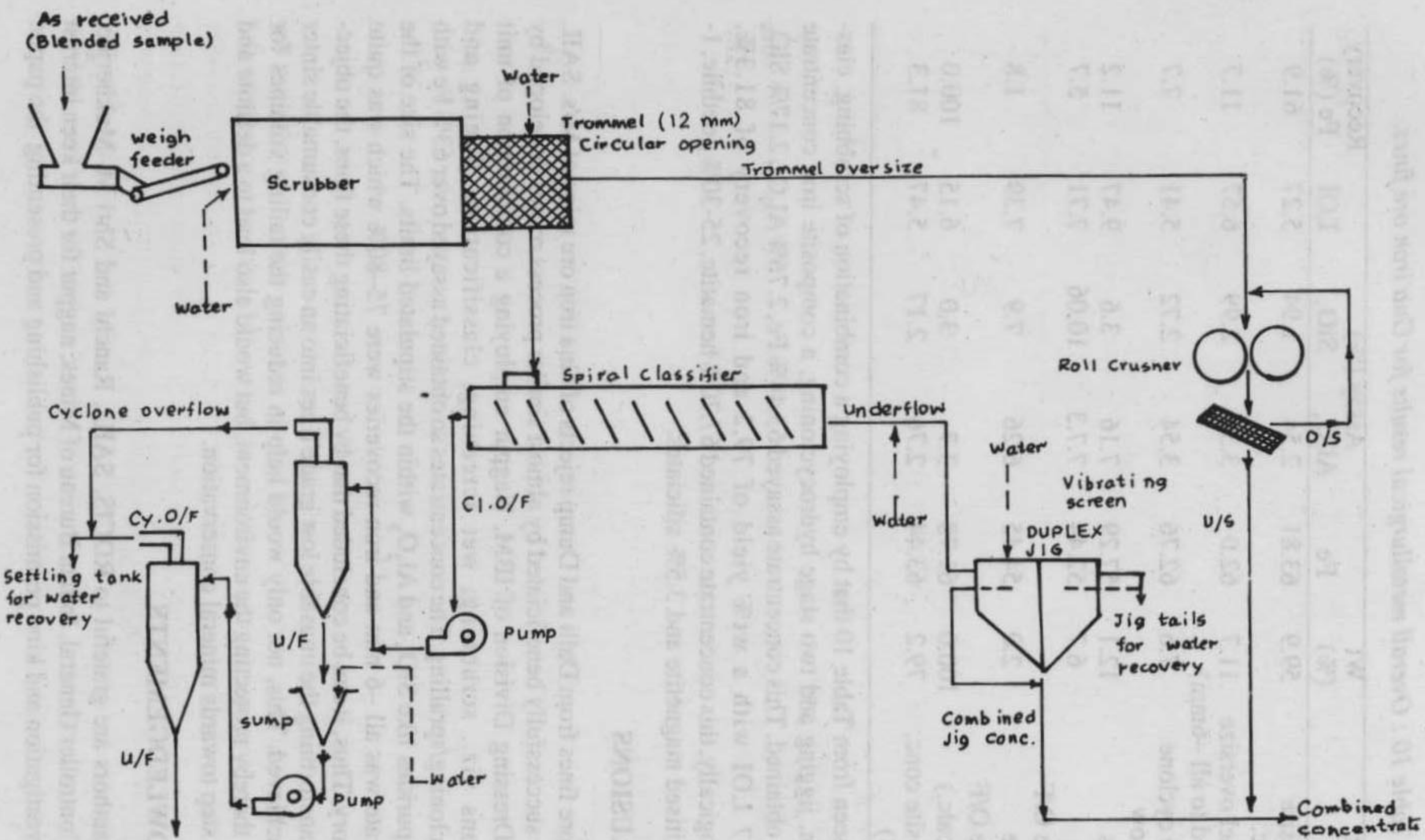

Fig. 2 : Process flow sheet for beneficiation of iron ore fines from reject dumps, Gua Mines, Bihar (for SAIL).

Table 10 : Overall metallurgical results for Gua iron ore fines

Product	Wt (%)	Assay (%) Fe	Al_2O_3	SiO_2	LOI	Recovery Fe (%)
Composite jig conc.	59.9	63.81	2.54	1.94	5.27	61.9
Trommel oversize (crushed to all –6mm)	11.7	62.0	3.39	2.99	6.57	11.7
II stage cyclone underflow	7.6	62.76	3.54	2.72	5.41	7.7
Jig tails	12.1	57.29	7.16	3.6	9.47	11.2
I stage cyclone O/F	6.7	52.44	7.7.3	10.06	7.71	5.7
II Stage cyclone O/F	2.0	54.45	6.26	7.9	7.39	1.8
Head (calc.)	100.0	61.78	3.7	3.0	6.15	100.0
Composite conc. (1+2+3)	79.2	63.44	2.76	2.17	5.47	81.3

It is seen from Table 10 that by employing a combination of scrubbing, classification, jigging and two stage hydrocycloning, a composite iron concentrate could be obtained. This concentrate assayed 63.44% Fe, 2.76% Al_2O_3, 2.17% SiO_2 and 5.47 LOI with a wt% yield of 79.2 and iron recovery of 81.3%. Mineralogically, this concentrate contained 67.70% hematite, 25-30% goethite, 1-2% martitised magnetite and 3.5% siliciates.

CONCLUSIONS

Iron ore fines from Dalli and Dump rejects of Gua iron ore mine of M/s. SAIL could be successfully beneficiated by almost similar process routes developed by the ore Dressing Division of IBM, Nagpur employing a combination of unit operations viz., scrubbing, wet screening, classification, jigging and hydrocycloning/spralling. The concentrates so obtained assayed over 63% Fe with other impurities like SiO_2 and Al_2O_3 within the stipulated limits. The size of the concentrate was all –6 mm and iron recoveries were 75–80% which was quite satisfactory. Thus, it can be concluded that by beneficiating these fines, the objective of transforming the unusable low grade fines into an easily consumable sinter feed is achieved. This, not only would help in reducing the tailing volumes for disposal thereby protecting the environment, but would also lead to a definite and positive step towards mineral conservation.

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