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ORIGINAL CONTRIBUTION

Processing of Goethitic Iron Ore Fines

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Abstract In the present investigation an attempt has been made to beneficiate goethitic iron ore containing 59.02 % Iron, 6.51 % Alumina, 4.79 % Silica, 0.089 % Phosphorus with 7.11 % loss on ignition. For this purpose, different beneficiation techniques such as gravity and magnetic separation processes have been employed. During the process two conceptual flow sheets were also developed for the beneficiation of goethite iron ore fines. In the prsent work it was possible to enhance grade of iron to 63.35, 63.18, and 65.35 % from Jigging, Multi Gravity Separation (MGS) and Wet High Intensity Magnetic Separator (WHIMS) respectively.

Keywords Goethitic iron ore · Jigging · MGS · WHIMS

Introduction

India is bestowed with rich iron ore resources which widely vary in their mineralogical association as well as geographical locations [1]. In the recent years, it has been observed that mining and processing activities, with special reference to iron ore, has increased by many folds. The enhancement of these activities has also increased complex mineralogical nature and degree of fineness of the ore mineral [2]. Apart from enhanced mining and processing activities, it may be observed that demand for the production of steel worldwide has necessitated effective utilization of low grade and finely disseminated iron ores [3]. Currently the low grade ore, fines and rejects are dumped and they are left unutilized. In India, for economic reasons and for increased efficiency of blast furnaces, there is a need for beneficiation of raw materials. Over the next few years, demand for Indian iron ore is expected to rise by more than 200 million tonnes per year for meeting the internal and external demand. Further, it has been observed that, over the years there is a change in the nature of the feed, particularly of iron i.e., from a totally lump oriented feed to those used for production of sinters and pellets. Therefore, the requirement of fines has gone up considerably. Hence, the emphasis on enriching the quality of fines through techno-economically viable beneficiation process has become more essential. It is in this regard that many attempts have been made by the various researchers to beneficiate such ores. However, the various methods employed for their beneficiation have proved to be uneconomic. These methods include Flotation, WHIMS, Gravity concentration process etc. [4, 5].

From the literature it may also be seen that Singhbhum, Odisha iron ore belt hosts important iron ore deposits with wide variety of mineralogical association and they are also characterized by the high alumina content. It is also reported that the ore in the particular belt has attained more complex and powdery nature and needs spiral technique for beneficiation process [1, 6, 7]. However, in India, there is considerable debate on the technology to adopt for the processing of such iron ores. Therefore, there is need for a tangible beneficiation technology to address various related issues with reference to low grade iron ore beneficiation [8]. Here it may be noted that goethitic iron ore fines are not being utilized in pelletization process because of the presence of combined moisture in it as well as high LOI. Goethitic iron ore is present in hydroxide form and leads to disintegration of pellets during firing process. Hence, it is in this direction an attempt has been made to study the processing of low grade goethitic iron ore fines obtained

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from Singhbhum, Odisha belt. The major objectives and scope of the present were included beneficiation of low grade iron ore from goethitic iron ore dump by employing various techniques such as jigging, MGS and WHIMS for its suitable use in further processes such as pelletization.

Raw Material and Benficiation Process Adopted

Iron ore fines from the dump were collected from Gua iron ore mines, Jharkhand. Chemical analysis of iron ore are shown in Table 1 and size-wise chemical analysis is shown in Fig. 1. For jigging, +0.5 mm samples were used and −0.5 mm samples were subjected to multi gravity separation. The tailings of multi gravity separation were fed to wet high intensity magnetic separator for their beneficiation. Prior to the beneficiation studies, detailed characterization studies on the sample were carried out and are discussed in the following sections.

Microscopic Study

The mineralogical analysis of iron ore samples were carried out using reflected light microscope. The studies indicated varying amounts of hematite, goethite, in association with quartz and claymass on the gangue forming minerals. Alumina was mainly contributed by clay, lateritic material and gibbsite and some alumina occurred as solid solution in iron oxide minerals such as, goethite and limonite. Hematite was observed to be laminated and speculeritic in nature as shown in Fig. 2a. Most of the bulk ore sample contained numerous cavities exhibiting colloidal textures with concentric zoning as shown in Fig. 2b.

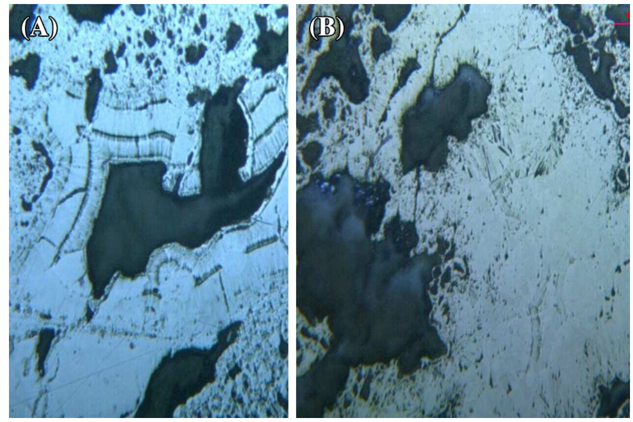

Fig. 2 Micrograph of goethitic iron ore sample. **a** Goethite exhibiting colloform texture and growth zoning character. The cavities were often filled with clayey material. In the periphers some microplaty hematite grains was also seen as microbands. **b** Massive to colloidal secondary hydroxy minerals like goethite and limonite was seen along with cavities

Table 1 Chemical analysis of iron ore

Constituents	Fe_2O_3	Fe (T)	Al_2O_3	SiO_2	CaO	MnO	P	K_2O	FeO(OH)
Wt%	69.00	59.03	6.51	4.79	0.1	0.089	0.089	0.085	11.63

LOI 7.11 loss on ignition

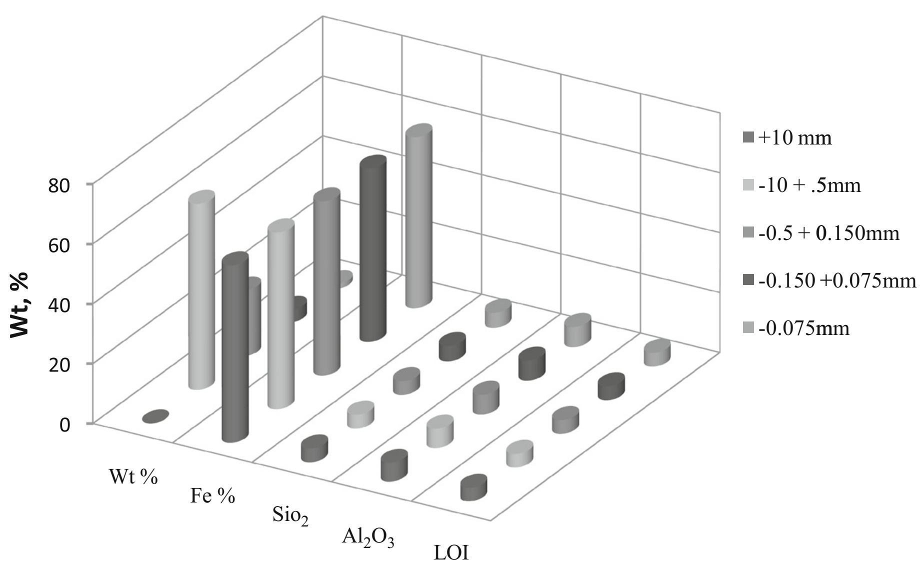

Fig. 1 Size wise chemical analysis

Table 2 Mineral analysis of iron ore fines

Minerals	Av. weight %
Hematite	69
Goethite	15
Kaolinite	6
Gibbsite	5
Limonite	1
Martite	3

The general mode of occurrence of aluminous minerals in the ore is as coating on lumps, as cavity fillings or as lateritic material. From the microscopic study, the various mineral phases observed in the samples were hematite, goethite, limonite, martite, kaolinite and gibbsite. The mineralogical analysis of the feed is shown in the Table 2. From the mineralogy, it may be also seen that magnetite grains completely transfer to the martite/hematite due to oxidation. The iron ore mineral present included oxy-hydroxy forms like martite (oxidation of magnetite to hematite) and lesser goethite.

TGA and DTA Studies

Thermo gravimetric analysis was carried out by using a modal STA449 F3 Jupiter. TGA/DTA of untreated sample was carried out in air in the temperature range 30–1000 °C at a heating rate of 10 °C/min. Nitrogen (99.99 % N_2) was used as an inert gas and 16.0 ± 0.1 % O_2 in N_2 was used as the oxidizing gas. The results of TGA/DTA are shown in Fig. 3, which indicates multiple weight losses in the temperature range 25–145 °C (∼1.83 %), and small changes in temperature range 375–660 °C (∼5.51). The first stage weight loss (∼5 %) was attributed to physically adsorbed water molecules. The second and third stage losses are mainly attributed to release of structural water from hydrous oxides. The total weight loss (∼7.34 %) compares well with the data obtained from loss on ignition.

Beneficiation Studies

In the first stage of beneficiation, gravity and magnetic separation methods such as, jigging, multi gravity separator and wet high intensity magnetic separator have been used. After sizing, on the basis of microscopic properties, further it was classified by sieve analysis. +0.5 mm size fraction was subjected to jigging and for −0.5 mm multi gravity separator wet high intensity magnetic separator were used.

Jigging

For this purpose, coarser fractions of +0.5 mm size were subjected to beneficiation using laboratory scale batch type jig. During the study, effects of stroke rate and water flow rate were investigated.

Effect of Stroke Rate and Water Flow Rate

For this purpose, three stroke rates 2, 3 and 4, stroke/min with water flow rate 1000–3000 l/min were used. The results of this study are given in Figs. 4, 5 and 6. It may be observed that grade of iron increases with increase in flow rate and a maximum of 63.35 % Fe was obtained with recovery of 70.54 % (Fig. 5) during the test at a stroke rate s/min. During the process it was also observed that alumina content was decreased to 4.01 and silica content decreased

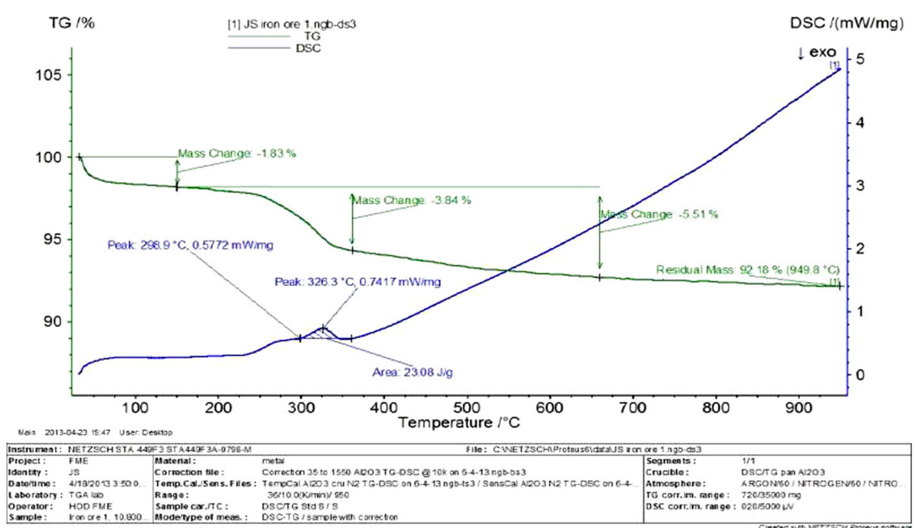

Fig. 3 TGA/DTA of iron ore fines

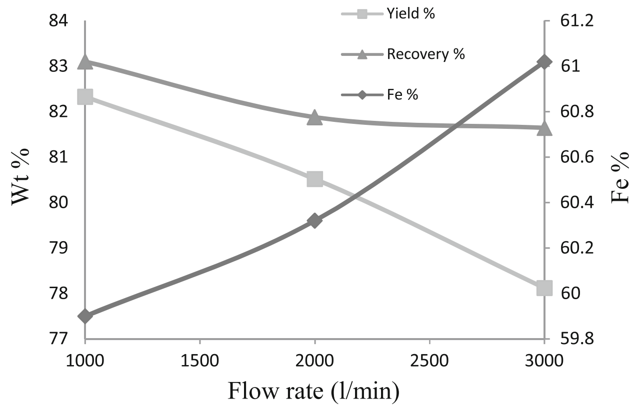

Fig. 4 Effect of water flow rate on yield and grade of concentrate at stroke rate 2

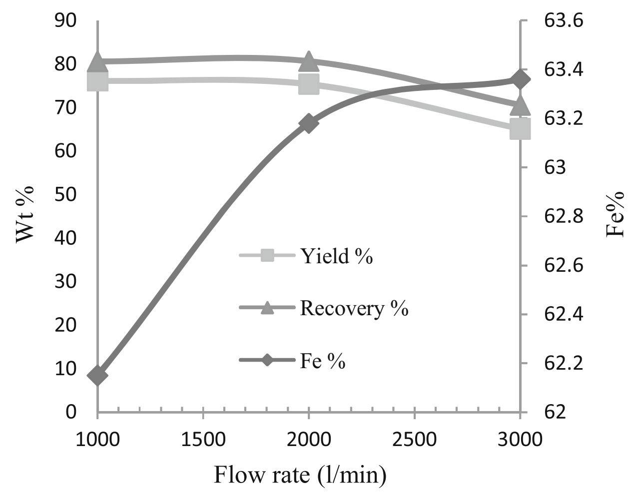

Fig. 5 Effect of water flow rate on yield and grade of concentrate at stroke rate 3

1.94 %. This clearly shows that the effectiveness of the separation was influenced by the operating variables of the jig and the particle size of the iron ore. Lower separation efficiency in finer particles is believed to be caused by the negligible mass associated with these size particles. A particle, which settles in accordance with Stoke's law, are unsuitable for concentration. From the recovery obtained, it may be said that concentrate grade is good enough to be acceptable as feed material for sintering & pelletizing.

MGS (Multi Gravity Separation)

The multi-gravity separator (MGS) is a separation device designed to use several of the traditional gravity separation techniques in one machine, allowing a separation of finer size materials or materials with much closer specific gravity than any of the traditional methods. Typical applications of the device include the recovery of valuable

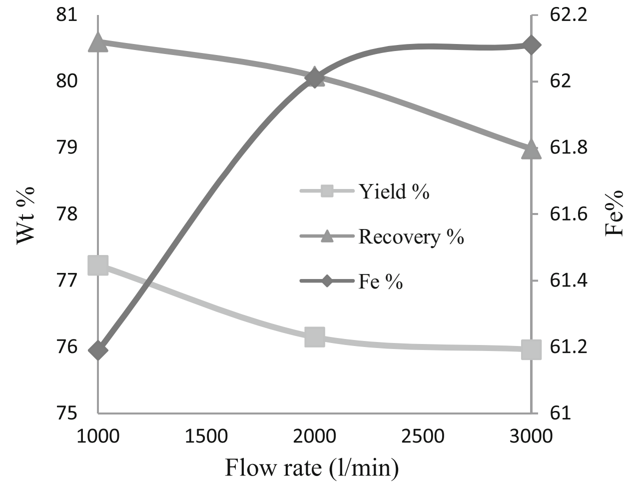

Fig. 6 Effect of water flow rate on yield and grade of concentrate at stroke rate 4

minerals from tailings or slime streams; pre-concentrating heavy mineral sands or industrial minerals; upgrading flotation concentrates; concentrating base metal oxides etc.

Further studies were carried out using multi gravity separator having −0.5 mm size fraction. The size fraction with size analysis having (−0.5 + 0.150 mm) 79.19 %, (−0.150 + 0.075 mm) 15.21 % and (−0.075 mm) 5.6 % was subjected to multi gravity separation. During this study, effect of different parameter such as drum speed and water flow rate was investigated on the yield and grade concentrate. The drum was rotated at 125, 150, 175 rpm and water flow rate was varied to 500, 1000, 1500 1/min. The results of the studies are shown in Figs. 7, 8 and 9. From the result it may be observed that better grade of the iron (63.18 %) can be obtain with recovery of 40.00 % at a drum speed of 175 rpm (Fig. 9). The typical results of the effect of drum rotational and wash water on recovery of mineral values are shown in Figs. 7, 8 and 9. As it can be seen from Fig. 8, with an increase in drum speed from 150 rpm, the grade increases however, yield was found to decrease. During the process, silica and alumina content were found to be 1.94 and 3.15 % respectively.

WHIMS (Wet High Intensity Magnetic Separator)

Wet high intensity magnetic separator was used for beneficiation of rejects obtained by multi gravity separator. During the study, effect of magnetic field intensity and slurry flow rate on the grade and yield of the concentrate was investigated. Further, beneficiation test were carried out using WHIMS and these results are given in Figs. 10, 11, and 12. During the study, magnetic field intensity was varied from 16 to 20 k/gauss and water flow rate from 1 to 2 l/min. From the results it was possible to obtain a

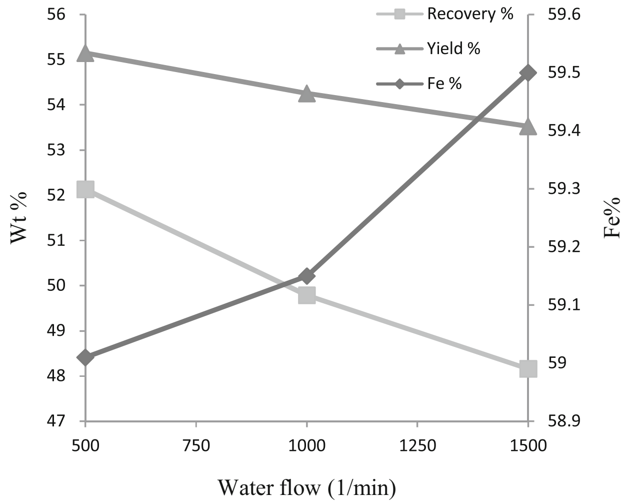

Fig. 7 Effect of water flow rate on the yield and grade of concentrate at a drum speed of 125 rpm

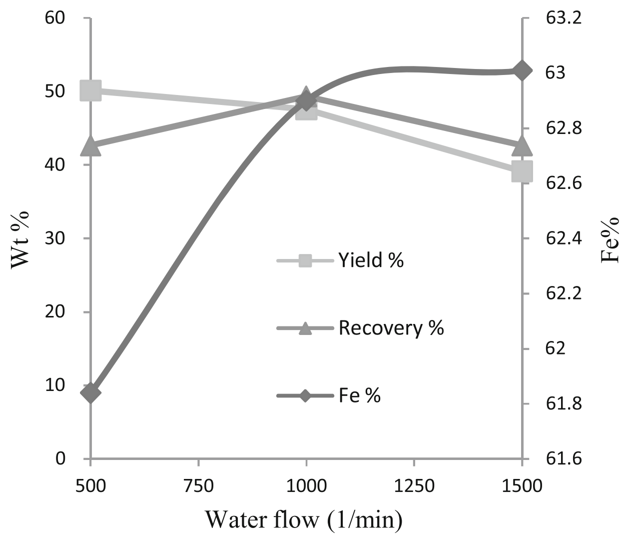

Fig. 8 Effect of water flow rate on the yield and grade of concentrate at a drum speed of 150 rpm

maximum of 65.35 % Fe with the recovery of around 35.00 %. It was also observed that there is a marginal decrease in grade with increase in field intensity. The results are clearly shown in the Figs. 11 and 12. The results show that the yield was relatively 35 % with alumina of 3.16 and 1.52 % silica. Based on the beneficiation test discussed earlier, conceptual flow sheet has been developed and is given in Fig. 13.

Second Stage Beneficiation

In the second stages of investigations, beneficiation technique such as multi gravity separation & WHIMS were used without classification of the mineral. Results of this

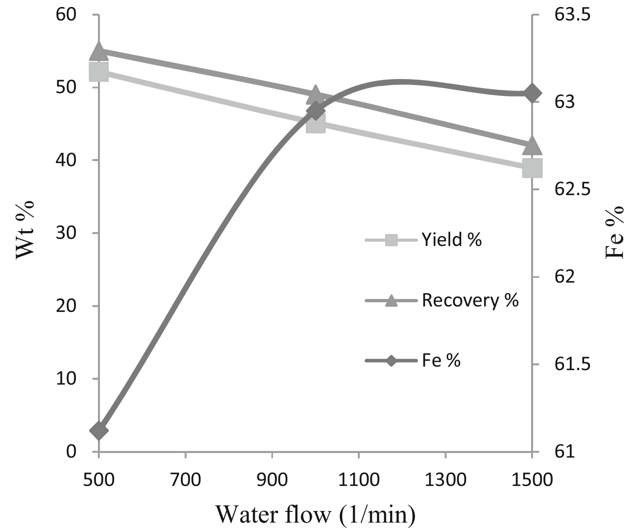

Fig. 9 Effect of water flow rate on the yield and grade of concentrate at a drum speed of 175 rpm

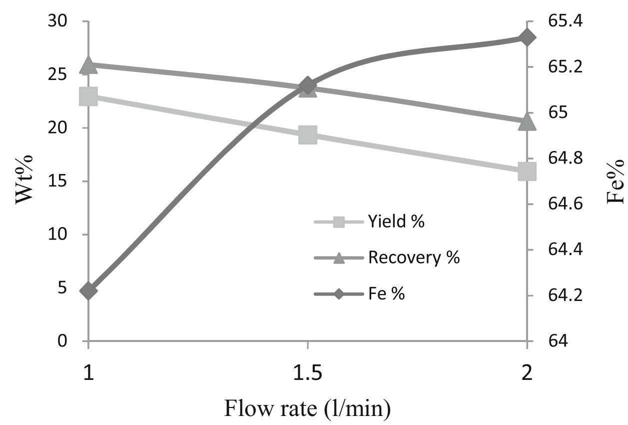

Fig. 10 Effect of slurry flow rate on the grade and yield of concentrate at 16 gauss field intensity

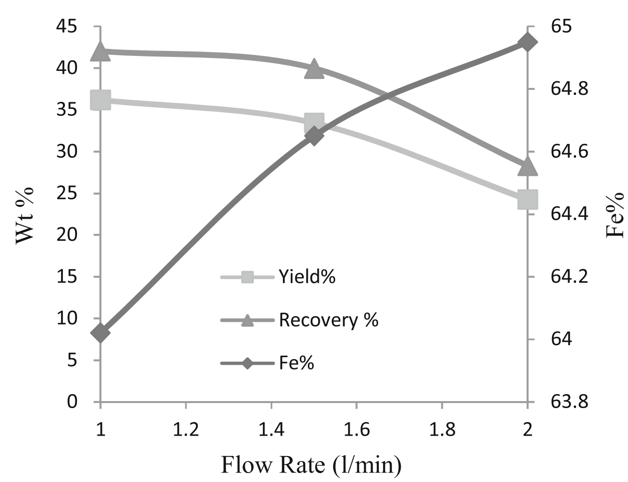

Fig. 11 Effect of slurry flow rate on the grade and yield of concentrate at 18 gauss field intensity

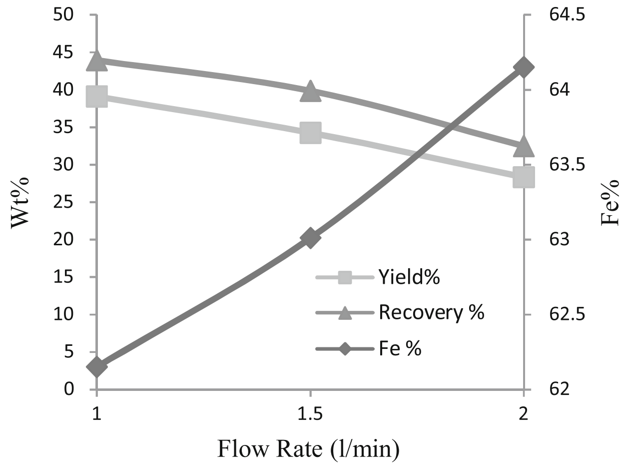

Fig. 12 Effect of slurry flow rate on the grade and yield of concentrate at 20 gauss field intensity

Table 3 Results of MGS after grinding of dump fines in second stage. Yield of Conc. 49.36 % and Yield of Tailing 50.64 %

MGS constituents	Feed (wt%)	Concentrate (wt%)	Tailing (wt%)
Fe (T)	58.90	63.89	53.63
SiO_2	4.70	1.78	7.76
Al_2O_3	6.34	3.19	9.76
LOI	6.50	3.63	4.60

Fe (T) total Fe grade %

Table 4 Results of WHIMS test on reject of MGS in second stage. Yield of Conc 32.36 % and Yield of Tailing 67.64 %

WHIMS constituents	Feed (wt%)	Concentrate (wt%)	Tailing (wt%)
Fe (T)	53.63	65.18	48.63
SiO_2	7.76	1.72	10.36
Al_2O_3	9.76	3.15	12.76
LOI	4.60	4.16	5.60

Fe (T) total Fe grade %

study are presented in Tables 3 and 4. From Table 3 it is seen that a maximum of 63.89 % Fe with recovery of around 55.00 % was obtained. From this study it was also possible to reduce alumina and silica to 3.19 and 1.78 % respectively. Similarly, studies carried out using wet high intensity magnetic separation indicated 65.18 % Fe in the concentrate along with 57.00 % recovery. Alumina and silica were found to be 3.15 and 1.72 % respectively. Based on the results obtained, a flow sheet was developed as shown in Fig. 14. From the flow sheet it may be said that dump fines can be beneficiated effectively using MGS and WHIMS without any classification. Similarly, the concentrate produced from the flow sheet (Fig. 14) was suitable for the pellet/sinter making.

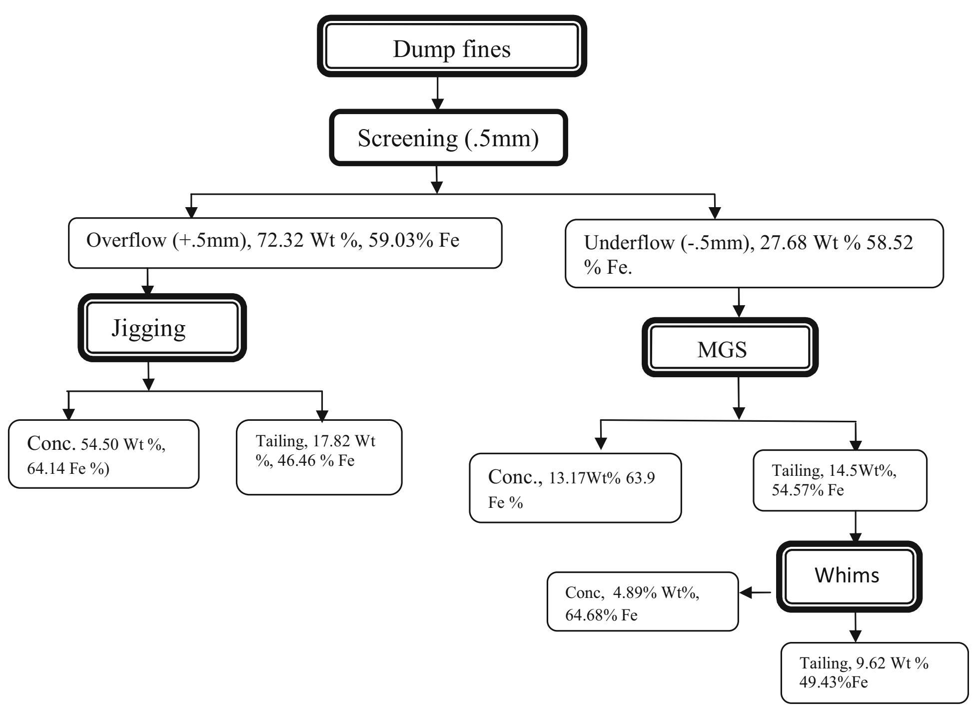

Fig. 13 Flow sheet for beneficiation of goethitic iron ore fines with classsification

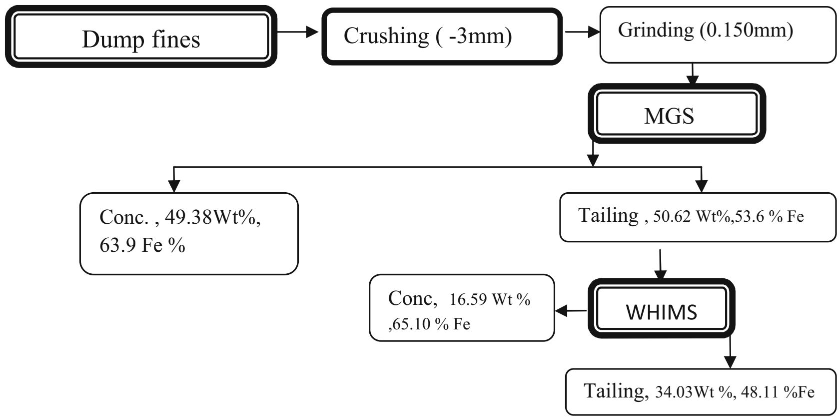

Fig. 14 Second stage flow sheet for beneficiation of goethitic iron ore fines without classification

Conclusions

Based on the results obtained and discussion the following conclusions are drawn:

- From the studies it was possible to upgrade iron to 63.00–65.00 % with an average recovery of 70.00 % using different studies carried out in the present investigation. The studies carried out without classification indicated maximum of 65.00 % Fe in the concentrate with more than 60.00 % overall recovery obtained using WHIMS and MGS.
- Reduction in alumina content was less in comparison with silica reduction. This may be attributed to presence of unliberated alumina in the iron mineral matrix.
- Based on the studies, two conceptual flow sheets (with or without classification) have been developed, which may be adopted for beneficiation of low grade goethitic dump fines.

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