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CHARACTERIZATION AND ITS IMPLICATION ON BENEFICIATION OF LOW GRADE IRON ORE BY GRAVITY SEPARATION

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ABSTRACT

Studies were undertaken on low grade iron ore sample from Noamundi iron ore mines. The objective of this study was to examine the possibility of the physical beneficiation of low grade iron ore sample by physical methods for the blast furnace route of iron production. The present investigation relies on petrography and ore mineralogical characterization, ore textures (primary, secondary, metamorphic), liberation characters and its impact on the mineral beneficiation methods to produce quality concentrate. The geological characters, alteration mineralogy, morphometric variation, ore microscopy (using model microscope with transmitted and reflected light) and thereby understanding the genesis has given proper insight into the occurrence of various minerals. In addition to this, representative samples were employed for detailed investigation by using XRD, SEM-EDS and cathodoluminescence (CL) studies for confirmation of major as well as minor ore minerals and associated gangue minerals.

Investigations suggest that lateritic iron ore samples obtained from the study area are composed of hematite (two generations), goethite (two generations) and limonitic material (younger generation) in association with major gangue minerals such as clay minerals (kaolinite, illite), bauxitic minerals(gibbsite, boehmite and diaspore), cryptocrystalline silica(japer, chert) and crystalline quartz as well as apatite and collophane. Fair liberation obtained below 74 micron size. It was interesting to find that inspite of the complex mineralogy of iron ore, beneficiation results using gravity separation like multi gravity separator (MGS), particularly in finer size ranges was encouraging. The result of ore-gangue mineralogical studies were found quite useful in evaluating the separation efficacy of gravity separation process. The process mineralogical data corroborated well with beneficiation results.

Keywords : Iron Ore, Characterisation, Beneficiation, Gravity separation.

INTRODUCTION

Iron ore is an important raw material for iron and steel industry, and its quality dictates the production strategy, and ultimately, the quality and cost of steel. It is a well established fact that, higher the alumina content in the feed for blast furnaces, poorer are the properties of iron and steel, virtually on all fronts. The use of high-alumina sinter decreases the productivity of the blast furnace and also results in an increased fuel consumption rate[1]. Presence of higher alumina content in the lower grade ores is one of the major hurdles in their large scale utilization. Alumina affects the quality of blast furnace burden in a variety of ways. It has an adverse role on sinter strength, causes higher slag volume, forms a viscous slag, decreases productivity and increases fuel rates as well as energy consumption. Thus removal of alumina and other deleterious elements from iron ores leads to a better sinter product with higher reducibility, lesser slag formation and fuel consumption and better slag separation; which ultimately leads to cost efficiency, higher blast furnace productivity and better quality of steel[2].

In India, the total estimated reserve of iron ore is 18 billion tonnes[3] and annual consumption is around 90-100 million tonnes, while the anticipated demand by next two years is going to cross 140-150 million tonnes/annum[4]. Although India is blessed with high-grade iron ores, it is estimated that proved metallurgical grade iron ore is going to sustain the production and consumption for another 30-35 years only. Therefore, in view of the sustainable development, exploitation of non-renewable iron ore resources now calls for innovation of such technologies, where generation of waste is either nil or minimum or converts to by-products. It is our belief, that to engineer strategies for fulfilling the afore-mentioned objectives, an integrated approach is required which encompasses studies such as geology, ore petrology, ore microscopy and mining as well as physical beneficiation processes.

Depletion of high grade iron ore reserves coupled with increasing market pressure for good grade iron ores/

concentrates and the threat of environmental pollution has made us to realize the need to maximize the utilization efficiency of availability of large tonnage of low grade iron ores/fines containing high alumina in our country. The knowledge of the level of dissemination of gangue minerals into the matrices of iron ore minerals is useful in deciding the extent to which they require finer grinding for their effective liberation[5].

In view of the above, this study was carried out with an objective to characterize the non-usable iron ores containing alumina as high as around 10%-12% in different types of iron ores namely (i) hard iron ore, (ii) lateritic iron ore, (iii) banded hematite jasper, (iv) shaly iron ores and (v) composite ore . Selection of processes for beneficiation through ore microscopic approach and parameters optimization was the prime interest of this research study.

Noamundi iron ore, selected for this investigation, is one of the earliest iron ore mines in India. The iron ore deposits of Noamundi belong to Iron Ore Group of Precambrian age. The main rock types of Noamundi are shaly quartzite, banded hematite jasper, phyllitic shale and iron ores. Here hematite ore bodies occur on the top of hill ranges in the Iron Ore Group of Precambrian age and are associated with ferruginous shale, banded hematite quartzite (BHQ), banded hematite jasper (BHJ) etc. The general strike of the iron ore body is NNE-SSW and average dip is about 350 to 400 towards West. The iron ore body around Noamundi mainly consists of hematite and has been classified as massive, hard, laminated, lateritic, powdery, hematite breccias, consolidated hematite debris, banded hematite jasper, banded hematite quartzite and banded hematite shale, soft ore, friable, flaky and biscuity ore[6]. In addition to this, there is large tonnage of non-usable iron ores due to their high alumina content. These are categorized into four groups: (i) hard iron ore, (ii) lateritic iron ore, (iii) banded hematite jasper and (iv) shaly type of iron ores.

EXPERIMENTAL

Different types of iron ores containing high alumina namely (i) hard iron ore, (ii) lateritic iron ore, (iii) banded hematite jasper, (iv) shaly iron ores and (v) composite ore were collected from Noamundi mines for the present studies. Chemical analysis was carried out by standard wet chemical analysis procedure for determination of percentage of their constituent elements (Table-1) Their size and size-wise chemical analysis was carried out in as collected sample as well as in feed prepared for beneficiation after crushing and grinding to optimum grain size by wet size analysis. Size-wise chemical analysis of the iron ore samples collected from the Noamundi mines, (Fig. 1 and Fig. 2).

The ore was characterized by employing various mineralogical techniques e.g. ore microscopy, ore petrography, cathodolumine-scence, XRD and SEM-EDS analysis. This data has been used to understand the results of beneficiation studies, whose target was to produce iron ore concentrate suitable for use in microballing / miropelletisation, followed by sintering to prepare feed for blast furnace.

Initial beneficiation experiments were carried out on hydrocyclone and wilfley table, where clean concentrate was not obtained even after complete optimization of different parameters of the machine. During the preliminary beneficiation studies, it was demonstrated that simple techniques of crushing, scrubbing and washing of iron ores met with limited success in the reduction of alumina, due to the finely dispersed nature of gangue into the matrices of iron ore minerals[7].

Various beneficiation experiments were carried out by applying advanced gravity separation technique of Multi-Gravity Separator (MGS). MGS were performed at optimum slurry density for beneficia-tion by changing the operating parameters such as wash water, slope and rotation speed of the drum.

RESULTS AND DISCUSSIONS

Size and Chemical Characterization

Size analysis of the iron ore samples collected from the Noamundi mines, indicated two broad classes of size distribution namely, coarse distributed (66-81% above 8 mm) banded hematite jasper, shaly ore and lateritic ore, and finely distributed (36-27% above 8 mm) hard and composite ore. The Composite ore has more uniform size distribution because of its blended nature.

Chemical analysis of the samples of hard ore, lateritic ore, shaly ore and composite ore was carried out, to know the concentration of iron and presence of deleterious elements such as alumina, silica, sulfur and phosphorous. Shaly ores show higher alumina content in comparison to the other ore-types, because of the high modal distribution of clay minerals (45%-50%) in shay ores. The results of chemical analysis are presented in Table 1.

Table 1: Chemical analysis of samples for beneficiation of high alumina iron ores

Constituents	Ore type			
	Composite (C) (%)	Hard (H) (%)	Lateritic (L) (%)	Shaly (S) (%)
Fe	58.62	59.12	57.65	55.25
Al_2O_3	8.66	8.52	9.32	11.52
SiO_2	5.32	5.01	5.75	6.89
S	0.52	0.45	0.67	0.68
P	0.25	0.30	0.42	0.57

Size-wise chemical analysis of the iron ore samples collected from the Noamundi mines, indicate two broad classes of iron distribution, namely, the first type characterized by hard ore (Fig. 1) with relatively higher iron (43-60%) and lower alumina (7- 23%) and second type characterized by shaly ore with relatively lower iron (44-56%) and higher alumina (10-27%) (Fig. 2).

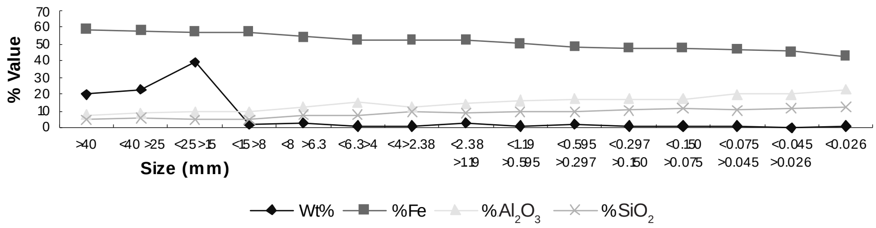


Fig. 1 : Size-wise chemical analysis of as collected sample of hard ore.

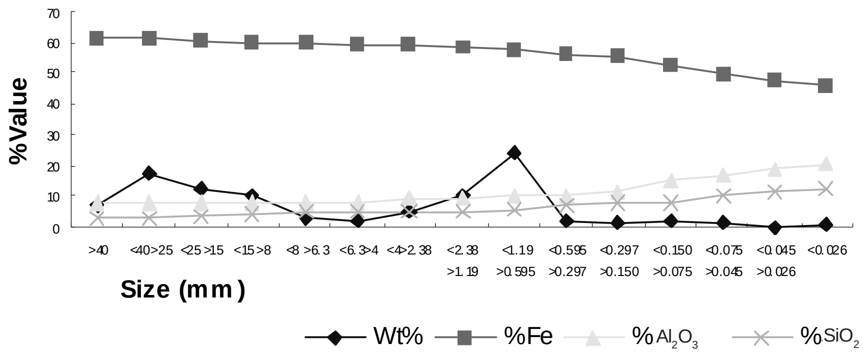
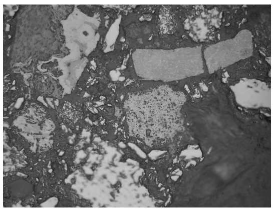


Fig. 2 : Size-wise chemical analysis of as collected sample of Shaly ore.

Microscopic Characterization

Mineralogical examination of the samples indicate that in low-grade iron ores, the phases of minerals present in order of abundance are mainly iron oxides/hydroxides, aluminous gangue, silicates and traces of sulphides. Oxide/hydroxide phases mainly comprise of hematite, goethite and limonite. Gangue mineral association (confirmed by ore petrography, XRD and SEM-EDS analysis) is mainly in the form of aluminous and siliceous minerals consisting of gibbsite, diaspore, bohemite, clays (kaolinite, illite etc), apatite, chert, collophane, jasper and quartz. Trace of sulphide phases were identified based on ore petrography and mainly comprised of pyrite, arsenopyrite, pyrrhotite, marcasite and cubanite. Detailed microscopic (transmitted and reflected light) characterization was carried out to delineate various phases, their textual arrangement, shape and size for effective liberation. The gangue minerals are mostly in disseminated form, randomly oriented and in many cases it has been observed as enclosed in a matrix of iron ore minerals such as hematite and goethite Fig. 3 (a-d). In such cases liberation of gangue minerals from the groundmass of iron ore minerals becomes difficult and very fine grinding is required for separation of gangue from the associated ore assemblages[7].

Hematite is present in varying types, sizes and shapes from 20 microns to 450 microns grains of acicular, lath shaped,



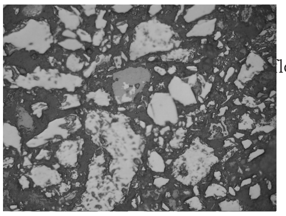
(a)
Composite ore, reflected light, (IPL) (500X)

(b)
Hard ore, reflected light, (IPL) (500X)

(c)
Lateritic ore, transmitted & reflected light (BCN) (100X)

(d)
Shaly ore, transmitted light (IPL) (100X)

(e)
BHJ ore, transmitted light (IPL)(100X)



flected Light (IPL)

(g)
Lateritic ore, reflected light, (IPL) (500X)

(h)
Shaly ore, reflected light, (IPL) (500X)

Fig. 3 : Photomicrographs of polished thick sections of processed ore of particular types (LHS: a to d) and corresponding types(except BHJ) of samples, in doubly polished thin sections (RHS: e to h), collected from Noamundi iron ore mines (study area).(IPL=In Polarized Light, BCN=Between Crossed Nichols, LHS = a - d indicate yellow/white -hematite, grey -goethite & brown-mounting medium. RHS: e, f and h indicate reddish pink-goethite / cherty quartz, red-hematite / lateritic / jasperoid, orange / yellow-limonite, light greenish-hematite, white/pale blue-open area / sample got removed during polishing. RHS:7-pale yellow-primary hematite surrounded by secondary, oolitic, gibbsitic material of younger generation; black-surrounding area must be of lateritic / jasperoid material).

equant, crystalline to irregular shapes Fig. 3 (a and d). These exhibit microbanding, microplaty, reticulate texture Fig. 3 (b and c) and varieties of colloform textures Fig. 3 (b). A variety of annealing textures and metamorphic ball textures are also observed in iron oxides, iron hydroxides, iron carbonates and iron sulfides collected from the study area. All these textures mainly indicate metamorphism of already existing sedimentary-hypogene-iron oxide ores as well as their later alteration in the form of supergene-sulphide-enrichment. Modal proportion of hematite is highest in hard ore: 40% followed by composite ore: 35%, lateritic ore: 25% and least in shaly ore and banded hematite jasper (BHJ) (around 15%). Concentration of goethite and secondary iron ore minerals e.g. limonite, specularite, siderite and martite are least in hard ore: 25%, in composite ore: 30%, in lateritic ore: 35% and the same is highest in shaly ore: 40% as it is given in Table 2. Aluminous gangue minerals are associated as surface coatings, scales, voids/fractures filers, finely disseminated and in free bauxitic/gibbsitic/kaolinitic clay. Finely disseminated aluminous gangue in modal proportion is highest in shaly ore:55% followed by lateritic : 52%, BHJ : 50% and least in hard ore: 36% (Table 3).

Table 2 : Modal proportion of minerals present in different type of iron ores

Minerals	Ore type				
	Hard (%)	Lateritic (%)	BHJ (%)	Shaly (%)	Composite (%)
Hematite	40	25	15	15	35
Goethite	15	16	15	13	15
Limonite	10	20	20	27	15
Clay	20	28	32	30	22
Quartz	15	12	18	15	13

Table 3 : Mode of occurrence of alumina constituents in different type of iron ores

Mode of occurrence	Sample type				
	Hard ore (%)	Lateritic ore (%)	BHJ ore (%)	Shaly ore (%)	Composite ore (%)
Surface coating,	12	10	10	10	11
Surface scales,	15	13	14	15	15
Void/fracture filers,	15	13	14	15	15
Fine dissemination	36	52	50	55	45
Free clay,	17	15	16	15	14

Cathodoluminescence (CL) petrography was employed on almost all the varieties of iron ores selected for the present investigation. Cold cathode instrument (CITL Mk5-1) fitted on petrological model microscope (Nikon Eclipse E600) having both transmitted and reflected light arrangements was used to record the CL emissions photographically. Different types of quartz were identified based on their variation in CL emission colors viz. blue, brown, brownish-red, violet and rarely red. This CL petrography has helped to characterize various quartz types i.e. whether magmatic or metamorphic (red or brownish red), anhydrous (blue) or diagenetic (violet)[8]. CL was also observed in authigenic clay minerals viz. kaolinite (blue) in shaly iron ores and collophene and apatite (yellow) mineral grains in the lateritic iron ores from the study area.

Beneficiation Studies

Size analysis of feed sample prepared from various types of ores indicates that shaly ore has a higher percentage of finer particles (< 60 microns) while all other types of ores produce coarser size distribution (> 60 microns). Size-wise chemical composition of the feed samples prepared for beneficiation, indicate two broad classes of iron distribution namely, the first type characterized by Hard ore with higher iron (49-60%) and lower alumina (7-16%) content in the finer fractions (Fig. 3) and the second, characterized by shaly ore with relatively lower iron (44-56%) and higher alumina (10-21%) content in similar size ranges (~500- 35 microns). Liberation studies on different grain sizes of the feed samples of hard ore, lateritic ore and composite ore have indicated that more than 90% grains are liberated below 45 micron, where as in case of shaly ore fair liberation is not obtained to the extent of below 45 microns. This is attributed to the fact that shaly ore have entirely different nature of association of ore and gangue minerals, which must have affected the grade and recovery of the concentrate considerably.

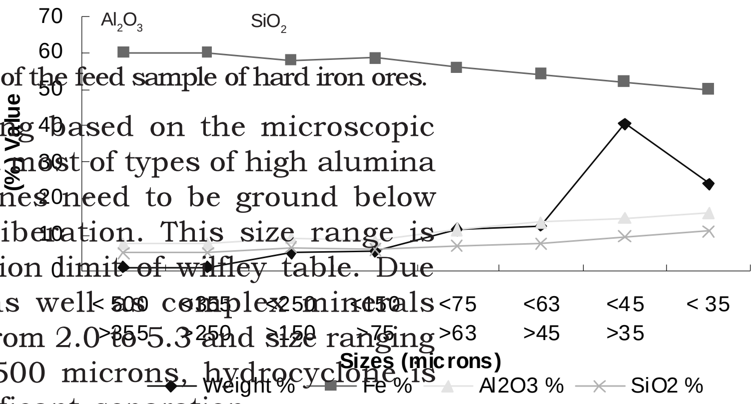


Fig. 3 : Size-wise chemical analysis of the feed sample of hard iron ores.

Separation obtained by tabling based on the microscopic examination which reveal that most of types of high alumina iron ores from Noamundi mines need to be ground below 45 microns for reasonable liberation. This size range is quite outside usable application limit of wilfley table. Due to the presence of simple as well as complex minerals having specific gravity range from 2.0 to 5.3 and size ranging from few tens of micron to 500 microns, hydrocyclone is not expected to provide significant separation

The difference between the specific gravity of secondary iron minerals such as goethite, limonite, siderite etc and associated gangue minerals like gibbsite, boehmite, jasper, chert and quartz is very small. This warrants the use of advanced techniques of enhanced gravity separation for their effective separation. Therefore studies on the separation of ground ore samples were carried out with Multi-Gravity Separator (MGS). Several preliminary experiments were carried out to know optimum slurry density by keeping other parameters constant viz. wash-water, shaking frequency, rotation per minute (RPM) of drum and deck inclination. The slurry density variables used were 10%, 15 % and 20% solid by weight. After finding optimum slurry density various experiments on MGS were performed by changing the variable parameters such as wash-water, slope and rotation speed of the drum for obtaining the higher grade of concentrate containing around 67% Fe.

Results obtained after applying the above- stated multi-gravity separation (MGS) techniques of beneficiation for all five varieties of high alumina iron ores from study area are represent that cleaner concentrate is obtained at higher rotation (RPM) of drum and wash water (LPM). Enhanced grade of concentrate is obtained in hard ore and composite ore containing more than 66% Fe at recovery of around 60% by weight. Concentration of hematite was highest (75%) in hard ore followed by composite ore (70%), lateritic ore (67%), BHJ (62%) and lowest in shaly ore (57%) as shown in Table-4. Where as in case of shaly ore and lateritic ore, desired grade of concentrate is not obtained may be due to their complex nature and intricate ore-gangue association.

Table 4 : Modal proportion of minerals present in concentrate generated by MGS from different types of iron ores

Minerals	Ore type				
	Hard ore (%)	Lateritic ore (%)	BHJ ore (%)	Shaly ore (%)	Composite ore (%)
Hematite	75	67	62	57	70
Goethite	15	18	21	21	16
Limonite	5	8	8	10	6
Clay	3	4	5	7	5
Quartz	2	3	4	5	3

These results Fig. 3 (e-h) indicate that beneficiation of high alumina iron ores depends less on the maintenance of variable operative parameters of the machine, and is more related to the nature of association of gangue minerals with iron ore minerals. From the ore petrographic and beneficiation investigations, it is opined that in case of shaly ores, even after complete optimization of the variable parameters of the operating machines, clean concentrates are not obtained. This may be due to the fact that these shaly ores have complex mineralogical composition, where gangue minerals are intricately associated in highly disseminated form, filled in voids, pores, fissures etc and with coating on iron oxide minerals like hematite, goethite etc and it appears that they are chemically combined. Due to these reasons, complete liberation and separation of iron-rich oxides and hydroxides is not possible even after very fine grinding. In the case of composite ore and hard ore samples, results show a higher grade of iron ore concentrate.

CONCLUSION

The deposition of Noamundi iron ore having similar occurrence of BIFs as that of Western Australia,North America and Canadian BIFs. Formation of iron ores are believed to be occurred by metamorphism, metasomatism, leaching, supergene oxide enrichment, replacement and weathering processes (limonitisation, lateritisation etc.).

Hard ore containing equant and platy hematite shows better separation at both coarse and fine ranges and thus shows best separation results by MGS (67.20 % Fe, 1.53 % Al_2O_3). The tailings have much lower iron (45%), which is largely occurring as particles of hematite locked inside concentric growth of limonitic material as well as encrustations of fine size hematite and goethite bands in association with gangue minerals.

Lateritic ore has hematite, goethite bands showing colloidal colloform growth, oolitic, pisolitic as well as cementing type of texture. Most of the textures will have difficulty in complete liberation of iron ore minerals as it is intimately entangled with variety of gangue minerals (lateritic, bauxitic, gibbsite, boehmite, diaspore), clay minerals (illite, kaolinite etc) as well as secondary cryptocrystalline silica material (chert, jasper, chalcedony) Thus even after fine grinding a significant amount of locked particles shall still present. This suggest that that if MGS is operated for higher grade, recoveries shall always be lower compared to those obtained for hard ore.

Shaly ore exhibits complex colloform colloidal growth as well as spheroidal growth textures: oolitic, pisolitic, colloform-colloidal banding, cavity line encrustations and disseminated nature. Overall the liberation is difficult. But in this case also, there is close association of hydrous alumina bearing minerals (such as bauxitic) which create problems in beneficiation. Ground ore has significant amount of locked particles. MGS concentrate has lower grade compared to hard ore. Microscopic examination revealed locked particles as well as clay bands interlocked with hematite and goethite.

From the ore petrographic and beneficiation investigations, it is opined that in case of shaly ores, even after complete optimization of the variable parameters of the operating machines, clean concentrates is not obtained. This may be due to the fact that this shaly ores have complex mineralogical composition, where gangue minerals are intricately associated in highly disseminated form, filled in voids, pores, fissures etc and with coating on iron oxide minerals like hematite, goethite etc and it appears that they are chemically combined. Due to these reasons, complete liberation and separation of iron-rich oxides and hydroxides is not possible even after very fine grinding.

The present investigation establishes that the role of ore-gangue mineralogy in beneficiation of complex and high alumina iron ores is very useful in formulating appropriate beneficiation process. The efficiency of separation process is further controlled by the nature of particles, their size, shape, distribution and textures. Thus process mineralogy plays an important role in beneficiation of high alumina iron ores (as shown in the present case study of Noamundi iron ore mines).

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