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Mineralogical characterization of Barsua iron ore slimes and its beneficiation through gravity and 2-stage magnetic separation techniques

In this study, characterization is done to understand the occurrence, quantity and quality of the ore and its characteristic to establish its physico-chemical properties and to pave way for its beneficiation for economic use. The results indicated the liberation size for beneficiation to be below 150 micron, contains approx. 58% Fe, 2.53% SiO_2 and 4.30% Al_2O_3. Different process such as hydro-cyclone, spiral concentrator and WHIMS were employed in series for the beneficiation of iron. The grade was significantly increased from 57.67% Fe in feed to 63.16% Fe in concentrate. Approx. 30% of SiO_2 present in feed is also reduced from 2.53% to 1.77% and approx. 50% of Al_2O_3 present in feed is removed.

Keywords: *Iron ore slime; WHIMS; spiral concentrator; hydro cyclone.*

1. Introduction

Iron and steel industry is considered as the backbone of industrial development in many countries. Mining of iron ore to supply raw materials to iron and steel making industry has major importance in iron ore beneficiation [1, 7]. The huge demand and low reserves of good quality iron ore has led to the beneficiation and utilization of low grade iron ores and iron ore slimes (or fines and ultra-fines iron ore) [2]. Major iron ore deposits occur in the eastern, central and southern parts of India in the states of Jharkhand, Odisha, Karnataka, Chhattisgarh, Goa, etc.[3, 4]. Indian iron ore are relatively rich in iron content, but also contains high amount of alumina as compared to the other major deposits of the world [4, 5]. The iron ore which is very low in grade cannot be used in metallurgical plants and needs to be upgraded to increase the iron content and reduce gangue contents [6, 7].

The comminution in order to achieve liberation of particles is economically not cost-effective because of large amount of energy consumption and also produces huge amount of fines [8, 9]. However, the enrichment of low grade iron ores involves comminution for mineral liberation which generates large amount of ultra-fines, which causes difficulty in beneficiation process [6]. Main difficulty in processing and utilization of low-grade iron ores primarily stems from their compositional characteristics as well as the separation at finer size ranges [4-10]. A detailed mineralogical characterization of iron ore is, thus, mandated as the characteristics of the ore in terms of its composition, mineral associations, etc. dictate the method of upgradation. Several techniques are available such as jigging, magnetic separation; enhanced gravity separation and floatation to enhance the quality and quantity of the Iron ore.

The understanding of the occurrence, quantity and quality of the ore plus its properties and characteristics is important in a bid to pave the way for its exploitation for economic use. From mineral processing point of view, it is important to identify the valuable and gangue minerals (mineralogical study), and their textural relationships (grain size, inter-granular relationship, relationship, inter growths etc.) [11]. It is also important to find out the distribution of valuable ore and gangue minerals which decide the grade of ore.The grain size of the minerals and their textural relationship helps in resolving the size reduction and liberation in mineral processing [10]. An effective liberation of gangue minerals and ore minerals influences the optimum separation efficiency. Thus it is important to characterize before subjecting to processing for high process and separation efficiency [5]. Therefore, that a precise understanding of the mineralogy, structure and texture of the ore would enable the selection of an appropriate methods of beneficiation, which is techno-economically viable and environmentally amenable. The paper outlines the characterization and preliminary beneficiation studies carried out on Barsua iron ore.

2. Material and methods

2.1 Sample description

The sample was collected from SAIL, Tensa, Barsua, India. Approximately 400 kg of ROM iron ore fines (mainly below 6 mm), was mixed thoroughly, prior to sampling. The sample was prepared, through a series of riffling, coning and

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quartering to obtain a representative sample for detailed characterization and beneficiation studies. The chemical analysis of bulk sample is represented in Table 1.

TABLE 1: BULK ANALYSIS OF THE SAMPLE

	Fe%	SiO_2%	Al_2O_3%	LOI%
ROM ore	57.67	3.52	6.29	6.93

2.2 CHARACTERIZATION STUDIES

2.2.1 Size and size-wise chemical analysis

The representative sample was subjected to size analysis by wet sieving method using series of BSS standard sieves. The retained fractions over different sieves were then dried, weight attained, weighed and stored in an air tight poly-bag for further studies. Size analysis of sample was carried out and the results are given in Fig.1

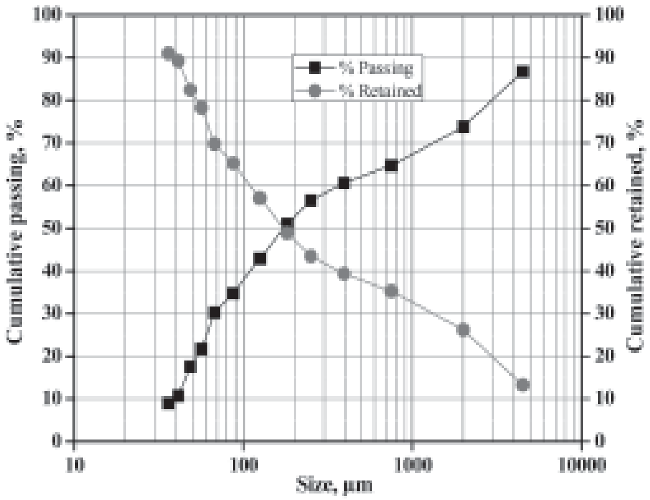

Fig.1 Size analysis of feed sample

Average size of the sample (d_{80}) was found to be 1.9 mm. The weight percentage of +1mm fraction is around 26% whereas higher proportion of material lies in the size range -150µm to +50 µm. The size wise chemical analysis of the samples was carried out to determine Fe, Al_2O_3, SiO_2, S and P contents. Table 2 presents the percentage of Fe, Al_2O_3, SiO_2 and LOI in size fractions.

TABLE 2: RESULTS OF SIZE-WISE CHEMICAL ANALYSIS

Size range, µm	Wt.%	Fe%	SiO_2%	Al_2O_3%	LOI%
-6000 +1000	26.16	52.73	6.42	9.34	8.70
-1000 +150	22.78	53.01	6.06	8.91	8.84
-150 +53	29.34	59.64	2.74	5.68	6.06
-53	21.72	61.19	2.80	4.64	4.78

2.2.2 X-ray diffraction and microscopic analysis

The X-ray diffraction analysis was conducted using Panalytical XRD spectrometer (Model XPERT-PRO) fitted with a goniometer PW3050/60. The anode material used was copper, and the generator settings were maintained at 30mA and 40kV. The X-ray patterns were acquired in the 2θ range 10- 90° with a step size of 0.001°/s. The room temperature was maintained at 25ºC during the measurements. The major minerals were identified based on the ratio of the peak heights of the most notable peak of each mineral [12].

X-ray diffraction methods are the most effective methods for determining the crystal structure of materials. The diffraction methods can be used for the identification of chemical compounds from their crystalline structure and also the different compounds (or phases) that have the same composition can be identified [13]. The minerals were identified by standard JCPDS data file [12]. XRD analysis revealed that the major iron bearing opaque minerals are hematite followed by goethite [FeO(OH)]. The hydroxide mineral identified is gibbsite ($Al(OH)_3$). The silicate gangue minerals identified are quartz (SiO_2) and kaolinite ($Al_2Si_2O_5(OH)_4$) (Fig.2).

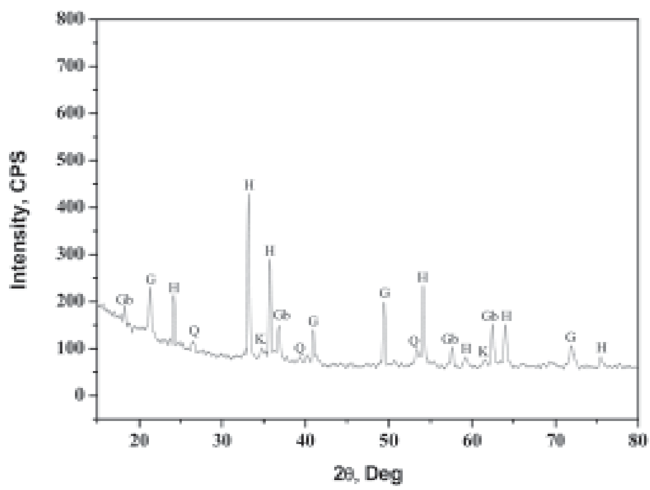

Fig.2 XRD patterns of Barsua iron ore feed represent the presence of hematite (H), goethite (G), gibbsite (Gb), kaolinite (K) and quartz (Q) minerals

Though this is a semi quantitative analysis, it is clearly visible that hematite and goethite are highly distributed at finer size fractions, but gangue elements such as gibbsite, quartz and kaolinite are highly concentrated at coarser sizes.Interlocking of particles is more at coarser fraction and lesser at finer fraction. Maximum percentage of free particles was found to be present at finer fraction. Maximum liberation can be acquired at finer fraction. Table 3 and Fig.3 show 150 µm, near about 85% could be found.

Leitz petrological microscope was used to carry out microscopic studies at different size fractions. The microscopic analysis deals with the geological aspects of the ore and provides information on the types of the ore formations [3-4]. Microscopic studies including counting and determination of the size of liberation indicate that the iron ore sample contains hematite and goethite and that they are interlocked very intimately and intricately along the clayey

TABLE 3: DATA REPRESENTATION OF MICROSCOPIC STUDY

Size, µm	Hematite (%)	Goethite (%)	Magnetite (%)	Interlocked (%)	Free gangue (%)	Other trace elements (%)
-6000+150	42.0	23.4	5.5	24.1	4.5	0.8
-150 to 0	47.5	27.0	4.5	15.0	5.4	0.6

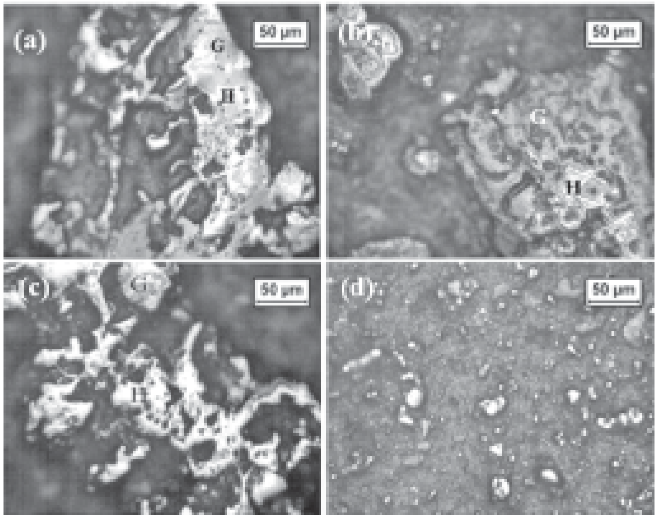

Fig.3 (a-b) Hematite and goethite interlocked very intimately and intricately along with the clayey matrices; (c) Occasionally goethite encloses patches of hematite (white); (d) General view of the hematite grains within the clayey matrices

matrices while quartz, gibbsite and kaolinite occur as gangue minerals. Quartz appears as minute grains of different sizes (as shown in Fig.3). The findings were similar to that of XRD analysis.

2.2.3 Scanning electron microscopic-electron dispersive spectroscopy (SEM-EDS)

Scanning electron microscopic (SEM) analysis was performed using a FEI 430 Nova nano-scanning electron microscope, equipped with a tungsten filament coated with zirconium oxide. The acceleration tension was kept at 15 kV for all the measurements.

SEM analysis gives the details of the individual minerals present in the ore, the crystal structure, hardness, abrasivity etc. and helps us to know about the morphology and elemental distribution of the minerals. It can give the result of intimate association of concentrate and gangue, such as hematite and goethite with kaolinite, gibbsite and quartz. SEM photomicrograph with EDX and their results are presented in Fig.4. This shows hematite grains stacked upon one another with some amount of goethite. The presence of clay is found to be less in comparison to alumina and quartz. EDX analysis represents the number of elements and their quantity present in the sample.

2.3 BENEFICIATION STUDIES/EXPERIMENTAL

The liberation study stated higher iron content is present in fines as comparison to coarser fraction and also beneficiation can be better for particles below 150 µm. The fines removed from ROM fines were treated with series of processes to recover fines and improve their grade. It involved hydro-cyclone, spiral concentrator, wet high intensity magnetic separator were used. The pulp density of 20% was used in the study. Detail flow chart is shown in Fig.5.

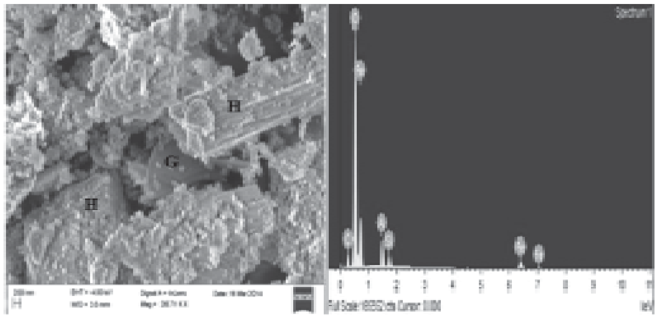

Fig.4 SEM images (hematite grains stacked upon one another with some amount of goethite) with energy dispersive spectroscopy

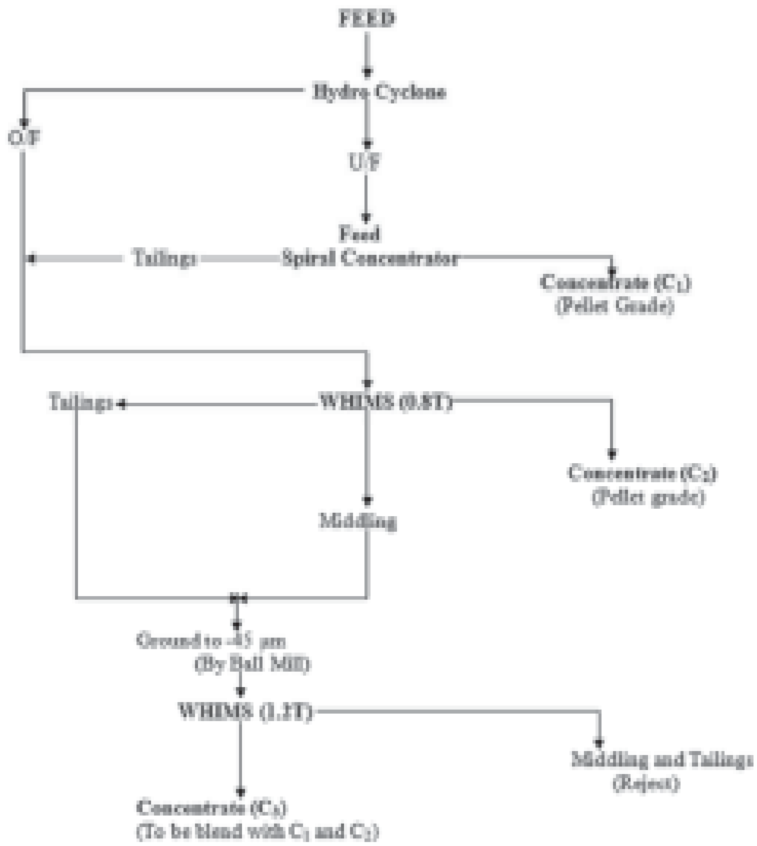

Fig.5 Process flow diagram

In the first step, hydro-cyclone was used for the removal of fines. The fines were collected in overflow and coarser, heavier in the under flow. In which more iron content (61.15% Fe) was reported. The underflow of hydro-cyclone was then ground to particle size below 150 µm. The underflow of hydro-cyclone was fed to spiral concentrator. Again, the tailings of spiral were blended with overflow of hydro-cyclone and used as feed for WHIMS Stage-I as because still some concentration of Fe was there to recover (Table 4). The magnetic field intensity was maintained at 0.8T. The tailings of WHIMS Stage-I were ground to below 45µm and again subjected to WHIMS Stage-II with increased magnetic intensity of 1.2T, for the separation of magnetic and non-magnetic particles present in the tailings of WHIMS Stage-I, thus grade of feed was increased over series of steps. The concentrate and rejects of each step and mixture of spiral tailings and overflow of hydro-cyclone were subjected to chemical analysis for % Fe, % SiO_2, % Al_2O_3 (Fig.6).

3. Result and discussions

As from the characterization studies, feed size of particle below 150 µm is used for the separation of iron and gangue minerals. The multiple stages of processes were used in this study for the beneficiation of fines. Layout of process flow of iron ore processing is formatted in the above flow chart. The feed subjected to hydro-cyclone was classified into two fraction based on the specific gravity and size of particles due to effect of centrifugal force and drag force. Thus heavier and coarser fraction with higher Fe content is reported in underflow leaving lighter and finer fraction in overflow. From the study, it was found that there is a small decrease in gangue content (2.53% to 2.22%) but the percentage of iron increased from 57.67% to 61.15%, but the increment in grade is not good enough for the purpose of pelletization. Thus the further beneficiation is required to get that grade. The results of hydro-cyclone were tabulated in Table 5.

In next stage, the underflow of hydro-cyclone was used as feed for spiral concentrator. The grade of iron was improved from 61.15% to 63.54%. The gangue minerals were also removed. The silica content is reduced from 2.22 % to 1.55%, similar behaviour found for alumina. The alumina was reduced from 3.49% to 1.96% (as mentioned in Table 5). The tailings of spiral concentrator was blended with overflow of hydro-cyclone and used as feed for WHIMS Stage-I. The magnetic field intensity was maintained at 0.8T. The magnetic separator increased the grade of iron from 55.76 to 63.19%.The reduction in silica and alumina is found to be significant. The silica was reduced

TABLE 4: PERFORMANCE OF DIFFERENT PROCESS AT DIFFERENT STAGES

Hydro cyclone (2", feed size 150 µm, pulp density 20%)				
	Fe%	SiO_2%	Al_2O_3%	LOI%
Feed	57.67	2.53	4.30	6.23
Underflow	61.15	2.22	3.49	5.97
Overflow	53.8	4.60	9.09	8.90
Spiral concentrator				
Feed	61.15	2.22	3.49	5.87
Concentrate	63.54	1.55	1.96	4.97
Tailing	56.98	2.90	6.33	8.12
Wet high intensity magnetic separator stage-I (0.8T)				
($Cyclone_{O/F}$ + $Spiral_{Tailing}$) feed	55.76	4.45	6.37	7.36
Concentrate	63.19	2.07	2.33	5.09
Middling	53.03	5.36	7.84	8.94
Tailing	47.23	7.84	11.98	10.16
Wet high intensity magnetic separator stage-II (1.2 T)				
Feed	49.84	6.85	10.40	9.69
Concentrate	61.99	2.50	3.15	5.41
Tailing	37.96	11.95	17.85	13.66

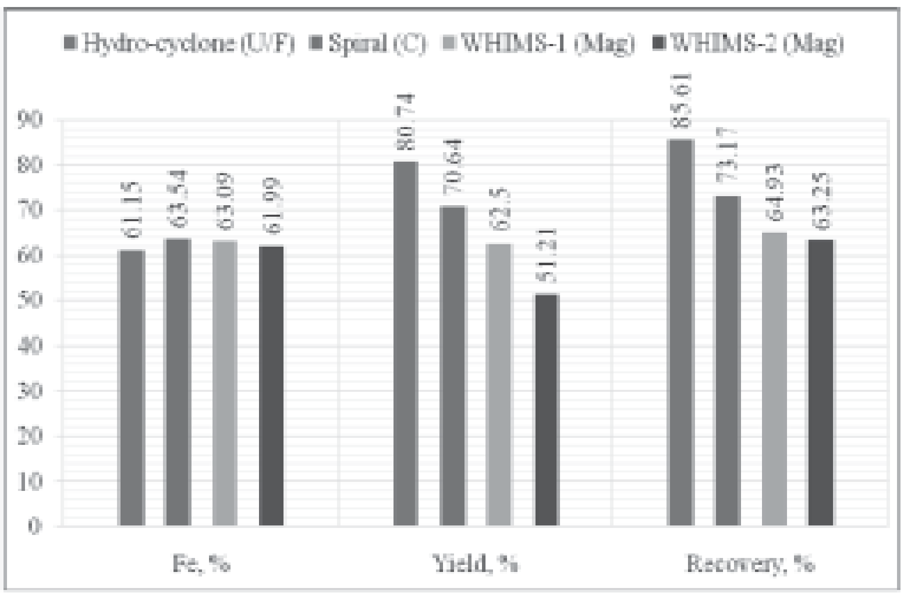

Fig.6 Grade improvement using different methods with respect to yield and recovery

TABLE 5: INCREMENT IN GRADE AND RECOVERY WITH DIFFERENT PROCESS UNITS

Equipment	Fe%	SiO_2 %	Al_2O_3 %	% yield	% recovery
Hydro-cyclone (U/F)	61.15	2.22	3.49	80.74	85.61
Spiral (conc.)	63.54	1.55	1.96	70.64	73.17
WHIMS-stage-1 (mag.)	63.19	2.07	2.33	62.50	64.93
WHIMS-stage-2 (mag.)	61.99	2.50	3.15	51.21	63.25

from 4.45% to 2.07% and alumina from 6.37% to 2.33%.

In WHIMS Stage-II, the magnetic intensity was maintained at 1.2T. The feed consists of tailing and middling of WHIMS Stage-I, the grade of iron was increased from 49.84% to 61.99%. The alumina was reduced from 10.40 to 3.15% and silica was reduced from 6.85 to 2.50%. This can be attributed to the presence of significant amount of paramagnetic particle present in the system which was unable to recover at low magnetic intensity because of low magnetic susceptibility of iron bearing minerals and also the reduction in particle size from 150µm to 45µm resulted in better liberation of gangue and iron. The overall concentrate from different steps can be used for pelletization purpose as overall grade of Fe, SiO_2 and Al_2O_3 from all three concentrates (C1+C2+C3) are 63.16%, 1.77% and 2.15%.

4. Conclusions

The characterization part revealed that the Barsua iron ore consists of hematite, goethite as major iron bearing minerals and quartz, kaolinite, gibbsite and clay constitutes the major gangue minerals. From the liberation study, it is adduced that significant improvement in grade can be achieved grinding to fines and ultra-fines particles i.e., below 150 µm. The grade of ROM fines significantly increased using series of methods. WHIMS at high intensity were found to be capable of significant removal of non-magnetic part from the iron ore.

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