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Feasibility Of Beneficiation Of Banded Hematite Jasper Of Eastern India

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ABSTRACT

Iron ore resource has its own typical mineral characteristics which require definite beneficiation process to produce quality raw material. Characterization has become an integral part of mineral processing and beneficiation depends on the nature of the gangue present and its association with the ore. Different characterization aspects like mineralogy, textural relationship, liberation size, chemical analysis and grain size analysis are studied to develop the beneficiation As reflected in the National Steel Policy, Hematite iron ore availability in the country will not last long. In order to ensure longer period of ore availability, it is very important that we should plan to use low grade BHQ & BHJ iron ores after beneficiation. Looking at the present scenario IBM has slashed the threshold value of 45% Fe(T). According to National mineral policy projections, exploitation of the low grade iron ore horizons like BHJ, BHQ, and BIF etc. is necessary to achieve zero waste mining. BHJ assaying up to 40% Fe(T) has to be upgraded above 60% Fe(T) to use effectively It may also be noted that attaining liberation may be an extremely difficult job requiring comminution down to about a few microns. Technically it is possible to enhance the quality of low grade as well as BHQ/ B HJ iron ores to an acceptable grade using various techniques like Flotation, Enhanced gravity separation, WHIMS etc.

Key words: IBM, BHJ, Flotation, EGS, WHIMS

1. Introduction

Due to increased production of steel in India, the pressure on iron ore producers is not only to enhance productivity from existing mines, but also to find out alternative resources, like low grade iron ores such as banded hematite quartz (BHQ)/banded hematite jasper (BHJ), which are available in abundance but yet to be utilized in lieu of suitable process technology. Banded Hematite Jasper (BHJ) deposits are abundant reserves available in India and are currently not being used for production purposes due to its high Silica content.

1.1 Iron Ore Scenario in India

India possesses hematite resources of 11,426 million tons of which 6,025 million tons are reserves and 5,401 million tons are remaining resources (Indian Mineral Year Book, 2008). Apart from BHJ and BHQ reserves. About 2,823 million tons (25%) are medium grade lumpy ore resources while 915 million tons (8%) are high-grade lumpy ore. In Indian iron ore deposits the Lump and fines ratios are almost 50:50 but out of the total reserve only 12.3% belong to high grade variety while medium grade covers 48%, low grade occupies 28% and rest comes under unclassified categories. Iron ore in the size range of 8 mm to 0.15 mm are designated as fines, whereas, the ore below 0.15 mm are known as slime. Major resources of hematite iron ore are located in Orissa (3,789 million tons (33%)), Jharkhand (3,044 million tons (27%)), Chhatisgarh (2,120 million tons (19%)), Karnataka (1,148 million tons (10%)) and Goa (642 million tons (16%)). The balance 4% resources are spread in Maharashtra, Andhra Pradesh and Madhya Pradesh. With the availability of high-grade ores and for the economic reasons, a simple washing scheme is being industrially practiced for beneficiation of the iron ores.

For economic reasons, quality raw material is not only required for blast furnace operation but also for the emerging technologies such as smelting reduction and direct reduction route. Beside that, India has set itself a target of achieving production capacity of 110 MT of Steel by 2020 and the required quantity of Iron ore is projected at 190 MT. Over the next few years, demand for Indian Iron ore is expected to rise by more than 200 million tons per year to meet the internal demand and export.

1.2. Geology of the Study area:

Samples were collected from Barsua region of the Barsua-Taldih-Kalta combined leasehold of SAIL. It is situated in the classic Iron Ore bearing formations of Odisha. The regional geological set up constitutes part of the Precambrian Meta-sedimentary Sequence, known in Indian Geology as “Iron Ore Series”. The regional structure of the Iron Ore Series was assumed as an asymmetrical overturned synclinorium plunging towards north. In geological literatures this regional structural feature is known as “Horse Shoe Synclinorium”. The western portion of this structure is almost continuously comprised of BHJ/BHQ, which forms the hanging wall of the Bonai Iron Ore body.

The Iron ore body was formed by secondary process of leaching and enrichment of Iron bearing rocks (BHJ/BHQ) under certain structural and meteorological controls. This process had also produced different ore types of varying physical, textural and chemical compositions. Pockets of un- replaced or partly replaced parent rocks are present in the ore body. BHJ occurs as Horses in the zone indicating the original unaltered rock.

BANDED HEMATITE JASPER

BHJ is unevenly banded with alternating layers of hematite and jasper, and the thickness of individual bands varies from a few mm to about 2cm while average thickness is observed to be 1 to 2 mm. The bands also vary in color from gray or white to red, brown or black.

2. Characterization

The characterization study would help to establish the evolutionary trends in the ore mineralization process which in turn help to select a suitable beneficiation route particularly in case of low grade ores.

The process of beneficiation is dependent on the variation in physical, chemical and mineralogical properties between constituent minerals and their grain sizes. Therefore, the mineralogy of the samples helps in deciding an appropriate beneficiation process for up-gradation. Ore characterization relates to physical, chemical and mineralogical properties of raw materials to their behavior during their processing such as comminution, physical beneficiation as well as their hydrometallurgical processing. All these information together used to determine the optimum processing route.

The principal objective of the beneficiation is to concentrate valuable minerals with satisfactory grade and maximum recovery there by rejecting gangue minerals. Beneficiation mostly comprises of 2 operations i.e. liberation and separation. The nature of characterization of minerals mainly depends on the method of processing, type of ore-dressing products and on the type of process problem to be solved. The nature of mineralogical information required includes mineral identification properties including mineral shape, size, and textural characterization, locking pattern and mineral proportions as well as quantitative analysis of various minerals.

Locking and liberation characteristics of the samples are closely related to the size distribution of the minerals and their textural relationships. On comminution of ore, different particles, ranging from fully liberated valuable and gangue minerals to those of different types of locked particles are generated

The bands in the BHJ consist of alternated layers of hematite and jasper/quartz with micro-folds and faulted features dissecting each other. Bands are generally parallel, while the concentration of iron ore minerals in an 'iron-rich band' is more or less uniform; in a 'silica-rich band' it is highly erratic (Fig.1a). The ore shows complex interlocking between hematite and jasper.

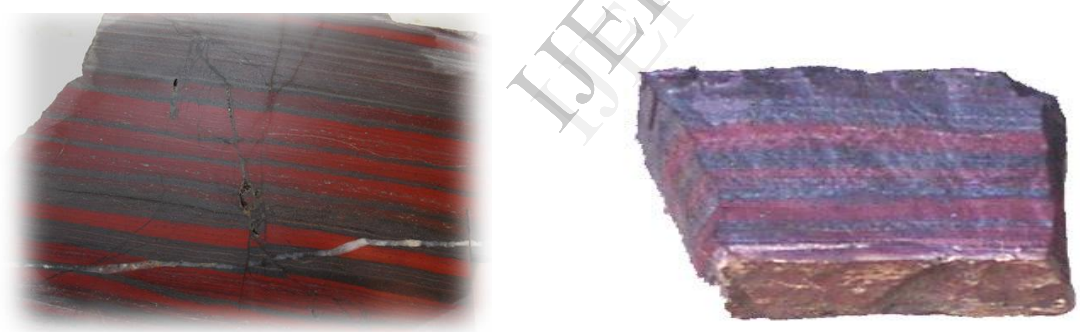
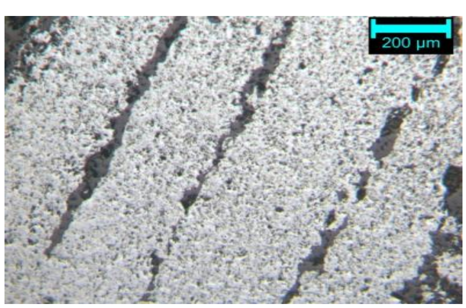
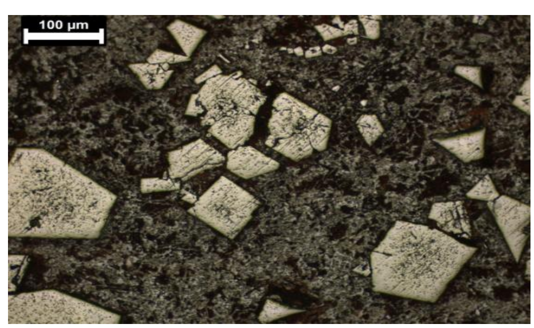


Fig. 1a: Cross-section showing alternating layers of Hematite & Jasper

2.1Optical Microscopic Studies:





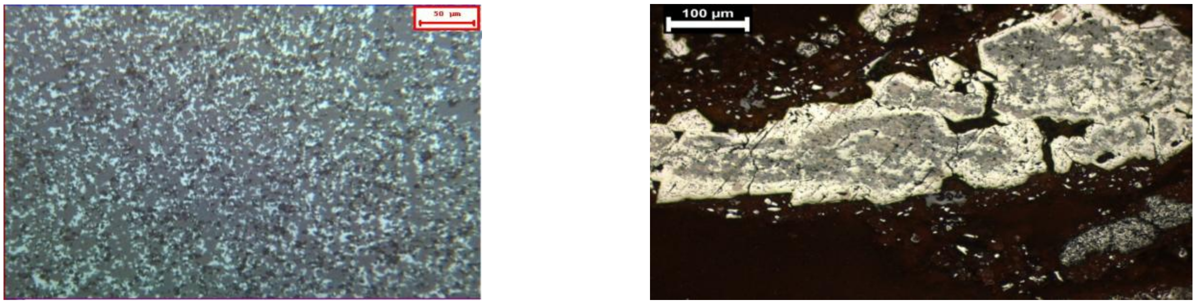


Fig. 1 (b): Photomicrographs of BHJ samples under reflected light microscope,
(i) Altrenate bands of Hematite and jasper in BHJ, (ii) Martite in banded hematite jasper,
(iii) Very fine grained ore shows complex interlocking between hematite and jasper,
(iv)Magnetite and Hematite in martite.

Hematite appears to be a martitized. The martite, which is pseudomorphs magnetite, in most cases, retains the shape of original magnetite (Fig.1b). Disseminated secondary quartz also occurs in many samples. At places there are enriched zones of hematite. In BHJ, transformation of one mineral to another happens under the influence of heat, temperature, pressure. Recrystallisation of Hematite might have produced due to hydrothermal fluids but here magnetite get converted to hematite due to oxidation.

The presence of Hematite and Quartz is further substantiated from XRD patterns as shown in Fig. 2.

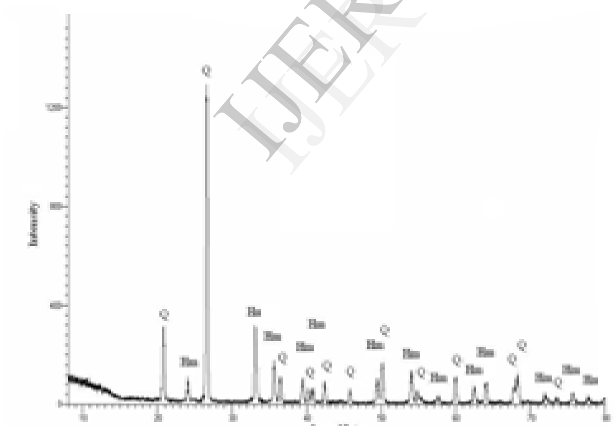


Fig. 2: XRD pattern Showing the presence of Hematite and Quartz

SEM pattern from hematitic band of Banded Hematite Jasper (Fig.3) shows presence of Acicular hematite with interstitial spaces occupied by quartz. EDS analysis shows a high percentage of Si and complex interlocking of hematite and jasper which made it very difficult for beneficiation.

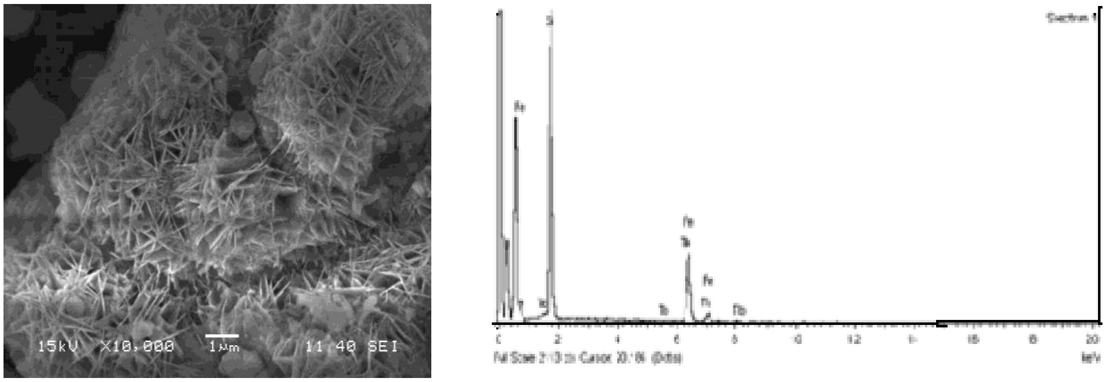


Fig. 3: Acicular Hematite crystals are arranged spherically in BHJ.

The chemical composition Banded hematite jasper is illustrated in Table1.

Table-1: Chemical Analysis of BHJ (ROM)

Radicals	%wt	Radicals	%wt	Radicals	%wt	Radicals	%wt
Fe	35.29	SiO_2	49.12	Al_2O_3	1.96	LOI	1.01

BHJ containing 35.29 % Fe, 49.12 % silica and 1.96% alumina with LOI of 1.01% had been taken for characterization study with a view to beneficiation. The liberation analysis (Table 2)says that in BHJ samples, clay content is negligible but silica content is very high. Hematite and quartz are medium to very fine grained. About 80% of hematite grains carry extremely fine grained inclusions of quartz.

Table2: Liberation data of banded hematite jasper showing abundance of various phases

Mineral phases/ Size in micron	**-1+600µ**	**-600+500 µ**	**-500+300 µ**	**-300+200 µ**	**-200+150 µ**	**-150+100 µ**
Banded Hematite Jasper						
Free goethite	0	0	0	0	0	0
% of Iron liberated	37.85	39.75	40.05	41.40	43.56	48.0
%of interlocking	43.45	40.06	36.59	24.22	17.44	13
%of gangue liberated	17.69	20.18	23.35	34.38	39	39

The interlocking of quartz with iron oxides is of very complex nature. From size analysis study (Fig. 4) it was found that the sample is very hard and coarser fraction comprises of around 80% indicating higher concentration of gangues in coarser fractions. Liberation analysis shows that about 50% interlocking still exists in -100+75 µm size. The complexity of interlocking between iron oxides and quartz wherein quartz ranging in size range of 5-10µ are intimately associate with the ground mass of hematite and vice versa creates difficulty in liberation. Some of the iron oxide grains that are free from interlocking also carry fine inclusions of quartz. In BHJ samples, clay content is negligible but silica content is very high.

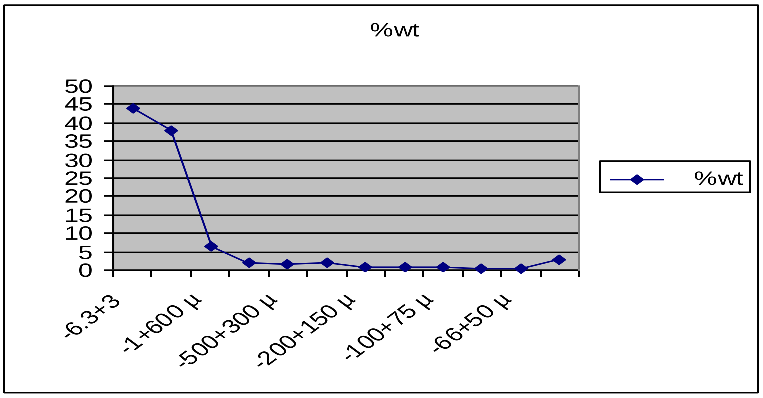


Fig. 4: Size Analysis of BHJ

3 Instrumentation:

3.1 Wilfley Table

Wilfley table utilizes a technique called flowing film concentration. This technique can be used to separate minerals, both on the basis of their shape as well as specific gravity. The equipment used for this study was of Carpco, USA make. The unit was driven by a 440 V, 3 phase motor.

3.2 Falcon Concentrator

Falcon concentrator (SB-40) is an enhanced gravity concentrator, which is usually used for separation of fine valuables from tailing or rejects. In Falcon concentrator, the rotating bowl is spinned at a very high speed and the materials experience a very high centrifugal force (G). The feed stream particles are subjected to gravitational force up to 300 G's and are segregated according to effective specific gravity along the smooth spinning rotor wall. The heaviest layers pass over the concentrate bed retained in the riffles at the top of the rotor bowl.

The addition of fluidization or back pressure water from behind the riffle beds enable heavy target particles to migrate to the bottom or outside of the bed and be retained in preference to the lighter particle.

3.3*Wet High Intensity Magnetic Separator*

The magnetic separation was conducted in Wet High intensity Magnetic Separator (model type JONES-wet high intensity magnetic separator P40, Germany). The variables include; Slurry density, feed rate, wash-water, field intensity. The field intensity is adjusted depending upon the susceptibility of the minerals to be treated. The ground material in the slurry with about 10 - 15 % solids is fed through a funnel. The magnetic particles are retained in the matrix and the non-magnetic particles are discharged and collected separately. Additional wash-water is added to wash the magnetic particles. The operation is continued till the non-magnetic particles are completely separated. At the end of the operation, the magnetic particles are collected separately. The parameters for the separation are fineness of the material, feed rate, quantity of wash water and field intensity.

3.4 Flotation cell

All flotation tests were performed in a 2.0 litre Denver D-12 Sub-aeration flotation cell. Time dependent concentrates were collected till the differences in cumulative weight of the concentrates became nominal. Most of the tests were carried out for 3 to 4 minutes. MIBC is used as frother; Sodium Oleate is used as collector and sodium silicate as depressant. PH of the pulp was measured by ORION 720-A pH meter.

4. Beneficiation of BHJ

From the detailed characterization studies, it has been observed that in BHJ, the clay content is low but silica content is very high. Consequently, the grade of the ore is very low (35% Fe). Also, the quartz is very finely disseminated rendering it extremely difficult to attain liberation. Such a low grade ore with such complex interlocking pattern may not render the beneficiation process economically viable. An elaborate flow sheet with multiple stages of comminution, classification, gravity and magnetic separation and froth flotation is required to produce a sufficiently high grade concentrate.

4.1 Gravity Separation using Wilfley Table

To study the efficacy of flowing film concentration of BHJ, it is subjected to concentration in Wilfley Table. The results obtained are reported in Table 3. It may be seen that about 45.40% solids (w. r. t. orig.) is recovered in the concentrate product. The experimental conditions, 3˚ deck slope and 1.68 cc. per cm. per. sec. water flow rate are kept constant in all tabling experiments. It is observed that the quality of the ores improved significantly by tabling. In the BHJ, the concentrate grade improved to 49% iron by processing the feed ground to <1mm.

Table3: Wilfley table test results with3˚ deck and 1.68 cc. per cm/sec water flow

Product	Fe%	Yield (%)
Conc.	49.0	45.40
Middling	27.0	43.24
Tailing	22.0	11.36
Feed	35.29	100

Further concentration is carried out in a falcon concentrator. The test results obtained under most suitable operating conditions are shown in Table 4. It may be seen that Fe content is enriched to 54.08% with overall yield of 53.9%. The concentrate grade is still not good enough to be acceptable.

Table 4: Falcon test results of Tabling concentrate with 60Hz and 15psi

Product	Fe%	Yield (%)
Conc.	54.08	53.9
Tailing	27.28	46.1
Feed	49.0	100

For further concentration, the Falcon concentrate is subjected to cleaning with optimum condition of 40Hz and 15psi. As indicated in Table 5 Fe content is increased to 60.01 with a yield of 56.08.

Table 5: Falcon test results in optimum condition of 40Hz, 15psi

Product	Fe%	SiO_2	Al_2O_3	Yield (%)
Conc.	60.01	10.08	13.70	56.08
Tailing	36.31	12.78	22.40	43.92
Feed	54.08	9.80	18.09	100

The second stage Falcon test results show that the grade is not satisfactory and for further concentration Wet High Intensity Magnetic Separation (WHIMS) or Flotation technique can be adopted.

In continuation with the earlier work the Falcon Concentrate of BHJ was subjected to Wet High Intensity Magnetic separator in accordance with mineralogical studies showing that in BHJ ore, most of the irons bearing particles are hematite, which are paramagnetic in nature. So Wet High Intensity Magnetic Separator (WHIMS) has been used to improve the grade further are shown in Table 6..

Table-6: WHIMS test results of Falcon concentrate with 10% solids, .5 Amp. Current and 20 lpm Wash water.

Product	Fe%	SiO_2	Al_2O_3	Yield
Conc.	61.03	5.26	10.7	80.19
Middling	34.56	11.56	9.40	9.40
Tailing	29.88	37.48	21.57	10.41
Feed	60.0	10.08	13.70	100

In a magnetic separator apart from the magnetic force, several competing forces act on a particle. These are, among others, the force of gravity, the inertial force, the hydrodynamic drag and surface and inter particle forces. However, among the competing forces gravity and hydrodynamic drag forces are the major competing forces.

The force of gravity is expressed as

$$\vec{F}_g = \rho V \vec{g}$$

where ρ is the density of the particle while g is the acceleration due to gravity.

The hydrodynamic drag is given by

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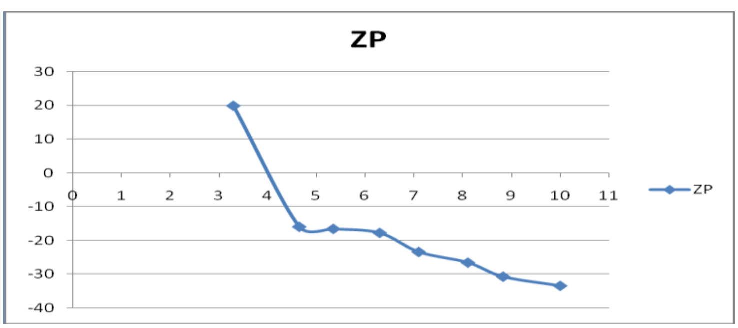
$$\vec{F}_d = 6\mu\eta b v_p$$

Where η the dynamic viscosity of the fluid, b is is the particle radius and ν_p is the relative viscosity of the particle with respect to the fluid. In order to lift the magnetic particle from the slurry, Fm should be larger than $F_{d.}$

WHIMS result (*Table-6*) of 150 µm size ground sample shows that due to relatively higher drag force significant amount of Fe is lost into the tailings and the desired grade couldn't achieved. Fines generated in the grinding process are not recovered in the concentrate. The WHIMS concentrate is further subjected to Flotation for further up gradation.

In flotation, the response of many minerals is often dramatically affected by P^H .Adsorption of collectors and modifying reagents in the flotation of oxide and silicate minerals is controlled by the electrical double layer at the mineral-water interface. In systems where the collector is physically adsorbed, flotation with anionic or cationic collectors depends on the mineral surface being charged oppositely. Adjusting the pH of the system can enhance or prevent the flotation of a mineral. Thus, the Iso electric point (IEP) of the mineral is the most important property of a mineral in such systems but raising the pH sufficiently above the IEP can repel chemisorbing collectors from the mineral surface. Zeta potentials can be used to delineate this interfacial phenomena.

The Zeta Potential studies were carried out in Zeta Meter (Model type Malvern Delsa Nano submicron particle analyser).



IEP=4.0

Fig. 5: Zeta potential vs pH

From the Zeta Potential study, the IsoEletric Point/ Zero Charge Point is found to be at at P^H 4.0 which in turn indicates that the ideal pHcondition for flotation is in the range of 6-10.

4.2: Flotation cell

All flotation tests were performed in a 2.0 litre Denver D-12 Sub-aeration flotation cell. Time dependent concentrates were collected till the differences in cumulative weight of the concentrates became nominal.

Most of the tests were carried out for 3 to 4 minutes. MIBC is used as frother, Sodium Oleate is used as collector and sodium silicate as depressant. pH of the pulp was measured by ORION 720-A pH meter.

Table7: Flotation test of WHIMS concentrate at a pH 9.3, 10% solids, 5 min. conditioning time,2.0kg/t collector(sodium oleate), 2.5kg/t depressant (sodium silicate), 0.3kg/t frother(MIBC)

Product	Fe%	SiO_2%	Al_2O_3%	Yield (%)
Concentrate	63.47	2.7	2.3	82
Tailing	42.08	18.1	9.12	18
Feed	61.03	5.26	10.7	100

5. Conclusion:

Ratio of Iron ore minerals to gangue minerals, their association infers size reduction is needed for further beneficiation. Textural study revealed the complex relationship of hematite and quartz due to its mineral association and intergrowth patterns developed among ore minerals and gangue minerals. The exact cut-off size of liberation of Quartz grains is difficult to ascertain due to its significant variation of grain sizes. The occurrence of free hematite is observed at a particle size < 50 µm. Technically it is possible to enhance the quality of low grade as well as BHQ/ B HJ iron ores to an acceptable grade.

6. References:

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