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SEPARATION RESPONSE OF IRON ORES DURING GRAVITY CONCENTRATION

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ABSTRACT

Two types of iron ores namely soft laminated ore and goethitic-lateritic ore is studied in details from Jilling-Langalota deposit, Singhbhum-N, Orissa Craton, Eastern India. The soft laminated iron ore contained relatively high hematite as compared to Goethitic-lateric ore which contained goethite in large quantity. Beneficiation of iron ores by gravity separation method is studied. The ore samples are beneficiated with a view to produce sinter quality concentrate. The soft laminated ore contained 61.29% total iron, 5.04% silica and 4.29% alumina while the Goethitic-lateritic ore contained 53.34% total iron, 7.4% silica and 5.49% alumina.

Liberation analysis of different size fraction suggested that grain size reduction lower than 150 μm size would be necessary to achieve sufficient liberation of iron ore minerals from the associated gangue (kaolinite and gibbsite). However, the percentage of interlocking is higher in case of Goethitic-lateritic ore compared to soft laminated ore. Considering the characterisation data, the soft laminated ore is ground separately to three size fractions namely 300 μm, 250 μm and 150 μm sizes, while the goethitic ore is ground to 150 μm size and subjected to flowing film concentration in Wilfley Table. The grade of the soft laminated ore is improved from 61% Fe to 66% Fe while for the Goethitic-lateritic ore the Fe content is enriched from 53% to 64% in simple one-stage concentration operation. The nature of the ore mineral plays important role in the separation process. Due to enrichment of goethite and friable nature of Goethitic-lateritic ore significant amount of Fe is lost during the process as compared to soft laminated ore.

Keywords : Characterization, Beneficiation, Liberation, Wilfley table, Iron ore.

INTRODUCTION

Important iron ore deposits occur in India in the eastern, central and southern parts in the states of Jharkhand, Orissa, Karnataka, Chhattisgarh, Goa etc. Geologically, the Eastern

Indian iron ores belong to Archean Iron Ore Group (IOG). Indian iron ore is relatively rich in Fe and contains higher amounts of alumina compared to the other major deposits of the world. With increasing global demand of iron ore owing to the huge requirement of iron ore by China, important iron ore producing countries have increased their production by initiating steps to utilize the low grade iron ores, fines and slimes.

The soft, laminated, friable and lateritic ores of India contain large amounts of Al_2O_3 and it has now been established both by laboratory and plant trials that alumina has an adverse effect on sinter and pellet properties. The reduction degradation behavior of the sinter can be improved considerably by lowering its alumina and silica content and increasing the iron content. The reducibility index of the pellets would also increase with lowering of alumina content. Thus, beneficiating the low grade iron ore to remove the gangue minerals and enhancing its grade is a prospective proposition today. However, without a thorough mineralogical characterization, such processing may not be very efficient. The characterization studies needed to be taken up with due emphasis prior to beneficiation. In the present study two iron ore samples were taken up for detail characterization and beneficiation. The effect of gravity separation by wilfley table is studied with a view to value addition of the ore.

EXPERIMENTAL

Raw Material

Two different iron ore samples namely soft laminated iron ore and goethitic-lateritic iron ore of varying characteristics are taken up for investigation. The samples belong to Jilling Langalota iron ore deposits. The two samples are contrasting in their physical as well as chemical character. These samples were obtained by removing the slime. The soft laminated iron ore taken up for the present study contained 61.29% total iron, 5.04% silica and 4.29% alumina, while the goethitic-lateritic iron ore sample had 53.34% iron, 7.4% silica and 5.49% alumina.

Ore Characterization

The characterization of the two iron ore samples consisted of their mineralogical study by microscopic examinations and liberation study by image analysis. These steps are described in detail in the following sections and corresponding results are presented.

RESULTS AND DISCUSSION

Mineralogical Characterization

Soft laminated friable ore is dark metallic grey in color with thin porous laminations with weak foliation surface of one or more sets separating two laminations (Fig. 1A). These weak surfaces appear to promote extensive supergene activity resulting in the deep penetration of porosity to the grain boundary and development of micro-platy hematite. Micro-platy hematite is interlinked like a network of minerals with pores in between. These pores are generally filled with clay (Fig. 1B). Micro-platy hematite has a dimension of less than 2-10 micron in thickness and to 20-30 micron in porous aggregates. Apart from hematite, the other major iron-bearing phase is goethite. It occurs as vein filling within the voids (Fig. 1C). The cavities are mostly developed along the weaker planes in between the mineral bands. This may have resulted due to the leaching out of pre-existing minerals. In many cases, these cavities are also subsequently filled by clay material (Fig. 1C) or secondary goethite.

Lateritic-goethitic ore is dull earthy in color with limonitic red, yellow and dull white patches. However, in fresh surface, it appears darker in comparison to soft laminated ore. Lateritic and goethitic ore mainly contain goethite, hematite, kaolinite, gibbsite and quartz. Microplaty hematite-goethite with clay patches are common features in this type of ore. Goethite is present in all the samples. It consists of spongy micro-platy hematite and martite, partly or wholly transformed to goethite and later concreted by goethitic precipitation along the wall of the tubular pores (Fig. 1D). At places, goethite is crystallised to perfect crystalline grains with high reflectivity (Fig. 1E). There are extensive features of cavity filling by goethite precipitation. These cavities are also partly filled by gibbsite and kaolinite. This ore also exhibits multiple joint and fracture surfaces along which the clay and goethite precipitation takes place (Fig. 5F). Most of the lateritic samples show high degree of porosity with substantial amounts of clay, which is mainly

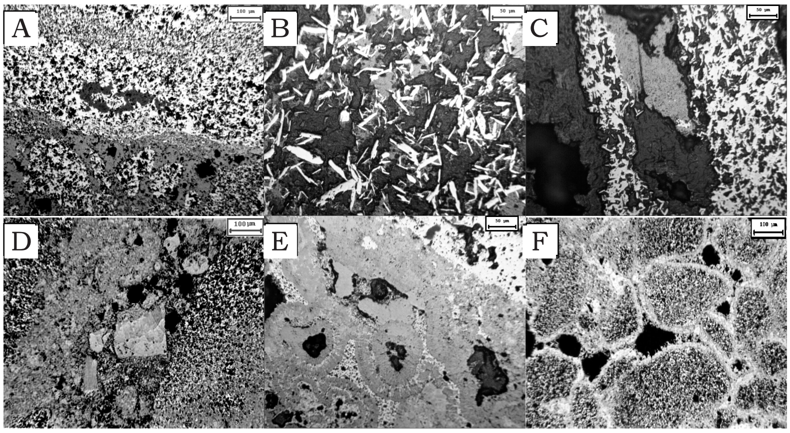

Fig. 1 : Photomicrograph of soft laminated and Goethitic-lateritic iron ore; (B) Microplaty hematite with pores in between, filled with clay; (C) cavities filled with clay; (D) colloform goethite; (E) Microplaty hematite partly transformed to goethite; (F) goethite crystallized to perfect crystalline.

responsible for the high alumina content in this ore that makes it difficult for use in iron making without rigorous beneficiation. The clay bearing laterites contain clusters of gibbsite grains in the voids an
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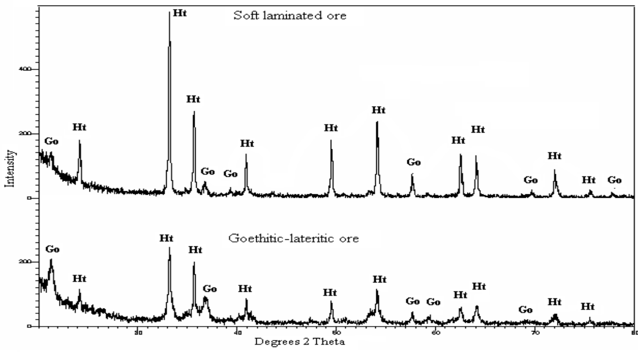

Fig. 2 : XRD pattern of iron ore samples with identified phases (Ht-hematite, Go-goethite)

LIBERATION STUDY BY IMAGE ANALYSIS

Image analysis of different size fractions of the iron ore samples are taken up for liberation study. These studies are carried out by taking representative sample of each size fraction of the ores. Each of these size fractions are carefully mounted using bakelite powder in Simplimet mounting press. More than 50 images for each size class are processed for field measurement method after binary conversion for liberation study. Through this study the volumetric percentages of interlocking of iron particles with gangue phases and percentage of gangue liberated in each size fraction is estimated. The analysis data for the iron ore is given in Fig. 3.

Liberation analysis (Fig. 3) shows that in coarser fractions of soft laminated iron ore, iron bearing minerals are highly interlocked with gangue. The percentage of interlocking decreases with decreasing particle size. The finer size fractions have minimum interlocking. Percentage of clay liberation also increases with decrease in particle size and maximum clay liberation values are obtained in the -150+100 micron size fraction.

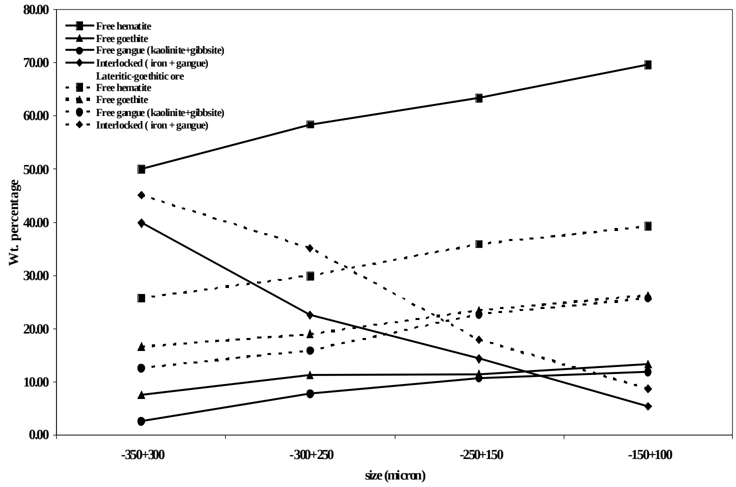

Fig. 3 : Liberation pattern of the two types of iron ores

Liberation analysis of goethitic- lateritic ore shows that in coarser fractions percentage of interlocking is very high and decreased with decreasing particle size. Low free hematite content and higher gangue contents indicate very low grade of this type of iron ore. Complex interlocking nature of the particles shows that the liberation can be achieved below 150 micron size. Achieving high purity concentrate in beneficiation of this ore is likely to be quite difficult due to the complexity of interlocking. Proper comminution is required to break the interlocking and attain good liberation in this case.

BENEFICIATION STUDIES

Detailed particle characterization of soft laminated iron ore reveals that in coarser size fraction iron bearing particles are highly interlocked with gangue. Liberation analysis of different size fraction of both the iron ores suggested that grain size reduction to less than 150 mm size would be necessary to achieve sufficient liberation of iron ore minerals from its gangue (kaolinite and gibbsite) content. Therefore, it is imperative that a grinding operation to liberate the interlocked gangue is required. However, the percentage of interlocking is higher in case of Goethitic-lateritic ore compared to soft laminated ore. Goethitic-lateritic ore due to complex intercloking nature of ore has been ground to 150 μm size for beneficiation studies. In order to study the efficacy of gravity concentration, this sample was subjected to concentration in Wilfley Table. In case of soft laminated ore percentage of interlocking is relatively low. So, this ore has been grinded separately in to three size fraction i,e 300 μm, 250 μm and 150 μm. These three size fraction of soft laminated ore has been treated separately in Wilfley Table for beneficiation study.

Experimental condition with 3° deck slope, 1.68 cc. per cm. per sec water flow rate was kept constant in all experiments. The results obtained from the best tests are reported in Table1 and Table 2 for soft laminated ore and Goethitic-lateritic ore respectively. It is observed that quality of the ore has been improved significantly. However, contrasting result has been obtained for two types of iron ores. In case of soft laminated iron ore, different concentration grade has been obtained from different sized ground feed. Higher grade has been obtained from 150 μm size ground feed. Processing of 150 μm size ground material shows that the grade of the soft laminated ore is improved from 61% Fe to 66% Fe while for the Goethitic-lateritic ore the Fe content is enriched from 53% to 64%.

However, the low concentration grade of Goethitic-lateritic ore indicates the requirement of further concentration process. It may be noted that the feed grade of this ore was lower than soft laminated ore.

Concentration criteria

Theoretically, effective gravity separation is possible when the concentration criterion[3]. for these ores is greater than 2.5 (Equation 1).

$$\frac{D_h - D_f}{D_L - D_f} > 2.5 \qquad (1)$$

Where, D_h is the specific gravity of the heavy mineral, D_l is the specific gravity of the light mineral and D_f is the specific gravity of the fluid medium.

When the quotient is greater than 2.5, then gravity separation is relatively easy. As the value of quotient decreases, so the efficiency of separation decreases, and below about 1.25 gravity separation is not commercially feasible[3]. The specific gravity of hematite is 5.5 to 6.5 whereas it is 4.1 to 4.3 in case of goethite. Specific gravity of kaolinite, gibbsite and quartz is in the range from 2.3 to 2.6. In case of hematite ore, separation criterion as shown in Equation (1), is estimated to be in the range from 2.81 to 3.44. On the other hand, separation criterion in case of goethite ore are estimated to be in the range from 1.93 to 2.06.

Therefore, the more goethitic the ore of specific gravity 4.1 to 4.3, the lower is the efficiency of separation. This leads to a greater percentage of the Fe going to the tailing during gravity separation. In the present work high percentage of Fe distribution (43%) in middling and tailing product of Goethitic-lateritic ore is due to higher concentration of goethitic ore in the feed which makes the concentration criterion lower than 2.5.

Effect of mineral interlocking

The effect of particle interlocking can be seen in Table 1. In the case of soft laminated iron ore the highest recovery is achieved at 150µm ground feed. Table 1 shows that in middling product Fe % is decreasing with decreasing the feed size, Distribution of Fe in middling product is also decreasing with decreasing the feed size. In the coarser size ground feed more iron minerals are interlocked with gangue which are reported in the middling product. With decreasing the ground feed more iron minerals are liberated and percentage and distribution of Fe in middling is decreases. In finer size fractions the liberated iron minerals are reported in the concentrate and tailing rather than in the middling product. Lower recovery of Fe in concentrate product of coarser ground feed is believed to be due to the higher interlocking of iron with gangue.

Table 1 : Wilfley Table test results of soft laminated iron ore 10% solids, 3° deck slope, 1.68 cc. per cm per sec water flow rate and 280 rpm speed

Products	Assay, %Fe	Distribution %Fe	$\%Al_2O_3$	$\%SiO_2$	Wt.%
300 μm size					
Conc.	64.91	48.02	2.11	2.45	45.3
Middling	61.97	37.90	4.65	5.53	37.5
Tails	50.26	14.09	9.25	10.81	17.2
250 μm size					
Conc.	65.54	69.69	1.97	2.23	65.2
Middling	57.79	17.58	5.86	7.26	18.7
Tails	48.21	12.73	11.8	13.8	16.2
150 μm size					
Conc.	66.43	71.90	1.38	1.83	66.3
Middling	54.56	10.24	6.91	8.37	11.5
Tails	49.47	17.86	1.65	13.71	22.1
Feed	61.29	100	4.29	5.04	100.0

Effect of particle size

In soft laminated iron ore, distribution of Fe in the tailing product is lower in 250 mμ size ground ore sample than 300 μm, however, in 150 μm ground feed it increases abruptly. Comparison of the result of two types of iron ores of feed 150 μm ground sample shows that Fe losses are more in case of goethitic-lateritic ore than soft laminated ore. Liberation analysis shows that with decreasing the particle size from 300 μm to 150 μm, more iron bearing minerals are liberated. So liberated iron minerals should report to the concentrate product rather than in tailings. The reason behind this can be demonstrated by following theoretical considerations.

The equation of downstream travel, before a particle at the top of fluid film settles at the deck surface [4] is given as,

$$z = \frac{9}{2} \frac{\mu Q}{(Ds - Df) r^2 g \cos \alpha} \quad (2)$$

In this equation, *z* is the downstream travel expressed in cm, Q the rate of fluid flow in cc per centimeter of running deck length per second, μ the viscosity, *r* the particle radius, *g* is the acceleration due to gravity, D*s* and D*f* the specific gravities of solid and fluid and a is the slope of the deck. The particle radius appears in the denominator raised to the second power.

Graphical representation of down stream travel of all types of particle is represented in Fig. 4 as estimated from Equation (2). The permissible distance is taken as 60 cm which is the length across the Shaking table. As seen from Fig. 4, the maximum size of particle of hematite and goethite traveling 60 cm or more are 11 micron and 13 micron respectively. The ore particles below these size limits are invariable lost in the tailings. Loss of fine sized goethite is relatively higher than fine hematite.

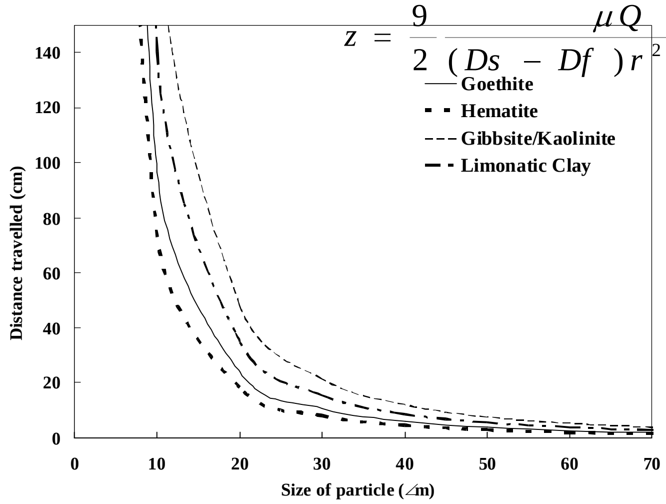

Fig. 4 : Graphical representation of down stream travel of all types of particle.

In the present study grinding of ore to -150 micron size causes formation of undesirable amount of fines below 20 µm size.

Goethitic-lateritc ores are relatively softer and more friable as shown by mineralogical study than soft laminated ore and produced relatively higher amount of fines as compared to soft laminated ore. Since, Goethitic-lateritic ore is relatively finer than soft laminated ore and contain maximum amount of goethite, relatively higher amount of Fe is lost in this ore type. It can be seen from Table 2, the distribution of Fe in tailings product of 150 micron ground feed is 17.86% and 24.90% for soft laminated and Goethitic-lateritic ore respectively. Apart from these the limonitic clay also plays important role in the loss of Fe in the tailings product since limonitic clay contains significant amount of Fe. As shown in the Fig. 4, down stream travel of this particle is 17 micron. Large amount of limonitic clay is removed by this effect.

Table 2 : Wilfley table test results of Goethitic-lateritic iron ore 10% solids, 3° deck slope, 1.68 cc. per cm per sec water flow rate and 280 rpm speed

Products	Assay, %Fe	Distribution %Fe	Al_2O_3	SiO_2	Wt.%
150 μm size					
Conc.	64.12	56.98	2.12	2.93	47.4
Middling	44.12	18.11	8.07	10.98	21.9
Tails	43.27	24.90	8.86	11.75	30.7
Feed	53.34	100	5.49	7.4	100

CONCLUSION

Two types of iron ore samples were thoroughly characterized and it has been established that the two ores are widely different from each other in mineralogy and composition.

Beneficiation studies indicate that gravity separation by Wilfley table may produce substantial enrichment in the concentrate. The nature of minerals in the ore plays important role in the separation process. Hematitic ores are handled more efficiently in gravity separation by Wilfley table than goethitic ores since the concentration criteria of hematite is higher than that of goethite.

Lateritic-Goethitic ore is more friable than Soft laminated ore. Therefore, it produces larger quantity of fines during comminution. Thus, the concentration efficiency of this ore is poorer. Also, downstream travel of fines is more prominent in goethite than in hematite. Therefore, concentration of goethitic ore is more problematic as fines are lost in tailings more vigorously.

For the Soft laminated ore, the finer the feed size, the better was the concentration efficiency. This was attributed to the greater interlocking observed in the coarser feed sizes. However, there is some increase in the tailings loss of valuables due to finer size distribution of the feed.

The authors believe that adoption of some advanced technologies, such as enhanced gravity concentrators, compound spirals and flotation columns may help significantly in improving the process yield of Goethitic-lateritic ore. A future study is being planned to prove this hypothesis.

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