Maximise the Iron Values from Low and Lean Grade Iron Ore Resources

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Abstract

Low grade Indian hematite iron ore contains high amount of kaolinite clay minerals which has high swelling index. It increases the viscosity of the slurry which has negative impact on the fluid dynamics of the slurry and ultimately reduces the separation efficiency of the process. Hence CSIR-IMMT has designed the screw scrubber and introduced the process flowsheet at the beginning of the process to discard around 80-90% clay minerals. As goethite percentage of low grade iron ore is high and it is fragile in nature, it generates huge amount of ultra fines and increases the Blaine number during preparation of pellet feed materials. CSIR-IMMT has optimised the process using combination of different classification equipment to control the Blaine number and reduce the ultra fine generation. Based on the developed process flowsheet, number of iron ore beneficiation plants has been set up by Essar Steel, BRPL, SMPL, BMM Ispat, Bajarang Steel and GM Steel in India.

To maximise the iron recovery from low and lean grade iron ore resources, CSIR-IMMT has done extensive work by adopting reduction roasting followed by low intensity magnetic separation. In reduction roasting process, iron phase minerals i.e., goethite and hematite converts to magnetite and simultaneously remove the swelling properties associated clay minerals. After reduction roasting, the ore is ground to its liberation size of iron phase minerals and concentrate the magnetite using low intensity magnetic separator. As the kaolinite losses its swelling properties, dewatering and filtration problem will not arise. Both tailings and concentrate can be filtered using low cost vacuum filter.

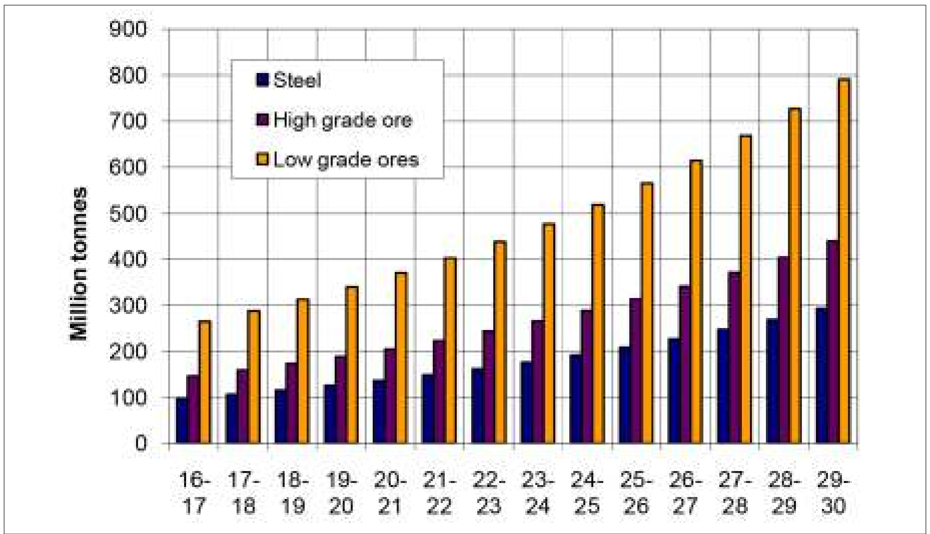
Introduction

Iron ores are valuable natural resources being finite and non-renewable. India has 28 billion tonnes of iron ores of magnetite and hematite ores. Odisha contributes about 33 percentage of national deposit. After revision of threshold limit from 58% to 45% Fe, the national reserve will improve further. Simultaneously the addition of BHQ/BHJ/BGQ lean grade resources in the reserve, the total national reserve again will improve further. They constitute the vital raw materials for iron and steel industries and are a major resource for national development. As per the recent National Steel Policy of Govt. of India, steel production will be enhanced to 300 MTPA in 2030 from current production of 96 MTPA as per new national steel policy 2017. For production of 300 MTPA, the country needs the high quality ore around 450MTPA in form of calibrated ores/sinter or pellet. The country is not endowed with high grade requisite iron ore resources. It is, therefore, imperative to achieve the best use of available low grade iron ore resources through scientific methods of mining, beneficiation and agglomeration processes. The total requirement of iron ore mining is needed about 780 million tonnes as shown in Fig.1.

(a) Iron Ore Beneficiation

In general, the rom ore is crushed and classified into different size fractions to cater the need of iron and steel industries. It is crushed to below 40/30 mm size and classified at 10 mm size to provide the suitable size of calibrated ore to blast furnace operation. For need of DRI process, rom ore is crushed to below 18 mm size and classified at 6 mm to produce calibrated ore at particular size range. Both calibrated ore should meet the other physical and chemical properties to meet blast furnace and DRI processes. When, the mining is operated to take the high grade hard ore from the mines by selective mining. In that case, the generation of calibrated iron ore is about 70%. But at present scenario, selective mining is not allowed. In continuous mining process, the generation of calibrated has gone down and it may be around 30%. The remaining 70% ore utilization in different Fe content is the challenging task. If the fine is high grade ores and meet the requisite specification, it may be utilized in the sintering plant in integrated steel plants.

Fig.2. Different types of iron ores



Financial Year

Fi1 Production of steel, high grade ores and low grade ores for beneficiation (Source: Ministry of steel)

Otherwise, it is kept in mine site as fine dumps. Utilization of fines dumps are the technological challenges to the R&D institutes as well as industries. The different types of iron ores are shown in Fig.2.

Problems of the Indian Iron Ore

- In general, Indian hematite ore contains good amount of clay minerals, which affects fluid dynamics due to its swelling properties in wet beneficiation process
- These ores are more fragile in nature due to presence of goethite.
- It contains mostly flaky type of shape of the particles which affects the separation in jigging in beneficiation process.
- This ore has more cavities in its matrix which gives negative impact in gravity and magnetic separation processes.
- Percentage of goethite increases when Fe content of rom sample decreases.

The formation of iron ore is looked in different stages, goethite generates from hematite after weathering in nature. One water molecule introduces in hematite molecular structure. The crystal structure of goethite changes accordingly as shown in Figs.3 & 4. The Characterisation of the iron ore plays the vital role to decide the suitable process flowsheet for up-gradation of low/lean grade iron ores. Kaolinite, gibbsite and quartzite mineral phases mainly contribute alumina and silica in iron ore. LOI of ore contributes by kaolinite, gibbsite and goethite mineral phases. Goethite presents in two forms i.e., vitreous goethite and ochreous goethite. Vitreous goethite is associated in hematite whereas ocherous goethite is associated in kaolinite and gibbsite. The microscopic modal analysis, heating cycle and detail chemical analysis will provide the availability of mineral phases in percentage in the ore. One classical example of one of the ore is given in the Table 1.

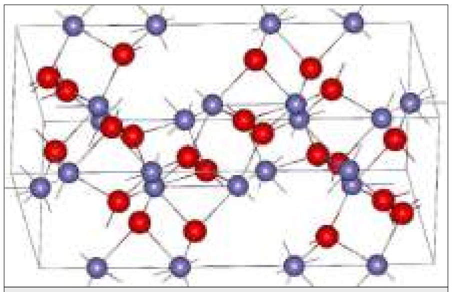


Fig.3 Crystal structure of hematite

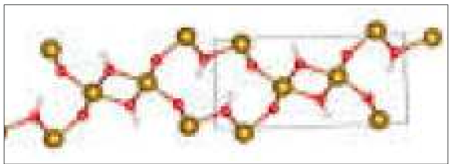


Fig.4 Crystal structure of goethite

Table 1
Microscopic modal analysis, heating cycle and chemical analysis of iron ore

Feed	Hematite, %	Vitreous Goethite, %	Ochreous Goethite, %	
Microscopic modal analysis	66.20	29.30	16.37	
	Hematite, %	Goethite & Gibbsite, %	Kaolinite, %	Quartzite, %
Heating cycle analysis	65.83	28.64	5.53	0.00
	Fe2O3, %	LOI, %	Al2O3, %	SiO2, %
Chemical analysis	80.08	7.73	8.67	2.60

During the beneficiation of low grade iron ore, the main objective is to reject ochreous goethite along with kaolinite, gibbsite and quartzite. As a result, tailings of iron ore beneficiation contain high Fe value in comparison with the tailings generated from magnetite based iron ore due to presence of goethite. In hematite ore, the percentage of goethite varies from 10-50% depending on Fe value of the rom ore. Low grade ore contains high goethite in comparison with high grade ore. Kaolinite presents in two forms i.e., crystalline and amorphous form in iron ore. Both types have hygroscopic and swelling properties. Amorphous type has high hygroscopic and swelling effects in comparison with crystalline kaolinite. In Indian iron ore, the percentage of amorphous kaolinite is high. Hence during wet beneficiation process, swelling effect has too high, as a result the viscosity of slurry increases and it makes negative impacts in fluid dynamics of the process starting from grinding till its filtration. It mostly presents in the ore in ultra fine particles and mostly coats on the surface of the iron ore particles.

The goethite becomes more fragile in comparison with hematite. During grinding process, reduction kinetic of goethite is high and generates more ultrafine particles. In conventional beneficiation process, the attempt was taken to remove the kaolinite at the beginning by attrition technique using screw scrubber or drum scrubber. As the kaolinite particles are mostly below 45 microns and mostly presents in the surface coating form on the iron ore particles, by attrition technique is removed in the screw scrubber overflow or screening of the drum scrubber product. The overflow product of screw scrubber is deslimed by hydrocyclone. The overflow of hydrocyclone is rejected directly to the tailings thickener. In general, the iron ore fines (below 10 mm size) contains around 15-25% of below 75 microns. The 10-15% material is rejected as hydrocyclone overflow which contains mostly clay particles and ochreous goethite. The screw scrubber underflow (coarse particles) and desliming hydrocyclone underflow are treated in the beneficiation circuit to improve the Fe content in the concentrate. Similarly to control the ultrafine generation in pellet feed preparation in the

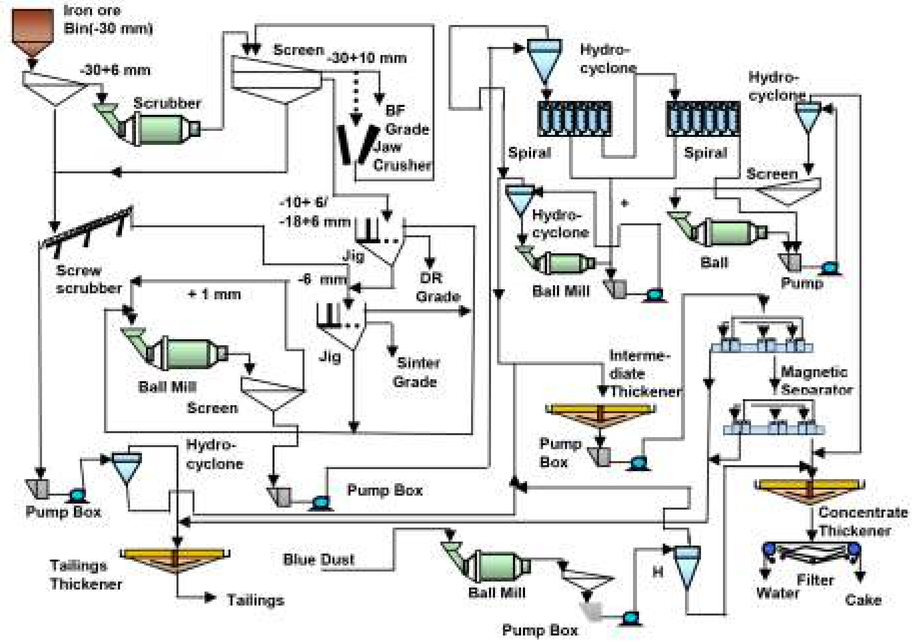


Fig.5 Process flowsheet for physical beneficiation of low grade ores

phases. The main variations in the reduction roasting process are temperature profile, residence time, particle size and reductant quantity and quality. The thermodynamics and kinetics of the reduction roasting process play the key role to control the phase changes up to magnetite by controlling the partial pressure of carbon monoxide. Otherwise the formation of wustite will give negative impact on recovery. The morphology photographs is shown in Figs.6& 7 from changing from rom ore to reduced magnetite and also recovery of magnetite concentrate by LIMS.

The schematic diagram of process flowsheet is shown in Fig.8 for maximum recovery of iron values from low and lean grade iron ores. Non-coking coal from Talcher coal field was used as reductant.

regrinding circuit, two stages classification are added in closed circuit manner. The blue dust should not mix in the normal iron ore. It should be treated separately and mixed with beneficiated concentrate to improve the Fe content as well as reduce the alumina content in the final concentrate. The general process flowsheet is shown in Fig.5

In general, it has been observed that less than 55% of Fe grade iron ore does not respond satisfactorily in conventional beneficiation process. Even more than 55% Fe content iron ore processing, it gives lot of problem in grinding circuit, settling the particles in the thickeners, filtration of concentrate and the tailings and also making green pellet formation. In overall, it does not meet the design capacity of the plant because of the mineralogical differences of the samples.

To maximize the recovery of iron values from low and lean grade resources, CSIR-IMMT has done lot of works on different lean and low grade ores by reduction roasting followed by low intensity magnetic separation processes. The main objective of the study was to change over the goethite to magnetite

Rom sample | Reduced magnetite | Magnetite concentrate

Fig.6 Morphology of rom sample reduced magnetite and magnetite concentrate

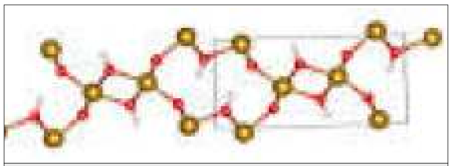


Fig.4 Crystal structure of goethite

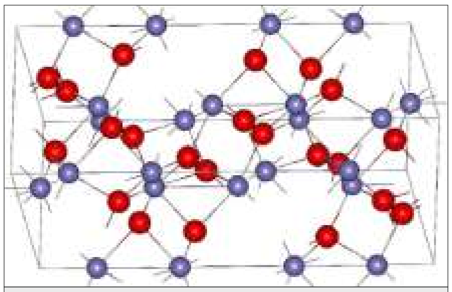
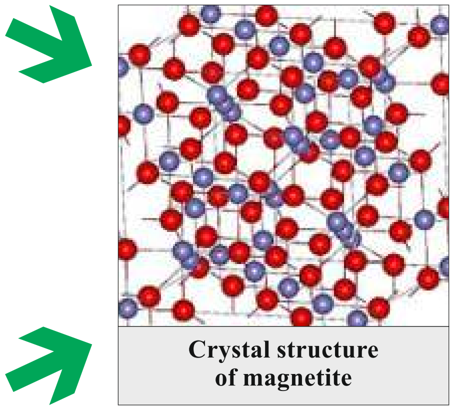


Fig.3 Crystal structure of hematite



Crystal structure of magnetite

Fig.7 Change of hematite and goethite crystal structures to magnetite crystal structure

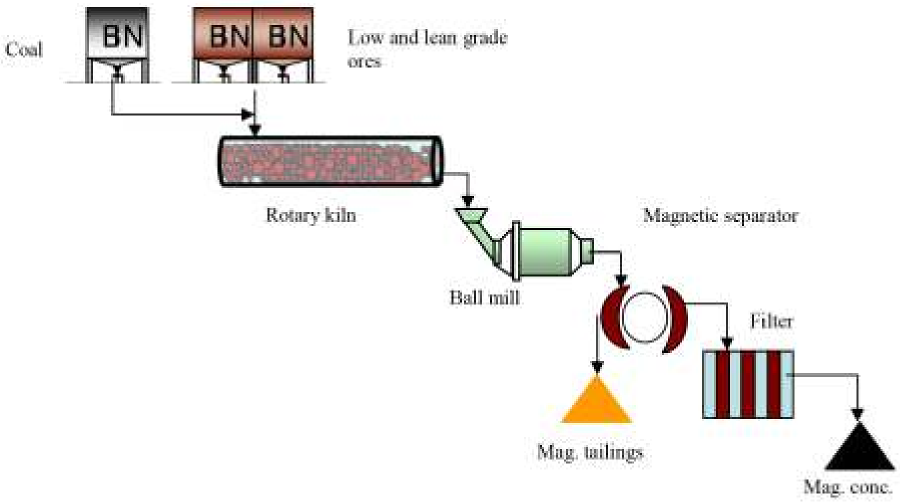


Fig.8 Schematic diagram of reduction roasting process for iron ore

The continuous study was carried out in rotary kiln at the feed rate of 60-100 kg/hr. To reduce the residence time and cost, fluidized bed roasting study is going on.

Conclusions

In overall the following challenges could be overcome

- Indian hematite ore contains good amount of clay minerals, which affects the process fluid dynamics reduces the separation efficiency
- It contains mostly flaky type of shape of the particles after crushing the ore. As a result it gives negative impact in coarse beneficiation in specific in jigging process
- It is difficult to control the ultrafine generation in the grinding circuit
- Ineffective dewatering of the tailings and concentrate
- These ores are more fragile in nature due to presence of goethite phase which increases the ultra-fines during grinding the ore for beneficiation or preparation of the pellet feed materials. It is extremely difficult to beneficiate high goethite low grade iron ores in conventional beneficiation process
- It is difficult to beneficiate in conventional process banded types of ore with economic feasibility
- The high energy requirement for grinding of banded ore

The following advantages can be achieved by adopting reduction roasting process;

- Increases 15-20% extra yield
- Increases grade of the concentrate
- Reduces the grinding energy minimum 30%
- Maximise the recovery of process water by filtration for both concentrate and tailings
- Handling of the reject is easy and it does not require tailings pond
- Transportation through pipeline is easy.
- Ease to make pellet and reduced 20-30% energy consumption in the pelletisation process due to exothermic reaction for conversion from magnetite to hematite
- Improve the pellet quality from magnetite concentrate
- Reduces the consumption of ores per tonne of production of concentrate
- Improve the ore conservation and reduces the environmental impact.