Separation of hematite from banded hematite jasper (BHJ) by magnetic coating

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Abstract: The separation of iron oxide from banded hematite jasper (BHJ) assaying 47.8% Fe, 25.6% SiO₂ and 2.30% Al₂O₃ using selective magnetic coating was studied. Characterization studies of the low grade ore indicate that besides hematite and goethite, jasper, a microcrystalline form of quartzite, is the major impurity associated with this ore. Beneficiation by conventional magnetic separation technique could yield a magnetic concentrate containing 60.8% Fe with 51% Fe recovery. In order to enhance the recovery of the iron oxide minerals, fine magnetite, colloidal magnetite and oleate colloidal magnetite were used as the coating material. When subjected to magnetic separation, the coated ore produces an iron concentrate containing 60.2% Fe with an enhanced recovery of 56%. The AFM studies indicate that the coagulation of hematite particles with the oleate colloidal magnetite facilitates the higher recovery of iron particles from the low grade BHJ iron ore under appropriate conditions.

Key words: banded hematite jasper ore; selective coating; oleate colloidal magnetite; magnetic separation; atomic force microscopy

1 Introduction

Large quantities of banded hematite jasper (BHJ) ores containing 35%–48% Fe, 40%–55% SiO₂ and 1%–4% Al₂O₃ are generated while mining the hematite ores. These low grade ores are kept separately, and no attempts have yet been made to enrich the iron content, mainly due to the lack of suitable beneficiation technology. Characterization studies of banded ores like banded hematite quartzite (BHQ) and BHJ indicate that these ores are liberated at extremely finer sizes [1–4]. The only option to liberate the iron particles is by fine grinding. Beneficiation studies by magnetic separation and flotation techniques on BHQ ore containing about 38% Fe indicate that it is possible to achieve about 65% Fe with 40% yield [5]. In contrast, the BHJ ores have complex mineralogical compositions compared to the BHQ ore and do not respond either to flotation or magnetic separation techniques easily. The comparative study between BHQ and BHJ ore indicates that the BHJ ore is in very finer form than the quartz particles in BHQ, and creates a problem in beneficication even after grinding the ore to a very fine size [6–7].

Some of the alternate methods for recovering the mineral values from the complex and difficult to treat ores are ultrasonic radiation, microwave heat treatment and reduction roasting that can be used to weaken the bond between the mineral and gangue particles [8–10]. Selective magnetic coating of minerals with very fine magnetite, colloidal magnetite or oleate colloidal magnetite followed by magnetic separation technique is another technique that has been applied to complex ores [11–14]. In this process, magnetic materials are selectively coated over the surface of the minerals under controlled conditions so that the coated grains develop better magnetic nature and become amenable to separation by magnetic separation technique at a lower magnetic intensity. The technique offers an efficient method for the separation of materials which are feebly magnetic in nature. The selective magnetic coating known as magnetic carrier technology is a rapidly growing research area where magnetic materials bind selectively on some non-magnetic materials to make them separable using magnetic separation. It is based on the surface modification of fine magnetic particles and offers some advantages over other conventional metal ion separation techniques such as ion exchange, carbon adsorption, and precipitation. The review of magnetic carrier technologies for metal ion removal has been carried out by BROOMBERG et al [15]. The environmental and industrial processes using magnetic carrier technology have been reviewed by MOFFAT et al [16]. In the present investigation, a BHJ iron ore of Odisha, India containing around 47.8% Fe, which did not respond to any conventional mineral processing techniques, was subjected to selective magnetic coating with colloidal and oleate colloidal magnetite followed by a magnetic separation process.
2 Materials and methods

2.1 Sample
Around 500 kg of representative BHJ samples were taken for characterization and beneficiation studies. The samples were ground to different particle size fractions in a standard laboratory ball mill before taking it up for selective magnetic coating. The chemical analysis of the BHJ sample was carried out by wet chemical and XRF analysis techniques. The sample was powdered to a very fine size in a laboratory sample grinder and subjected to the chemical analysis to determine Fe, SiO$_2$, Al$_2$O$_3$ and loss on ignition (LOI). The LOI of the sample was carried out after heating around 1.0 g of the sample in a silica crucible at around 1000 °C for 4 h. The difference in mass after and before heating was taken as the loss due to ignition. The size analysis of the slime sample was carried out by using standard sieves down to 45 µm size.

The chemical analysis of the BHJ ore indicates that it contains 47.8% Fe%, 25.6% SiO$_2$ and 2.30% Al$_2$O$_3$.

2.2 Preparation of colloidal and oleate colloidal magnetite
Colloidal magnetite was prepared by mixing FeCl$_2$·4H$_2$O and FeCl$_3$·6H$_2$O with molar ratio of 1: 2 and dissolving in distilled water as per the standard procedure [14]. The obtained precipitated magnetite was washed several times with distilled water to remove salts and excess sodium hydroxide. The oleate colloidal suspension was prepared by the addition of 50 mL of 2×10$^{-2}$ mol/L sodium oleate to the colloidal magnetite suspension. The pH was adjusted to about 11.3, and the solution was boiled until the magnetite was dispersed. The volume of suspension was made up to 100 mL. Both the suspensions colloidal magnetite and oleate colloidal magnetite were used separately in the experimental studies.

Besides that, the natural magnetite powder obtained from magnetite mines having a Fe content of 69.95% was used in the test. The fine magnetite sample was prepared by grinding the sample for a few hours in a standard ball mill.

2.3 Selective magnetic coating
The selective coating studies of the finely ground BHJ ore with colloidal magnetite particles were carried out in a 1 L glass beaker equipped with a stirrer so as to keep the particles in suspension. The pH of the suspension was regulated by the addition of acid or alkali. All the coating tests were carried out at 10% solids. After conditioning the slurry, the coated particles were separated by a wet magnetic separator supplied by Rapid Box Mag, England. The experiments of magnetic separation were carried out by varying the pH and magnetic intensity.

2.4 Characterization studies
The sample was subjected to various characterization studies such as X-ray diffraction (XRD), stereo microscopy, reflected microscopy, atomic force microscopy (AFM) and Fourier transform infrared spectroscopy. The XRD studies of the samples were carried out using a Phillips diffractometer (PW-1710) with Co-K$_\alpha$ radiation operated at 40 kV and 30 mA. Stereo and reflected microscopic studies were carried out using instruments made by Leitz, Germany. Nature of the deposition of magnetite particles on the surface of hematite was investigated using atomic force microscopy (Dualscope 95-200, Denmark). The AFM images for the BHJ samples without application of any reagent were first obtained by equilibrating with distilled water. In the second stage, a known concentration of oleate colloidal magnetite was added to the sample, and the surface was equilibrated thoroughly for 30 min. The AFM images were recorded after preparing the discs. Topographical AFM images for each experiment along with their image profile were recorded. The contact AFM mode was selected in order to obtain the topographical images during the contact between the surface and the colloidal solutions. The values for surface roughness and maximum height were recorded by the use of the software supplied along with the equipment (DME Scanner). FTIR spectra of the samples were recorded in the range of 400–4000 cm$^{-1}$ using the Perkin Elmer instrument. A pellet made of a mixture of 1–2 mg of samples with 100 mg KBr was prepared for these studies. The mixture was mixed thoroughly and then transferred into the form of a disc.

3 Results and discussion

3.1 Microscopic and XRD studies of BHJ ore
The stereomicroscope and reflected microscope studies of BHJ ore sample were taken up to identify the different mineral phases. Stereo microscope studies of the samples reveal the presence of limonite, quartz and jasper in various amounts along with clayey materials (Fig. 1). The reflected light microscopic studies reveal that the sample consists of hematite as the major mineral phase, whereas goethite occurs in subordinate phase (Fig. 2). The XRD pattern shown in Fig. 3 indicates the presence of hematite, goethite and quartz.

3.2 Studies on magnetic separation
The coating experiments were carried out by varying different variables such as particle size, magnetic