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Concentration of a Sudanese low-grade iron ore

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ABSTRACT

The iron ore deposit of the Northern State of Sudan, at Wadi Halfa, is a huge deposit, but is low in grade. It assays 36% Fe and 48% silica. The present study is an attempt to investigate the amenability of this newly discovered ore for upgrading. Based on the appreciable differences in specific gravity and magnetic susceptibility between the desired iron minerals and the gangue minerals, it was suggested that gravity separation and/or magnetic separation may be useful to concentrate this type of low-grade ore. As a result of the fine dissemination of the iron minerals and the most abundant gangue mineral, quartz, the optimum degree of grind is around 150 μm. Using two-stage separation, roughing and cleaning, it was possible to obtain a high grade concentrate assaying about 64% Fe at a recovery of 72%.

1. Introduction

With increasing global demand of iron ores due to the huge requirement of steel all over the world, important iron ore producing countries have increased their production by initiating steps to utilize the low-grade iron ores, fines, and slimes. Upgrading these low-grade ores is becoming an attractive proposition today. The most commonly used beneficiation methods for iron ores are the gravity and magnetic separation techniques. Gravity separation is widely used in mineral beneficiation practices for its low-cost, ease of operation and easy to control, and eco-friendly nature. They are based on the differential settling velocities of the constituting particle of the ore. Upgrading iron ores by jigging has been an emerging trend (Mukherjee et al., 2006; Roy, 2009; Mansar et al., 1991). Tabling efficiency is quite high when the specific gravity difference between valuable and gangue minerals is high. In addition, magnetic separation may be preferred solely or in combination with gravity separation, depending on the ore characteristics (Svoboda and Fujita, 2003). Abouzeid (1967) studied the possibility of using high intensity magnetic separator for the beneficiation of El-Gedida iron ore in Egypt. He obtained a final product assaying 61% Fe at a recovery of about 90%. Rowayshed (1983) also treated El-Gedida iron ore using a dry high intensity magnetic separator. He did not recommend this technique because of the very limited size range of the feed to the separator. Using a high intensity magnetic separator, Fatma and Arafa (1999) obtained a magnetic concentrate assaying 64.2% Fe and 0.24% BaO from a feed assaying 44% Fe and 20% BaO at feed size fraction of −0.106 + 0.074 mm. Faraghaly (2002) attempted upgrading an iron ore sample containing 23.5% Fe and 34% BaO using a dry high intensity magnetic separator fed with a feed size fraction of −1 + 0.125 mm. A concentrate containing 56.78% Fe and 1.61% BaO at a recovery of 82.8% was obtained. Reduction roasting and low-intensity magnetic separation were carried out to concentrate the fine fraction (−0.125 mm) which represents about 31% by weight of the head sample. This same iron ore sample, El-Gedida iron ore, was treated by anionic flotation using Na-DDS as a collector for floating barite, and sodium silicate as a depressant for iron minerals (Mussallam, 2004). The feed for the flotation cell was −250 + 80 μm assaying 36.5% Fe and 23% BaO. After several cleaning stages, an iron concentrate assaying 62% Fe with less than 2% BaO at a recovery of 71.3% was obtained.

The iron ore deposit of Wadi Halfa is located on both sides of Nasser Lake. The ore reserves are estimated to be about 400–800 Tg (teragrams or million tons) at an average assay of about 36% Fe (Ali et al., 2004; Moslim, 2010).

Wadi Halfa iron ore, is a low-grade iron ore. The iron minerals occur as a mixture of goethite and hematite in an oolitic pisolitic texture. The existence of the suitable infra-structure favors exploiting the mineral resources in the area. It is worth mentioning that the Wadi Halfa iron ore deposit was discovered recently by the Geological Research Authority of Sudan (Ali et al., 2004). No beneficiation studies have been reported concerning this deposit until now. The main objective of this study is to investigate the amenability of Wadi Halfa low-grade iron ore for upgrading by gravity and magnetic separation techniques. The main parameters affecting the effectiveness of a shaking table and a high intensity magnetic separator were investigated.

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2. Experimental work

2.1. Materials and techniques

2.1.1. Ore sample and feed preparation

A composite sample of about 200 kg was collected from the iron ore deposit at Wadi Halfa area. It was crushed and split into representative samples for chemical analysis, mineralogical studies, and beneficiation. Samples for beneficiation were ground in a ball mill to different degrees of fineness: −500 μm, −350 μm, and −150 μm, and deslimed using a hydro-cyclone at a cut size of 20 μm, to produce feed fractions of −500 + 20 μm, −350 + 20 μm, and −150 + 20 μm for processing experiments. The amount of iron rejected in the slimes ranges from 2.5% (in the case of −500 μm) to 8.0% (in the case of −150 μm) depending on the size fraction required. Liberation of more than 90% of the iron minerals particles in the ore was obtained in the size fraction −150 + 20 μm.

2.1.2. Mineralogy and chemical characterization of the ore

Using X-Ray Diffraction analysis, it was found that the ore consisted of goethite, hematite, quartz, calcite, kaolin, and feldspar. The main gangue mineral was quartz. Under the optical microscope, it was observed that the iron minerals and quartz are finely disseminated. The head sample assayed about 36% Fe and 48% SiO_2 (Table 1).

2.1.3. Beneficiation techniques

A laboratory shaking table of 50 cm × 120 cm was used for gravity separation, and a High Intensity Magnetic Separator (H. T. Readings, PTY LTD, Series No. 88.1), of maximum field intensity of 1.8 Tesla, was used as an alternative technique for upgrading this type of iron ore.

3. Results and discussion

3.1. Gravity separation

Effects of two important operating parameters of the shaking table, feed size range and table tilt, were investigated. The following summarizes the obtained results.

3.1.1. Effect of feed size range

The assay of the concentrate obtained using the coarse size fraction is not significantly different from that of the feed. The assay of the concentrate as well as the metal recovery continued to increase as the feed size gets finer. The assay increased from 37.4% Fe to 44.9% Fe at an iron recovery of 81.2% Fe when the feed size fraction was −150 + 20 μm and the table was tilted at an angle of 5°. This is due to the fact that the degree of liberation increases as the size fraction decreases.

3.1.2. Effect of angle of table inclination (table tilt)

The tilt angle was varied between 3° and 8°. The optimum tilt angle was 5°. At 3° table inclination, large amount of middling particles are driven towards the concentration end of the table, which increased the recovery (90.1%) and had an adverse effect on the grade of the concentrate (41.1% Fe). At higher tilt angle, 8°, large amounts of the iron-bearing particles was washed towards the tailing section of the table, resulting in the iron recovery as low as 66.0%. The optimum parameter values for using the shaking table as a roughing stage are: feed size of −150 + 20 μm when the table tilt angle was 5°. The concentrate assay was 44.9%Fe at a recovery of 81.2%.

Table 1
Chemical analysis of Wadi Halfa iron ore sample.

Constituent	Fe_2O_3	Fe (Total)	SiO_2	CaO	MgO	MnO	Al_2O_3	SO_4	P_2O_5
Percent	45.3	36.1	47.5	1.6	0.3	0.3	1.8	nil	0.1

3.2. Magnetic separation

Three parameters affecting the performance of the high intensity magnetic separator, feed size fraction, magnetic field intensity, and drum rotating speed, were investigated. The effect of each of these operating parameters is discussed in the following paragraphs.

3.2.1. Effect of feed size fraction

This series of experiments was carried out at current intensity of 0.3 Ampere and drum rotational speed of 100 rpm. The optimum feed size fraction was at −150 + 20 μm. The iron assay of the concentrate under these conditions was 42.4% Fe at a recovery of 86.3%. Although the recovery is relatively high, the selectivity was poor because of the high percentage of silica that may have been mechanically trapped with the concentrate.

3.2.2. Effect of electric current intensity to the electromagnetic coil

The current intensity to the coil is an indication of the magnetic field intensity, as the current increases the field intensity increases. The range of the current variation in the magnetic separator which was used is from 0.1 to 0.5 Amperes. The drum rotational speed was 100 rpm and the feed size fraction was −150 + 20 μm.

The assay of the concentrate decreases with increasing the magnetic field intensity. This result is due to the degree of selectivity as a function of the field intensity. The optimum result was obtained at a current intensity of 0.3 Ampere, where the assay of the concentrate was 42.4% Fe at a recovery of 86.3%. At lower current intensity, 0.1 Ampere, only the high magnetically susceptible particles are picked up by the rotating drum, which produced a relatively high grade concentrate (45.0% Fe) at low recovery (79.6%). The low recovery is due to the fact that a large portion of the locked particles goes with the non-magnetic fraction. At higher current intensities, there was no noticeable change in recovery or grade.

3.2.3. Effect of the drum rotational speed

The drum rotational speed was varied from 60 to 220 rpm. The main effect of the drum rotational speed is the induced centrifugal force to the flowing particles which is function of the particle mass. However, because of the difference in behavior of the main ore constituents, iron minerals and quartz, during size reduction, the quartz particles are coarser than the iron minerals particles. Also, the particle mass (density multiplied by volume) is a main parameter in this case because of the gravitational force affecting the individual particles. This means that there are several forces that act on the flowing particles, namely, centrifugal force, gravitational force, and magnetic force. A combined effect of these acting forces determines the optimum operating conditions in this case. As a result of this combination of forces, the optimum result, as represented by the concentrate assay and recovery, was obtained at drum speed of 100 rpm. Above this speed, the metal recovery dropped considerably whereas the assay of the magnetic product was not significantly affected.

The above results show that the conditions under which the optimum concentrate was obtained, using the HIMS, are: feed particle size of −150 + 20 μm, electric current intensity of 0.3 A, and 100 rpm drum rotational speed. This concentrate assays 42.4% Fe, at a metal recovery of 86.3%.

However, the concentrate assay under optimum operating conditions is low, 44.9% Fe, at a recovery of 81.2% in the case of the gravity

Table 2
Cleaning of the rougher concentrates using HIMS (at 0.3 A, drum speed 100 rpm).

Feed	Assay, Fe %	Recovery of the cleaning stage, %	Overall recovery w.r.t. original sample, %
Table concentrate	65.4	87.2	71.5
Mag.product	63.5	82.3	72.1