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EFFECTIVE PROCESSING OF LOW-GRADE IRON ORE THROUGH GRAVITY AND MAGNETIC SEPARATION TECHNIQUES

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Abstract. This study investigates the effectiveness of gravity and magnetic concentration techniques for the beneficiation of a Sudanese iron ore, the newly discovered Wadi Halfa iron ore deposit. It is a low-grade type of ore with high silica content, more than 45% SiO_2, and an average iron content of about 35% Fe. Based on the fact that there are 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 ore. These two techniques were adopted for the beneficiation of the Wadi Halfa low-grade iron ore. As a result of the fine dissemination of the iron minerals and the most abundant gangue mineral, quartz, the optimum degree of grinding is around 150 micrometers. The rougher tests of both the gravity separation and magnetic separation produced concentrates of about 44% Fe. Each of these two concentrates was cleaned in a second stage of processing using high intensity magnetic separator. Final iron concentrates, assaying about 64% Fe at a recovery of about 70%, were achieved.

keywords: Wadi Halfa iron ore, low-grade iron ore, gravity concentration, magnetic concentration, combined gravity/magnetic concentration

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. The main difficulty in processing and utilization of low-grade iron ores primarily stems from their mineralogical characteristics as well as the soft nature of some ores and their high silica content. Thus, beneficiating the low-grade iron ores to remove the gangue minerals and enhancing their grade is an attractive proposition today. Among the known iron deposits in Sudan, many are of low-grade which require beneficiation to produce an acceptable feed for steel making plants.

Wadi Halfa iron ore, in Northern Sudan, is one of these types. The problem in upgrading this deposit is two-fold. Firstly, the iron minerals occur as a mixture of

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goethite and hematite in an oolitic pisolitic texture. Secondly, the iron minerals are finely disseminated in silica and silicates. This requires fine grinding to obtain adequate degree of liberation of the desired iron mineral and the gangue constituents. The location of Wadi Halfa iron ore deposit, in the Northern State, is bounded by latitude 21º 45' and 22º 00' N and longitudes 31º 15' and 31º 45' E. The iron ore deposits of this area are located on both sides of Lake Nasser. The ore exists in several layers in stratified succession. The iron ore tonnage is estimated for only one layer of the deposit to be about 400-800 Tg (teragrams or million tons) at an average assay of 36% Fe. Since the ore is multi-layered, the tonnage given could be an underestimation of the whole reserves. In addition, the western part of the area is not yet assessed but it could add some additional reserves (Ali et al., 2004; Moslim, 2010).

The processing of this particular iron ore is worthy to be considered for many reasons. It's occurrence beside the Nile River; hence water will be available in terms of quantity and quality. Electricity is underway in the near future when the national grid reaches Halfa from Merawe Dam. Railway line connects Halfa to the rest of the country. Skilled labor is available in the area**.**

The most commonly used beneficiation methods for iron ores are the gravity and magnetic separation methods. Recovery of valuables from natural ores by gravity concentration process is one of the oldest and most economic techniques (Brut, 1999). Although in the twentieth century gravity concentration has been partially replaced by other techniques, notably, flotation and magnetic separation, they have not made it obsolete. Gravity separation techniques are widely used in mineral beneficiation practices for its low-cost, ease of operation, and eco-friendly nature. They are based on the differential settling velocities of the constituting particle of the ore.

The settling velocity of particles is governed jointly by weight (volume and density), buoyancy, and drag forces. The most commonly used gravity techniques for beneficiation of iron ores are shaking tables, jigs (Roy, 2009) and spirals. Upgrading iron ores by jigging has been an emerging trend (Mukherjee, 2006). Flowing film gravity concentration using Wilfley table is a powerful technique for the recovery of fine iron minerals. Many theoretical and experimental investigations of Wilfley table performance have been reported (Gaudin, 1987; Mansar, et al., 1999; Shivamohan, and Forssberg, 1985). Tabling efficiency is quite high when the specific gravity difference between valuable and gangue minerals is high (Samykina et al., 2005). In addition, for upgrading iron ores, magnetic separation may be preferred solely or in combination with gravity separation, depending on the ore characteristics (Svoboda, and Ross, 1989; Svoboda, 1994; Svoboda and Fujita, 2003).

Beneficiation of Camdag iron (oolitic) hematite ore containing limonite-hematite or goethite-limonite using gravity separation and high intensity magnetic separation, increases the grade of ore about 5-7% in concentrates with about 60% recovery by both methods (Guney et al., 2000). Abouzeid (1967) studied the possibility of using high intensity magnetic separator for the beneficiation of El-Gedida iron ore. An ore sample containing 51.6% Fe, 8.76% SiO_2 and 3.06% BaO was used for the study. He found that high intensity magnetic separator tests were limited to very close range of sizes between 2 and 0.125 mm. The final magnetic product assayed 61% Fe at an iron recovery of 90.3%. However, 5% by weight was obtained as middling assaying 31.4% Fe. These middling products, together with the fine fraction minus 0.125mm which constitute 35% by weight of the whole sample, were not possible to be upgraded by magnetic separation. The barite-riche iron ore of the same deposit was treated by anionic flotation using Na-DDS as a collector for floating barium sulfate, and sodium silicate as a depressant for iron minerals (Mossallam, 2004). The feed size fraction for the flotation cell was -250+80 μm assaying 36.5% Fe and 23% BaO. After several cleaning stages by flotation, an iron concentrate assaying 62% Fe with less than 2% BaO at a recovery of 71.3% was obtained.

Rowayshed (1983) studied the possibility of using high intensity magnetic separator for beneficiation of El-Gedida. He found that high intensity magnetic separator is limited by a much-closed range of sizes less than 2 mm, neither the coarse nor the very fine sizes can be treated by this method. The dominant iron minerals present in this ore are the hydrated minerals, goethite and hydro-goethite, which are difficult to treat through the high intensity magnetic separator.

Fatma et al. (1999) studied the beneficiation of an iron ore sample containing 44% Fe, 1.59% SiO_2 and 20% BaO. By magnetic separation, two products of iron ore and barite concentrates were obtained by using a high intensity magnetic separator. The fine fraction (-0.125 mm) is about 20% by weight assaying 54.6% Fe, and 3.91% BaO, which needs further cleaning to reduce the barite content to meet the smelter specifications (52% Fe, and 2% BaO). The size (0.74 +0.106 mm) fraction, after concentration by H.I.M.S., still contains 41.9% Fe and 11.55% BaO. After cleaning several times using H.I.M.S, an iron concentrate assaying 58.48% Fe, and 0.73% BaO is obtained. Final iron concentrate was obtained assaying 64.2% Fe, and 0.24% BaO.

Faraghaly (2002) studied an iron ore containing 23.5% Fe and 34% BaO using a dry high intensity magnetic separator for the processing of a feed size fraction of -1+0.125 mm (about 69% by weight of the original feed size). A concentrate containing 56.78% Fe and 1.61% BaO at a recovery of 82.76% was obtained. Reduction roasting process was carried out on the fine fraction (-0.125mm) which represents about 31% by weight of the head sample. A concentrate assaying 56.78%Fe, and 1.61%BaO, with recovery of 82.76% was obtained.

The iron ore at Wadi Halfa is intercalated with Nubian sedimentary rock faces and overlies these rocks. The stratigraphy of the area from bottom to top is composed of whitish to violet clayey sandstone, followed by iron-bearing rocks (usually varied in thickness), conglomerates, and then ferruginous layes intercalated with Nubian sandstone, which is usually capped with oolitic ironstone. The stratigraphy is repetitive in nature indicating several or multiple depositional sedimentary cycles. Chemically and structurally, the oolitic iron ore of Wadi Halfa can be classified into three types. These are: 1) hematitic oolitic type is red in color because hematite is domination in the ore. It is fine grained and is always found at the base of the iron oolitic form colony, 2) oolitic goethitic iron ore which is black in color indicates supergene sedimentary conditions associated with the precipitation of the iron ore, 3) brown oolitic iron formation is an intermediate species between the above two mentioned types in terms of composition and color (Ali et al., 2003).

It is worth mentioning that the Wadi Halfa iron ore deposit was discovered recently by the Geological Research Authority of Sudan (GRAS) (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 (Northern Sudan) low-grade iron ore for upgrading by gravity and magnetic separation techniques. The main parameters affecting the effectiveness of a shaking table (exploiting the difference in specific gravity of the main ore constituents), and a high intensity magnetic separator (exploiting the differences in magnetic susceptibility of the ore constituents) were investigated

2. Experimental

Ore sample. A composite sample of about 200 kg was collected from the iron ore deposit at Wadi Halfa area. The sample was collected from different pits in the deposit area to represent, to some extent, the actual deposit. It was crushed, well mixed, and quartered to small samples of about 1 kg each. Representative samples were prepared for chemical analysis and mineralogical studies.

Feed preparation. Some of the samples were ground in a ball mill to different degrees of fineness: -500 μm, -350 μm, and -150 μm to be used in the beneficiation experiments. These fractions were deslimed using a hydro-cyclone at a cut size of 20 μm, which made the feed fractions to be: -500+20 μm, -350+20 μm, and -150+20 μm.

Beneficiation techniques. A laboratory shaking table of dimensions 50 cm x 120 cm was used to exploit the difference in specific gravity between the iron minerals and the gangue minerals. Also, as a result of the significant difference in magnetic susceptibility between the desired and no desired minerals, a High Intensity Magnetic Separator (H. T. Readings, PTY LTD, Series No. 88.1) was used as an alternative technique for upgrading this type of iron ore.

3. Results and discussion

3.1. Characterization of the ore

Mineralogy of the ore. Using X-Ray Differential Analysis, it was found that the iron ore sample consisted of goethite, hematite, quartz, calcite kaolin, and feldspar. The major constituents were goethite as an iron mineral and quartz as a gangue mineral, and the rest were minor minerals. Under the optical microscope, it was observed that the iron minerals and quartz are finely disseminated. The ore exists in the form of oolitic and pesolitic texture.

Chemical analysis. Table 1 gives the chemical analysis of the iron ore sample used in this research work. It is clear that the iron content is relatively low, in the range of

36% Fe, and the major gangue mineral is quartz, in the range of 48% SiO_2. The rest of the undesired constituents is less than 2% each.

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

Desliming of the ore sample. The three ball mill products: -500 μm, -350 μm, and -150 μm were deslimed using a hydro-cyclone to remove the -20 μm particles. Table 2 shows the results of the desliming tests. The slimes fraction ranges from 6% by weight in the coarse size fraction, -500 μm, to 10% by weight in the fine size fraction, -150 μm, with rejected amounts of 2.5% Fe and 8.0% Fe, respectively.

Table 2. Classification of the feed fractions

Size fraction, μm	Fraction weight, %	Assay, Fe %	Metal distribution, %
-500+20	94.3	36.7	97.5
-20	5.7	34.7	02.5
Total	100.0	36.6	100.0
-350+20	92.4	37.0	94.7
-20	7.6	31.9	5.3
Total	100	36.6	100
-150+20	90.5	37.7	92.0
-20	9.5	30.0	08.0
Total	100	36.9	100

Liberation study. The degree of liberation of the iron minerals was studied by the point counting technique. Polished sections of the different size fractions were prepared and studied under the microscope in reflected light mode. Both the free particles of iron minerals and the grains of iron minerals locked with gangue minerals in the microscope view were counted, and the percentage of free iron minerals grains relative to the sum of the two types of particles was calculated. Table 3 gives the counting results and the degree of liberation of the iron minerals

Table 3. Degree of liberation of Wadi Halfa iron ore as a function of size fraction

Size fraction, μm	No. of free iron minerals grains	No. of locked grains	Total number (free +locked)	Degree of liberation, %
-500+20	2957	2254	5211	56.7
-350+20	3053	960	4013	76.1
-150+20	2396	235	2631	91.1
-105+20	2408	105	2513	95.8

The above counts suggest that the degree of liberation increases as the grain size gets finer, which is obvious.

Concentration of the Wadi Halfa iron ore. Gravity and magnetic separation techniques seem to be two suitable candidates for upgrading this type of iron ore due to the significant differences in specific gravity and magnetic susceptibility between the desired and no desired constituents in the ore. The important parameters in both of these techniques were investigated to find out if one of them or both could be applied to concentrate the Wadi Halfa iron ore. The following is a brief discussion of the results obtained throughout this study.

3.2. Gravity separation

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

Effect of feed size range. The feed size ranges used in this study were +500-20 µm, -350+20 µm, and -150+20 µm. Table 4 summarizes the effect of the feed size fraction to the table on the assay and metal distribution of the iron concentrate.

Table 4. Effect of feed size fraction on the efficiency of tabling (table tilt is 5 degrees)

Size fraction, µm	Product	Product weight, %	Assay, Fe %	Metal distribution %	Metal distribution relative to original sample, %
-500+20	Concentrate	70.0	38.8	74.3	72.5
	Tailing	30.0	31.4	25.7	25.1
	Total	100	36.7	100.0	97.6
-350+20	Concentrate	72.6	41.5	82.3	77.9
	Tailing	27.4	23.6	17.7	16.8
	Total	100.0	36.5	100.0	94.7
-150+20	Concentrate	72.5	44.9	86.7	79.9
	Tailing	27.5	18.2	13.3	12.1
	Total	100	37.6	100.0	92.0

The assay of the concentrate obtained using the coarse feed 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 fraction decreased. The assay increased from 38.8% Fe to 44.9% Fe and the recovery increased from 74.3% to 86.7% as the feed size fraction decreased from -500+20 to -150+20 µm, respectively. These effects are logical because the degree of liberation increases as the size fraction decreases (Fig. 1).

Effect of angle of table inclination (table tilt). The tilt angle was changed between 3º and 5º. Table 5 presented the results as a function of the table tilt angle.

The optimum tilt angle is 5º. At 5º table inclination large amount of middling particles are driven towards the concentration end of the table, which increased the recovery and decreased the assay. At higher tilt angle, the wash water washes away large amounts of the iron-bearing particles towards the tailing section of the table (Fig. 2).

The above results show that the optimum parameter values for using the shaking table as a roughing stage for concentrating this type of iron ore are: feed size fraction of -150+20 µm when the table tilt angle was 5º. At these parameter values, the concentrate assay was 44.9%Fe and the stage recovery was 86.7%. Taking the lost material in desliming into consideration, the overall recovery was 79.9%.

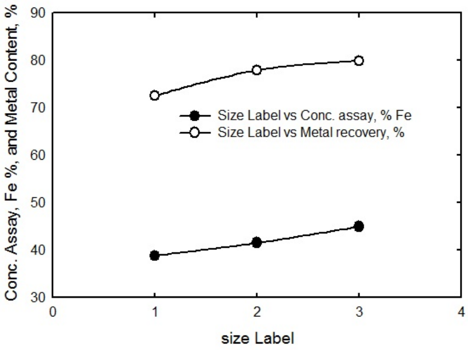

Fig. 1. Concentrate assay and metal recovery as a function of the feed size fraction to the table. The size labels are: 1 for -500+20 µm, 2 for -350+20 µm, and 3 for -150+20 µm

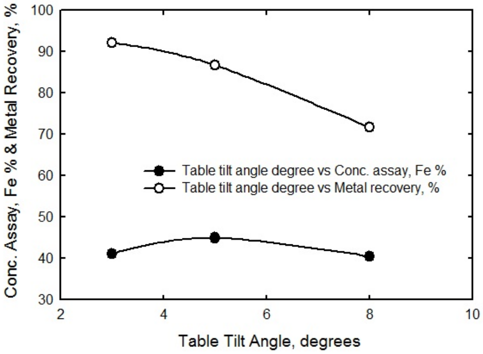

Fig. 2. Concentrate assay and metal recovery as a function of the table tilt angle

Table 5: Effect of Table inclination. Feed size fraction is -150+20 µm

Table inclination, degree	Product	Product weight, %	Assay, Fe %	Metal distribution, %	Metal distribution relative to original sample, %
3	Concentrate	83.8	41.1	92.1	79.2
	Tailing	16.2	18.0	07.9	06.8
	Total	100	37.4	100.0	86.0
5	Concentrate	72.5	44.9	86.7	79.9
	Tailing	27.5	18.2	13.3	12.1
	Total	100.0	37.6	100.0	92.0
8	Concentrate	66.0	40.5	71.7	66.0
	Tailing	34.0	31.0	28.3	28.3
	Total	100.0	37.3	100.0	94.3

3.3. 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 will be discussed in the following paragraphs.

Effect of feed size fraction. The feed size fractions used in this study were: -500+20 µm, -350+20 µm, and -150+20 µm. Table 6 summarizes these results.

Table 6: Effect of feed size fraction on efficiency of magnetic separation at 0.3 Ampere and 100 rpm

Size fraction µm	Product	Product weight, %	Assay Fe %	Metal distribution, %	Metal distribution relative to original sample, %
-500+20	Magnetic	65.1	38.8	74.3	72.5
	Non-magnetic	34.9	31.4	25.7	25.1
	Total	100	36.7	100.0	97.6
-350+20	Magnetic	75.3	41.5	82.3	77.9
	N0n-magnetic	24.7	23.6	17.7	16.8
	Total	100.0	36.5	100.0	94.7
-150+20	Magnetic	81.5	42.4	92.4	84.9
	Non-magnetic	18.5	16.0	7.8	7.1
	Total	100.0	36.5	100	92.0

As it was observed in the gravity separation, the optimum results were obtained at feed size fraction of -150+20 µm, where the iron assay of the concentrate was 42.4% Fe at a recovery of 92.2%. Again, this is because the finer the size fraction, the more is the liberation of the desired minerals from the gangue minerals (Fig. 3). However, the selectivity was low because of the high percentage of silica.

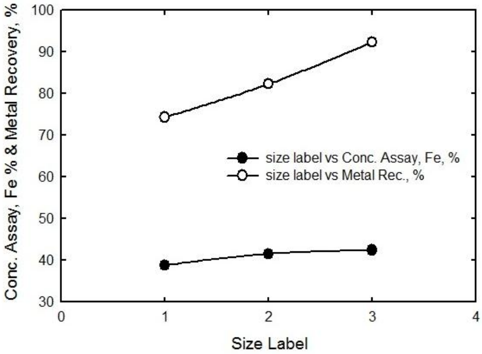

Fig. 3. Effect of feed size fraction on the concentrate assay and metal recovery using high intensity magnetic separator. The size labels are: 1 for -500+20 µm, 2 for -350+20 µm, and 3 for -150+20 µm

Effect of electric current intensity to the electromagnetic coil. The current intensity to the coil is an indication to the magnetic field intensity, as the current increases the field intensity increases. The range of the current variation in the magnetic separator that was used is from 0.1 to 0.5 Amperes. Table 7 and Figure 4 give the results of the effect of the current intensity on the assay and recovery of the concentrate.

From Table 7, it can be seen that 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. At low field intensity only the high magnetically susceptible particles are picked up by the rotating drum, which produces 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. The optimum result was obtained at a current intensity of 0.3 Ampere.

Table 7. Effect of magnetic field intensity. The magnet drum runs at 100 rpm

Current Ampere	Product	Product weight, %	Assay Fe %	Metal distribution, %	Metal distribution relative to original sample, %
0.1	Magnetic	66.0	45.0	79.6	73.2
	Non-magnetic	34.0	22.5	20.4	18.8
	Total	100.0	37.4	100.0	92.0
0.2	Magnetic	76.5	42.7	87.3	80.3
	Non-magnetic	23.5	20.2	12.7	11.7
	Total	100.0	37.4	100.0	92.0
0.3	Magnetic	81.5	42.4	92.2	84.8
	Non-magnetic	18.5	16.0	07.8	07.2
	Total	100.0	37.5	100.0	92.0
0.4	Magnetic	82.0	41.9	91.8	84.4
	Non-magnetic	18.0	17.0	08.2	07.6
	Total	100.0	37.4	100.0	92.0
0.5	Magnetic	83.0	41.2	91.7	84.3
	Non-magnetic	17.0	18.3	08.3	07.7
	Total	100	37.3	100.0	92.0

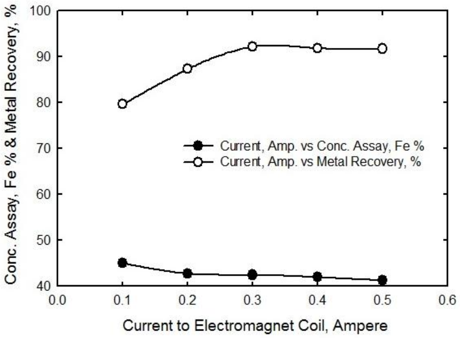

Fig. 4. Iron assay and metal recovery of the concentrate as a function of current intensity to the electromagnetic coil at this current intensity, the magnetic intensity

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 a function of the particle mass. However, because of the nature of the main ore constituents, iron minerals and quartz, during size reduction, the quartz particles are coarser than the iron minerals particles although less in density than the iron minerals. Also the particle weight (density multiplied by volume) is a main parameter in this case because of the gravitational force acting on the individual particles. This means that there are several forces which 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 revolution of 100 rpm (Table 8 and Fig. 5).

The above results show that the conditions under which the optimum concentrate was obtained, using the high intensity magnetic separator, 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 92.2%. However, as we have seen from the presented results of both the gravity separation and the magnetic separation processes, the concentrate assay under optimum operating conditions is low, 44.9% Fe, at a recovery of 86.7% in the case of the gravity separation process and 42.4% Fe, at a recovery of 92.2% in the case of the magnetic separation process. These results suggest that a cleaning stage of the concentrate obtained from the first stage may improve the assay of the final product. Based on this conclusion, the concentrates obtained from the shaking table and from the high intensity magnetic separator were, separately, subjected to a second run on the high intensity magnetic separator.

Table 8. Effect of drum speed (current to the electromagnetic coil 0.3 Ampere, feed particle size fraction is -150+20 micrometers)

Drum speed rpm	Product	Product weight, %	Assay Fe %	Metal distribution, %	Metal distribution relative to original sample, %
60	Magnetic	84.0	40.3	91.2	83.9
	Non-magnetic	16.0	20.0	08.8	08.1
	Total	100.0	37.1	100.0	92.0
100	Magnetic	81.5	42.4	92.2	84.8
	Non-magnetic	18.5	16.0	07.8	07.2
	Total	100.0	37.5	100.0	92.0
140	Magnetic	56.0	43.0	64.2	59.1
	Non-magnetic	44.0	30.5	35.8	32.9
	Total	100	37.5	100.0	92.0
180	Magnetic	41.3	44.3	49.5	45.5
	Non-magnetic	58.7	31.9	50.5	46.5
	Total	100.0	37.0	100.0	92
220	Magnetic	36.2	44.3	43.2	39.7
	Non-magnetic	63.8	33.0	56.8	52.3
	Total	100.0	37.1	100.0	92.0

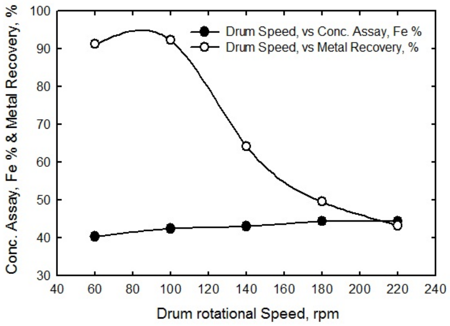

Fig. 5. Effect of drum rotational speed on the performance of the magnetic separator

3.4. Cleaning of the Rougher Concentrates

The rougher concentrates obtained from the shaking table as well as the magnetic separator were both relatively low in grade. The shaking table concentrate assayed 44.9% Fe at metal recovery of 86.7%, and the magnetic separator concentrate assayed

42.4% Fe at metal recovery of 92.2%. These two rougher concentrates were passed through the high intensity magnetic separator, at its optimum operating conditions (current to the coil is 0.3 Ampere, drum rotation speed 100 rpm), for cleaning. Table 9 presents the results of the cleaning stage of the shaking table concentrate. The final assay of the concentrate is 65.4% Fe, at an overall metal recovery of 69%.

The rougher concentrate from the magnetic separator was passed again on the high intensity magnetic separator, at its optimum operating conditions, for cleaning. The cleaned concentrate assayed 63.5% Fe at an overall metal recovery of 67.7%. Table 10 shows the results of the cleaning stage for the magnetic separator rougher concentrate.

Table 9. Cleaning of the table concentrate using the high intensity magnetic separator (magnetic field intensity is at 0.3 A, drum speed 100 rpm)

Product	Product wt. %	Assay Fe %	Metal distribution, %	Metal distribution relative to original sample, %
Magnetic	60.1	65.4	87.2	69.0
Non-magnetic	39.9	14.5	12.8	10.2
Total	100	45.0	100	79.2

Table 10. Cleaning of the magnetic rougher concentrate (magnetic field intensity at 0.3 A, drum speed 100 rpm)

Product	Product wt. %	Assay Fe %	Metal distribution,%	Metal distribution relative to original sample, %
Concentrate	53.2	63.5	79.7	67.7
Tailing	46.8	18.4	20.3	17.3
Total	100.0	42.4	100.0	85.0

4. Conclusions

The low-grade iron ore sample obtained from the Wadi Halfa iron ore deposit, North of Sudan, was analyzed mineralogically and chemically. The major mineral constituents were hydrated iron minerals and quartz. The trace constituents were calcium, magnesium, aluminum, manganese, and phosphorus oxides. The average iron assay was about 36% Fe, and the silica content was about 57% SiO_2. Three samples were ground such that the first sample passed 500 μm, the second passed 350 μm, and the third passed 150 μm. Each of the three samples were deslimed to remove the -20 μm fraction, such that the feed size ranges to be tested were -500+20 μm, -350+20 μm, and -150+20μm. The ore was beneficiated using the shaking table and the high intensity magnetic separator. The beneficiation took place in two stages: roughing and cleaning. The optimum operating conditions for the table were: feed size fraction of -150+20 μm and table tilt angle of 5^{o}, and those of the magnetic separator were: feed size fraction of -150+20 μm, 0.3 Ampere, and drum rotational speed of 100 rpm. The rougher concentrates from both the gravity separation and the magnetic separation were, separately, subjected to the second stage of concentration, the cleaning stage. In the cleaning stage, the rougher concentrates were passed on the high intensity magnetic separator at its optimum operating conditions: 0.3 Ampere and 100 rpm drum speed. The cleaned concentrate obtained by using the shaking table followed by magnetic separator assayed 65.5% Fe, at a recovery of 69.0%, and the cleaned concentrate obtained by passing the ore twice on the magnetic separator assayed 63.5% Fe, at a recovery of 67.7%. The obtained results suggest that the Wadi Halfa iron ore could be beneficiated using either of the two routes: gravity separation (shaking tables) followed by high intensity magnetic separation, or two stage high intensity magnetic separation.

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