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BENEFICIATION OF GIDAN JAJA IRON ORE, ZAMFARA STATE NIGERIA USING MAGNETIC CONCENTRATION METHOD

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ABSTRACT
This research work focused on the possibility of upgrading GidanJaja iron ore deposit located in Zurmi Local Governmental Area of Zamfara State, Nigeria using magnetic concentration technique.250 g of the representative sample was ground to the liberation size of the ore containing 52.08% Fe and 15.0% TiO_2 *and then fed to the low intensity magnetic separator, the machine separated the ground sample into concentrate and tailing based on their magnetic susceptibility. Chemical analysis of the concentrate revealed 56.87% Fe and 12.20%* TiO_2 *with recoveries of 76.24% Fe and 48.67%* TiO_2 *respectively. The result obtained from concentration test inferred that GidanJaja iron ore can be upgraded using magnetic separation technique to produce a concentrate suitable for lump direct charging in the conventional Blast furnace. However, the presence of 12.20%* TiO_2 *is still a concern. The result fell below the standard specification for the concentrate to be used for sinters and pellets production for the blast furnace in Ajaokuta, Nigeria.*
***Keywords**: GidanJaja iron ore, low intensity magnetic separator and concentration.*

INTRODUCTION

The impact of iron and steel in any economy is usually tremendous because its production and consumption are measures of the rates and levels of industrialization. Iron and steel are the most widely used engineering materials for production, fabrication, construction and manufacture of items, including ships, vehicles, military hardware etc. This explains why the per capita consumption of steel is an index for assessing development in the economy of any nation. The availability and development of the iron and steel sector is essential for industrial growth, increased engineering capacity and enhancement of technical skills (Raw Materials Research and Development Council, 2010).

Iron ore deposits are usually present as iron oxides (magnetite - Fe_3O_4; hematite - Fe_2O_3), hydroxides (geotite – FeO (OH); limonite - $2Fe_2O_3.H_2O$) and carbonates (siderite - $FeCO_3$) (Olatunji and Durojaiye, 2010). These minerals do not occur alone; the main iron (Fe) content of the ores is lower due to certain impurities. Thus, qualities of iron ore is also influenced by the presence of minor and trace constituents such as Mn, Cu, Ni, Ti, Co, Pb and Zn. Iron ore could also contain some deleterious elements such as phosphorus, silica, potassium, alumina, sulfur and sodium (Astrup and Hammerbeck, 1998; Yusfin *et al*., 1999).

Low grade ores require extra technology and investment in beneficiation plant to process the ores to meet the required standard for iron and steel production (Elijah 2013).There are two fundamental operations in mineral processing namely; the release or liberation of the valuable minerals from their waste gangue minerals and separation of these values from the gangue, this latter process is also known as concentration. The liberation of the valuable minerals from the gangue is accomplished by comminution and one of the major objectives of comminution is the liberation or release of the valuable minerals from the associated gangue minerals at the coarsest possible particle size, if such an aim is achieved, then not only is energy saved by the reduction of the amount of fines produced but any subsequent separation stages become easier and cheaper to operate. If high – grade solid products are required then good liberation is essential, (Wills and Atkinson, 1993).

Iron Ore Beneficiation Processes

For the purpose of beneficiating any type of ore for its minerals or metal values and for design of accompanying flowsheet (s) after chemical and mineralogical investigation. The ore is subjected to some concentration processes that can separate the minerals into two or more products. Separation is usually achieved by utilizing some specific differences in physical and chemical properties between the valuable and gangue minerals in the ore (Yaro, 1997). However, mineral processing operations are mainly concerned with utilizing the physio-chemical methods of separation. Some of these methods are: gravity, magnetic, electrostatic, froth flotation and the combination of these methods (Agava, 2006). In the course of this study, only the low intensity magnetic separation technique was used.

Magnetic Separation Processes

The principle of magnetic separation involves the action of several external forces with a dominant magnetic force. The separation of one mineral from another depend upon their motion in response to the dominant force and other competing forces namely gravitational frictional, inertia and centrifugal. In the case of separation involving ferromagnetic minerals, the magnetic force acting on the particles must be greater than the sum of all the other competing forces. As a result of which the mineral will be attracted to the magnet. For non-magnetic minerals the magnetic force will be smaller than the sum of all the competing forces and the minerals will then be repelled away from the magnetic field (Agava, 2006).

The capacity of a magnet to lift a particular mineral is dependent not only on the value of the field intensity, but also the field gradient, for instance, the rate at which the field intensity increase, towards the magnetic surface. It can be shown that:

$$F \alpha\ H\frac{dH}{dL} \quad (1)$$

where, F is the force on the particle, H is the field intensity, and $\frac{dH}{dL}$ is the field gradient.

Thus, in order to generate a given lifting force, there is an infinite number of combinations of field and gradient, which will give the same effect. Production of a high field gradient as well as high intensity is therefore an important aspect of magnetic separator design (Wills and Napier-Munn, 2006). Table 1 present some minerals and their magnetic susceptibilities.

Magnetic separator can be broadly classified into categories, namely:

1. Low intensity: this is the separator used for ferromagnetic minerals such as magnetite.
2. High intensity: this is the separator used for paramagnetic minerals.
3. High gradient separator
4. Superconducting magnetic separator (Yaro, 1997).

Gidan Jaja Iron Ore Deposit

GidanJaja iron ore deposit is in Zurmi Local Government Area of Zamfara State. It is about 50 km from Kauran Namoda Rail line and 100km from Katsina airport. The deposit is bounded by Latitudes 12^0 45' and 13^0 00N' and longitudes 6^0 45' and 7^0 00'E, and its preliminary estimated deposit is over 50 million tonnes (Ministry of Mines and Steel Development, 2012).

Previous Literatures on some Nigerian Iron Ores

Asuke *et al*. (2018) studied the chemical and mineralogical characteristics of GidanJaja iron ore. They reported that the ore has an average content of 73.79% Fe_2O_3, 0.52% MnO, 17.50% TiO_2, 0.11% CaO, 0.50% Cr_2O_3, 3.84% SiO_2, 0.43% Al_2O_3, 0.034% CuO, 0.02% NiO, 0.46% PbO, and 2.76% LOI. Phosphorus and Sulphur were below limit of detection. They also revealed that the iron bearing minerals of the ore are predominantly Ilmenite and Magnetite, with subordinate amount of hematite, spinel and quartz. Their SEM analysis showed that the iron bearing minerals are separated from other minerals in the ore by smooth grain boundaries.

Muzzammil *et al*. (2018) worked on the determination of liberation size and work index of GidanJaja iron ore and reported that the liberation size of the valuable mineral (Fe_2O_3) in the ore to be -355+250 μmsieve size having 74.40% Fe_2O_3 (51.65% Fe). They also determined the work index of the ore using modified Bond's method and found it to be 15.50 kWh/t.

Agava *et al*. (2016) studied the upgrading of Ochokochoko iron ore using gravity and magnetic concentration methods. From their findings, they reported that separation test of the ore by gravity method produced an optimum concentrate with a maximum iron content of 64.90% (Fe) with a recovery of 96.27 % at a particle size of -180+125 μm while magnetic separation test produced an optimum concentrate with a maximum grade of 66.54% (Fe) and recovery of 91.27% at -180+125 μm particle size fraction. They concluded that both Gravity and Magnetic separation technique can be used to produce concentrate suitable for pig iron production by conventional blast furnace route.

Oladunni *et al*. (2016) beneficiated the Ajabanoko Iron Ore Deposit using froth flotation and reported that the ore assaying 40.72% Fe crude and 34.40% SiO_2 was upgraded to45.48% Fe and 33.30% SiO_2. They concluded that the results obtained from the work fell below the standard specification of 64% Fe and 68% Fe for iron and steel production in Nigeria and hence, the use of floatation reagents is not advisable for upgrading low grade Ajabanoko Iron Ore.

Agava (2006) worked on up-grading of Agbado-okudu iron ore using magnetic separation and shaking table techniques. He reported that the results obtained from gravity separation shows a concentrate with a maximum grade of 55.81% (Fe), and a recovery of 66.40% at particle size fraction of -56 + 45 μm. While magnetic separation produced a concentrate with an optimum grade of 57.43% (Fe), and a recovery of 82.12% at particle size fraction of –80+60 μm. However, combination of gravity separation followed by magnetic separation could produce a concentrate with an optimum grade of 57.17% (Fe), and a recovery of 80.85% at a particle size fraction of –63+53 μm and concluded that the ore can be best beneficiated using magnetic technique to produce a concentrate that can serve as feed for pig iron production by conventional blast furnace route.

The percentage contents for the most important raw materials in iron production are given in Table 2.

Table 1: Some minerals with their magnetic susceptibilities and electrostatic properties

Mineral	Magnetic susceptibility	Electrostatic response
Cassiterite	Diamagnetic	Conductor
Chalcopyrite	Paramagnetic	Conductor
Chromite	Paramagnetic	Conductor
Galena	Diamagnetic	Conductor
Biotite	Paramagnetic	Non – conductor

Geothite	Paramagnetic	Non – conductor
Hematite	Paramagnetic	Conductor
Ilmenite	Paramagnetic	Conductor
Magnetite	Ferromagnetic	Conductor
Pyrite	Paramagnetic	Conductor
Pyrrhotite	Ferromagnetic	Conductor
Siderite	Paramagnetic	Non - conductor
Sphalirite	Diamagnetic	Conductor
Monazite	Paramagnetic	Conductor
Malachite	Paramagnetic	Conductor
Borrnite	Paramagnetic	Conductor
Gypsum	Diamagnetic	Conductor
Rutile	Paramagnetic	Conductor

Source: Oyeladun, 2015

Table 2: The specifications for sinters and pellets production for conventional blast furnace and direct reduction processes

Process/Parameter	Blast Furnace Process		Direct Reduction Process
	Concentrate for Sinter Production	Lump Direct Charging	Super Concentrate Pellet Production
Fe_{total} %	63.0	54.82	66.80 Minimum
Fe_2O_3 %	88.9	74.5	95.50 Minimum
FeO %	1.0	3.5	0.5
CaO %	0.15	4.0	0.1
Gangue(SiO_2+Al_2O_3)	9.60	12.0	< 2.70
MgO %	Trace	1.0	0.1
P%	0.003	0.044	0.003 Maximum
S%	0.004	0.08	0.003 Maximum
LOI%	0.21	4.4	1.20 Maximum

Source: (Yaro *et al*., 2004)

In line with the above literatures and importance of iron and steel production in our national development, it has become imperative to look at the possibility of beneficiating GidanJaja iron ore deposit to achieve a concentrate that can be used as feed in metallurgical smelting plant towards the production of iron and steel in Nigeria.

MATERIALS AND METHODS

Materials

Material used in the course of this research is the GidanJaja iron ore. The equipment includes; Sledgehammer, Laboratory jaw crusher, Ball mill, pulverizing machine, set of sieves/Laboratory sieve shaking machine, Electronic Weighing Scale, X-ray florescence (XRF) Machine, Low Intensity Magnetic Separator and Stopwatch.

Methods

Sample collection

Samples of the iron ore were collected from various points at the deposit site located at GidanJaja village, in Zurmi Local Government Area of Zamfara State. Grab method of sampling was adopted in collecting the samples. 60kg of the samples were collected in total from four different pits at interval of 150 m apart 3 m depth in order to have a representative sample of the ore deposit.

Sample Preparation

The lump sizes of the ore collected from different locations at the deposit site were crushed and ball milled. The milled samples were mixed and homogenized. Coning and quartering method of sampling was used to have a representative sample. The sample was prepared to the liberation size of -355+250 μm as earlier reported by Muzzammil *et al*. (2018).

Magnetic Separation test using low intensity magnetic separator

250 g of the prepared sample was fed into the low intensity magnetic separating machine. The machine then separates the ore sample into concentrate and tailing based on magnetic susceptibility. Both the concentrate and tailing were weighed and analyzed using XRF machine in order to know their chemical composition.

RESULTS AND DISCUSSION

Chemical analysis of GidanJaja iron ore at the liberation size before and after beneficiation

Table 3 present the chemical analysis of the iron ore at the liberation size before beneficiation. Table 4 and 5 present the chemical analysis, percent assays and recoveries of iron (Fe) and TiO_2 contents of the concentrate and tailing produced using low intensity magnetic concentration respectively.

Table 3: Chemical analysis of GidanJaja iron ore before beneficiation

Compound	Percentage Composition
SiO_2	<LOD
Al_2O_3	7.4
CaO	0.5
TiO_2	15.0
V_2O_5	0.46
Cr_2O_3	0.18
MnO	0.20
Fe_2O_3	74.40
CuO	0.04
ZnO	0.22
Rb_2O	0.02
BaO	1.91
Eu_2O_3	0.22
Re_2O_7	0.06
Bi_2O_3	0.17
Ln_2O_3	0.25

<LOD – Bolow limit of detection

Table 4: Chemical analysis of processed GidanJaja iron ore using magnetic separation

Compound	Concentrate	Tailing
SiO_2	1.0	9.88
Al_2O_3	2.0	<LOD
CaO	0.24	5.48
TiO_2	12.2	33.93
V_2O_5	0.58	0.13
Cr_2O_3	0.474	0.080
MnO	0.20	0.41
Fe_2O_3	81.24	45.11
CuO	<LOD	0.055
ZnO	0.18	0.19
K_2O	0.11	0.18
Rb_2O	0.036	0.01
BaO	1.1	1.3
Eu_2O_3	<LOD	0.22
Re_2O_7	0.02	0.01
PbO	0.37	0.30
Bi_2O_3	0.12	0.098
MgO	<LOD	3.0

Table 5: Metallurgical balance for magnetic concentration using low intensity magnetic separator

Product	Weight (g)	% Assay		Unit		% Recovery	
		Fe	TiO_2	Fe	TiO_2	Fe	TiO_2
Feed	250	52.08	17.50	13020	4375	100	100
Concentrate	174.54	56.87	12.20	9926.10	2129.39	76.24	48.67
Tailing	63.20	31.58	33.93	1995.86	2144.38	15.33	49.01
Loss	12.26	-	-	-	-	8.43	2.32

From Table 3, the ore contains 74.40% Fe_2O_3 (52.08% Fe) and 15.0% TiO_2 before beneficiation, while Table 4 presents the chemical analysis of concentrate and tailing produced after the magnetic separation, the concentrate contains 81.24% Fe_2O_3 (56.87% Fe) and 12.2% TiO_2, while the tailing gave 45.11% Fe_2O_3 (31.58% Fe) and 33.93% TiO_2.This means that more of the iron content reported at the concentrate and more of the TiO_2reported at the tailing as compared to the feed. This phenomenon is attributed to the fact that the major iron bearing minerals reported in the iron ore are ilmenite and magnetite as reported by Asuke *et al.*, 2018. The high amount of Fe_2O_3 and TiO_2 in the tailing is a confirmation that most of the ilmenite report in the tailings.

From Table 5, the metallurgical balance of processed GidanJaja iron ore (Products) also shows that the concentrate contain 56.87% Fe and 12.20% TiO_2 with recoveries of 76.24% Fe and 48.67% TiO_2 respectively, while the tailing produced contained 31.58% Fe and 33.98% TiO_2 with recoveries of 15.33% Fe and 49.01% TiO_2 respectively. This means that there is an upgrade in the iron content from 52.08% Fe in the feed to 56.87% Fe in the concentrate after magnetic separation. There is a decrease in TiO_2 from 15.0% TiO_2 in the feed to 12.2% TiO_2 in the concentrate. The result could be ascribed to the reason that the iron bearing mineral is liberated from its associated gangue minerals because the iron mineral of magnetite type is magnetic in nature, hence the effect of magnetic attraction on the iron mineral enhanced the increase in percentage assay and percentage recovery of the iron (Fe) in the concentrate. For the tailing, moderate percentage of iron mineral was recorded, but much of theTiO_2 mineral (ilmenite ($FeTiO_3$)) was found to be present in the tailing due to the weak magnetic property of ilmenite. SiO_2 which is nonmagnetic also reports in the tailings.

CONCLUSIONS

GidanJaja iron ore assaying 52.08% Fe and 15.0% TiO_2 was upgraded using low intensity magnetic separating machine. The products from the magnetic separator contained a concentrate of 56.87% Fe and 12.20% TiO_2 with recoveries of 76.24% and 48.67% for iron and Titanium oxide respectively. The result obtained shows that GidanJaja iron ore can be upgraded using magnetic separation technique to produce a concentrate suitable for lump direct charging in the conventional Blast furnace. However, the presence of 12.20%TiO_2 is still a concern. The result fell below the standard specification for the concentrate to be used for sinters and pellets production for the blast furnace in Ajaokuta, Nigeria.

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