

## UPGRADING OF OCHOKOCHOKO IRON ORE USING GRAVITY AND MAGNETIC CONCENTRATION METHODS

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### ABSTRACT

In this work the possibility of upgrading Ochokochoko iron ore deposit located between Jakura and Ochokochoko village, Lokoja Local Government Area of Kogi State, Nigeria was investigated using gravity and magnetic concentration technique after calcination. The result of the tests carried out revealed that the Ochokochoko iron ore has 53.45 % (Fe<sub>T</sub>), 19.29 % (SiO<sub>2</sub>), (2.42 ) % CaO, 0.16 % MnO, 0.27 % (K<sub>2</sub>O), 2.98 % (Al<sub>2</sub>O<sub>3</sub>), 0.2 % (MgO), 0.3 % (P<sub>2</sub>O<sub>5</sub>) and 0.2 % (S). The thin section microscopy revealed the iron bearing minerals are predominantly magnetite and hematite with minor limonite and a combined average percentage distribution of 82 %. This was further collaborated with the result of X-Ray Diffraction (XRD) which revealed the major mineral constituents as hematite and magnetite. Separation test by gravity method produced an optimum concentrate with a maximum iron content of 64.90 % (Fe<sub>T</sub>) 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<sub>T</sub>) and recovery of 91.27 % at -180+12 5μm particle size fraction. The results obtained from the two different concentration tests inferred that Ochokochoko iron ore deposits can be upgraded using both Gravity and Magnetic separation technique to produce concentrate suitable for pig iron production by conventional blast furnace route.

**Key words:** Ochokochoko Iron Ore, Gravity. Magnetic Separation and Beneficiation

### INTRODUCTION

Iron is unarguably the most dominant metal of industrial application and accounts for well over 90 % of all metals mined, refined and used [1]. As the fourth most abundant element on the earth's crust which constitutes 4 % by weight, it is believed to be the major component of the earth's core. The principal ores of iron ore are haematite (ferric oxide, Fe<sub>2</sub>O<sub>3</sub>) and

limonite (ferric oxide trihydrate, Fe<sub>2</sub>O<sub>3</sub>.3H<sub>2</sub>O). Other ores include siderite (ferrous carbonate, FeCO<sub>3</sub>), taconite (an iron silicate), and magnetite (ferrous-ferric oxide, Fe<sub>3</sub>O<sub>4</sub>), which often occurs as a white sand. Iron pyrite (iron disulfide, FeS<sub>2</sub>) is a crystalline gold-coloured mineral known as fool's gold. Chromite is a chromium ore that contains iron of

Lodestone a form of magnetite that exhibits natural magnetic properties [2].

Among the parameters, which make iron, a fundamental metal resource of industrial development and application are its strength, workability and ability to combine with a large suite of other metals to form alloys with diverse sets of desirable properties. Though, iron is the cheapest metal, its combination with carbon in a chemical process to produce steel makes this alloy the most versatile basic engineering material for the manufacturing and construction industries. There is therefore a positive correlation between iron and steel consumption and industrial and infrastructural development. In realization of this fact the Federal Government of Nigeria in 1971 launched the Country into a new era of Iron and Steel technology by the establishment of the Delta and Ajaokuta steel projects. Although the establishment of the project was good and welcomed idea, the project never got completed because of a number of factors. The Delta Steel project was commissioned but was closed a few years later due to lack of continuous supply of local raw material. At inception, it was conceived to be supplied with high grade iron ore concentrate from Guinea, Brazil and Liberia. The cost of importing these raw materials in terms of foreign exchange and the continuous devaluation of the Naira made it impossible and uneconomical for the plant to be operated [1]. Even with the present arrangement the government had gone into for the Ajaokuta, and

Delta Steel plants, the same problem of sourcing and continuous supply of the basic and important raw material (Iron ore concentrate and coking coal) locally will prevent continuous flow of fluid steel. This is because the Itakpe Iron ore deposit estimated at 200 million tonnes can be upgraded to supply Ajaokuta and Delta Steel plant and last only for a few years [3]. Presently, the plant cannot meet the demand of Ajaokuta and Delta steel plants in terms of quantity and quality. Therefore the viability of any iron ore and steel plant is dependent on the availability and long-time continuous supply of the basic raw material (iron concentrate). Also because the iron ores are bulky there is the need to source them locally, not only to reduce dependence on the imported source but scarce foreign exchange will also be saved.

Fortunately, Nigeria is endowed with large reserves of iron ore deposits concentrated along Kogi – Benue trough. One of the deposits is the Agbaja iron ore deposit, the largest in Nigeria (over one billion tonnes in reserve) with extremely fine grained texture. To achieve a reasonable degree of liberation, it has to be ground to  $-5 \mu\text{m}$ . However, at this extremely fine size, most conventional beneficiation techniques, such as froth flotation, gravity concentration cannot be used to recover the fine iron oxides. Economically, to grind the ore to that size will not be wise in case of iron ore because of its low market value coupled with its very high phosphorus content which has discouraged its utilization to date [4]. In fact, for each type of production

process of the iron and steel there are specific raw materials requirements. For example while the conventional Blast furnace route for iron production requires iron or sinter produced from a concentrate of at least 63 % Fe and coal that must be coking to produce coke, the Midrex Direct Reduction process must be provided with a higher grade iron ore (at least 67 % Fe) for the production of direct reduced iron using either non-coking coal or natural gases [5]. Tables I and II present summary of chemical compositions and specific requirements of raw materials for iron production by the blast furnace (Ajaokuta) and direct reduction (Delta) processes respectively. The estimated reserves of iron ores in Nigeria are in excess of over 3 billion metric tonnes (Fig. 1, showing the map of occurrences and coordinates of Nigeria iron ore) and hence the utilization of these deposits in iron and

steel plants will reduce cost of importation, thereby saving our foreign exchange, improves our agriculture machineries, the necessary technology for our oil and gas sector, medicine and a lot of other industries [6].

Due to the importance of iron ore and steel in our national development, it has become imperative to look at the possibility of beneficiating low grade locally available iron ore deposits for use as feed stock to the indigenous iron and steel plant located at Delta and Ajaokuta. This prompted this work on 'Beneficiation of Ochokochoko iron ore so as to produce a concentrate that can be used in the conventional blast furnace iron making process by magnetic and gravity separation method' and covers an area of approximately 400 km.

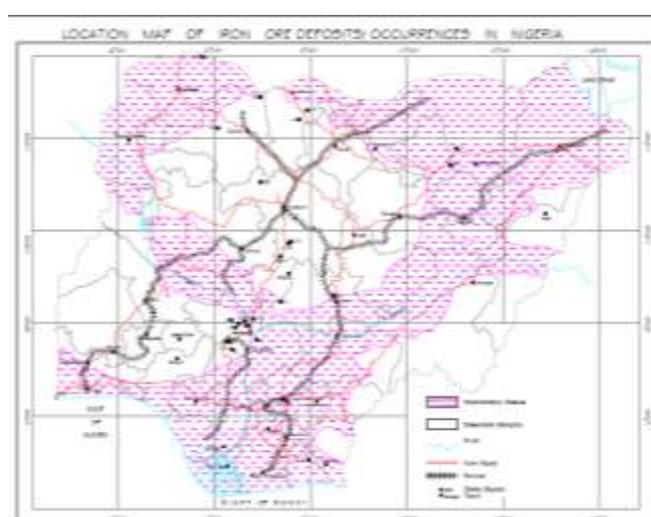
Table I: Chemical Composition of some Nigerian Iron Ores

%	Toto-Muro	Itakpe	Ajabanoko	Agbaja	Birin-Gwari	KotonKarfe	Bassa-Nge	Gujeni	AgbadoOkudu
K <sub>2</sub> O	0.11	0.42	0.26	0.04	1.35	0.02	0.02	Trace	0.53
CaO	2.01	0.30	0.15	0.72	0.78	0.45	0.17	Trace	0.15
TiO <sub>2</sub>	0.10	0.10	Trace	0.37	0.19	0.24	0.26	12.01	0.16
MnO	Trace	0.05	0.01	0.14	9.30	0.56	0.31	0.20	0.08
Fe	31.60	36.88	37.22	47.80	34.76	48.13	46.90	48.60	34.45
MgO	0.01	0.20	0.15	0.38	0.22	0.07	0.47	Trace	0.18
Al <sub>2</sub> O <sub>3</sub>	0.12	1.00	3.39	9.60	3.49	6.70	10.87	4.40	9.67
SiO <sub>2</sub>	56.54	48.0	46.50	10.89	28.50	5.13	8.28	6.00	51.07
P <sub>2</sub> O <sub>5</sub>	0.15	0.18	0.10	2.08	0.16	2.14	1.45	2.06	0.03
S	0.20	0.05	0.03	0.12	0.04	0.04	0.05	0.20	Trace

Sources: Oyeyinka, (1997); Yaro and Thomas, (2009); Yaro and Agava, (2009); Salawu et al, (2015)

Table II: Specifications for Sinters and Pellets Production for Conventional Blast Furnace and Direct Reduction Processes  
Source: (Yaro et al, 2004)

Process/ Parameter		% Fe <sub>T</sub>	% Fe <sub>2</sub> O <sub>3</sub>	% FeO	% CaO	Gangue (SiO <sub>2</sub> +Al <sub>2</sub> O <sub>3</sub> )	% MgO	%P	% S	% LOI
Blast Furn. Proc.	Con. For Sinter Prod.	63.0	88.9	1.0	0.15	9.60	Trace	0.03	0.04	0.21
	Lump Direct Charging.	54.82	74.5	3.5	4.0	12.0	1.0	0.044	0.08	4.4
Direct Red. Proc.	Super Con. for Pellet Prod.	67.80 Minimum	95.5 Mini mum	0.5	0.1	<2.70	0.1	0.03 Max.	0.03 Max	1.20 Max



- Iron Ore Deposits**
1. Ebiya (Kogi) Fe (N7.4439, E6.3621)
  2. Itakpe (Kogi) Fe (N7.6188, E6.3102)
  3. Ajabanoko (Kogi) Fe (N7.6253, E6.2518)
  4. Egeneja (Kogi) Fe (N7.6577, E6.8744)
  5. Obajana (Kogi) Fe (N7.9233, E6.4269)
  6. Agbaja (Kogi) Fe (N7.9622, E6.6863)
  7. Agbado Okudu (Kogi) Fe (N8.0075, E6.4983)
  8. Chokochocho (Kogi) Fe (N8.0853, E6.3491)
  9. Tajimi (Kogi) Fe (N8.0593, E6.6215)
  10. Koton Karfe (Kogi) Fe (N8.1047, E6.7966)
  11. Toto Muro (Nasarawa) Fe (N8.4740, E 7.3803)
  12. Mada Station (Nasarawa) Fe (N8.6165, E8.4829)
  13. Kateri (Kaduna) Fe (N9.7729, E7.5879)
  14. Gyaza (Katsina) Fe (N12.4042, E7.7570)
  15. Tama (Katsina) Fe (N12.6082, E7.9192)
  16. Gidan Jaja (Zamfara) Fe (N12.8883, E6.9398)
  17. Taluka (Sokoto) Fe (N13.7584, E5.7388)
  18. Kuka Soba (Zamfara) Fe (N12.2253, E6.0641)
  19. Nsude (Enugu) Fe (N6.3738, E7.4195)
  20. Jaruwa (Kaduna) Fe (N11.0592, E6.9526)
  21. Gidan Buzu (Yobe) Fe (N11.7787, E11.0221)
  22. Lamba (Bauchi) Fe (N11.4354, E10.9054)
  - \* All Coordinates in Decimal Degree
  23. Kateri (Kaduna) Fe (N9.7423, E7.5402)
  24. Gujeni (Kaduna) Fe (N9.4527, E7.3743)

Figure 1: Location Map of Iron Ore Deposits and Occurrences in Nigeria (NSRMEA, 2012) 3.3.

### DESCRIPTION OF STUDY AREA

The deposit is in Ochokochocho village, 35 km from Lokoja. It was discovered by the Nigerian Geological Survey department and has an estimated ore preliminary reserves of over 60 million tonnes and bounded by geological coordinates of Latitude (N8.0853 – N8.1623) and Longitude (E6.3491--

E6.4034) and covers an area of approximately 400 km Fig. 2. The iron ore lumps which are inter-layered with quartzite are generally medium to fine grained. The chemical and mineralogical characteristics of the ore have been determined by [7] as shown in Figs. 3 and 4.



Figure 2: Map of Lokoja Local Government showing Ochokochoko; Study area (Google 2017)

## MATERIALS AND MEHODS

### Material

Fifty kilograms (50 kg) of the ore sample was sourced from five pits at the deposit site, 400m inter-pit distance and 6 m depth beneath the earth crop.

### EQUIPMENT

The equipment used for the research work were: Jiangsu SkyRay EDX3600B XRF machine with 21 probes and EDS X-ray fluorescence (XRF), Energy Dispersive Spectrometer (EDS) made in China, Meiji MT17000 Metallurgical Microscope with Automated focus drive, made in USA, Denver, sieve shaker, made in USA, Denver, PE-400x900 Jaw crusher, made in USA, Denver, MXD-13321S Pulverizing machines, made in USA, Denver Magnetic separating machine model X-342ES made in USA and beakers.

## Methods

### Magnetic Concentration Method of Calcined Sample

Calcination was first carried out on the pulverized sample based on the result of mineralogical examination which revealed high percentage haematite and goethite in other to reduce them to magnetite. The result of calcination revealed that magnetic concentration method can be used for upgrading the sample. 3242 grams of the calcined samples were sieved into various sieve size fractions of +355  $\mu\text{m}$ , -355+250  $\mu\text{m}$ , -250+180  $\mu\text{m}$ , -125+90  $\mu\text{m}$ , -90+63  $\mu\text{m}$  and -63  $\mu\text{m}$  (Pan) for 15 minutes using  $\sqrt{2}$  as the basis [8]. A low Magnetic separator of the Department of Mineral resources Engineering of Kaduna Polytechnic, model 4-3 -15 OG was used. The sieved size samples from each fraction were fed into the Magnetic separator with a standard setting of 20 Amperes

(1.8 Tesla or 18,500 Gauss) [9]. The Concentrate (Iron) and Tailing (silica) were collected as products and thereafter, analyzed to ascertain their assay. The result of the test is presented in Table V.

**Gravity Concentration Method  
(Heavy Liquid Medium) of head  
Sample**

The concentration test was conducted using liquid (Tetra- bromo – ethane  $\text{CBr}_4$  (sp.gr 2.96) solution). The Specific gravity of iron and silica which are the principal minerals present in the ore were determined to be 4.5 and 2.2 respectively. 200 g of head sample from each of sieved size fractions was

taken for the separation test. The samples were introduced into 1000 ml beakers containing 300 ml of the solution and then thoroughly mixed after which were allowed to separate into the sink and float for 2 h. The floats were decanted and the Tetra-bromo – ethane solution was recovered. After which the sinks and floats were washed, dried in oven set at  $100\text{ }^\circ\text{C}$  and their weights were taken. Then representative samples of sieved size fractions were taken from the sinks and float for analysis of iron (Fe) and silica ( $\text{SiO}_2$ ) content. The result of the test is presented in Table VI.

## RESULTS AND DISCUSSION

### Determination of Chemical, Petrological and Mineral Phase of Ochokochoko Iron Ore

Table III. Elemental Compositions of the Ochokochoko Iron Ore Deposit

Elements	Pit A (%)	Pit B (%)	Pit C (%)	Pit D (%)	Pit E (%)P	Harmonized Sample/ Assay (%)
Fe	53.51	47.70	56.92	54.47	54.67	53.45
Si	17.70	20.68	18.00	18.58	17.47	19.29
Mg	0.33	0.34	0.46	0.01	0.00	0.25
Al	1.53	2.20	1.95	2.83	1.38	1.98
P	0.02	0.04	0.03	0.05	0.02	0.03
S	0.03	0.00	0.02	0.02	0.01	0.02
K	0.64	0.40	0.10	0.15	0.05	0.27
Ca	2.51	2.42	0.85	0.93	0.91	1.52
Ti	0.26	0.30	0.00	0.00	0.00	0.11
Cr	0.05	0.04	0.05	0.05	0.05	0.05
Mn	0.39	0.17	0.07	0.12	0.07	0.16
Co	3.38	3.20	3.95	3.83	4.53	3.78
Ni	0.04	0.03	0.03	0.04	0.04	0.04
V	0.04	0.02	0.02	0.01	0.02	0.02
Cu	0.03	0.02	0.018	0.02	0.02	0.02
Zn	0.07	0.08	0.03	0.06	0.03	0.05
Pb	0.09	0.07	0.09	0.10	0.12	0.09
Mo	0.15	0.24	0.16	0.16	0.11	0.16
Sn	0.22	0.18	0.13	0.24	0.16	0.19
Sb	0.13	0.12	0.10	0.19	0.12	0.13

]

Table IV. Chemical analysis of the Calcined and Uncalcined Sample of Ochokochoko Iron Ore

Sieve size fraction ( $\mu\text{m}$ )	Uncalcined ore			Calcined ore ( $1200^\circ\text{C}$ )		
	Weight retained (g)	Assay of $\text{Fe}_T$ in each fraction (%)	Assay of $\text{SiO}_2$ in each fraction (%)	Weight retained (g)	Assay of $\text{Fe}_T$ in each fraction (%)	Assay of $\text{SiO}_2$ in each fraction (%)
+355	1443.00	56.70	11.60	1211.00	59.60	9.74
-355 + 250	357.00	57.30	10.70	268.00	60.80	8.10
-250 + 180	577.00	54.80	10.50	521.00	58.20	8.70
-180 + 125	461.50	60.60	9.60	341.00	64.40	7.98
-125 + 90	423.50	57.40	9.20	213.00	58.10	7.88
-90 + 63	731.00	49.30	8.70	564.00	52.60	7.93
-63 + 45	132.00	51.30	8.50	73.00	54.70	3.81
-45	101.00	52.20	8.10	51.00	53.30	3.74
	4226.00			3242.00		

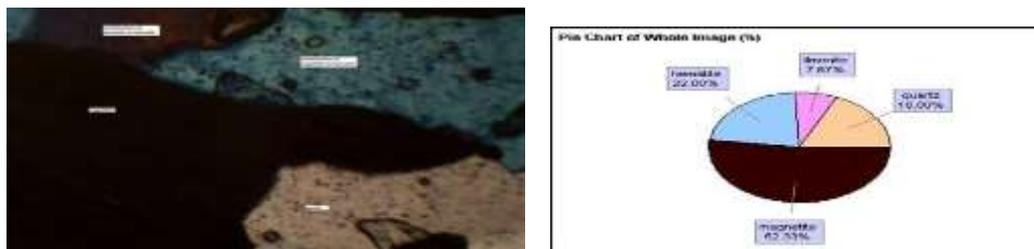


Figure 3: Petrological analysis of the Ochokochoko iron ore sample

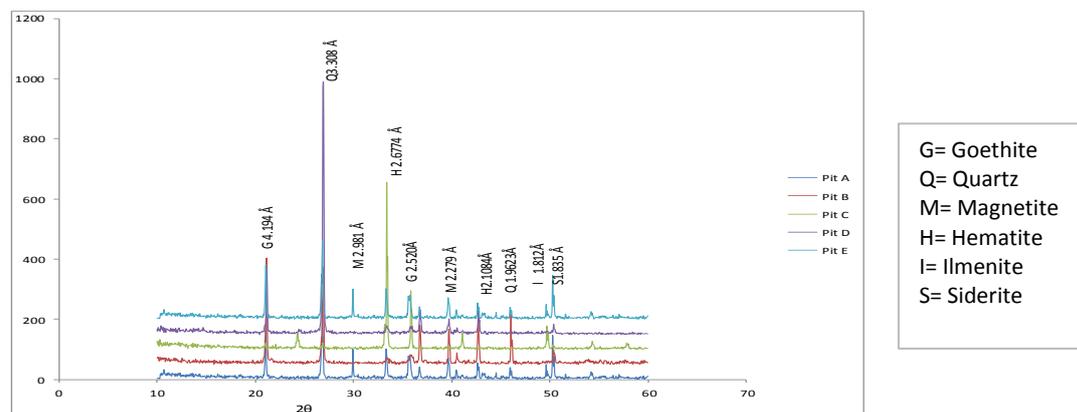


Figure 4: XRD analysis of the various pits of the Ochokochoko iron ore sample

Table III: present the chemical compositions of pits A, B, C, D, E and the harmonized head sample of the ore determined using XRF. The result

revealed that the harmonized sample of the five pits contained 53.45 %  $\text{Fe}_T$ , 19.29 % Si, 1.98 % Al, 3.78 % Co, 0.27 % K, 0.16 % Mn, 1.52 % Ca, 0.25 % Mg,

0.11 % Ti, 0.03 % P and 0.02 % S on the average. From the results it could also be observed that the iron contents of the pits vary from one pit to the other and seems to be distributed uniformly in all the pits that samples were sourced. It was observed that the variation in the contents of the chemical compositions of the various pits could be attributed to the mineralization of the pits that may have been caused by differential and segregation solidification processes of the molten magma created by the tectonic movement of the earth. Similar observation has been reported by [10]. The silica content of the ore is less than that of Toto-Muro, Itakpe, Ajabanoko, Birnin Gwari and Agbado-Okudu but higher than that of Koton-Karfe, Bassa-Nge, Gujeni, and Agbaja. The phosphorus contents of the ore from the various pits are less than that of Toto-Muro, Itakpe, Ajabanoko, BirninGwari and Agbado-OkuduKoton-Karfe, Bassa-Nge, Gujeni except Agbaja. The sulphur contents of the ore compared favourably with the nine [9] iron ore deposits cited in Table I of this work. [6], [8], [11], and [12] have reported in different fora that the presence of silica, phosphorus and sulphur in ores can be reduced during beneficiation and blast furnace route of iron and steel making to a tolerable limit when it is above acceptable level. Therefore the presence of the minerals in the ore cannot be a threat to the utilization of the ore for iron and steel making in the nation's iron and steel plants. The iron mineral textural grains are also oolitic in nature, a phenomenon that characterized the weakness of the ore matrix and its ability to undergo

fragmentation during comminution. In an attempt to identify the types of the iron oxide present in the ore, a thin section of the samples was examined under a polarized light. It was observed that the majority of the iron oxides in the ore have brown colour with black dots patches in their matrix, which are peculiar characteristics of hematite ( $\text{Fe}_2\text{O}_3$ ) while the blue region display a typical characteristic of magnetite ( $\text{Fe}_3\text{O}_4$ ) iron bearing mineral and the region occupied by non-iron bearing oxide mineral is purely black, displaying characteristic feature of silica mineral ( $\text{SiO}_2$ ) as shown in Fig.3. The point count, which is a measure of the percentage distribution of each mineral in the ore, gave 52.33 % magnetite, 22 % haematite, 7.67 % ilmenite and 18 % silica. Figure 4 shows the XRD phase diffraction patterns of the peaks of the various mineral compounds of the ore sample from the five pits. From the diffractogram the iron mineral phases depicts the following: magnetite, goethite, hematite, quartz, ilmenite and siderite. The iron bearing minerals are predominant when compared to other minerals in the matrix of the ore. This could be attributed to the mineralization of the ore with iron and silica being the parent differential minerals. The iron ore is more of magnetite, goethite and hematite than silica (quartz) as the main gangue. Hence, the XRD result further confirmed the dominant of iron bearing minerals in the matrix of the ore. These results therefore, have shown that the ore deposit could be another potential source of iron ore that can be beneficiated and use in the nation's iron and steel plants.

## SINK AND FLOAT GRAVITY CONCENTRATION METHOD TEST

Table V: The percent assay of Sink, Float and Recovery of Fe<sub>T</sub> and SiO<sub>2</sub> of Sink and Float Test

Sieve size range (μm)	Feed			Sink					Float				
	Weight (g) retained	(%) Fe <sub>T</sub>	(%) SiO <sub>2</sub>	Weight (g)	% Assay		% Recovery.			Weight (g)	% Assay		% Recovery.
					Fe <sub>T</sub>	SiO <sub>2</sub>	Fe <sub>T</sub>	SiO <sub>2</sub>		Fe <sub>T</sub>	SiO <sub>2</sub>	Fe <sub>T</sub>	SiO <sub>2</sub>
+355	200	56.70	11.60	187.36	59.71	0.82	98.65	6.62	12.64	49.73	1.36	5.54	0.74
-355+250	200	57.30	10.70	183.84	61.20	0.76	98.18	6.52	16.16	44.28	1.03	6.23	0.77
-250+180	200	54.80	10.50	180.08	58.70	0.63	96.45	5.40	19.92	41.98	1.13	7.62	0.79
-180+125	200	60.60	9.60	179.80	64.90	0.57	96.27	5.34	20.20	35.06	0.75	5.84	0.79
-125+90	200	57.40	9.20	174.88	58.70	0.43	89.42	4.09	25.12	37.63	0.78	8.23	1.00
-90+63	200	49.30	8.70	172.32	52.40	0.38	91.58	3.76	27.78	36.78	0.62	10.36	1.01
-63+45	200	51.30	8.50	169.03	55.10	0.34	90.78	3.38	30.70	30.34	0.57	9.08	1.01
-45	200	52.20	8.10	168.54	53.51	0.31	86.38	3.23	31.46	30.01	0.52	9.04	1.01

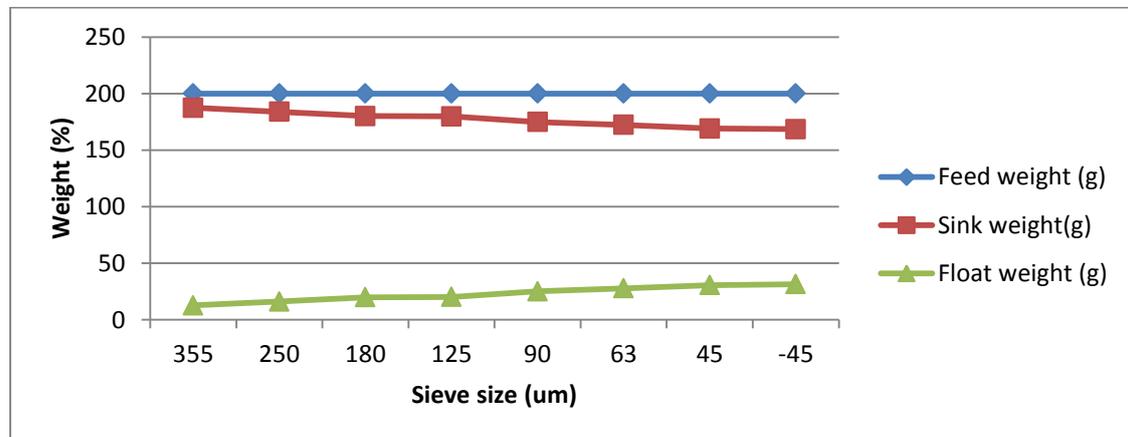


Figure 5: Weight of Sink and Float products of the calcined samples of the various sieves size fractions separated using heavy liquid separation medium

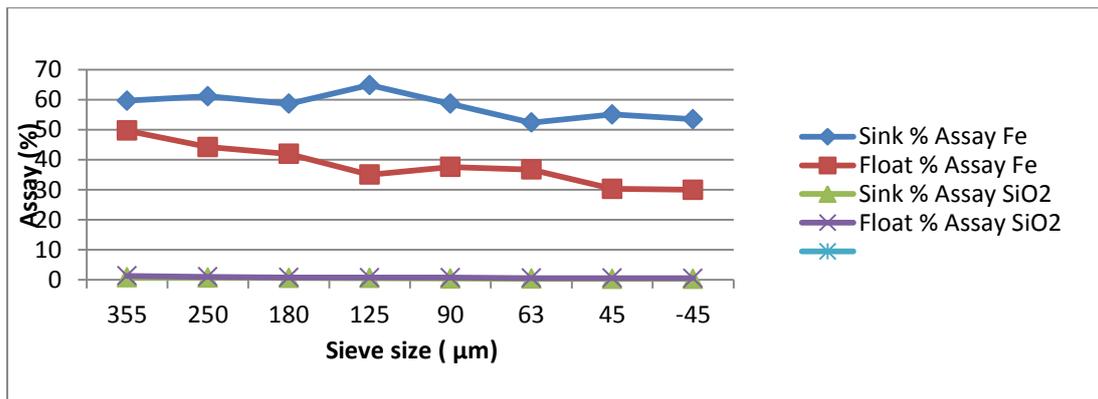


Figure 6: Percent assays of iron and silica contents of sink and float products of the calcined samples of the various sieves size fractions separated using heavy liquid separation medium

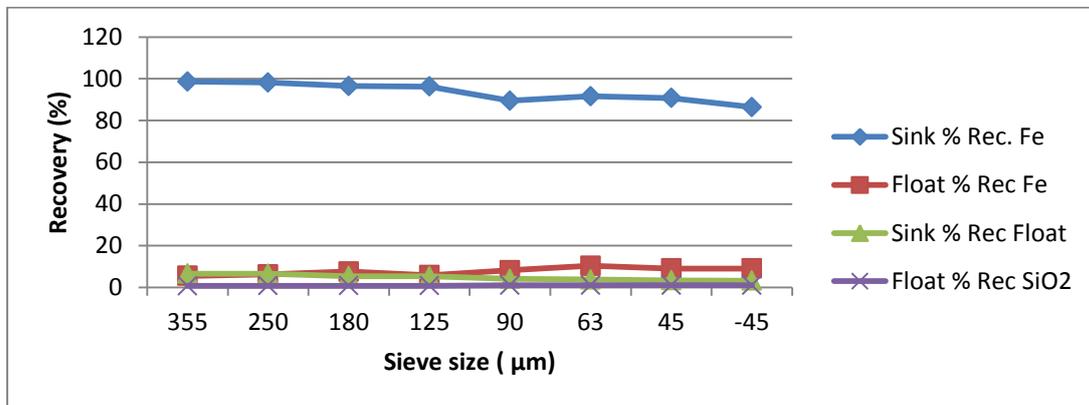


Figure 7: Percent recoveries of the iron and silica contents of sink and float products of the calcined samples of the various sieves size fractions separated using heavy liquid separation medium

Fig 5, 6 and 7 show the weights, percent assays and recoveries of iron and silica contents of the sink and float products of the ore sample of the various sieves size fractions of the separation test using heavy liquid medium. Table V presents the result of the percent assays and recoveries of iron and silica contents of the various sieves size fractions of the ore sample separation test using heavy liquid medium. From the result shown in Fig. 5 it could be observed that 97 % of the ore samples of the various

sieves size fractions sink while 3 % float. The reason could be attributed to the relative density of the iron minerals of the head sample which are denser than the liquid medium and thus make them to sink (concentrate) while the free silica constituents of the head sample float (tailings) since they are lighter than the liquid medium. Fig. 6 shows the behavioural patterns of assays of iron and silica contents of the head sample of the various sieves size fractions of the concentration test of gravity method using heavy liquid separation medium. From the result it

could be observed that the assays of the iron contents of the sink (concentrates) are higher than that of the float (tailings) and decreased as the sieve size fractions reduced. This reason could be attributed to the liberation size and specific gravity of the iron minerals of the head sample. Also from the result pattern it could be observed that -180+125  $\mu\text{m}$  (64.90 %  $\text{Fe}_T$ , 0.57 %  $\text{SiO}_2$ ) has the highest value content of the iron total when compared to other sieves size fractions an indication that this sieve size fractions is the liberation size of the ore. Considering the silica contents of the sink (concentrates) and float (tailings) it could be observed that the silica contents of the floats are higher when compared to that of the sink as the sieve size fractions of the ore sample is reduced. This reason could be attributed to specific gravity of the free silica constituents that are present in the ore sample. Furthermore the coarse sieves size fractions of +355 to -250 + 180  $\mu\text{m}$  of the floats are found to have the highest contents of silica when compared to other sieves size fractions an indication that the silica are liberated at the most coarse particle size fractions. Fig. 7 shows the pattern of percent recoveries of the iron and silica constituents of the sink and float of the ore sample. From the trend of the result, it could be observed that the recovery of the iron constituent of the sink decreased with reduction in sieve size fractions. This

phenomenon could be attributed to the distribution of the iron constituents in all the sieves size fractions in which most of the iron constituents reported in the sink portion of the concentration test. Thus, the sink (concentrates) have higher percent recoveries values of iron mineral when compared to the float. Also considering the percent recoveries values of silica in the sink, it could be observed that the recoveries values are lower when compared to that of the iron, but increased as the sieves size fractions are reduced. Furthermore the trend also indicates that the silica constituents are distributed in all the sieves size fractions just like the iron minerals but in smaller proportions when compared to the iron. Table IV presents the result of the percent assay of sink, float and recovery values of  $\text{Fe}_T$  and  $\text{SiO}_2$  of sink and float test of the ore sample of the iron ore. From the result it could be observed that -180+125  $\mu\text{m}$  sink have highest recovery values of 64.90 % and 0.57 % for iron and silica when compared to other sieves size fractions. Reason for this phenomenon has earlier been reported. [9] and [11] have reported similar observed trends of some of the works conducted on some USA and Nigerian iron ores deposits concentrated using heavy liquid medium separation of gravity concentration method.

### MAGNETIC CONCENTRATION TEST OF THE CALCINED SAMPLE

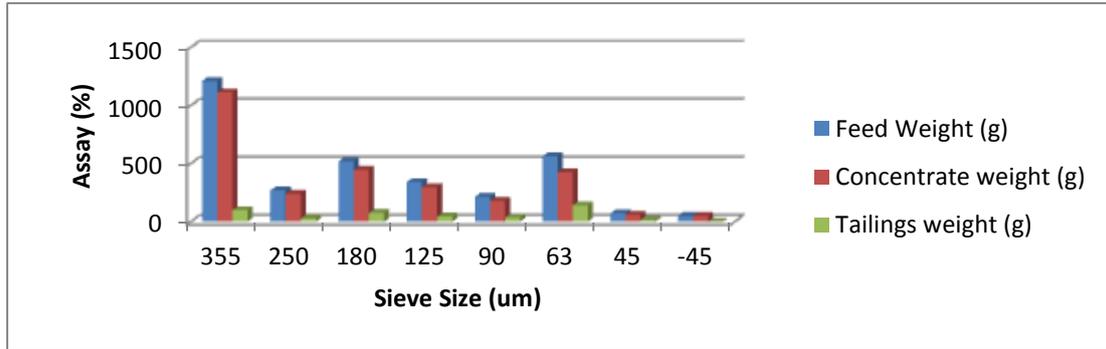
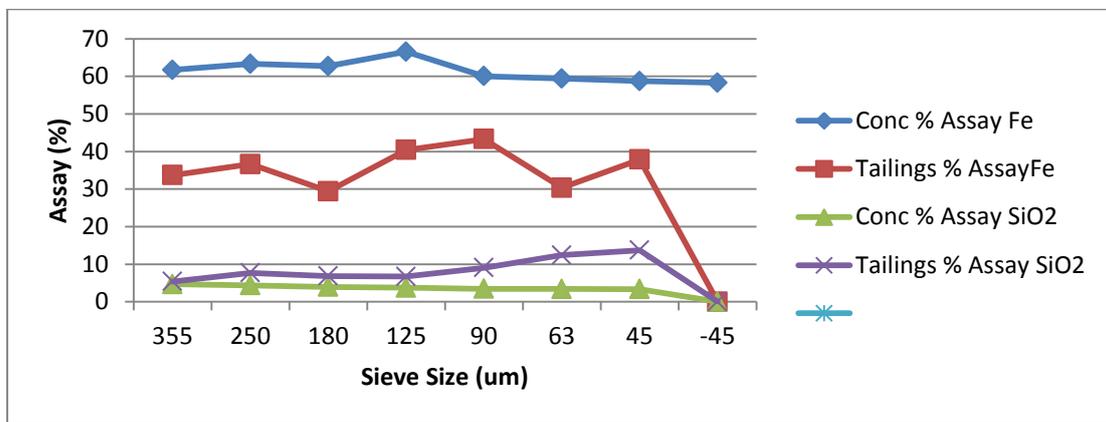


Figure 8: Weights of concentrates and tailings of the calcined sample produced using magnetic concentration method.



Calcined sample produced using magnetic separation method.

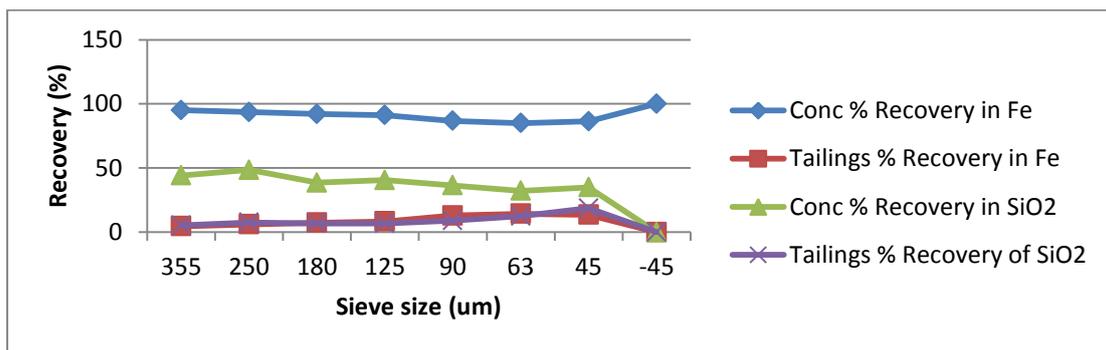


Figure 10: Percent recoveries of iron and silica contents of concentrates and tailings of calcined sample produced using magnetic separation method

Table VI: The Percent Assays and Recoveries of iron and silica contents of concentrates and tailings of calcined sample produced using magnetic concentration

	Feed			Concentrate					Tailing				
	Weight (g) retained	(%) Fe <sub>T</sub>	(%) SiO <sub>2</sub>	Weight (g)	% Assay		% Recovery		Weight (g)	% Assay		% Recovery	
Sieve size range (μm)					Fe <sub>T</sub>	SiO <sub>2</sub>	Fe <sub>T</sub>	SiO <sub>2</sub>		Fe <sub>T</sub>	SiO <sub>2</sub>	Fe <sub>T</sub>	SiO <sub>2</sub>
+355	1211.00	59.60	9.74	1112.10	61.70	4.69	95.07	44.22	98.90	33.71	6.43	4.61	5.39
- 355+250	268.00	60.80	8.10	240.78	63.30	4.38	93.54	48.58	27.22	36.64	6.37	6.12	7.67
- 250+180	521.00	58.20	8.70	445.35	62.70	3.93	92.09	38.61	75.65	29.38	4.09	7.33	6.83
- 180+125	341.00	63.40	7.98	296.54	66.54	3.72	91.27	40.54	44.46	40.41	4.12	8.31	6.73
-125+90	213.00	58.10	7.88	178.93	60.02	3.44	86.78	36.44	34.07	47.29	4.45	13.02	9.03
-90+63	564.00	52.60	7.93	424.42	59.40	3.40	84.98	32.26	139.60	30.35	3.98	14.28	12.42
-63+45	73.00	54.70	3.81	58.72	58.70	3.35	86.32	34.98	14.28	37.860	3.65	13.54	18.74
-45	51.00	53.30	3.74	51.00	53.30	-	-	-	-	-	-	-	-

Figure 8, 9 and 10 show the behavioural patterns of weights, percent assays and recoveries of iron and silica of the calcined sample produced using magnetic concentration method. From the chart of Fig. 8 it could be observed that the weights of the ore sample sieves size fractions are found to be more in the concentrates than in the tailings produced. This could be attributed to the magnetic property of the iron minerals enhanced by the calcination of the ore sample (see Table IV). The effects of the magnetic property of calcined sample are more pronounced in sieves size fractions of -180+125  $\mu\text{m}$  to -45  $\mu\text{m}$  where 100 % of the sieve size fractions were magnetized as concentrates. This phenomenon confirmed that the goethite, hematite and other minor iron bearing minerals associated with the ore transformed to magnetite during the calcination process of the ore sample. [8] and [13] also observed and reported similar trends.

Fig. 9 shows the behavioural patterns of the percent assays of the iron and silica contents of the concentrates and tailings of the calcined sample produced using low intensity magnetic concentration method. The behavioural patterns of concentrates and tailings assay represented in Fig. 9 shows that there is wide margin of percentage contents of the iron minerals of the concentrates and tailings of various size fractions with -180 +125  $\mu\text{m}$  having the highest peak. This further confirmed that, the sieve size fraction is the liberation size of the ore. And also, the no tailings syndrome of the lower sieves size fractions of -90+63 to -45  $\mu\text{m}$  could also be due to the effect of calcination, which eliminated some volatile materials that could have possibly existed below -180 + 90  $\mu\text{m}$  and posed as tailings. Furthermore, the lack of

tailings recorded for these sieves size fractions could be attributed to the reason that the silica minerals of the calcined sample liberated are retained in the higher sieves size fractions of +355 to -125+90  $\mu\text{m}$  and also much of the silica minerals could have undergone transformation, fusing to form larger grain size a phenomenon that agreed with the calcination of self-flux hematite and goethite based iron ores as reported by [9]. From results presented in Table VI for sieve size fractions of +355  $\mu\text{m}$ , it was observed that the concentrate produced contained 61.70 %  $\text{Fe}_T$  and 4.69 %  $\text{SiO}_2$  with recoveries of 95.07 % for iron and 44.22 % for silica. Sieve size fractions of -355 +250  $\mu\text{m}$  concentrate produced contain 63.30 %  $\text{Fe}_T$  and 4.38 %  $\text{SiO}_2$  with recoveries of 93.54 % of iron and 48.58 %  $\text{SiO}_2$ . Sieve size fractions of -250+180  $\mu\text{m}$  concentrate produced contained 62.70 %  $\text{Fe}_T$  and 3.93 %  $\text{SiO}_2$  with recoveries of 92.09 % of iron and 38.61 % of silica. Sieve size fractions of -180 +125  $\mu\text{m}$  concentrate produced contained 66.54 %  $\text{Fe}_T$  and 3.75 %  $\text{SiO}_2$  with recoveries of 91.27 % of iron and 40.54 %  $\text{SiO}_2$ . Sieve size fractions of -125 +90  $\mu\text{m}$  concentrate produced contained 60.02 %  $\text{Fe}_T$  and 3.44 %  $\text{SiO}_2$  with recoveries of 86.78 % of iron and 36.44 %  $\text{SiO}_2$ . Sieve size fractions of -90 +63  $\mu\text{m}$  concentrate produced contained 59.40 %  $\text{Fe}_T$  and 3.40 %  $\text{SiO}_2$  with recoveries of 84.98 % of iron and 32.26 %  $\text{SiO}_2$ . Sieve size fractions of -63+45  $\mu\text{m}$  concentrate produced contained 58.70 %  $\text{Fe}_T$  and 3.35 %  $\text{SiO}_2$  with recoveries of 86.32 % of iron and 34.98 %  $\text{SiO}_2$ . Sieve size fractions of -45  $\mu\text{m}$  concentrate produced contained 53.30 %  $\text{Fe}_T$  and 3.27 %  $\text{SiO}_2$  with recoveries of 100 % of iron. Comparing the results of the test sieve size fractions of -180+ 125  $\mu\text{m}$  concentrate has the highest content of 66.54 %  $\text{Fe}_T$  and a recovery of 91.27 % when compared to the iron

contents and recoveries of other sieves size fractions. This could be attributed to the particle size factor of the iron mineral, which at coarse particle size the iron minerals are not completely liberated from the associated mineral like silica. Hence, the tendencies for the iron minerals at the coarse sieves size fractions to be completely magnetized into the concentrate are hindered by the encapsulation of iron by the silica minerals. Further observation revealed that as the particle size reduces the percent iron content increases in some portion while recovery decreases. This could be ascribed to the reason that as the particle size reduces, the iron bearing mineral is liberated from the associated mineral, hence the effect of magnetic attraction on the iron mineral increased and it also enhanced the increase in percentage assay content and decreased percentage of recovery because iron mineral of magnetite type is magnetic in nature. For the tailings, moderate low percentages of iron mineral for all the sieve size fractions was recorded, but much of the  $\text{SiO}_2$  mineral was found to be present in the tailings.

Furthermore comparing the two units single stage concentration methods of magnetic and gravity using heavy liquid medium for the concentration of the ore sample it could be observed that the percent assay content of iron mineral of  $-180 + 125 \mu\text{m}$  (66.54 %  $\text{Fe}_T$ ) concentrate obtained using magnetic method is higher when compared to that obtained by gravity method of sink and float heavy liquid separation medium ( $-180+125 \mu\text{m}$  (64.90 %  $\text{Fe}_T$ )). Reason for this phenomenon could be attributed to the magnetic property induced by the calcination of the ore sample [13] and the liberation size of the iron mineral of the ore which seems to be at semi coarse sieve size fractions rather than at coarse sieve size

fractions which could have favoured gravity method. From the findings of the research work it is evidenced that magnetic concentration method is the best suitable adoptable concentration method for the beneficiation of the Ochokochoko iron ore sample.

## CONCLUSION

Ochokochoko iron ore contains hematite, magnetite and goethite as the major valuable minerals in the ore matrix together with silica as the major gangue material. The 66.54 % ( $\text{Fe}_T$ ) iron concentrate produced from the magnetic concentration technique surpassed the 63/64 %  $\text{Fe}_T$  grade concentrate usually required for blast furnace route of iron and steel making. This work has therefore established that magnetic concentration method is the best suitable and adoptable method for the concentration of calcined Ochokochoko iron ore sample at single stage process. However, the concentrate produced from single stage Magnetic concentration technique can be further subjected to double stage concentration techniques to achieve super concentrate of 68 %  $\text{Fe}_T$  minimum that can be use as feed for the iron and steel plants in Nigeria.

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