# Froth Flotation of Ajabanoko Iron Ore Deposit in Kogi State towards Nigerian Iron and Steel Development

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***Abstract—*** *Low grade Ajabanoko iron ore assaying 40.72% Fe crude and 34.40% $SiO_2$ was subjected to Froth Floatation process with the intension of upgrading it to standard specification of 60% Iron (Fe) concentrate towards production of pig iron which could be used for iron and steel development in Nigeria. Chemical analysis conducted on the concentrate samples from Froth floatation process using Methyl Isobutyl Ketone (MIBK) and Flotanol gave highest Fe content at underflow of 41.52% and 45.48% respectively and high silica as gangue of 39.63% and 33.30% respectively. The acceptable iron concentrate of a beneficiated ore that can be used in Blast furnace and direct reduction steel making process are 64% Fe and 68% - 70%Fe respectively. The results obtained from the work fell short of this standard, hence, the use of floatation reagents is not advisable for upgrading low grade Ajabanoko Iron ore.*

***Keywords—Ajabanoko iron ore, Flotanol, Methyl Isobutyl Ketone (MIBK), Blast Furnace***.

## I. INTRODUCTION

One of the most useful metals in the world is iron. It is extracted from iron ore. Iron ore is a mineral substance which when heated in the presence of a reductant will yield metallic iron (Fe). The iron ore is usually very rich in iron oxides ($Fe_3O_4$ and $Fe_2O_3$) (Steel world, 2013). They ores are mostly dark grey to rusty red in color and of high specific gravity ranging from 5.0 – 7.0 (Wills, 1992). Two main types of iron ore used for iron making are: Magnetite ($Fe_3O_4$) and Hematite ($Fe_2O_3$) (AMM, 2013). Other iron ores includes:

- **Limonite** - $Fe_2O_3$ + $H_2O$ - 50 percent to 66 percent iron
- **Siderite** - $FeCO_3$ - 48 percent iron

Iron ore is the source of primary iron for the world's iron and steel industries. It is therefore essential for the production of steel, which in turn is essential to the maintaining of a strong industrial base (Metal Bulletin, 2013).

Hematite deposits are mostly sedimentary in origin, such as the banded iron formations (BIFs). BIFs consist of alternating layers of chert (a variety of the mineral quartz), hematite and magnetite. Magnetite are also mostly found in banded iron formations (BIF). They are fine grained metamorphosed sedimentary rocks composed predominantly of magnetite and silica. Mining and processing of Banded Iron Formations involves coarse crushing and screening (Min Metandequip, 2008; Pasranawat, 2014).

Nigeria has several Iron ore deposits, many of which are found in Kogi State. They include Itakpe, Agbado Okudu, Chokochoko, Ajabanoko and the Agbaja Iron ores. None of these deposits contain prime ores and therefore researchers over the past two decades have attempted the processing of these ores (Chuck, 1998). Indeed, Nigeria has gone ahead in the past years to establish Steel plants – Ajaokuta Steel Complex (ASC) located in Kogi State, the Delta Steel Company, (DSC), Aladja situated at Delta State; and the inland rolling mills. The preferred characteristics of DRI grade pellet is typically 67% (Minimum ) Fe and 3.0% silica+ alumina+ titanium oxide (RMPSSI, 1994).

This paper investigated the chemical characteristics of the Ajabanoko iron ores as it relates to processing of the ore to achieve a higher concentrate that can be use as feed in metallurgical industries towards the production of iron and steel in Nigeria.

## II. EXPERIMENTAL PROCEDURES

### Method

Representative sample of Ajabanoko Iron ore was picked out of the whole sample (from the mine site in Ajabanoko village) using random sampling method. The boulders were crushed using Denver Jaw crusher and were further reduced employing Endeco Cone crusher and finally by Denver roll crusher running at 500kg per hour. It was followed by screen/sieve analysis to determine the Economic Liberation size of the ore and the chemical analysis of each sieve size fractions in order to determine the actual liberation size as in Table 1. The entire sample used in this research work was first reduced to the liberation size of -500 + 355um using ball milling machine before carrying out the froth floatation process.

**Screen/Sieve Size Analysis**

Set of screens were arranged ranging from +1.4mm to -0.063mm on Automated Denver Sieve Shaker machine for a period of Thirty (30) minutes, with charge of 100 grams. After which contents of each sieve were weighed and recorded. Representative samples from each sieve size was taken for analysis using ED-XRF spectrometer analyzer. The result is as shown in Table 1.

**Froth Flotation Method**

Analysis of crude Ajabanoko Iron as received was carried out and the following result obtained; Fe – 40.72%, $SiO_2$ - 34.40%. This was followed by grinding the Iron ore to 80 percent passing – 500 + 355µm liberation size from the sieve analysis result as in Table 3, as a feed for the flotation cell towards concentrate production.

Froth flotation was carried out using D12 Denver laboratory flotation equipment under the following conditions: pH set at 9.0, Oleic acid as the collector, Starch (M&B) gelatinated with 25% soda as the depressant. Methyl Isobutyl Ketone (MIBK) as the frothier; with the Impeller speed set at 1500 rpm. The charge was conditioned for 2 minutes at 50% soild by weight, with cleaning done after 5 minutes and the re - cleaning carried out after 2 minutes (Wills,1992; CSIRO, 2004)

The concentrate produced was dried at 105°C in laboratory electric oven. Thereafter, the samples were analyzed. The process was repeated using Flotanol as the frothier at pH of 10.0 implace of MIBK with all other conditions remaining the same. The results of the study were shown in Tables 1 and chemical analysis in Tables 4 – 6.

## III. RESULTS AND DISCUSSION

**Results**

The results obtained on Froth floatation of Ajabanoko iron ore, grain-size distribution, screen analysis, composition analysis are presented in Tables 1 – 6 respectively.

*Table 1: Result obtained from froth floatation of Ajabanoko Iron ore.*

| Frother | Underflow (gms) | Overflow (gms) | Charge (gms) |
|---|---|---|---|
| Metyl Isobutyl Ketone | 378.5 | 118.7 | 500.0 |
| Flotanol | 367.8 | 115.8 | 500.0 |

*Table 2: Result of measured grains crystals of Ajabanako Iron Ore.*

| Class Interval | Mid-Point X | Frequency F | Fx |
|---|---|---|---|
| 0.001-0.200 | 0.100 | 122 | 12.2 |
| 0.201-0.400 | 0.300 | 173 | 51.9 |
| 0.401-0.600 | 0.500 | 102 | 51.0 |
| 0.601-0.800 | 0.700 | 59 | 41.3 |
| 0.801-1.000 | 0.900 | 29 | 26.1 |
| 1.01-1.200 | 1.100 | 16 | 17.6 |
| Total | | ΣF = 500 | ΣFx = 200.1 |

From Table 2, grain crystal of Ajabanoko iron ore was measured using Standard deviation to be 0.40mm, which is scientifically 0.45mm (450µm).

$$X = \frac{\Sigma Fx}{\Sigma F} = \frac{200.1}{500.0} = 0.4002mm = 0.40mm\ (400\mu m)$$

*Table 3: Result of Screen Size Analysis of Ajabanoko Iron Ore.*

| Sieve Size (mm) | Weight (gm) | Weight (%) | Cumulative Wt. % Retained. | Cumulative Wt. % Passing. |
|---|---|---|---|---|
| +1.0 | 29.2 | 29.38 | 29.38 | 70.62 |
| - 1.0 + 0.71 | 12.2 | 12.27 | 41.65 | 58.34 |
| -1.07 + 0.500 | 12.9 | 12.98 | 54.63 | 45.36 |
| - 0.500 + 0.355 | 12.2 | 12.27 | 66.90 | 33.10 |
| - 0.355 + 0.25 | 9.5 | 9.56 | 76.46 | 23.54 |
| - 0.25 + 0.180 | 7.3 | 7.34 | 83.80 | 16.20 |
| - 0.180 + 0.125 | 5.5 | 5.53 | 89.33 | 10.67 |
| -0.125 + 0.09 | 3.8 | 3.92 | 93.15 | 6.85 |
| -0.09 + 0.063 | 2.8 | 2.82 | 95.97 | 4.02 |
| - 0.063 | 4.0 | 4.02 | 100 | 0 |
| | 99.4 | | | |

*Table 4: Results of Chemical Analysis of Ajabanoko Iron Ore Crude and Sieve fraction using (ED-XRF) in Percentage.*

| Sample | $SiO_2$ | $P_2O_3$ | $SO_3$ | $K_2O$ | CaO | $TiO_3$ | $Cr_2O_3$ | MnO | $Fe_2O_3$ | $Ft_T$ | CuO |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Crude | 34.4 | ND | ND | 0.08 | 0.23 | 0.06 | 0.2 | ND | 58.22 | 40.72 | 0.04 |
| +1.4mm | 37.8 | ND | ND | 0.08 | 0.26 | 0.05 | 0.26 | 0.05 | 54.52 | 38.35 | 0.04 |
| -1.4+1.0mm | 35.6 | ND | ND | 0.05 | 0.21 | 0.02 | 0.31 | ND | 65.25 | 39.35 | 0.03 |
| -1.0-0.71mm | 31.3 | ND | 0.31 | 0.05 | 0.15 | 0.11 | 0.31 | ND | 60.16 | 42.07 | 0.06 |
| - 0.71+0.5mm | 32.5 | ND | 0.17 | 0.21 | 0.48 | 0.06 | 0.4 | 0.06 | 59.53 | 41.63 | 0.05 |
| -0.5+0.355mm | 25.9 | ND | ND | 0.04 | 0.17 | 0.02 | 0.3 | 0.06 | 67.86 | 47.46 | 0.04 |
| -0.355+0.25mm | 27.2 | ND | 0.11 | 0.05 | 0.16 | 0.03 | 0.36 | 0.06 | 66.09 | 46.22 | 0.04 |
| -0.25+0.180mm | 32 | ND | 0.11 | 0.06 | 0.24 | 0.03 | 0.37 | 0.06 | 60.09 | 42.3 | 0.04 |
| -0.180+0.125mm | 34.1 | ND | 0.17 | 0.11 | 0.27 | 0.03 | 0.39 | 0.06 | 60.48 | 40.51 | 0.04 |
| -0.125+0.09mm | 35.6 | ND | 0.16 | 0.21 | 0.38 | 0.05 | 0.4 | 0.06 | 57.92 | 39.12 | 0.05 |
| -0.09+0.063mm | 29.2 | 0.2 | 0.26 | 0.21 | 0.64 | 0.1 | 0.75 | 0.11 | 61.77 | 43.2 | 0.05 |
| -0.063mm | 27.3 | ND | ND | 0.03 | 0.14 | 0.07 | 0.27 | ND | 65.58 | 45.87 | 0.04 |

*Table 5: Chemical Analysis of Processed Ajabanoko Iron Ore using Froth Floatation.*

| **Sample** | $SiO_2$ | $K_2O$ | CaO | $Cr_2O_3$ | $Fe_2O_3$ | CuO | $La_2O_3$ | MnO | $Fe_t$ |
|---|---|---|---|---|---|---|---|---|---|
| **MIBK** $_{underflow}$ | 39.63 | 0.067 | 0.17 | 0.176 | 59.40 | 0.062 | 0.055 | 0.046 | 41.52 |
| **MIBK** $_{overflow}$ | 39.80 | 0.12 | 0.27 | 0.245 | 59.09 | 0.056 | 0.065 | 0.066 | 41.30 |
| **Flotanol**$_{underflow}$ | 33.30 | 0.033 | 0.142 | 0.15 | 65.06 | 0.054 | 0.025 | 0.047 | 45.48 |
| **Flotanol**$_{overflow}$ | 41.23 | 0.110 | 0.244 | 0.21 | 57.58 | 0.056 | 0.055 | 0.060 | 40.35 |

*Table 6: Theoretical Recovery of Froth Floatation using Floatanol and MIBK*

| Process/ Reagent | Charge (g) | Fe Charge (%) | Product (g) | Fe Product (%) | RECOVERY Cc / Ff x 100 |
|---|---|---|---|---|---|
| MIBK underflow | 500.0 | 40.72 | 378.5 | 41.52 | 77.19 |
| MIBK overflow | 500.0 | 40.72 | 118.7 | 41.30 | 24.09 |
| Flotanol underflow | 500.0 | 40.72 | 367.5 | 45.48 | 82.09 |
| Flotanol overflow | 500.0 | 40.72 | 115.8 | 40.25 | 22.89 |

## IV. DISCUSSION

Table1, shows the result of Froth Floatation of Ajabanoko iron ore using MIBK and Flotanol as frothers at a charge of 500 grimmest of crude iron ore; using MIBK as frother results obtained show that quantity recovered as underflow is 378.5g, overflow is 118.7g, likewise using Flotanol as frother the underflow is 367.8g and overflow is 115.8g with a minimum loss during the process.

Table 2, shows the result of measured grain crystals of Ajabanoko iron ore, revealing that the estimated grain crystal is at 0.40mm. Table 3; is the result of the screen size analysis of Ajabanoko iron ore using various sieve size. This shows that the economic sieve size of the ore is at -0.500 + 0.355mm (Wills,1992).This was confirmed in Table 4 which shows the results of chemical analysis of Ajabanoko iron ore sieve fraction for -0.500 + 0.355mm to assay 67.86%,$Fe_2O_3$, 47.46%Fe as analyzed using ED-XRF analyzer at the laboratory of National Metallurgical Development Centre, Jos. While iron content in the crude was also confirmed to be 40.72% during characterization. The result of analysis confirmed that liberation size for the processing of the iron ore is -0.500 +0.355mm.But because this sieve size is so large for its particles to be attached to bubbles towards floatation the sieve with next highest iron content i.e -0.063mm (45.87%Fe) sieve was employed for the Froth Floatation process.

Table 5; shows the chemical analysis of processed Ajabanoko iron ore (Products) using froth floatation. MIBK- underflow gave 41.52%Fe, 39.635%$Sio_2$, overflow gave 41.30%Fe, 39.80% $SiO_2$, Frotanol underflow gave 45.48%Fe, 33.30%$SiO_2$, overflow gave 40.355% Fe, 41.23% $SiO_2$ .This means that more of the iron content reported at the underflow (Iron ore depressed) in both cases and automatically shows that the underflow is the concentrate while overflow (Silica suppressed) remain as tailing (Chuks, 1998).

Table 6; shows the theoretical recovery of froth floatation using flotanol and MIBK as frothier. Using MIBK - underflow gave 77.19% recovery, overflow – 24.09%.While using Flotanol-underflow-82.09% and overflow- 22.89%. The results therefore, show that flotanol is a better floatation reagent for the production of iron ore concentrate from Ajabanoko iron ore compared to MIBK.

## V. CONCLUSION

The Ajabanoko iron ore that assay 40.72% iron was upgraded by way of value addition to concentrate the iron ore using Froth flotation method in the presence of MIBK and flotanol as the flotation reagent; with iron content of 41.52% Fe in underflow and 45.48 % Fe respectively. However, these figures does not meet the requirements for a concentrate to be used in iron ore production in Nigerian Iron and Steel Plants; Other means of processing such as Magnetic method is hereby recommended to be looked into for the processing of the Ajabanoko iron ore to meet the requirement of $\geq$65%Fe for production of the iron ore.

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