DEPARTMENT OF METALLURGICAL ENGINEERING
AHMADU BELLO UNIVERSITY, ZARIA

UP-GRADING OF AGBADO-OKUDU IRON ORE USING MAGNETIC SEPARATION AND SHAKING TABLE TECHNIQUES

BY

AGAVA ABDULLAHI ABDULRASHEED
(M.Sc/ENG/ 57529 /2005-2006)

A THESIS SUBMITTED TO THE POST-GRADUATE SCHOOL, AHMADU BELLO UNIVERSITY, ZARIA.
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN METALLURGICAL ENGINEERING.

NOVEMBER, 2006

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DECLARATION

I declare that the work in this thesis entitled 'The Up-grading of Agbado-Okudu Iron ore using Shaking Table and Magnetic Separation Techniques' has been performed by me in the Department of Metallurgical Engineering under the supervision of Drs. S.A. Yaro and I. Madugu.

The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at any other university by means of reference.

AGAVA ABDULLAHI ABDULRASHEED

CERTIFICATION

This research thesis entitled “Up-grading of Agbado-Okudu Iron Ore using Magnetic Separation and Shaking Table Techniques” by Agava Abdullahi Abdulrasheed, meets the regulations governing the award of the Degree of Master of Science in Metallurgical Engineering of the Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

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Dr. S. A. Yaro Date
(Chairman, Supervisory Committee)

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Dr. I. Madugu Date
(Member, Supervisory Committee)

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Dr. S. B. Hassan Date
(Head of Department)

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Prof. J. U. Umoh
(Dean Post-graduate school) Date

DEDICATION

To my mother, Hajia Amina, for appreciating education as an asset.

My wife, Hajiya Suliyat A. Abdulrasheed, for being there for me always.

And my lovely children, Hanifat and Shafiq Abdulrasheed, for their patience. I love you all.

ACKNOWLEDGEMENT

All honour to the Almighty ALLAH who maketh all things possible and who made the completion of my M.Sc programme a reality. May your name be glorified.

I wish to express my gratitude to those who so generously contributed to my course work and research. My deepest appreciation goes to Dr S.A. Yaro, my major supervisor for his constructive criticisms, which made this project work to see the light of the day. To Dr I. Madugu, my minor supervisor, I say thank you for your encouragement.

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Word cannot express my heart felt love to my wife, Hajia Suliyat Abdulrasheed, for her moral support. To my wonderful children, Hanifah and Shafiq Abdulrasheed, for their understanding. To my mum, Hajiya Amina, who believe that education is the only legacy one can leave for his or her child. To my uncle, Senator M. S. Ohiare, who is always there to support me both morally and financially. May Almighty Allah prolong your live and always see you through as you pursue your political career.

ABSTRACT

The beneficiation of the Agbado Okudu iron ore deposit located in Kogi State, Nigeria was investigated. The investigation involved determining the chemical composition and mineralogical characteristics of the run-of-mine. Followed by determination of the work index of the ore and then separation tests using shaking table, magnetic technique and a combination of the two techniques. The results of the tests carried out revealed that the Agbadu okudu iron ore contained on the average a total iron content (38.82% $\mathbf{Fe_T}$), 49.10% ($Si0_2$) and other element. Thin sections of the ore sample examined under polarized light revealed that the iron bearing minerals are predominantly magnetite and hematite with a combined average percentage distribution of 69% and the mineral in abundant after the iron bearing minerals is quartz. The grindability test reveals that the Agbado Okudu iron ore has and average work index of about 4.32 kwh/tonne. The results of gravity separation shows that a concentrate with a maximum grade of 55.81% **($\mathbf{Fe_T}$)**, and a recovery of 66.40% at particle size fraction -56 + 45μm could be produced. While magnetic separation alone produced a concentrate with an optimum grade of 57.43% ($\mathbf{Fe_T}$), and a recovery of 82.12% at particle size fraction of –80+63μm. However, combination of gravity separation technique (shaking table) followed by magnetic separation technique could only produce a concentrate with an optimum grade of 57.17% ($\mathbf{Fe_T}$), and a recovery of 80.85% at a particle size fraction of –63+53μm. Hence, based on the results obtained from the concentration tests, the Agbado Okudu iron ore deposit 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.

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CHAPTER ONE

1.0 INTRODUCTION

Iron is one of the most common elements on earth. Nearly every structure put on by man contains at least a little iron. It is also one of the oldest metals and was first fashioned into useful and ornamental objects about 3,500 years ago (Lambert and Mark, 1988).

One of the most important determining factors for establishing Iron and steel plants is the availability of iron ore deposit with good geological, mineralogical and metallurgical properties. There is an estimated 2,707 million tonnes of iron ore deposit in the country out of which 200 million tones are in the proven reserve (Umunnakwe, 1988). Iron ore is simply the largest single raw material input in iron and steel making process and the country is endowed with abundant reserves of it but with varying characteristics. The deposits abound in different parts of the country as shown in Table 2.1. Most of the iron ores discovered in the country are however, low grade (their iron content in the crude ranges between 28-45% Fe_T). This meant that for them to be used in iron and steel production they have to undergo substantial beneficiation and upgrading. (Also and Yakubu, 1995). The Itakpe iron ore had been the most intensively studied and exploited deposit with a proven reserve of 200million tones with an average iron content of 36% Fe_T. This is presently being up-graded to obtain a

concentrate of 64% Fe_T for use at Ajaokuta and Aladja steel plants. Apart from the Itakpe iron ore deposit there are other deposit which reserves are estimated at over 2.3 billon tonnes as shown in (Table 2.1) within 150km radius of the Ajaokuta steel plant. To ensure security of supply of the iron ore for the nation Steel industries, further research and development need to be carried out on these new founded deposits to enable their full exploitation. With these reserves, conservative estimates indicate that the nation could be self-sufficient in iron ore for a period ranging between 100-150 years (Umunnakwe1988).

The role of iron and steel in the national economy is enormous. One cannot name an economic branch where iron and steel find no application and to some extend the economic power of a country is determined by its consumption and output of steel products. It is on this basis, that 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. Though, the establishment of these projects was laudable inadequate attention was given to the development of local raw materials to feed the plants thus, making the plants on commissioning to import iron ore concentrate form countries like Brazil, Liberia and Guinea. Recently there has been renewed interests on the souring of locally available raw materials to feed these plants because the Itakpe iron ore project and the total iron ore requirement of Ajaokuta at 1.3 million tonnes of steel per

annum is about 2.135 million tones of iron concentrate and at this rate the Itakpe iron ore project is conservatively estimated to last for about 25 years, (Also and Yakubu, 1995).

Also, the Itakpe iron ore plant commissioned on the 80s to deliver iron concentrate to Ajaokuta and later closed and now concessioned to Indians. Would not be able to meet the demand of Ajaokuta Steel plant when it finally takes off fully. It is therefore, important that these types of studies be conducted so as to increase the source of Iron Ore for Ajaokuta plant. And through such studies the technology for the beneficiation of various Nigerian iron ore deposits for onward supply to Ajaokuta and Delta steel plants will be developed.

Since the goal of every beneficiation process, mineral-processing operation in particular, is to effectively separate the valuable material from the gangue with minimum loss to the tailings; the need to develop and employ a sustainable, effective and relatively economical method of separation is imperative. The concentration of the valuable minerals from the gangue involves exploitation of the differences in physical, chemical and electrical properties of the ore after effective comminution Akande et al (2000). This work, therefore, is aimed at developing a process route for the beneficiation of the Agbado- Okudu iron ore deposit located close to Jakura village in Kabba, Kogi State for its possible utilization in Ajaokuta and Delta Steel Plants.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Nigeria Iron Ore Deposits.

Nigeria is endowed with abundant iron ore deposit of which some of them have been investigated and some are still under investigation as shown in Table 2.1. Iron ore is the major raw material in Iron and steel industry. It occurs as iron oxide [magnetite (Fe_3O_4) and hematite (Fe_2O_3)], hydro oxide [goethite ($HFeO_2$) and Limonite ($2Fe_2O_3. xH_2O$)], and carbonates [siderite ($FeCO_3$)]. The Nigeria iron ore deposit fall into two (2) categories depending on their mode of occurrence: the sedimentary Oolitic/Pisolitic type in which the mineral occurs as an aggregate of rounded pellets either small or large .The second group are deposits of cretaceous recent years age and of metasedementary banded iron ore formation of the Precambrian (early years) age (Famuboni, 1990). The Agbado-Okudu Iron ore deposit belongs to the later.

Table 2.1 Iron ore deposits of Nigeria with their iron content and proven reserve.

Locality	Type	State of occurrence	Approx. reserves $x10^6$ tones	Grade ($\%Fe_T$)	Remarks
Agbaja	Hematite	Kogi	1,159	47.6	High P_2O_5(2.13%)
Ajabanoko	Hematite Magnetite	"	60	40	
Itakpe	Hematite magnetic	Kogi	200	36.8	
Koton-karfe	Siderite	Kogi	803	48.18	High P_2O_5(2.3%)
Muro Hills	Hematite magnetite	Nasarawa	Large	31.6	
Chokochoko	Hematite	Kogi	12	33.5	
Dakin gari	Hematite	Kebbi	Large	37.0	
Egeneja	Siderite	Benue	369	45.7	High P_2O_5(2.2%)
Nguje	Siderite	Anambra	40.6	40.0	
Tajimi	Hematite	Kogi	N.A	39.05	
Birnin Gwari	Hematite, magnetite	Kaduna	N.A		

Source: Also and yakubu (1995)

2.1.1 **Agbado-Okudu Iron Ore**

Agbado-Okudu iron ore deposit is located along longitudes $6^0$28'23"E and latitudes $7^0$52'29"N and $8^0$00'29"N. The deposit is near Jakura village, is about 40km North of Lokoja and could easily be reached by road. The National Steel Raw Materials Exploration Agency (NSRMEA) first reported the occurrence of iron ore at Agbado- Okudu in May 1978 and recommended that exploration should be carried out on the deposit to ascertain whether or not the deposit can be profitably processed by

establishing its quality and quantity (Olukoya et al, 1978). The Agbado Okudu iron ore is principally hematite with little occurrence of magnetite. Usually it is dark coloured with an average density of about 3.60gm/cm^3. In the thin section, the ore consists of unaligned grains of iron and quartz. While hematite grains are identifiable under reflected light NSRMEA (1978). It has an estimated reserved of about 24, 600, 263 metric tones.

2.1.2 **Mineralogy of Agbado-Okudu Iron Ore**

Agbado- Okudu iron ore occurs as ferruginous quartzite and fine to medium grained in texture. It is banded, and characterized by an alternation of a dark iron-rich bands and light gray to brownish quartz rich band. It is hard, compact, massive and crystalline. Microscope studies revealed that the dark bands of rich iron bearing minerals alternate with milky-white silica rich minerals. The iron bearing minerals are mainly hematite and minor magnetite.

The milky-white minerals are principally quartz other minerals in the ore are dolerite; micro granites and pegmatite quantize veins. Silica accounts for more than 60% of the minerals in the rock while the iron bearing minerals accounts for 33% and other accessory minerals for the balance of 7%. (Olukoya, 1979).

2.2 **Study of some Nigerian Iron Ores Characteristics**

Research on the up-grading of locally available iron ores in Nigeria has recently received interest after earlier efforts dating back to the last two decades when the defunct Nigeria Steel Development Authority (NSDA) was established. A metallurgical research laboratory was also set up as an appendage of the NSDA with a mandate to characterized and process locally available iron ores and other raw materials for the then springing Iron and Steel industries (Uwadiale, 1989). The first recorded indigenous reports on the beneficiation of a locally available iron ore are those of Adigwe, (1973) and Edah, (1974) who worked on the Itakpe iron ore deposit, which at that time was the only geologically characterized iron ore reserve that was focused on. However, between 1973 upwards, many other iron ore deposit have been located and their beneficiation characteristics ascertained, Table 2.1 and 2.2, give the summaries of the findings of the studies carried out on the characterization of the locally available iron ore deposits.

Table 2.2 Chemical Compositions Of Some Nigerian Iron Ore Deposits

DEPOSITS	K_2O	CaO	TiO_2	MnO	Fe_T	MgO	Al_20_3	SiO_2	P_2O_5	S
Itakpe	0.42	0.3	0.10	0.05	36.88	0.20	1.00	44.80	0.18	Trace
Chokochoko	0.53	0.15	0.61	0.08	34.45	0.18	9.67	51.07	0.02	Trace
Ajabanoko	0.26	0.21	Trace	0.01	37.22	0.15	3.39	46.50	0.01	0.33
Agbaja	0.04	0.75	0.37	0.14	47.80	0.38	9.60	10.89	2.08	0.12
Koton Karfi	0.02	0.45	0.25	0.56	48.18	0.07	6.70	5.13	2.14	0.04
Bassa –Nge	0.02	0.17	0.17	0.13	46.90	0.46	10.87	8.28	1.45	0.05
Toto-Muro	0.10	2.39	0.10	0.10	33.06	0.00	0.12	54.14	0.13	0.20

Source: **(Raw Materials Research and Development Council. 2000)**

Table 2.3 Characteristics of some Nigerian iron ore

ORE	MINERALOGY	BENEFICIATION TECHNOLOGY
Agbaja	Principal constituent mineral is goethite with minor hematite, magnetite, siderite quartz, kaolinite and pyrite, Fe content 46-50%, 1.5%P_2 O_5 Liberation size less than 5μm	Most conventional beneficiation techniques may not be suitable due to its fine grain size, selective oil agglomeration and magnetizing reduction may be applicable.
Itakpe	Coarse grain with magnetite, hematite and quartz. Liberation is achieved at about 600-800μm	Gravity concentration on a shaking table produces a concentrate assaying 65% Fe with 80% recovery
Toto Muro	Coarse grain with magnetite, hematite and quartz. Liberation is about -80-63μm	Gravity concentration on a shaking table produces a concentrate assaying 54.10% Fe with 77.3% recovery. For magnetic separation 57.20% for assay and recovery of 80.01%

Sources: Dungka, 2000

2.2.1 **Iron Ore Beneficiation Processes**

For purpose of beneficiating any type of ore for its minerals or metal values and for design of accompanying flow-sheet(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. However, mineral processing operations are mainly concerned with utilizing the physiochemical methods of separation. Some of these methods are: gravity, magnetic, froth flotation and the combination of these methods.

2.2.2 **Gravity Concentration Process**

Gravity concentration processes are those processes used in the separation of mineral of different specific gravity by inducing variance movement in response to the force of gravity and one or more forces, natural or applied with the assistance of the flowing film. They are widely used alone or in combination with other processing techniques, in particular flotation, magnetic separation and /or chemical treatment. The main disadvantage of gravity separation processes is the recovery of fine particles, which is inherent in the process itself. Gravity separation processes are effective, practical and economical in the treatment of so

many ores. But their applicability to the processing of any specific ore alone or in combination with other processing methods must be determined through knowledge of the mineralogical composition and characteristics of representative sample of the ore and from careful and comprehensive testing (Yaro, 1997).

This technique separates minerals of different specific gravity by utilizing their relative movement in response to gravity and one or more other forces, the later often being the resistance to motion offered by a viscous fluid, such as water or air. It is important for effective separation to occur, that a marked density difference exists between the mineral and the gangue. The feasibility of separation by gravity method can be assessed from the concentration criterion (Cc).

$$Cc = \frac{Du-Df}{DI-Df} \quad \text{.....(1)}$$

Where

Cc- concentration criterion
Du- is the specific gravity of the heavy mineral
DI- is the specific gravity of the light mineral and
Df- is the specific gravity of the fluid medium.

In every general terms, when the quotient is greater than 2.5, whether positive or negative, then gravity separation is relatively easy. As the value of the quotient decreases, so the efficiency of separation decreases, and below 1.25 gravity concentration is not generally commercially feasible (Wills, 1985).

In mineral concentration using shaking table, flowing current of water is employed to effect separation. The ore is fed to the table from a feed box in the upper corner of the table near the motion –head end. As the feed comes into the table it is affected by the main drag force, the forward push by the shaking motion and the friction force between the table surface and the particles, in addition to some jigging action (particular in the presence of riffles). The result of the above action at a steady state is the production of certain degree of material separation modified by differences in their density and particle size of the feed components. The coarse lighter particles take the shortest path across the feed box (due mainly to the water film), and the fine heavy particles are the last to arrive at the end of the raffles, affected more by the shaking action and frictional forces than by the water film (Abowzeid, 1990).

Shaking table has been used at the laboratory scale for the concentration of Agbaja, Toto Muro and Itakpe iron ores, etc, and the results using this method of gravity concentration showed that by this method those ores can be up –graded for use in Ajaokuta steel plant (Dunkgan,2002).

2.2.3 **Magnetic Separation Processes**

The principle of magnetic separation involves the action of several external forces with a dominant magnetic force. The separation of 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 in the magnetic field of a separator, 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 (Dwight, 1976).

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.

$F \propto H\, dH/dL$……(2)

Where **F** is the force on the particle, **H** is the field intensity, and **dH/dL** is the field gradient.

Thus in order to generate a given lifting force, there are an infinite number of combination 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, (1995).

2.2.4 Froth Flotation

This technique is used to get rid of silicates from most iron ores especially after pre-concentration. In this technique the silicates are activated and floated while the iron bearing minerals are depressed and is called reverse flotation because the gangue is now floated instead of the valuable. In reverse froth flotation of iron ore pre concentrate, the silicates are usually activated with lime and collected using carboxylic collectors at PH of 10 to 11 with a wide range of depressants which may include modified starches, tannins (such as quebrachol, cellulose, starch, xanthates and metaphosphates Crozier R.D. (1984).

2.3 Methods for the Beneficiation of Iron Ores

Several beneficiation methods have been developed for the beneficiating different types of iron ores taking into cognizance the grade, mineralogy and gangue type. These processes include gravity separation, magnetic separation, froth flotation and a combination of these methods. The susceptibility of any iron ore to beneficiation by one of these methods is a major determinant in the development of a process route for its concentration. The amenability of any type of ore to beneficiation depends on its mineralogical characteristics. These characteristics include grain size of the minerals, gangue type and their association with the valuable minerals.

2.3.1 **Beneficiation Route for the Itakpe Iron Ore**

The Itakpe iron ore beneficiation flow sheet consists of the comminution section, gravity and magnetic sections. The comminution section consists of crushing and semi-autogenous machines. The ground and screened product from the autogenous grinding plant is classified at a mesh of 150μm in a double stage primary cyclone. The underflow of the first stage is recycloned in the second stage so as to eliminate the residual fine products. Then, the proportion of fine product. The overflow of the two stage primary cyclone contains fine magnetite ($Fe_3 O_4$) particles, which cannot be recovered using gravity method. The fine magnetite particles are recovered using low intensity magnetic separation (separator) with parallel single drum (primary Low Intensity Magnetic LIM separators). Magnetic products treated in gravity section are recovered in two one-stage low intensity magnetic (LIM) separators with single parallel drum installed on the tailing circuit. The primary LIMS concentrates as well as the concentrate in the tailings are screened using screening panels partitioned so as to retain eventual middling coarse particles, which may be misplaced. The undersize concentrate from screening panel is purified in a secondary LIM separator with two drums in series. This purified concentrate is the final concentrate. The non-magnetic products are classified at a mesh of 40μm in a one stage cycloning in which the

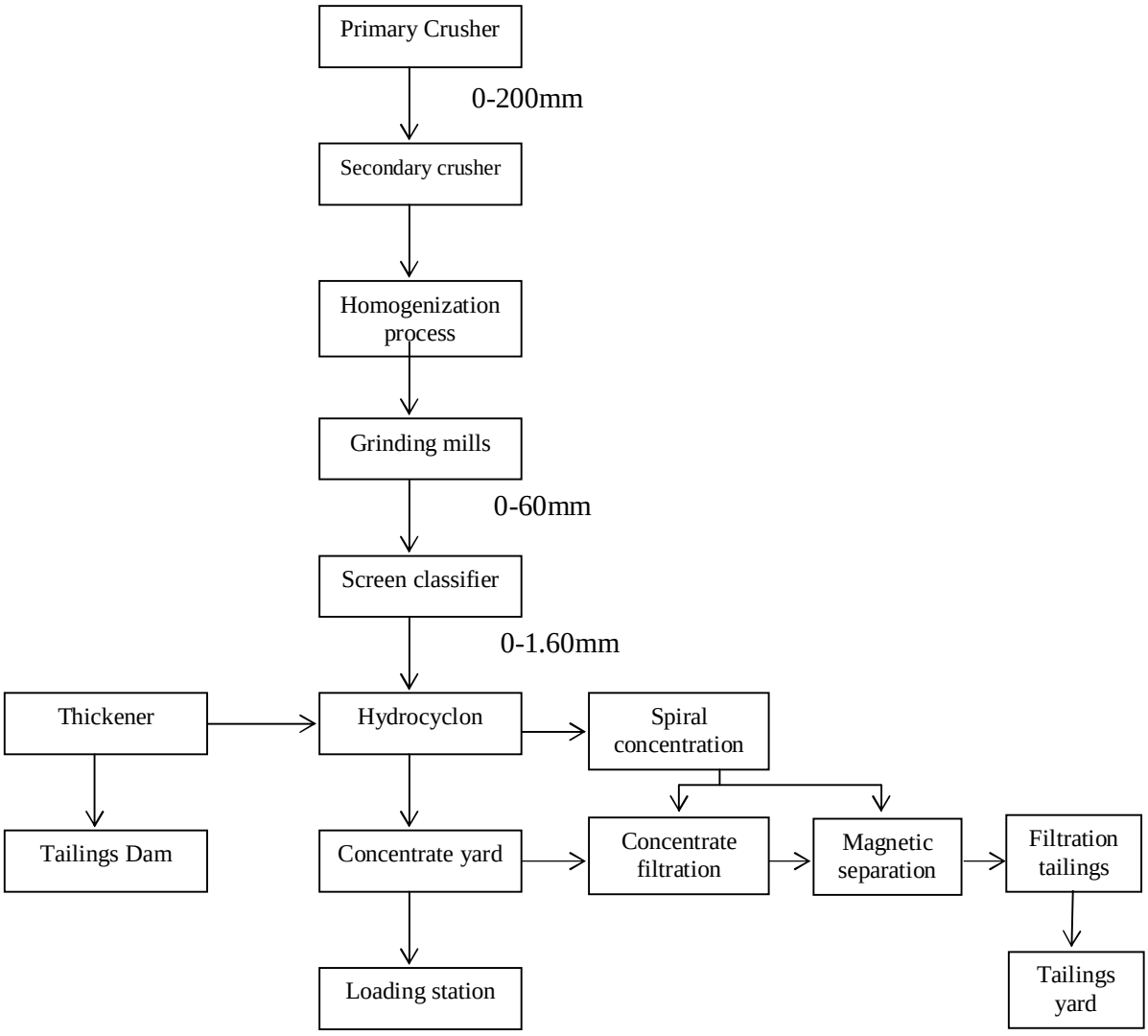

Figure 2.1. Block diagram of Itakpe Beneficiation process.

Overflow fine particles that cannot be upgraded by gravity separation are sent to the tailing thickener and the underflow coarse particles (-150 +40μm) are properly deslimed and mixed with –1600+150μm particles from the primary cycloning. This overall product constitutes the feed to the

gravity concentration circuit. The gravity concentration circuit consists of three stages (1) spirals, roughing stage, which produces a pre-concentrate and a final tailing. (2) Cleaning stage – which produces an intermediate concentrate and middling recycled to the feed of the roughing stage, and (3) re-cleaning stage – which produces a final concentrate and middling recycled to the feed of the cleaning stage. The control being used in the gravity concentration circuit is to maintain constant feed at each stage via pump rotation with a speed variation to keep the density constant and to maintain a unit feed rate per spiral in a definite range by measuring the pulp feed and by splitting up this capacity among a variable number of spirals. The concentrates coming from the gravity concentration circuits as well as from the magnetic circuits are mixed and sent to the filtration, where the pulp is thickened to (more than 40% of solids). In the event of the pulp being dilute (when starting the circuit for instance), it is recycled to the feed of the re-cleaning circuit. The tailings from the gravity concentration circuit are highly diluted and required a thickening prior to filtration. This thickening is made in a bank of cyclones. The thickened underflows as well as the fine tailings coming from the thickener underflow are directed to the tailings filter the overflow pulp of cyclones, almost free of solids, is used as dilution water in the grinding circuit (Hoffmann, 1992).

2.4 Procedures for Development of Conceptual Flowsheet for a newly Discovered Ore

The following are the standard procedures normally followed in the development of conceptual flow sheet for the beneficiation of a newly discovered ore deposits after the geological investigation has been carried out:

a. Chemical analysis of representative sample of the ore, this is to establish the chemical composition of the ore and also confirm the result of geological investigation and probably mining engineers who had already worked on the ore.

b. **Size/Assay Analysis:** This is to establish the distribution of both the valuable and gangue minerals in the various size fractions.

c. Mineralogical characteristics of the ore with the aim of establishing the major, minor and trace minerals in the ore, allocation of each element to each mineral, the grain size of each mineral in the ore in particular the mineral of economic importance and the degree of association of the valuable and gangue minerals.

d. **Liberation studies:** This is to establish the liberation size of the individual mineral in the ore, liberation studies is usually concerned with the grain size of the valuable minerals and probably the gangue which may likely affect the subsequent separation process.

e. Determination of the work index of the ore, which will be used in calculating the energy requirement for the comminution of the ore from a certain size to any size. Hence, in selecting the appropriate comminution equipment for the ore.

f. Then, concentration tests the method of concentration to be used in the beneficiation of the ore will depend on the information gathered from item a to d.

From the above information, the size to which the ore will be ground in order to liberate all the minerals is obtained and also how the different minerals in the ore are going to affect the concentration process, meaning whether there will be interaction between the valuable and other associated minerals. The association of the valuable minerals with other minerals i.e. whether it is finely disseminated or it is an inclusion in the rock or intimately associated. From this also, the feasible method of concentration of the valuable minerals will be conceived depending on the size fractions in which the mineral of interest lies. This will also show whether waste rejection techniques is feasible and how much of the material will be lost with the waste. If it is found out that the minerals are liberated at coarse sizes, the gravity method of separation can be used in order to separate the valuable minerals from the gangue. To do this at laboratory scale, heavy liquid analysis is carried out on representative sample ground to reasonable size fractions. Assays of the different fractions obtained at different

densities are also determined, and then a reasonable density of separation is selected. Alternatively, if the valuable mineral in the ore can only be liberated at fine particle size then the possibility of using flotation technique will be looked into and laboratory scale flotation test will be carried out Yaro, (1997)

2.5. **Particles size Analysis**

This is the most important method of size analysis and it is a accomplished by passing a known weight of sample material successively through finer sieves and weighing the amount collected on each sieve to determine the percentage weight in each size fraction. Sieving is carried out with wet or dry materials and the sieves are usually agitated to expose all the particles to the openings (Wills 1985) The process of sieving may be divided into two stages, first the elimination of particles considerably smaller than the screen apertures, which should occur fairly rapidly and, secondly, the separation of so-called ‘near size” particles, which is a gradual process rarely reaching final completion. Both stages require the sieve to be manipulated in such a way that all particles have opportunities for passing the apertures. The effectiveness of a sieving process depends on the amount of material put onto the sieve (the “charge”) and the type of movement imparted or the sieve Finch et all, (1982)

2.6 **Size/Assay Analysis**

The size/Assay analysis is usually carryout to determine the distribution of various minerals, specifically valuable and non-valuable metal bearing minerals of the ore in the various size fractions. The analysis is use to obtain information on the possibility of using waste rejection techniques so as to reject the gangue minerals at a coarse size as possible. It is also use to obtain clues on the liberation sizes of the various minerals in the ore and their degree of associations (Yaro, 1997).

2.7 **Determination of Liberation size of the Valuable Minerals in the Ore**

Liberation is the first step in processing crude Iron ore and consists mostly of crushing and grinding. The ore must be ground to a particle size sufficiently close to the grain size of the iron-bearing mineral to allow for a high degree of mineral liberation. Most of the ores used today requires very fine grinding. Prior to grinding, the ore is dry-crushed up to six stages, depending on the hardness of the ore. One or two stages of crushing may be performed at the mine prior to shipping the raw material to the processing facility. Gyratory crushers are generally used for primary crushing, and cone crushers are used for secondary and tertiary fine crushing. Intermediate vibrating screens remove undersize material from the feed to the next crusher and allow for closed-circuit operation of the fine crushers. After crushing, the size of the material is further reduced by wet

grinding in rod mills or ball mills. The rod and ball mills are also in closed circuit with classification systems such as cyclones. An alternative to crushing is to feed some coarse ores directly to wet or dry semi-autogenous or autogenously grinding mills (using larger pieces of the ore to grind/mill the smaller pieces), then to pebble or ball mills. Ideally, the liberated particles of iron minerals and barren gangue should be removed from the grinding circuits as soon as they are formed, with larger particles returned for further grinding.

Concentration is the second step in ore processing. As the crushing steps liberate the iron ore minerals, the iron-bearing particles must be concentrated because only about 33 percent of the crude ore becomes a shippable product for iron making. If high –grade solid products are required, then good liberation is essential, in practice complete liberation is not achieved, even if the ore ground down to the grain size of the desired mineral particles (Anon, 1980). The degree of liberation refers to the percentage of the mineral occurring as free particles in the ore after grinding in relation to the total mineral contents in the ore. This can be high if there are weak boundaries between mineral and gangue particle, which is often the case with ores composed mainly of rock forming minerals, particularly sedimentary materials usually, if the adhesion between valuable mineral and gauge is strong one and, during comminution, the various constituents are cleft across. This produces much middling and low degree of liberation.

New approaches to increasing the degree of liberation involve directing the breaking stresses at the mineral grain boundaries, so that the rock can be broken without breaking the mineral grains. This can be achieved by heating the rock to a high temperature, although this has not, as yet, been exploited in practice (Scheduling, 1981) and (Geller et al, 1975).

Many researchers have tried to quantify degree of liberation with a view to predicting the behavior of particles in a comminution process. The first attempt at the development of a model for the calculation of liberation was made by Gaudin (1939) and King (1979, 1982) who developed an exact expression for the fraction of particles using certain models, However, these suffer from many unrealistic assumption that must be made with respect to the grain structure of the minerals in the ore. A high degree of liberation may only be possible by intensive fine grinding, which may reduce the particles to such a fine size that separation becomes very inefficient. In practice, ores are ground to an optimum mesh of grind, determined by laboratory and pilot scale test work, to produce an economic degree of liberation Wills, (1985).

2.8 **Work Index Determination**

Grinding characteristics of an ore called grindability refers to the ease with which the ore can be comminuted. It is an important factor in estimating and controlling the power requirement of industrial grinding operations. The most widely used parameter to measure grindability of an ore is the Bond work index (Wi) which is defined as the power in Kilowatt hour per tonne required to grind an ore from an infinite size to size 80% passing 100μm. Several empirical methods have been developed for evaluation of grindability of ores; most of them have not been widely accepted because results obtained do not correlate very well with each other or with the corresponding industrial data. Probably the most wildly used method is the standard Bond Method.

2.8.1 **Standard Bond Method**

The bond grindability test and the resulting work obtained have been successfully used for predicting ball mill and rod mill energy requirements and for selection of plant scale comminution equipment. The work index has also been widely used to evaluate the grinding efficiency in operating plants. Although the bond grindability test provides an accurate measurement of ore grindability, the test procedures are time consuming. This method involves the use of a standard laboratory ball mill specifically made for the purpose with specified charged balls of varying diameters. The

ore is ground in this ball mill at various revolutions of the mill. However, when making plant evaluations a simplified procedure requiring less time is needed.

Several methods to stimulate the bond work index parameter are used and some have been reported in the literature. Smith et al, (1968) for example, used batch type grindability tests to arrive at the work index. The bath type test results were found to compare favorably with the standard grindability test data. The potential advantage being that less time is required to determine the work index using this method. Another method of determining work index is the Barry and Bruce otherwise know as modified bonds method. The method requires the use of a reference ore whose work index is known using the bond's energy equation.

$W = 10wi/\sqrt{P} - 10wi/\sqrt{F}$ ……..(3)

Where P = product

W = work input

Wi = work index

F = feed

The work index of the unknown ore is determined when the work input (w) is the same for the identical weights of the reference and unknown ore, ground under the same conditions in the same laboratory ball mill. The energy input of the unknown is equal to the energy input of the reference. For the above conditions where r and u denote reference and unknown ores

respectively the following holds.

Wr=Wu= Wir10/√pr-10/√Fr]=wiu[10/√Pu–10/√Fu] ……(4)

Where Wr = Energy input in grinding the reference

Wir = Work index of the reference ore

Wiu = Work index of the unknown ore

Fr = 80% passing feed of reference ore

Pr = 80% passing product of the reference ore

Fu = 80% passing feed of the unknown ore

Pu = 80% passing product of the unknown ore

Therefore, the work index of the unknown ore is then

Wiu=Wir[10/ √pr- 10/√Fr] / [10/√Pu – 10/√Fu] ……(5)

This method is a relatively simple procedure and is called the comparative method of determining the grindability parameter (work index).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

50Kg sample of Agbado-Okudu Iron ore were received from Steel Raw Material Exploration Agency, kaduna. The agency collected the samples from three trenches at an average of forty meters along the profiles.

3.2 METHODS

3.2.1 Preparation of the Bulk Sample for Chemical Analysis

The 50kg sample taken for the project was subjected to crushing in a small laboratory jaw crusher. The crushed product was then pulverized and sieved using a 45μm aperture sieve.

3.2.2 Chemical Analysis

The test was carried out to determine the full chemical composition and the grade of the ore. The prepared sample from the deposit used was placed on the machine and the area of interest on the sample was marked. Electron beam is then focused into the sample by a system of electron-magnetic lenses and by means of deflection coils. The electron beams are made to scan across several lines to cover a rectangular area enclosing the marked area of interest. The signals of the characteristic X-rays produced

was detected and amplified, using crystal spectrometers the signals produced were then collected from the point and recorded. The recorded signals were used to determine the percentage composition of each of the sample and then the average percentage composition of the ore was computed. The results of chemical composition of the Agbado – Okudu iron sample is shown in Table 4.1.

3.2.3 **Microscopy**

The mineralogical analysis carried out involved identifying the major, minor trace minerals and also the grain size of the mineral of economic importance. In carrying out the mineralogical analysis, the iron ore sample was mounted on the surface of a glass slide using adhesive glue, the ore sample was then ground and polished very well on laboratory cutting, grading and polishing machine until a thin transparent surface was obtained on the glass slide. The thin section transparent glass slide was then observed under a polarized light of a metallurgical microscope with an in–built camera and a point -counter machine attached to it. The percentage of distribution of the various minerals present in the ore sample was determined using the point counting machine. The result is given in Table 4.2.

3.2.4 **Size/ Assay Analysis**

The size/ Assay Analysis was carried out to determine the distribution of the various minerals specifically (SiO_2) and iron bearing minerals in the various size fractions. It was also carried out in order to have an idea of the liberation sizes of the various minerals in the ore and the degree of their association with each other.

About 10.5kg of the Agbado- Okudu iron ore sample was used. The size analysis was carried out using standard screen designation sieves consisting of ten (10) size fractions arranged on the basin of root two- ($\sqrt{\mathbf{2}}$) ranging from +355 μm to +45μm. The series being (+355μm, -355 +250μm, -250+180μm, -180+125μm, -125+100μm, -100+90μm, -90+80μm, -80+63μm, -63+56μm, and -56+45μm). The sieve analysis was performed dry during which the material was shaken for 15 minutes using an electric sieve shaker. The amount of material retained on each sieve size was collected and weighed and the iron (Fe_T) and the silica (SiO_2) content in each sieve size fraction were determined using Atomic Abortion Spectrometer. The assay results of each size fraction together with their weight were then used in determining the distribution of silica and iron into the various size fractions. The results are given in Tables 4.3, 4.4 and 4.5.

3.2.5 **Work Index Determination**

Berry and Bruce method, otherwise known as the modified Bond's method used in determining the work index of the Ore. A representative sample of the reference ore granite of known work index 15.13kwh/tonne was ground and sieved. The weighed and the amount of the reference ore refined on each sieve were determined as a feed to the ball mill. This retained each sieve size fractions were further subjected to grinding so as to obtain a product that is 80% passing 100μm. The same series of test were repeated for the Agbado-Okudu iron ore. The weight of materials retained on each sieves were then tabulated against the sieve size for both reference ore and the Agbado-Okudu iron ore (test ore). The voltage used was 240volts, power (watts) was 370W, Ampere was 3.8A, number of balls used per container was 20 and the period of grinding was for 1 hour. The results of the test are given in Tables 4.6, 4.7, 4.8 and 4.9.

3.2.6 **Concentration by the Shaking Table**

The test was under taken using the ore which has been ground and sized into particle size ranges +335μm, -335+250μm, -250 +180μm,-180+125μm,-125-100μm,-100+90μm,-90+80μm,-80+63μm,-63+56μm, and -56+45μm. Each particle size fraction was prepared using 25% solid by weight and used for each batch of the concentration test. Appropriate

adjustments for the treatment of each size range were made necessary to the motion mechanism (Amplitude 1400rev/min inclination 180degrees, frequency 50Hz,). Each sized material was then placed at the feed box at the top edge of the deck and gently wetted using wash water. Irrigation water (wash water) was introduced at approximately 1000ml/9sec. The deck was set in motion of different density of each sieve size fraction allowed to separate. The irrigated wash water flow in the direction so that the heaviest minerals travel along the head of the table deck and the lighter minerals travel on a wider band (riffles) towards the middlings and tailings launder. At the end of each test the concentrates, middlings and the tailings were collected, decanted, filtered, dried and weighed. Then representative samples were taken from each of the portions and assayed for iron total and silica. The result of this test is given in Table 4.10.

3.2.7 **Concentration by the Magnetic Separator**.

Sample of the ground ore was used, sized into various size fractions ranging from +335μm,-335+250μm,-250+180μm,-180+125μm,-125+100μm,-100+90μm,-90+80μm,-80+63μm,-63+56μm and -56+45μm. The various sieve fractions were subjected to magnetic separation after which two products (concentrates and tailings) were produced. The tailings and concentrates of each size fractions were weighed and analyzed for iron and silica content using AAS techniques. The tests were carried out using a

laboratory magnetic separation machine, with a magnetic field intensity of 20 amperes/metre. The results of these tests are given in Table 4.11.

3.2.8 **Concentration by Shaking table followed by Magnetic Separator.**

The pre-concentrates of each size fraction obtained from the separation using shaking table were used as feed to the magnetic separation. From these feeds concentrates and tailings were obtained after the magnetic separation. The concentrates and tailings obtained after magnetic separator were then dried and weighed. They were assayed for iron and silica using AAS technique; the results obtained from this investigation are given in Table 4.12.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 Results

The results obtained from the tests and analyses carried out are presented in Tables 4.1 to 4.12 and figures 4.1 to 4.7.

4.2 DISCUSSIONS

4.2.1 Chemical Analysis

The result of the investigation of the chemical composition of Agbado-kudu iron ore given in Table 4.1 confirms the fact that, the average Iron content of (38.82%) compared favourably with those of the four major Nigeria iron ore deposits shown in Table 2.2. Though, having a lower iron ore content compared to Agbaja, Koton-Karfi and Bassa Nge iron ore deposits, the Agbado- Okudu Iron ore can still serve as another valuable source of raw material for our steel plants. However, further comparison of the chemical composition of the seven, major iron ore deposits with that of the Agbado- Okudu Iron ore reveals that the percentage of phosphorous pentoxide (0.05% P_2O_5) in the Agbado –Okudu is less than that of Itakpe (0.18%), Agbaja (2.08%) Koton. Karfi (2.14%), Bassa Nge (1.40%) and Toto-Muro (0.13%). The Agbado Okudu iron ore has a lower percentage of sulphur (0.03%) compare to that of the major seven (7)-iron ore deposit in Table 2. Also the proportion of silica (49.10%) in the Agbado-Okudu Iron

Ore is high compared to that of Itakpe (44.80%), Ajabanoko (46.50%), Ajabanoko (46.50%), Agbaja (10.59%), Bassa Nge (8.28%) and Koton karfe (5.13%). This silica can be drastically removed or reduced during beneficiation and slag formation (Wills, 1985) and (Kudrin, 1985). The proportions of other compounds in the iron ore are within the acceptable limits required for iron and steel making (Kudrin 1985, Also and Yakubu 1995).

4.2.2 **Mineralogical Analysis**

Table 4.2, gives the result of mineralogical composition of Agbado-Okudu Iron ore. The iron bearing minerals are predominately magnetite (Fe_3O_4) and hematite (Fe_2O_3) with quartz ($Si0_2$) and other associated minerals. The point count, which is a reflection of the percentage distribution of minerals in the ore show that on the average 69% of the mineral distribution in the ore samples are iron oxides, even though it was not possible to quantitatively determine the population of each of iron oxides in the ore, while 31% are quartz and others. Also examined thin sections of the samples under a polarized light revealed that most of the iron oxides mineral present displayed a silver colour with black dots patches in their matrix a characteristic associated with magnetite (Fe_30_4) iron bearing minerals. While few amount of the iron oxide mineral display a silver colour with black dot particular in there indicate the characteristic feature of

hematite (Fe_20_3) iron bearing minerals. While pure black colour, indicate characteristic feature of quartz minerals ($Si0_2$) (Kerr, 1959). These characteristics of the Agbado- Okudu iron ore confirm the result of the early work by (Olukoya et al, 1979). The understandings of the mineralogy of an ore provide an insight into the liberation size of the ore and the separation technique likely to be adopted in the concentration of the valuable minerals.

4.2.3 Size/Assay Analysis of the Head Sample

The result of the distribution of iron bearing mineral and silica given in Table 4.3 reveals that the iron bearing mineral and silica are evenly distributed equally in each of the various sieve fractions. This implies that the silica and the iron bearing mineral are interlocked making the liberation of the two minerals difficult and hence, subsequent separation. Also the graph of percentage distribution of iron and silica plotted against particle size fraction show in Figure 4.1. From this Figure it can be seen that at each of size fractions the proportion of iron and silica in the ore remains the same. However, there is more of the Iron and Silica in the coarser size fractions (250-355μm) and these decreases with size fraction 90μm having the lowest of the Iron Ore and Silica.

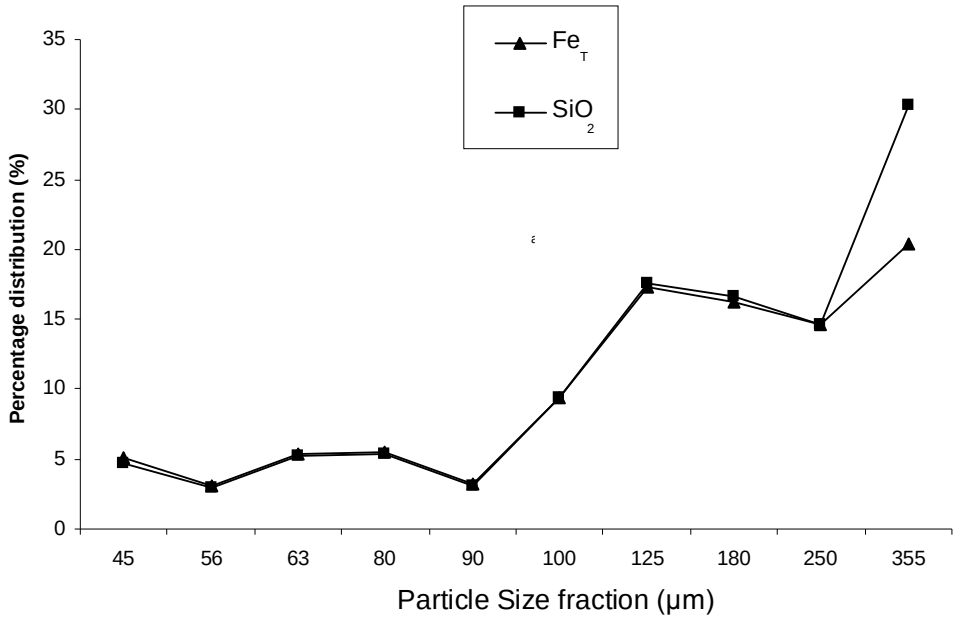

Fig 4.1: Graph of percentage distribution of Fe_T and SiO_2 of Agbado-Okudu Iron Ore versus particle size fractions

4.2.4 **Work Index Determination**

Table 4.6 and 4.7 gives the result of particle size distribution of the feed and discharge of the ball mill for the reference ore (granite). Table 4.8 and 4.9 give the particle size distribution of the feed and discharge of the ball mill for the test ore. From these Tables, the 80% passing products and feeds for both reference ore (granite) and the test ore (Agbado-Okudu) were calculated from a plot a particle size µm against % passing and the work index of the test ore was calculated using the empirical equation. The work

index was found to be 4.32 kwh/tone. This value of the work index indicates that the ore is moderately soft as compared to the reference ore (granite). This also implies that the energy required to comminute this ore is lower than that required to comminute the granite.

4.2.5 **Concentration by the Shaking Table.**

Table 4.10, gives the result of the separation test using shaking table for the particle size ranges from +355 to +56 -45μm in which the assay of the iron (Fe_T) and silica (SiO_2) for each of the three (3) products and their recoveries are computed. The grades of the concentrates produced increases with decrease in particles size. This increase with decrease in particle size could be attributed to the fact that much of the iron-bearing mineral is being liberated as the particle size decreases. However, the silica (SiO_2) in the concentrates also decreases with decrease in particle size while in the tailings, the silica content increase with decrease in particle size showing that the silica (SiO_2) bearing mineral is being transferred to the tailings. The percentage recovery for Iron in various sieve size fraction also increase as the particle size decreases.

Sieve size fraction -56+45μm has the highest assay value of 55.81% Fe followed by size fraction -63+56μm with 55.43% Fe_T, yet the recovery of iron in the concentrate of –56 + 45μm is higher (66.40%) compared to

that of -63+56μm (64.72%). The iron content in the middling of sieve size fraction +335 to -56+45μm decrease as the size fraction reduces; this means that as the particle size decreases more of the iron is misplaced into the middlings and this is one of major disadvantage of gravity separation at fine particle size.

The graph of percentage recovery and grade plotted against particle size fraction for the gravity separation technique (shaking table) is given in Figure 4.2. From this graph it can be seen that as the particle size decreases, both concentrate and recovery increases. This is because as the particles decreases more and more of the iron bearing minerals are liberated from the gangue (silica). An optimum grade of 55.81 %(Fe) and a recovery of 66.40% and at sieve size fraction of –56+45μm could be attained.

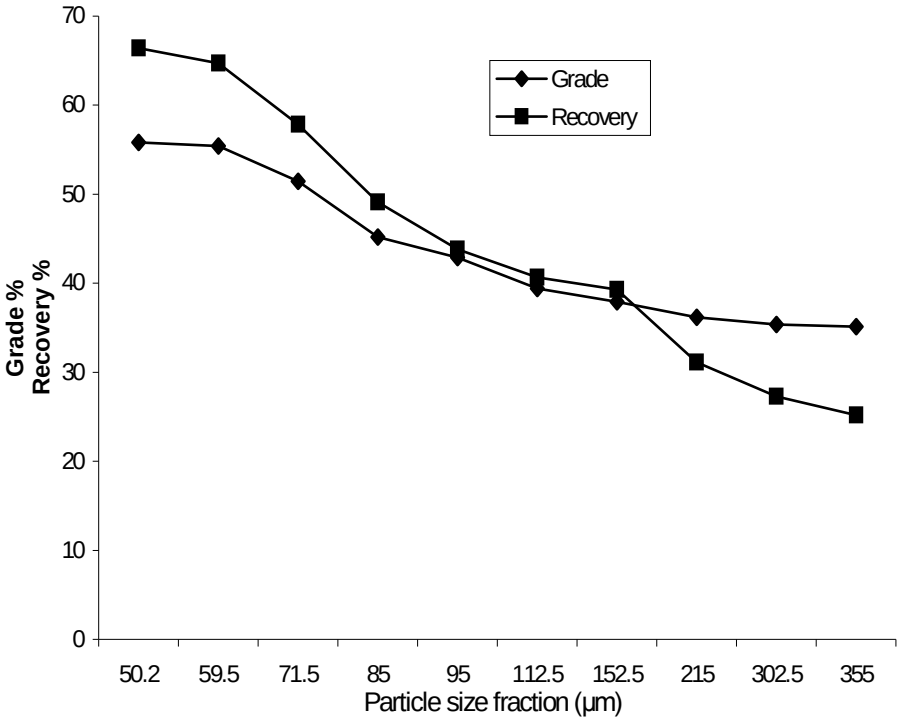

Fig 4.2: Graph of concentration test using shaking table versus particle size

From the Data gathered from gravity separation test, and out from the series of comminution processes (crushing and grinding) A block diagram flow sheet for gravity separation (shaking table) technique circuit given in Figure 4.3 is proposed for the up-grading of the ore by gravity separation.

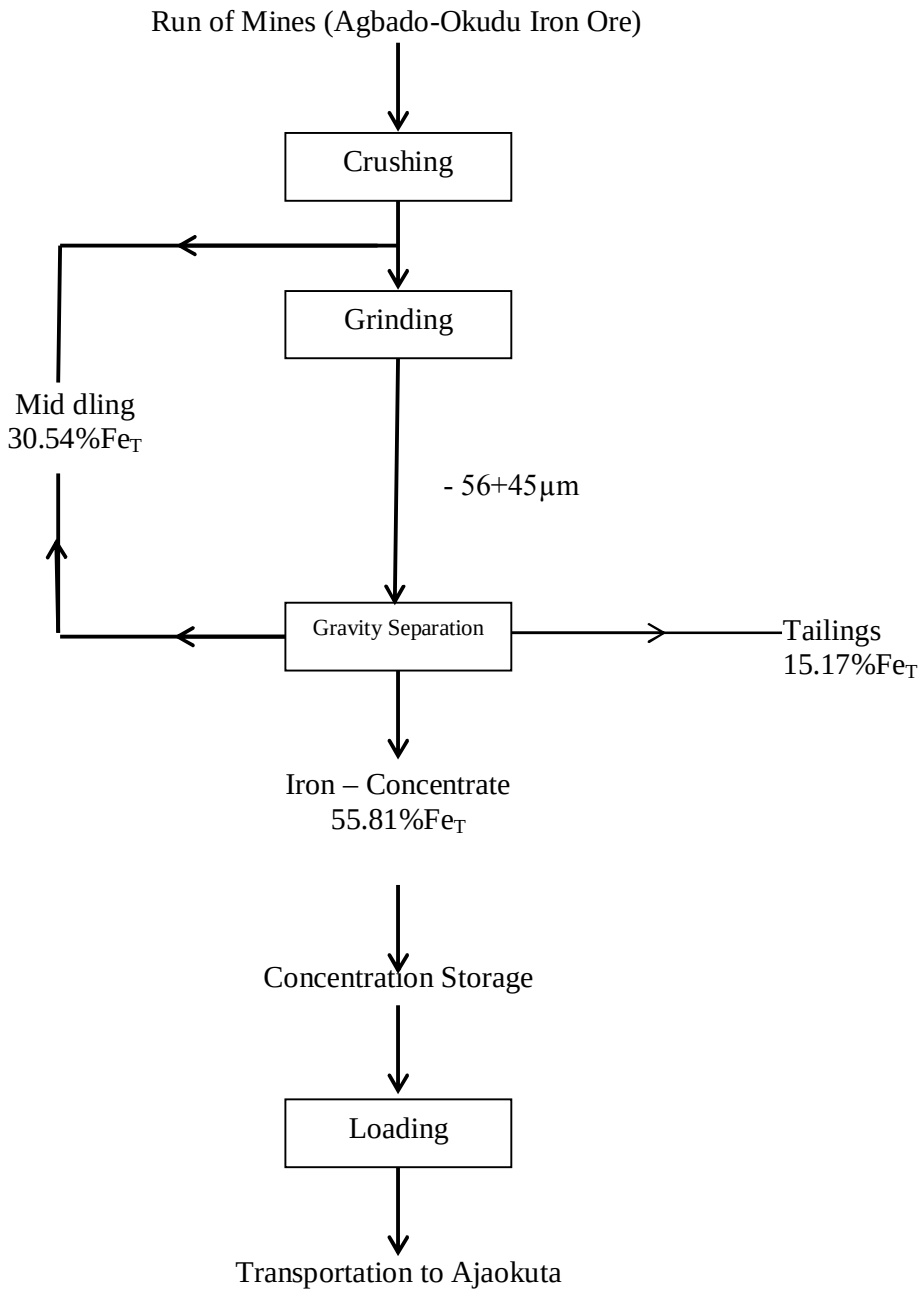

Fig. 4.3: Proposed schematic diagram of shaking table concentration Technique

4.2.6 **Concentration by the Magnetic Separator**

Table 4.11, gives the result of concentration test using magnetic separator. The assay of iron (Fe_T) and silica (SiO_2) determined for each concentrate from each size fraction and the percentage recoveries computed. From this table, it can be seen that the assay of iron (Fe_T) in the concentrate increase as the particle size decreases, with size fraction –56+45μm having the highest assay value of 57.61% Fe_T and a recovery of 75.21%. The high grade and recovery at this particle size fraction could be attributed to high degree of liberation that must have been achieved. The next to this sieve size, is the sieve size fraction –63 + 56μm while

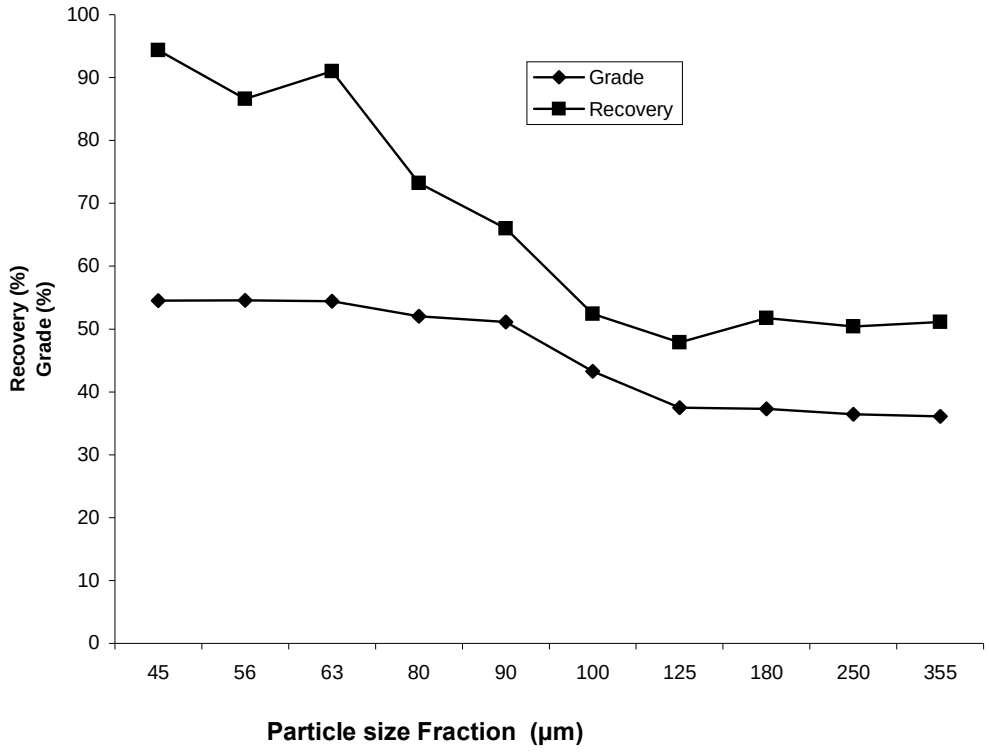

Fig 4.4: Graph of percentage recovery and grade versus particle size fractions of Fe_T content of concentration using using magnetic separation technique

Sieve size –80+63μm has the high value of iron recovery of 82.12% and low assay value of 57.43%$Fe_{T,}$

The graph of percentage recovery and grade plotted against particle size fraction using magnetic separation technique is given by Figure 4.4. From the graph it can be seen that an optimum grade of 57.43% (Fe_T) and a recovery of 80.85% at a sieve size of –65+56μm could be attained. The graph also shows that both concentrate grade and recovery decreases with decrease in particle size. However, both grade and recovery tends to remain constant as from particle size fraction -63μm.

Using the Data obtained from the concentration test by magnetic techniques and the series of comminutioin stages (crushing and grinding) underwent by the ore prior to separation process, a diagram flow sheet is proposed for the up-grading of the ore by magnetic separator as shown in Fig. 4.5.

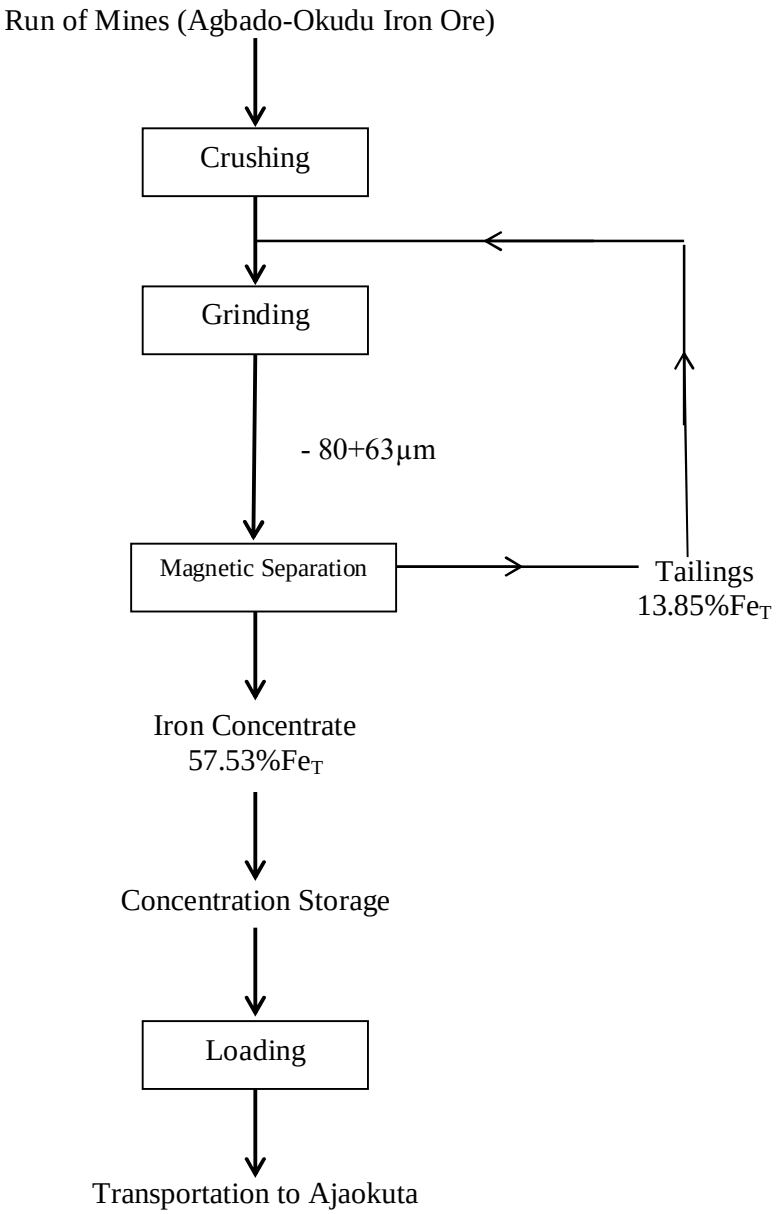

Fig. 4.5: Proposed schematic diagram of Magnetic separation technique

4.2.7 **Results of Concentration by the Shaking Table followed by Magnetic Separation (Concentrate).**

Table 4.12, gives the result of gravity concentration using test in a combination of shaking table followed by magnetic separation technique conducted on the ore at various size fractions ranging from +355 to -56 +45μm. From this results, it can be seen that the highest assay of iron (Fe_T) 57.34% was achieved at size fraction -56+45μm with a recovery value of 76.03% followed by -63+56μm with (57.17%) Fe assay and recovery of 80.85%.

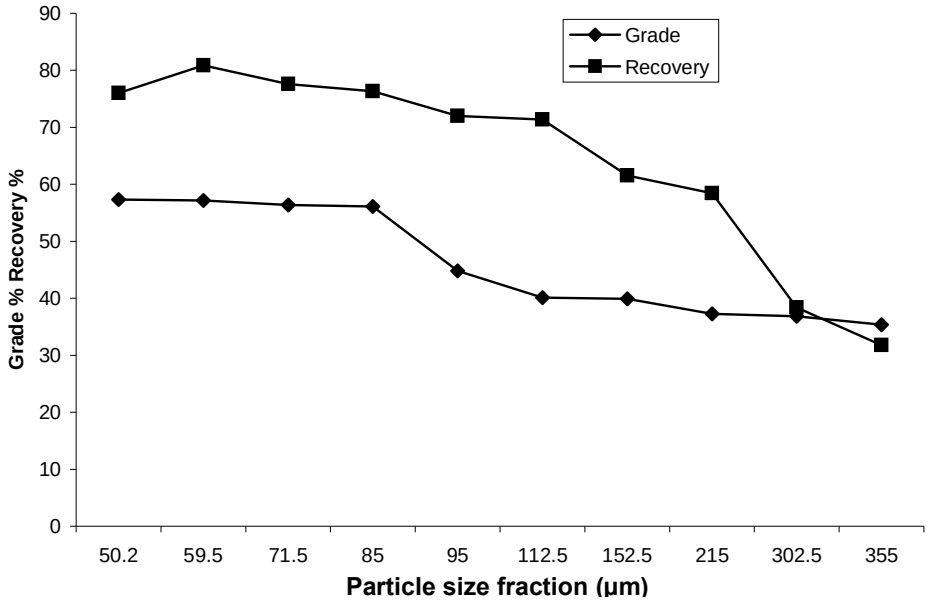

Fig 4.6: Graph of concentration test using shaking table followed by magnetic separator versus particle size

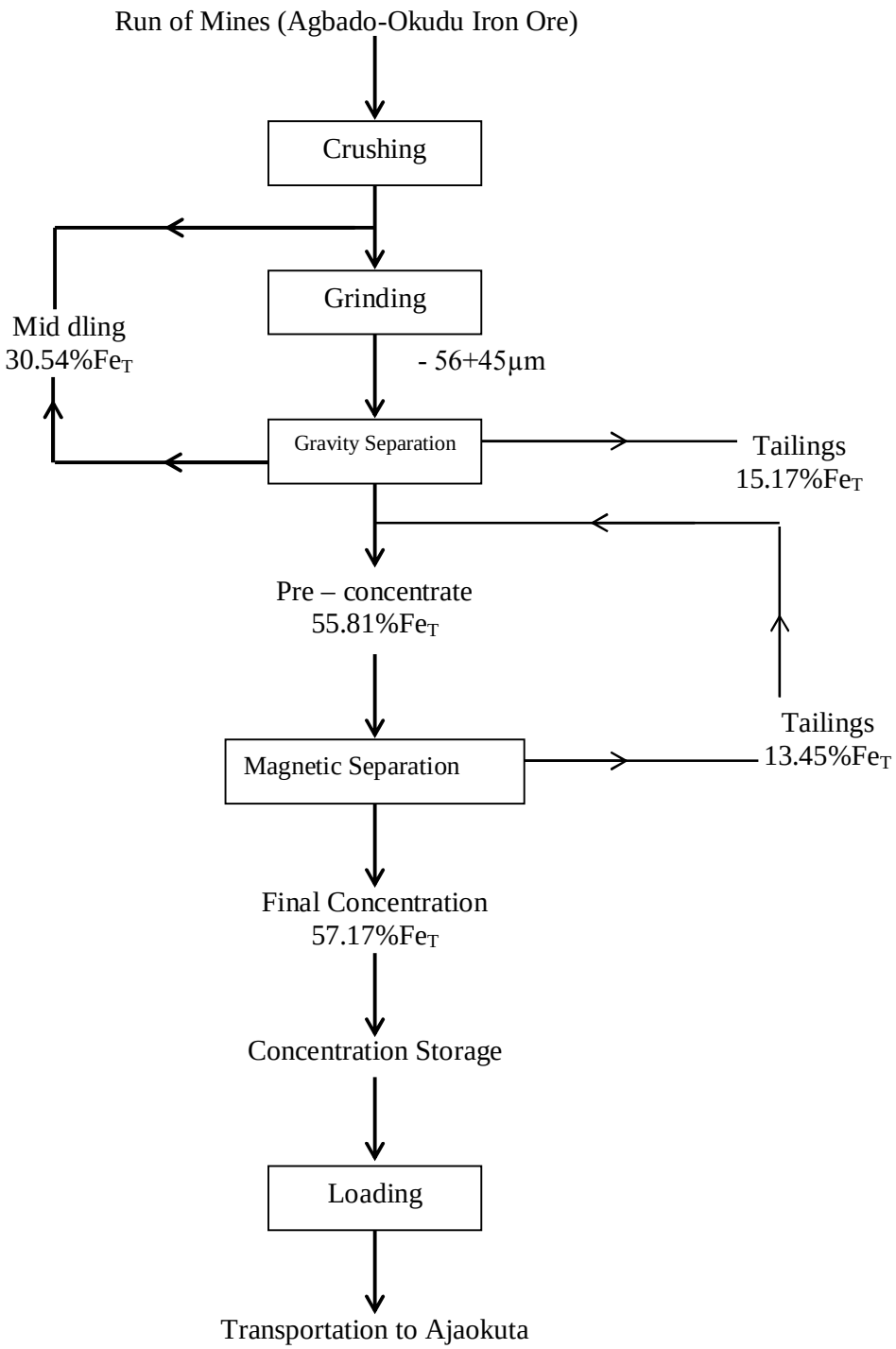

Fig. 4.7: Proposed schematic diagram of Shaking Table concentration followed by Magnetic concentration techniques of Agbado-Okudu iron ore

The graph of percentage recovery and grade plotted against particle size fraction for the separation using gravity technique (shaking table) followed by magnetic

Separation is given by Figure 4.6. The graph reveals that an optimum concentrate grade of 57.17% (Fe_T) and a recovery of 80.85% at a sieve size fraction of –63+56μm could be attained.

Using the data obtained from the concentration test by gravity test followed by magnetic techniques and the series of comminution stages (crushing and grinding) underwent by the ore prior to separation by gravity test followed by magnetic method. A block diagram flow sheet (Figure 4.7) is being proposed for the up-grading of the Agbado-Okudu Iron Ore using these concentration techniques.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The development of a process route for the up-grading of Agbado Okudu Iron ore deposit to a concentrate that can be used at Ajaokuta iron and steel plant was thoroughly investigated and conducted in two phases. The first phase involved characterization of the run-of-mine ore encompassing determination of the chemical composition, size/assay analysis, mineralogical composition and work index of the ore. From these analyses and tests, the grade, mineralogical composition, distribution of the valuable minerals in different size fraction, work index of the Ore were determined.

The second phase of the research, concentrated on the separation of valuable minerals from the gangue using shaking table, magnetic and a combination of the two concentration techniques. The summary of the results of the concentration tests is as shown in Table 5.1.

Based on the results obtained, their analysis and discussion, the following conclusions are drawn.

1. The Agbado- Okudu is a moderate grade iron ore, having an average assay of Iron (38.82%) and that of silica (49.10%). Therefore, it is apparent from these results that the iron ore requires upgrading before used for iron making.

2. The mineralogical composition of the ore reveals that most of the iron bearing minerals are predominantly magnetite (Fe_30_4) and hematite (Fe_20_3) constituting 69% of the total mineral content in the ore, while silica is the major gangue mineral.

3. The results of grindability test show that the Agbado-Okudu iron ore is soft with a moderate work index of about 4.32kwh/tonne

4. Based on the results of separation tests carried out, it can be concluded that magnetic separation technique is the best method that can be used in the upgrading Agbado Okudu iron ore. This is because a concentrate with a grade of 57.43% and recovery of 82.82% could be obtained.

5.2 **Recommendation**

Based on the results of the various tests carried out, their analysis and discussion, the following recommendations are drawn:

1. The Agbado-Okudu iron ore can be used after upgrading as source of iron ore concentrate for the conventional blast furnace route iron making process at Ajaokuta.
2 Reverse-Froth Flotation technique for the removal of the silica can be used to upgrade the ore further for use in the Delta Steel plant.
3 The mineralogical composition of the ore can be determined using more accurate and sensitive machine if available. Like, Electron Probe Micro Analyzer (EPMA). This will give the percentage composition of each of the mineral in the ore.

Table4.1 Determine Chemical Composition Of Agbado-Okudu Iron Ore head Sample.

Compound	Chemical formula	Percentage composition%
Total iron	Fe_T	38.82
Silica	$Si0_2$	49.10
Calcium oxide	Ca0	0.13
Magnesium oxide	Mg0	0.17
Manganese oxide	Mn0	0.16
Potassium oxide	K_20	0.04
Titanium oxide	$Ti0_2$	0.00
Alumina	Al_20_3	1.13
Phosphorous Oxide	P_20_5	0.05
Sulphur	S	0.03
L.O.I		10.37

Table4.2 The Mineralogical Composition and Characteristic of Agbado-Okudu Iron Ore

Mineral	Chemical formula	Average percentage distribution %	Description of observation
Magnetite	Fe_30_4	69	Silver colour with dot patches
Hematite	Fe_20_3		Silver colour without dot patches
Silica others	$Si0_2$ +others	31	Black colour

Table4.3 Size/Assay Analysis Of Head Sample Of Agbado-Okudu Iron Ore sieve size fractions.

S/No	Size fraction (μm)	Weight of sample retained (g)	Assay of Fe_T (%)	Assay of $Si0_2$ (%)
1	+335	2150.00	34.62	49.10
2	-335+250	1539.00	34.57	49.15
3	-250+180	1711.00	34.55	50.62
4	-180+125	1827.00	34.51	50.02
5	-125+100	1000.00	34.52	48.89
6	-100+90	336.00	35.02	48.56
7	-90+80	567.00	35.12	48.50
8	-80+63	555.00	35.15	48.52
9	-63+56	321.00	35.24	48.51
10	-56+45	514.00	36.12	47.55

Table 4.4 Size/Assay Analysis Of The Agbado-Okudu Iron Ore Fe_T Content

Sieve size fraction (μm)	Weight retained (g)	Percentage Weight retained %	Assay of Fe_T in each fraction	Metal content (g)	Percentage distribution (%)	Cumulative percentage distribution (%)
+335	2150.00	20.44	34.62	74433.00	20.37	20.37
-335+250	1539.00	14.63	34.57	53203.23	14.56	34.94
-250+180	1711.00	16.26	34.55	59115.05	16.18	51.12
-180+125	1827.00	17.37	34.51	63049.77	17.26	68.24
-125+100	1000.00	9.51	34.52	34520.00	9.45	77.69
-100+90	336.00	3.19	35.02	11766.72	3.22	80.91
-90+80	567.00	5.39	35.12	19913.04	5.45	86.36
-80+63	555.00	5.28	35.15	19508.25	5.34	91.70
-63+56	321.00	3.05	35.24	11312.04	3.10	94.80
-56+45	514.00	4.89	36.12	18565.68	5.08	100.00
	10520.00			365386.78		

Table4.5 Size/Assay Analysis Of The Agbada-Okudu Iron Ore Silica ($Si0_2$) Content

Sieve size fraction (μm)	Weight retained (g)	Percentage Weight retained	Assay of $Si0_2$ in each fraction	Silica content (g)	Percentage distribution	Cumulative percentage %distribution
+335	2150	20.44	68.70	105565.00	20.35	20.35
-335+250	1539	14.63	62.53	75641.85	14.58	34.93
-250+180	1711	16.26	61.63	86610.82	16.69	51.62
-180+125	1827	17.37	61.30	91386.54	17.61	69.23
-125+100	1000	9.51	63.5	48890.00	9.42	78.65
-100+90	336	3.19	63.91	16316.16	3.15	81.80
-90+80	567	5.39	56.6	27499.50	5.30	87.10
-80+63	555	5.28	39.40	26928.60	5.19	92.29
-63+56	321	3.05	45.30	15571.71	3.00	95.29
-56+45	514	4.89	47.00	24440.70	4.71	100.00
	10520			518850.88		

Table 4.6 Particle size Analysis of Feed to the Ball Mill Reference Ore (granite)

SIEVE SIZE FRACTION (μM)	WEIGHT RETAINED (g)	PERCENTAGE WEIGHT RETAINED (%)	CUMULATIVE PERCENTAGE WEIGHT RETAINED (%)	CUMULATIVE PERCENTAGE PASSING (%)
+ 355	48.00	15.047	15.047	84.953
- 355 +250	50.00	15.674	30.721	69.278
-250 +180	61.00	19.122	49.843	50.157
-180+125	53.00	16.614	66.457	33.543
-125 +100	28.00	8.777	75.234	24.766
-100 +90	19.00	5.956	81.190	18.810
-90 +80	11.00	3.448	84.638	15.362
-80 + 63	12.00	3.762	88.400	11.600
-63 +56	23.00	7.210	95.610	4.390
-56+45	14.00	4.389	100.00	000
	319.00			

Table 4.7 Particle Size Analysis of Ball Mill Discharge Reference Ore (granite)

SIEVE SIZE FRACTION (μM)	WEIGHT RETAINED (g)	PERCENTAGE WEIGHT RETAINED (%)	CUMULATIVE PERCENTAGE WEIGHT RETAINED (%)	CUMULATIVE PERCENTAGE PASSING (%)
+ 355	32.00	10.738	10.738	89.262
- 355 +250	46.00	15.436	26.174	73.826
-250 +180	59.00	19.799	45.973	54.027
-180+125	52.00	17.450	63.423	36.577
-125 +100	28.00	9.396	72.819	27.181
-100 +90	16.00	5.369	78.188	21.812
-90 +80	10.00	3.356	81.544	18.456
-80 + 63	11.00	3.691	88.235	14.765
-63 +56	27.00	9.060	94.295	5.705
- 56+45	17.00	5.705	100.00	0.000
	298.00			

Table 4.8 Particle Size Analysis Of The Feed To The Ball Mill Test Ore (Agbado-Okudu)

SIEVE SIZE FRACTION (μM)	WEIGHT RETAINED (g)	% WT RETAINED	C WT % RETAINED	CUMULATIVE % PASSING
+ 355	3.00	2.326	2.326	97.674
- 355 +250	4.00	3.101	5.427	94.573
-250 +180	17.00	13.178	18.605	81.395
-180+125	28.00	21.705	40.310	59.690
-125 +100	18.00	13.954	54.264	45.736
-100 +90	10.00	7.752	62.016	37.984
-90 +80	9.00	6.977	68.993	31.007
-80 + 63	16.00	12.403	81.396	18.604
-63 +56	10.00	7.752	89.148	10.850
-56+ 45	14.00	10.853	100.00	0.000
	129			

Table 4.9 Particle Size Analysis of Ball Mill discharge Test ore (Iron Ore)

SIEVE SIZE FRACTION (μM)	WEIGHTY RETAINED (g)	PERCENTAGE WEIGHT RETAINED (%)	CUMULATIVE PERCENTAGE WEIGHT RETAINED (%)	CUMULATIVE PERCENTAGE PASSING (%)
+ 355	0.00	0.00	0.00	0.00
- 355 +250	0.00	0.00	0.00	0.00
-250 +180	9.00	7.826	7.826	92.174
-180+125	25.00	21.739	29.565	70.435
-125 +100	18.00	15.652	45.217	54.783
-100 +90	11.00	9.565	54.782	45.218
-90 +80	10.00	8.696	63.478	36.522
-80 + 63	19.00	16.522	80.000	20.00
-63 +56	11.00	9.565	89.565	10.435
-56+ 45	12.00	10.435	100.00	0.000
	115.00			

Table4.10 Results Of Gravity Concentration Using Shaking

SIEVE SIZE FRACTION (μM)	WT OF FEED (g)	ASSAY OF FEED (%)		PRODUCTS	WEIGTH PRODUCTS (g)	ASSAY OF PRODUCT (%)		RECOVERY (%)	
		Fe_T	SiO_2			Fe_T	SiO_2	Fe_T	SiO_2
+355	1159	33.11	52.81	Concentrate	275.00	35.11	28.91	25.16	12.99
				Middling	597.00	32.51	62.86	50.58	61.31
				Tailings	287.00	32.44	54.81	24.26	25.70
-355 +250	794	33.14	52.90	Concentrate	203.00	35.35	45.19	27.27	21.84
				Middling	411.00	32.44	53.21	50.69	52.07
				Tailings	180.00	32.15	60.87	22.06	26.09
-250 +180	951	34.11	56.07	Concentrate	279.00	36.17	43.11	31.11	22.56
				Middling	388.00	40.81	74.57	48.81	54.26
				Tailings	284.00	34.64	65.75	20.08	23.18
- 180 +125	730	35.68	56.81	Concentrate	270.00	37.89	55.89	39.28	36.39
				Middling	380.00	36.11	59.72	52.68	54.72
				Tailings	80.00	26.18	46.09	8.04	8.89
- 125 +100	364	38.85	58.91	Concentrate	146.00	39.40	48.35	40.67	32.91
				Middling	173.00	43.28	65.85	52.95	53.13
				Tailings	45.00	20.03	64.49	6.38	13.96
-100 + 90	170	39.70	59.12	Concentrate	69.00	42.87	47.11	43.83	32.34
				Middling	84.00	42.34	62.70	52.70	52.40
				Tailings	17.00	13.79	45.59	3.47	15.26
-90 +80	244	40.56	54.51	Concentrate	101.00	45.17	58.80	49.10	44.65
				Middling	127.00	37.36	49.28	47.94	47.06
				Tailings	16.00	11.42	68.92	5.96	8.29
-80+63	216	40.82	53.33	Concentrate	82.00	51.43	62.62	57.83	58.23
				Middling	127.00	35.31	25.76	50.86	37.11
				Tailings	7.00	16.50	58.65	1.31	4.66
-63+56	125	41.11	51.82	Concentrate	60.00	55.43	50.55	64.72	46.82
				Middling	51.00	28.85	44.66	28.63	35.16
				Tailings	13.00	26.36	50.73	6.35	17.96
-56+45	99	36.12	47.55	Concentrate	47.00	55.81	31.83	66.40	30.13
				Middling	43.00	30.54	69.96	30.24	60.58
				Tailings	9.00	15.17	51.28	3.36	9.29

Table 4.11 Results Of concentration test using Magnetic Separation Techniques

SIEVE SIZE FRACTION (μM)	WT OF FEED (g)	ASSAY OF FEED		CONCENTRATE					TAILINGS				
				Wt (g)	Assay		Recovery		Wt (g)	Assay		Recovery	
		Fe_T	$Si0_2$		Fe_T	$Si0_2$	Fe_T	$Si0_2$		Fe_T	$Si0_2$	Fe_T	$Si0_2$
+355	820	34.62	49.10	371	36.11	30.11	47.19	39.35	449	33.19	64.79	52.81	60.65
- 355 +250	540	35.11	49.18	258	36.46	29.76	47.61	28.91	282	33.87	66.95	52.39	71.09
-250+180	599	36.16	50.12	287	37.32	29.73	48.45	28.42	312	35.09	66.88	51.55	74.18
-180 +125	770	36.58	50.65	339	37.51	29.71	49.14	25.82	431	35.84	67.12	50.86	74.18
-125 +100	535	37.45	51.35	224	43.27	29.55	49.95	24.10	311	33.26	67.05	50.05	75.90
-100 + 90	117	37.78	53.11	53	51.12	28.11	61.29	23.98	64	26.73	73.81	38.71	76.02
- 90 +80	261	39.34	54.52	129	54.03	27.45	65.37	24.88	132	24.98	80.93	34.63	75.12
-80 +63	245	40.10	53.51	148	57.53	20.21	82.12	22.20	97	13.58	82.11	17.88	77.80
-63 +56	143	40.16	51.06	80	57.55	19.32	80.17	21.17	63	18.07	91.36	19.83	78.83
-56+45	80	41.17	51.89	43	57.61	19.21	75.21	19.90	37	22.06	89.86	24.79	80.10

Table 4.12 Results Of Concentration Test Using Shaking Table Followed By Magnetic Separator

SIEVE SIZE FRACTION (μM)	WT OF FEED (g)	ASSAY OF FEED		CONCENTRATE					TAILINGS				
				Wt (g)	Assay		Recovery		Wt (g)	Assay		Recovery	
		Fe_T	$Si0_2$		Fe_T	$Si0_2$	Fe_T	$Si0_2$		Fe_T	$Si0_2$	Fe_T	$Si0_2$
+355	244	35.09	38.91	93	35.35	27.75	31.79	36.59	151	34.93	36.98	61.60	63.41
- 355 +250	449	35.36	40.81	137	36.84	27.61	38.40	20.64	312	34.71	46.59	68.21	79.36
-250+180	312	36.20	50.11	177	37.28	27.57	58.42	31.21	135	34.78	59.66	41.58	68.79
-180 +125	504	37.80	53.12	294	39.89	27.53	61.56	30.23	210	34.87	58.95	38.44	69.77
-125 +100	117	39.41	54.18	82	40.12	27.33	71.35	48.60	35	37.75	60.11	28.65	51.77
-100 + 90	49	42.81	41.90	29	44.83	27.27	61.98	38.51	20	39.88	58.13	38.02	61.49
- 90 +80	69	45.17	40.81	49	56.11	20.11	7635	29.68	20	18.37	59.15	24.65	70.32
-80 +63	70	51.55	40.12	53	56.38	18.91	77.57	35.69	17	36.49	60.38	19.43	64.31
-63 +56	44	55.44	39.13	23	57.17	18.13	80.85	24.22	21	53.45	65.89	23.15	75.78
-56+45	38	55.80	39.10	24	57.34	17.19	76.03	27.77	14	53.16	58.60	23.97	72.23

Sample calculation for the determination of Agbado-Okudu iron ore work index using the Berry and Bruce method

From the Plots of the results given in Tables 4.6 to 4.9 the followings were obtained;

80% passing feed size for reference ore (granite)

80% passing feed size =334um

80% passing discharge for reference ore (granite)

80% passing product size= 318um

For the test ore (Agbado-Okudu)

80% passing feed size = 177um

80% passing product size = 156un

The energy expanded in grinding the ores from 80% passing feeds to 80% passing products suing the Berry and Bruce Method and the equation derived from equals.

$Wr = 10Wi [1/\sqrt{Pr}-1/\sqrt{Fr}]$

$Wt = 10Wi[1/\sqrt{Pt}-1/\sqrt{Fr}]$

$Wr = Wt= Wir [10/\sqrt{Pr}-10/\sqrt{Fr}]= wit = [10/\sqrt{Pt} -1/\sqrt{Fr}]$

But Wir = 15.13 kwh/tonne

$$\text{Therefore } Wit = Wir \frac{[10/\sqrt{318} - 10/\sqrt{334}]}{[10\sqrt{156} - 10/\sqrt{177}]}$$

$$Wit = \frac{15.13 [10/17.83 - 10/18.28]}{[10/12.49 - 10/13.30]}$$

$$= 4.32 \text{kwh/tonne}$$

REFERENCES

Abowzeid, A.,(1990): Mineral Processing Laboratory Manual. 2nd edition. Trans Teck Publishers. Republic of Germany.

Adepoju, S. O. and Olaleye, B. M., (2001): Gravity concentration of silica sand from Itakpe iron-ore tailings by tabling operation. Nigerian Journal of Engineering Management. Vol. 2, No. 2, pp 51-55.

Akande, J.M. and Olaleye, B.M., (2005): Recovery of Galena Concentrate from lead zinc. *Journal of Minerals & Materials Characterization & Engineering,* Vol. 4, No. 1, pp 21-30.

Also, A.K. and Yakubu, N.A., (1995): Local Raw Materials for Steel production. The Case of Ajaokuta, College of Engineering, conference series, vol. 2, No. 1, Kaduna Polytechnic proceeding.

Anon, (1980): A new Approach "Mining Magazine" Hienberg publishers, New York. pp115

Bond, F. C., (1953): The theory of comminution transaction of American Institute of Mining Engineers, vol. 193.

Berry, T. F. and Bruce R. W, (1966): A Simple method of determining the grindability of ores. Canadian Mining Journal. Pp 63

Corran, I. J. (1980): A development in the Application of wet high intensity Magnetic Separation. International Symposium on fine particles processing (edited by P. Suma Sunderam) Vol. 2, AIME, New York.

Crozier, R.D., (1984): Plant Reagents, part of changing pattern in the supply and use of flotation reagents. Mining Magazine 202.

Diesters, R.J., (1987): How to determine the bond work index using Laboratory ball mill. Grindability test, Engineering and Mining Journal

Douglass A. D, (1972): Principle of Instrumental Analysis, Halt Remehart and Unison Inc. New York, pp125.

Dunkgka, G. T., (2002): Beneficiation of Toto Muro Iron Ore Deposit. M.Sc Thesis. Dept. of Metallurgical Engineering, A.B.U. Zaria.(unpublished).

Dwight, F. K., (1976): Experimental Technique with general applicability for the study of magnetic phenomena, Journal of applied physics, vol. 5 No. 1, pp 24-29.

Famuboni A.D, (1990): Sourcing of Mineral Raw Materials. The Nigerian Iron and Steel Industries. A paper delivered at the distinguished lectureship programme, department of Mineral Resources Engineering, Kaduna Polytechnic. Unpublished.

Finch J. A, and Ceroux M, (1982): Fine Sizing by Cyclosizing and micro sieve CIM Bulletin. Pp75 and pp235.

Geller L.B. and Tervo R.O. (1975): Grinding of Preheated rocks, Trans International Magazine on Minerals. Gan Publishers New York. Pp 117-182.

Geological Survey Of Nigeria(1987), Annual Report, pp 23-24.

Hoffmann C. (1992): Cannon initiation course Nigerian, Iron ore Mining Project Industrial Plant. Unpublished.

Jam S. K. (1982): Introduction to Metallurgical Analysis. Vikas publishing house. Pp 40 - 41

Kerr, P.F., (1959): Optical Mineralogy. 4th edition Mcgraw Hill Book Company, New York. Pp 17-21

Kudrin, V., (1985): Steel Making, Mir Publishers, Moscow. Pp415.

Lambert ,A.K. and Mark, T.A., (1989): Spotlight on Iron and Steel. Rourke Enterprises, vol. 2 No 3, pp 43-48.

Levin, J., (1989): Observation on Bond Standard Grindability Test and a proposal for a Standard Grindability Test for fine Particles. Journal South-African Institute of Mining and Metallurgy, vol. 1, No 5, pp 60-76.

Mathur G. P. (1983): A mineral Beneficiation Expert Terminal Report, Central Metallurgical Research and Development Institute Jos, Nigeria.

Smith, R. N., and Lee, K. H., (1968): A Comparison data from Bond type Stimulated close circuit and batch type grindability test, transaction of AIME pp 45-47.

Sroboda F. (1987): Magnetic methods for treating of minerals. Development in mineral processing. Vol.8 Elsevier Science Publishers, Amsterdam. pp 54.

Uwadiale, G. G. O. O., and Nwoke M. A. U. (1985): Journal of mineral and metallurgical processing. Volume 2, No.3 Pp 38-43.

Uwadiale, G. G. O. O., (1989): Up-grading of Nigerian Ore, Journal of Mineral and Metallurgical Processing, pp 117-123.

Wills, B.A., (1985): Mineral Processing Technology,3rd edition Pergamon Press, United Kingdom, pp 78 –90.

Yaro, S., (1998): Development of a Process Route for the Beneficiation of Mallam Ayuba Manganese Deposit. Dept. of Metallurgical Engineering, A.B.U. Zaria. Unpublished PhD Thesis, pp 23 –26.