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A SYSTEMATIC STUDY AND DESIGN OF PRODUCTION PROCESS OF ITAKPE IRON ORE FOR A PRODUCTION CAPACITY OF 1.5MT

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ABSTRACT

Before undertaking a detailed study of the processes involved in steelmaking, it is helpful to have an overview of the whole operation, so that the inter-relation of the various steps can be seen in perspective. The present study presented a systematic study and design of iron ore production process in Itakpe for 1.5mt. The study revealed that with the adoption of blast furnace method, it was possible to produced 1.5mt of steel from Itakpe iron ore. It was concluded that implementing the processes in this work will be profitable considering the economic situation of Nigeria.

Keywords: Design, Blast Furnace, Processes, metric tons, Iron Ore, Limestone, Steel Making.

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Introduction

Nigeria is a fast developing nation blessed with abundant mineral resources. With major economic development in the country, more minerals are in demand hence increasing the mining activities. Itakpe iron ore deposits in Ajaokuta, Kogi State, Nigeria, is where such mining activities are going on, and has a total estimated reserve of about 182.5 million metric tonnes. It designed to treat a minimum of 24000 tonnes of ore per day while operating for 300 days per year. The waste material from the processing is approximately 64 % which translates into 3,072 tonnes/day (Ajaka, 2004).

Itakpe iron ore deposit, with an estimated reserve of about 200 million ton, was found in 1977. The deposit is embedded in the Itakpe Hill near Okene in the north-central Kogi State of Nigeria. The deposit extends approximately 3,000 m in length and includes about 25 layers of ferruginous quartzite. From a tectonic point of view, the Itakpe deposit is confined to the southern limb of a large Itakpe-Ajabanoko anticline with enclosing rocks and conformable ore layers striking sub-latitudinally and slightly bending to the north and dipping southward at angles ranging from 40% to 80% with local minor-fold complications. The deposit contains a mixture of magnetite and hematite with ratio varying throughout the deposit. The ore consists of coarse, medium and fine grained particles. The fine ores are located mainly in the eastern part of the deposit and in thin layers, while the coarse and medium ores are relatively mixed. However, the coarse ore predominates in the north and west of the central layers while the medium one does in the centre of the central layers. The average iron content of the ore deposit was determined to be approximately 35% (Ajaka, 2004). The Itakpe iron ore deposit in Nigeria which has a total estimated reserve of about 182.5 million metric tonnes consists mainly of quartzite with magnetite and hematite (Soframines, 1987; Madu and Uyaelumuo, 2018). The deposit has been developed to supply iron ore concentrates to Ajaokuta steel plant and the Delta steel plant, Aladja, in Nigeria.

The world production of direct reduced iron (DRI) has increased from 1 million ton in 1970 to 40 million ton currently. The Midrex process has accounted for over 60% of the annual worldwide DRI production (Ola, Adewale and Usman, 2009). Steelmaking slag contains calcium oxide, magnesium oxide, silica, alumina and other compounds in smaller concentrations. Pure silica has a very high viscosity, but the addition of other metal oxides, except alumina, reduces the viscosity. The preferred characteristic for DRI grade pellets is typically 67% (minimum) Fe and 3.0% (maximum) silica + alumina + titanium oxide (Ola *et al.,* 2009)

A major determining factor in establishing an iron and steel plant is the availability of an iron ore deposit that can be economically upgraded for the intended processing route. The Itakpe iron ore deposit has been earmarked by the Federal Government of Nigeria to supply iron ore concentrate and super-concentrate for the blast furnace process at Ajaokuta and the Midrex-based direct iron reduction plant at Delta steel plant, Ovwian-Aladja respectively. The gravity concentration route currently installed at the National Iron Ore Mining Company (NIOMCO), Okene, was designed to produce iron ore concentrate for the Ajaokuta steel plant while the froth flotation route that requires imported chemical reagents was proposed to produce super-concentrate for Ovwian-Aladja. This work presents the design of a production process to produce 1.5MT of steel from Itakpe iron ore for the economy sector of Nigeria.

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Udo, Esezobor, Apeh and Afolalu (2018) investigated the factors affecting ballability of mixture iron ore concentrates and iron oxide bearing wastes in metallurgical processing. This was done by balling different volume fractions of mix containing iron oxide concentrate and IOBS using a balling disc and testing the resulting balls for green compressive strength using a universal testing machine. Their results showed that the ballability of the mixture of iron ore concentrate and IOBS increases as grain sizes of the materials reduce but increases as the moisture contents and IOBS content increase up to an optimum value of moisture content in the mix before it starts to reduce. Also the ballability increases along with the speed of the balling disc.

Itodo, Egbegbedia, Eneji and Asan (2017) researched on characterization of preliminary iron ore deposit and its tailing impact on the toxic metal level of neighboring agricultural farmland. This was done using Fourier Transform Infrared Spectrometer (FTIR), Scanning Electron Microscope (SEM) and Ultraviolet Visible (UV-Vis) spectrometer for functional group analysis, micro-structural morphology and spectral profile respectively. Physicochemical parameters were investigated following routine classical (wet) chemistry procedures. Levels of toxic metals including Iron (Fe), Lead (Pb), Manganese (Mn), Cadmium(Cd), Chromium (Cr), Zinc (Zn), Nickel (Ni) and Copper(Cu) in both ores and soils were estimated using Atomic Adsorption Spectrophotometer (AAS). Their results showed that that the mineral has possibly leached from the parent ore to the nearby soils at similar range through UV –Visible Spectral since iron ore SEM images appeared compact with irregular shapes. Also the parametric factors of the soil samples, soil quality and metal distribution among ore-rich soils showed levels that could be linked to both geogenic and anthropogenic activities.

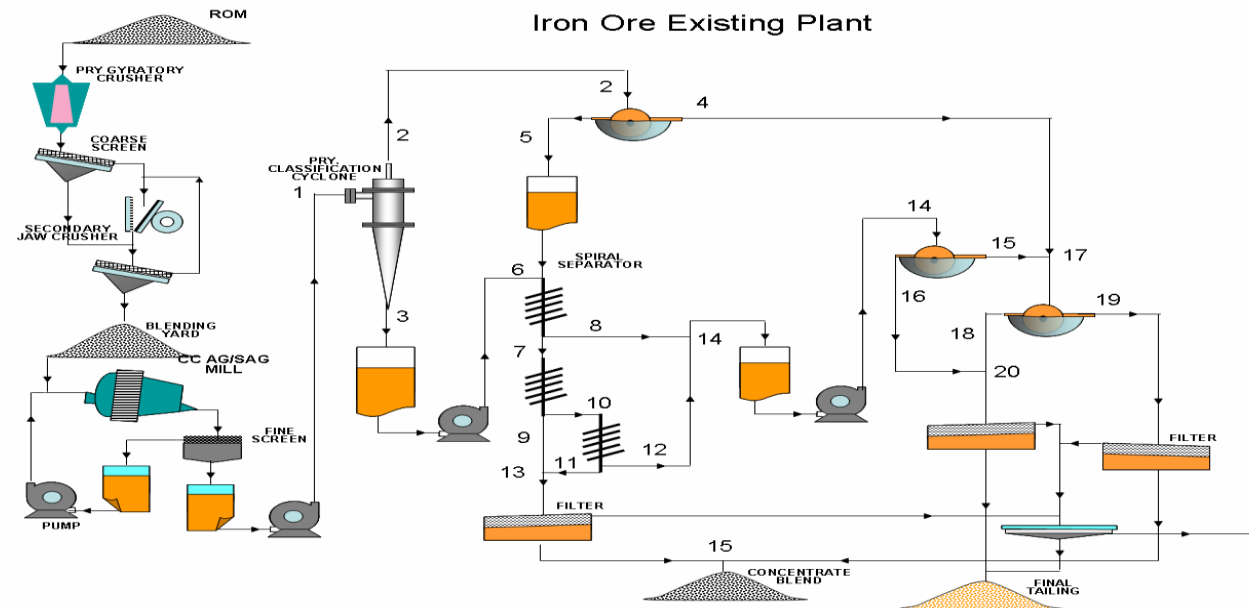

Figure 1: Simplified process flowsheet of Itakpe iron ore processing plant
Source: Ajaka (2009)

Production methods and procedures for the production of 1.5mt capacity of Iron Ore

The materials used in this work are iron ore from Itakpe, coal (which must be converted to coke), limestone, steel scrap, fluxing materials, refractory materials; and alloys and method that will be adopted is blast furnace method of iron ore extraction in production of 1.5MT of steel from Itakpe iron ore.

Reducibility Experiments: Determination of the isothermal mass-change in the range 800-100^{o}C will be carried out on 0.1- 0.2g of samples using a CI Electronic 2CT5 and electrobalance in carbon monoxide and hydrogen will recorded. Also determinations of critical gas-flow rate will examined for both gases in the CI Electronic 2CT5. Fully- reduced and partially reduced samples will also be retrieved from the CI Electronic 2CT5 for study.

X- ray diffractiin analysis: it was observed that Itakpe ore is made up of more hematite with a detectable amount of magnetite, a considerable amount of quartz and a trace of corundum.

The extraction of iron ore and refining process: Before iron ore can be used in a blast furnace, it must be extracted from the ground and partially refined to remove most of the impurities. The mined ore is crushed and sorted as mined iron ore contains lumps of varying size, the biggest being more than 1 metre (40 inches) across and the smallest about 1 millimetre (0.04 inch). The blast furnace, however, requires lumps between 7 and 25 millimetres, so the ore must be crushed to reduce the maximum particle size. The best grades of ore contain over 60% iron. Lesser grades are treated, or refined, to remove various contaminants before the ore is shipped to the blast furnace. The majority of impurities present in the ore and fuel are removed as a separate liquid product called slag. Collectively, these refining methods are called beneficiation and include further crushing, washing with water to float sand and clay away, magnetic separation, pelletizing, and sintering.

Chemical analyses of Itakpe iron ore

Table 1: Chemical analysis of Itakpe iron ore

	Itakpe (crushed)		
Element	Itakpe(As received wt%)	Dark particles (wt%)	Light particles (wt%)
Fe	59.10	66.51	5.04
Si	6.80	1.60	40.40
Al	0.38	0.66	nd
Ca	0.36	0.35	nd
Mg	0.028	0.04	0.042
Mn	0.007	nd	nd
P	Nd	nd	nd

nd= not detectable

Source: Adapted from Adedeji and Sales (1984).

The making of Iron ore using Blast Furnace Method

- **Charging the blast furnace**

Since production of iron in the blast furnace is a thermochemical process, during which the metal is reduced from its oxides by a series of chemical reactions and carburised to reduce its melting temperature, after processing, the ore is blended with other ore and goes to the blast furnace.

The raw materials charged into a blast furnace are:

- iron ore (Fe2O3 + gangue) as lump, sinter and/or pellets, according to availability;
- coke (C + ash) to provide the reducing agent (CO) and the heat necessary to melt the iron;
- minor amounts of limestone, dolomite and quartzite fluxes to control slag chemistry; and
- air (O2 + N2) to burn the coke (the air is preheated to about 1150□ C).

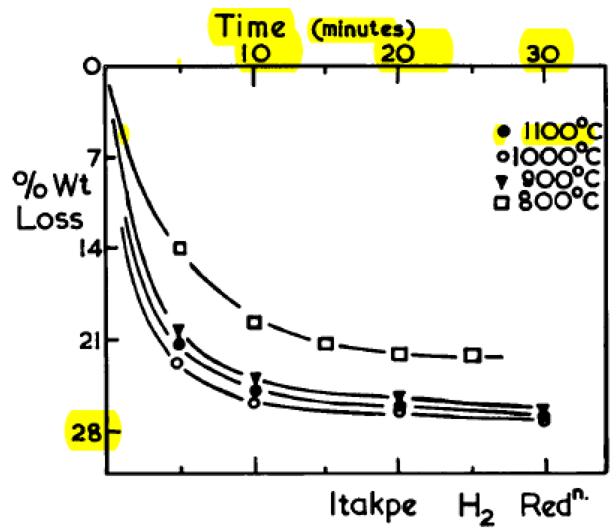

Figure 2: Isothermal mass change data foe H_2 reduction of Itakpe Ore

Source: Adapted from Adedeji and Sales (1984).

The fluxes are added, mainly as part of the sinter or pellets, to control slag chemistry, i.e., to make slag containing typically, 34% SiO2, 41 % CaO, 15% Al2O3 and 7% MgO. The gangue and ash are mainly acidic SiO2 and Al2O3 so the fluxes are primarily basic CaO and MgO.

The blast furnace is a countercurrent heat and oxygen exchanger in which rising combustion gas loses most of its heat on the way up, leaving the furnace at a temperature of about 200° C (390° F), while descending iron oxides are wholly converted to metallic iron.

A blast furnace is a tower-shaped structure, made of steel, and lined with refractory or heat-resistant bricks. The mixture of raw material, or charge, enters at the top of the blast furnace. At the bottom of the furnace, very hot air is blown, or blasted, in through nozzles called tuyeres. The coke burns in the presence of the hot air. The oxygen in the air reacts with the carbon in the coke to form carbon monoxide. The carbon monoxide then reacts with the iron ore to form carbon dioxide and pure iron.

The melted iron sinks to the bottom of the furnace. The limestone combines with the rock and other impurities in the ore to form a slag which is lighter than the iron and floats on top. As the volume of the charge is reduced, more is continually added at the top of the furnace. The iron and slag are drawn off separately from the bottom of the furnace. The melted iron might go to a further alloying process, or might be cast into ingots called pigs. The slag is carried away for disposal.

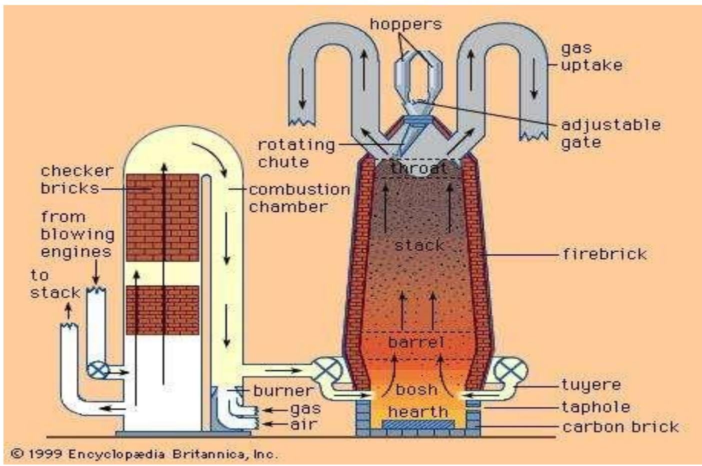

Figure 3: Schematic diagram of modern blast furnace (right) and hot-blast stove.
Source: Encyclopædia Britannica (2016).

- **Chemical Reactions**

The basic reactions that control the iron rnaking processes are relatively few and simple. They are the reactions between carbon, oxygen, iron and its oxides, and those that lead to the formation of slag.

- **Reactions of carbon**

The oxygen in the blast reacts with the incandescent carbon (coke) to produce very high temperatures:

$$C + O_2 \longrightarrow CO2$$

The incandescent carbon rapidly reduces the CO_2, thus: $C + CO_2 \longrightarrow 2CO$

The first reaction is highly "exothermic" (heat releasing); and the second, which mildly absorbs heat, is called "endothermic".
The great quantities of heat released by carbon reactions melt the burden materials (except the coke itself) in the melting zone of the furnace. Coke is the only charge material which retains its solid structure while passing through the furnace. The coke thus provides the necessary porosity in the hearth and melting zone as liquid slag and iron are formed, refined and drained away.

- **Reactions involving iron**

Reaction 1. At 400-700°C: Fe_2O_3+ CO 2FeO + CO_2
Reaction 2. At 700-1000°c: FeO +CO Fe + CO_2
Reaction 3. At 1000-1400°C: FeO + C Fe + CO
Reaction 4. At 1400-1450°C: Fe melts as it dissolves carbon.

Carbon monoxide is the main reducing agent but, at temperatures of above l000C, the resultantCO2 reacts with the coke to produce more CO, so the FeO appears to react directly with the C, (reaction 3).

Hydrogen (H_2), from the moisture (steam) in the hot blast and from supplementary fuels, behaves similarly to CO. The fully reduced iron can only become molten after it absorbs carbon, and so the final reduction/carburisation in the melting zone is extremely complex.

- **Slag formation**

In modern practice, the great majority of flux is introduced through sinter as calcined CaO. Note that, when present, MgO reacts similarly throughout. Any lump limestone added with the burden decomposes rapidly and the decomposition is normally completed at l000°C. The reaction
$CaCO_3 \longrightarrow CaO + CO_2$ is highly endothermic. It is much preferable for this reaction to occur elsewhere than in the furnace bosh.

The resultant CaO enters the fusion zone and combines with silica (SiO_2) and alumina (Al_2O_3) to form a liquid slag. The most significant properties of the slag are its melting point and fluidity (so that it can be removed from the furnace easily) and its basicity (the ratio of basic oxides, mainly CaO, to acid oxides, mainly SiO_2), which determines its chemical affinity for sulphur, silicon and manganese.

- **Other reactions**

The percentage of silicon and sulphur in the molten iron can be controlled to a certain degree by the furnace operators. The percentages of phosphorus and manganese, however, are dependent on the composition of the raw materials.

The total silica load, temperature in the furnace hearth, and composition of slag, control the amount of silicon which will be dissolved in the iron. High hearth temperatures, high silica and low basicity slag tends to increase the silicon content of the product, since more of this element can be reduced. Sulphur readily combines with iron and can only be removed by contact with a basic slag in the presence of carbon at the high temperature of the hearth.

$$FeS + CaO + C \longrightarrow CaS + Fe + CO$$

All of the oxides of phosphorus in the raw materials are reduced and the resultant phosphorus dissolves in the iron.

$$P2O5 + 5C \longrightarrow 2P + 5CO$$

About 60% of the manganese oxide in the charge will be reduced and enter the iron; the slag takes up the remainder in the form of dissolved MnO.

By-Products

- **Slag**

At the blast furnace, slag is run off in an adjacent pit, poured into ladles for transfer to a slag dump ("rock slag"), or granulated by rapid cooling with a high velocity water stream. The slag contains the impurities in the raw materials. Liquid slag is immiscible (cannot be mixed) with liquid iron and floats on its surface. Control of slag chemistry is complex, and in many respects, slag properties control furnace efficiency. Rock slag is allowed to cool and is then broken up and crushed into various sizes for reclamation, road-making, bitumen sealing materials, and for manufacture of insulating material. A significant proportion of slag is granulated. The resulting material has a self-cementing tendency, and the finely ground portion may be added to cement to produce a concrete of lengthened durability. It has also been used as a high quality road base and soil enhancer.

- **Gas**

Another product of the blast furnace operation is gas which is extracted from the top of the furnace. It has the following composition:

CO_2 22% H_2 5%
CO 22% N_2 51%

Its calorific value is about 3.4 MJ/m3. As the gas passes through the furnace it carries with it small particles of solid raw materials, which then have to be removed. This is done sequentially in dust catchers, scrubbers and electrostatic precipitators, cleaning the gas thoroughly. The flue dust, because of its high iron content, is collected and recycled as a feed for the making of sinter.

The gas is used as a fuel. It is this ongoing use of the products and by-products of a plant which gives it the term 'integrated steelworks'.

Conclusion

The results obtained from this work showed that with careful design, it is possible to design a production process that will produce 1.5MT of steel from Itakpe iron ore since Itakpe iron ore contains about 60% of iron with silica as the major impurity. It is also known from the view point of standard mineral processing plant practice that the profit accruable from this design will far outweigh the cost of imported ore. Considering the present economic condition in Nigeria, production cost of 1.5MT of steel will be lower than the same in the use of imported one. Hence, it can be concluded that implementing the processes tested in this work will be profitable.

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