Beneficiation of Iron Ore in Kishushe for the Steel Manufacturing Plant

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Abstract: Beneficiation is a variety of processes whereby extracted ore from mine is reduced to particles that can be separated into mineral and gangue/waste. The beneficiation process improves the physical or chemical properties of the ore so that the metal may be recovered profitably. Beneficiation involves milling (crushing and grinding), washing, filtration, sorting, sizing, gravity concentration, magnetic separation, flotation, and agglomeration (pelletizing, sintering, briquetting, or nodulizing).

Keywords: Beneficiation, iron ore, sintering, pelletizing, agglomeration, BIFs, smelting.

I. INTRODUCTION
Following the discovery of rich iron ore deposits in certain parts of the country, the prospects of Kenya setting up her first iron & steel manufacturing plant have increased. It is envisaged that the creation of an iron & steel industry in Kenya will contribute to the enhancement of economic progress, social cohesion and political stability in line with the aspirations of vision 2030.

A. Problem Statement
In the absence of a smelting plant, Wanjala Mining Co. Ltd exports overseas for smelting and manufacturing into steel products. The form in which it’s traded could be enhanced through beneficiation of the iron ore in order to fetch a higher economic value.

B. Objectives of the Project:
To come up with techniques on how iron ore can be beneficiated and processed into pure metallic iron, and consequently evaluate and recommend the best route for the iron ore in Kishushe. It also highlights impurities contained in processing of ore, cost effectiveness and minimum environmental disturbance.

C. Geology and occurrence of Iron Ore
Hematite deposits are mostly sedimentary in origin, such as the BIFs Magnetite is also mostly found in Banded iron formations (BIF). They are fine grained metamorphosed sedimentary rocks composed predominantly of magnetite and silica. BIFs are metamorphosed sedimentary rocks composed predominantly of thinly bedded iron minerals and silica (as quartz).

II. METHODOLOGY
A. Methodological review of mining and processing methods used at Wanjala Mining Co. Ltd
The mined out reef material is loaded into the ore bin and passes through a grizzly screen before the milling process begins in the primary Jaw crusher to a product of 100mm and below. A Havells vibrating screen is used to separate the crushed material; Sizes <10mm and 10-60mm are conveyed to different conveyors and stocked in different piles, > 60mm is then conveyed and subjected to ne Symsons crusher secondary crushing using co until the right size of < 60mm is attained. Next, it is passed through a series of horizontal magnetic separators where it is separated into magnetic and non-magnetic material and heaped separately.

The alluvial material is mined through a combination of an excavator and a mobile screen; a Novum Keestrack. The Novum Keestrack separates the material using a 2-decked screen into particles >60mm which are loaded into a waiting truck, the material between 60-2mm falls into the middle deck and loaded into a different truck. The material <2mm which is comprised mainly of soil and dust; is dumped at the mined spot. The material >60mm is subjected to hand picking and taken for crushing. The rest of which is between 2-60mm is taken to a screening unit where it is separated in 3 categories: - >30mm, 30-4mm and <4mm which is treated as waste. The particles of size between 30-4mm are taken through magnetic separators. The magnetic ones are heaped on one side, separate from the non-magnetic ones which are treated as waste. Ore particles >30mm are mixed with the reef material that has been reduced to <60mm and heaped together.

B. Beneficiation processes proposed
Grinding: This step is not carried out in the present operations at the plant in Wanjala mine plant. Grinding is
required so as to further reduce the ore particles to the consistency of fine powder (325 mesh, 0.0017 inches). A semi-autogenous wet grinding operation involving a rod mill and a ball mill is recommended. Ball mill is better suited for fine grinding than rod mills as balls have a greater surface area than rods. Regrind ball mill is used for grinding the middling from the flotation cells (Barry A. Wills, 2006). A hydrocyclone is to be used to classify coarse and fine particles. Coarse particles (material above 150 mesh) emerge as the underflow and are taken to the ball mill for further size reduction. The overflow (fine particles) is taken to floatation cells.

**Magnetic Separation:** The recommended process is the high intensity wet separation method. High intensity separators employ fields as strong as 20,000 gauss. High intensity wet separators produce high magnetic field gradients by using a matrix of shaped iron pieces that act as collection sites for paramagnetic particles. These shapes may include balls, rods, grooved plates, expanded metal, and fibers. The material after grinding in the rod mill is taken through a 2-drum magnetic separator (Barry A. Wills, 2006).

**Flotation Process:** The next step after magnetic separation is flotation. Flotation is primarily used to upgrade concentrates resulting from magnetic separation. Chemical reagents of three main groups are used in flotation. These include:

1. **Collector/Amines**—cause adherence between solid particles and air bubbles in a flotation cell. Iron ore uses collectors such as amines, oleates, Sulphanates, or Sulphates.
2. **Frothers**—are used to stabilize air bubbles by reducing surface tension, thus allowing collection of valuable material by skimming from the top of the cell.
3. **Antifoams**—react with particle surfaces in the flotation cell to keep materials from remaining in the froth. Instead, materials fall to the bottom as tailings [1].

**Thickening and Filtration:** This step is used to remove most of the liquid from slurried concentrates and waste slurries (tailings). Thickening techniques may be employed in two phases of iron ore production:

1. Concentrates are thickened to reduce moisture content and reclaim water before agglomeration, and
2. Slurried tailings are thickened to reclaim water.

When concentrates are being thickened, underflow from the thickener (concentrate) is collected and may be further treated in a vacuum filter. The filter removes most of the remaining water from the concentrate. Filtration is the process of separating solids from liquid by means of a porous medium which retains the solids but allows the liquid to pass [1].

**The rotary drum filter:** The drum is mounted horizontally and is partially submerged in the filter trough into which the slurry is fed and maintained in suspension by agitators. The periphery of the drum is divided into compartments each of which is provided with a number of drain lines, which pass through the inside of the drum, terminating at one end as a ring of ports which are covered by a rotary valve to which vacuum is applied [1]. The filter medium is wrapped tightly round the drum surface which is rotated at low speed, usually 0.1-0.3 rev min⁻¹.

**Pelletizing:** operations produce a "green" (moist and unfired) pellet or ball, which is then hardened through heat treatment. These pellets are normally relatively large (3/8 to 1/2 inch) and usually contain at least 60 percent iron, see Fig. 1 below. Pelletizing turns very fine-grained iron ore into balls of a certain diameter, also known as pellets, which are suitable for blast furnace and direct reduction. Pellet plants can be located at mines, near harbors or be attached to steel mills. Equipped with advanced environmental technology, they are almost pollution-free, generating no solid or liquid residues.

### C. Steps in pelletizing iron concentrates.

**Raw material preparation**—Prior to the formation of green pellets, water is added to the fine iron ore to adjust the moisture content to approximately 9% and the ore is mixed with small amounts of binding agents such as betonies (approximately 0.5%) and fluxes such as limestone, olivine and dolomite (1–5%). These give the pellets the proper physical and metallurgical properties needed in further processing. Mixing takes place in continuously operating drum pan-type mixers with a capacity of 450–700 t/h.

**Forming the green pellets**—This is usually accomplished in a series of balling drums or discs. The pellets are formed by the rotating of the drums, which act to roll the concentrate into pellets. One of three different systems may then be used to produce hardened pellets: Travelling-Grate, Shaft-Furnace, Grate-Kiln

**Pellet hardening**—Since green pellets have low mechanical strength, they need to be hardened for the processes. The Travelling grate carries the green pellets on a bed 30–50 cm thick through a furnace with updraft drying, downdraft drying, preheating, and firing, after firing and cooling zones.
D. Iron Smelting.

Blast furnaces are tall and roughly cylindrical and are most often used for melting iron and ferro alloys as shown in Fig.2 below. Alternating layers of metal and ferro alloys, coke, and limestone are fed into the furnace from the top. Coke makes up 8 - 16% of the total charge to provide the heat that melts the metal [2].

Limestone or other fluxes may be added to react with and remove the acidic impurities, called slag, from the molten iron. The limestone-impurities mixtures float to the top of the molten iron and are skimmed off after melting[3].

Sintering products may also be added to the furnace. Sintering is a process in which solid wastes are combined into a porous mass that can then be added to the blast furnace. These wastes include iron ore fines, pollution control dust, coke breeze, water treatment plant sludge, and flux. Sintering plants help reduce solid waste by combusting waste products and capturing trace iron present in the mixture. Sintering plants are not used at all steel production plants.

(i) Reduction of iron oxides using coke:
\[ 2 \text{C}(s) + \text{O}_2(g) \rightarrow 2 \text{CO}(g) \]
\[ \text{Fe}_2\text{O}_3(s) + 3\text{CO}(g) \rightarrow 2 \text{Fe}(s) + 3\text{CO}_2(g) \]
\[ 2 \text{Fe}_2\text{O}_3(s) + 3 \text{C}(s) \rightarrow 4 \text{Fe}(s) + 3\text{CO}_2(g) \]

(ii) Introduction of limestone:
The furnace temperature is also high enough to decompose limestone into calcium oxide:
\[ \text{CaCO}_3(s) \rightarrow \text{CaO}(s) + \text{CO}_2(g) \]

This oxide helps to melt and remove some of the acidic impurities such as silicates from the ore as shown below:
Calcium oxide + Silica \( \rightarrow \) Calcium silicate
\[ \text{CaO}(s) + \text{SiO}_2(s) \rightarrow \text{CaSiO}_3(l) \]
The impurities to be removed react with calcium oxide to make a liquid slag that floats on top of the molten iron. The slag is collected after the denser iron has been run out of a tap hole near the bottom of the furnace.

E. Waste and Pollution Management

The following are various wastes and pollution that arise in each of the beneficiation stage and ways to curb it as highlighted below:

A Milling Dust Control Materials: mills use a wet milling operation and employ water to control dust from crushing and grinding. Slurried value-bearing process water from dust control contains both suspended and dissolved solids. The solid content of the slurry varies with each operation, ranging between 30 and 60 percent. The dust control slurry is typically pumped to a ball mill overflow/ hydrocyclone feed sump for further beneficiation[4].

B Magnetic Separation Wastes and Materials: The primary wastes from magnetic separation (either wet or dry operations) are tailings made up of gangue in the form of coarse- and fine-
grained particles, and waste water slurry in the case of wet separation. Particulate wastes from dry separation may also be slurred. Following separation of solids in a thickener or settling pond, solids are sent to a tailings impoundment and most of the liquid component can be recycled to the mill or discharged if water quality criteria are met.

C Flotation Wastes and Materials: Discharge from a typical flotation cell system is made up of 25 to 50 percent solids, mostly gangue material and small quantities of unrecovered iron minerals. The liquid component of flotation waste is usually water, along with any remaining reagents not consumed in the flotation process. Most operations send these wastes to tailings dams where solids settle out of the suspension. The liquid component may then be used in other mining activities as needed or discharged if water quality criteria are met.

D Gravity Concentration Wastes and Materials: Waste from gravity concentration is mainly tailings (made up of coarse- and fine-grained particles and process water). These tailings are pumped as slurry to a tailings dam. The solid content of the slurry varies with each operation, ranging between 30 and 60 percent. Following the separation of solids, process water may be recycled to the mill or discharged if water quality criteria are met.

E Agglomeration Wastes and Materials: The agglomeration process may generate carbon dioxide, sulfur compounds, chlorides, and fluorides, which are driven off during the pellet production process. Large amounts of dust, containing metals and other ore and additive constituents, may also be generated. These wastes are usually collected using cyclones, electrostatic precipitators, and scrubbing equipment and create both dry and slurry forms of waste [4].

F Pollution Sources and Prevention for Coke-making: Coke production is one of the major pollution sources from steel production. Air emissions such as coke oven gas, naphthalene, ammonium compounds, crude light oil, sulfur and coke dust are released from coke ovens [4]. Emissions control equipment can be used to capture some of the gases as they escape into the atmosphere. Some of the heat can be captured for reuse in other heating processes. Pollution associated with coke production is best reduced by decreasing the amount of coke used in the iron melting process. The smaller the volume of coke produced, the smaller the volume of air and water emissions. It is the surest method that can be economically sustained.

G Water pollution: Quenching water becomes contaminated with coke breezes and other compounds. While the volume of contaminated water can be great, quenching water is fairly easy to reuse. Coke breezes and other solids can usually be removed by filtration. The resulting water can be reused in other manufacturing processes or released.

F. Environmental Effects of Iron Ore Processing

- Loss of landscape due to size of land needed to set up of pant.
- Noise.
- Atmospheric pollution due from the various stages of extraction: Co₂ – Green house effect; Co – Poisonous; So₂ from the sulphur content of iron – Poisonous and acid rain
- Disposal of slag – Land degradation.
- Iron making uses up a large amount of coal for production of coke needed during the reduction process. The chemical by products of coking are toxic.

III. CONCLUSION & RECOMMENDATIONS

1. The ore from the mine; both alluvial and reef material will be subjected to milling. The reef material starts from the jaw crusher, while the reef material which is >60mm is taken directly to the secondary crusher.
2. Screening of the alluvial material at the screening plant should be maintained, but as opposed to the current practice where the material <4mm is treated as waste, these material should be stocked separately for blending purposes.
3. The mobile screen should still be used while extracting the alluvial ore since the screening eliminates most of the soil and dust that would be a nuisance in the plant.
4. A jaw crusher although already in use is recommended for the primary crusher. The discharge capacity of the current one is 150 tons/hr which is sufficient for production of iron to supply a local steel plant. The crushing should be a dry process.
5. A cone crusher is recommended for the secondary crushing still to be done under dry condition. This is also already in use.
6. A rod mill with a capacity of 200 ton/ hr should be introduced for wet grinding. The reason it should be of a higher capacity is because it should be able to handle all the crushed material without causing a jam. (industries)
7. High intensity wet magnetic separation will be a dominant process used; after the rod mill using a 2-drum magnetic separator, after the ball mill, and then just before and after flotation. This method is capable of separating weakly magnetic iron minerals, such as hematite from less magnetic gangue.
8. A ball mill is recommended for further grinding of the coarse particles.
9. Between the grinding operations in the rod mill and the ball mill, a hydrocyclone should be used to classify the coarse and fine particles.

10. The fine particles from the hydrocyclone should then be taken to the flotation cells after going through the conditioning tanks where collectors, frothers and depressants are added.

11. The following chemical reagents have been recommended for the flotation process: ether amine for the collector, oil grades or cassava starch for froth inhibitor, starches for iron oxides depressant and caustic soda or magadi soda for PH modifier.

12. The flotation cells will include the rougher, scavenger, cleaner cells and regrind cells. The slurry moves from the rougher cells to the scavenger cells as values are removed, which are then sent to cleaner cells to produce the final iron-bearing metallic mineral concentrate.

13. The next stage should be thickening and filtration. The thickener is used to increase the concentration of the suspension by sedimentation, accompanied by the formation of a clear liquid. The filter removes most of the remaining water from the concentrate.

14. The liquid from the above process should be recycled to a holding pond or dam to be reused at the mill. The thickened tailings are discharged to a tailings impoundment.

15. The thickened final concentrate is taken for agglomeration and processing.

16. The recommended type of agglomeration is pelletizing in a grate-kiln. Its main advantage is that the heated gas discharge from the kiln is recycled for drying and pre-heating.

17. Blast furnace/smelting in a copula furnace is recommended for the final processing of the iron ore. The furnace can also use scrap metal.

ACKNOWLEDGEMENT:
I dedicate this work also to Caren (Bsc. Biotechnology, JKUAT) Mr. Kaburu Sanghani, RK Sanghani and Wanjala Mining Co. Ltd.

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