International Journal of Modern Engineering Research (IJMER)
www.ijmer.com Vol. 3, Issue. 6, Nov - Dec. 2013 pp-3733-3739 ISSN: 2249-6645

Environmental Issues of the Ajaokuta Steel Complex in Nigeria

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ABSTRACT: *The aim of this article is to analyse the various industrial processes in the Ajaokuta and the waste products each produces, with the view to highlighting some conservation measures that will enhance the environmental management plan of the Ajaokuta steel complex. A background information was provided on the general production system of steel, was provided, before a detailed description of major plants in the complex that produce environmental wastes, these included Sintering Plant, Cake Oven, Blast Furnance, Iron and steel making plants, Rolling Mills and the Thermal Power Plant. Pollution inventory of these were made and its highlights revealed that the Cake oven and Sinter plants are highly polluting, while the Electric Arc Furnanace (EAF) and Electric Induction Furnanace (EIF) plants that use scrap and DRI are relatively less polluting due to lower scales of operation and the nature of the feedstock being used in the Ajaokuta complex. Generally the air pollutants most visible are those of particulate matter, oxides of sulphur and nitrogen. Some corrective measures were proposed including the introduction of emission control technologies like scrubbers, bag filters and electro static precipitators. Water quantity and quality measures were also recommended in order to reduce water use from the existing 15m^3/tcs to less than 5m^3/tcs. Similarly the existing volume of solid waste being generated by the processes inventoried at 600 to 800kg per ton of steel and adequate measures were recommended in order to reduce it to the global average of 400 to 500 kg per ton of steel.*

Keywords*: Environment, Steel, Ajaokuta, Pollutants, Emission, Sludge*

I. INTRODUCTION

Steel as a finished product may be one of the most environment friendly products used in our daily life, owing to its excellent mechanical properties, versatility and its recyclability. Today steel usage also ranges from the ordinary household items to the complex construction and defence equipments. However, the process of steel making itself is highly energy and fossil fuel‘ intensive and therefore the cause of environmental concerns across the world. In fact, the manufacturing process involves a myriad operations which may contribute to three basic sources of pollution i.e., of Air via volumes of emissions by the plants, of water via liquid effluents discharged and of soil via disposal of solid wastes.

Steel can be defined as an alloy of iron and carbon. The carbon in steel varies from 0.04 – 1.7%. By nature of the raw materials and method of producing steel, all steels contain varying amounts of sulphur, manganese, phosphorus and traces of other elements. When other elements are added to the steel, such as chromium, cobalt, or nickel, the steel becomes an alloy steel (Agba 2006; DCM 2012;AISi 2005). Steel making may therefore be defined as the production of an extensive series of complex alloys of iron, carbon and other elements. There are many processes for making steel which had developed over time with the production of iron bloom or sponge iron, to wrought iron and to higher quality steel produced in through the crucible technique (Oyebanji and Oluwale, 1988; Banergee 2002). The crucible technique is a system that allowed broken ingots of bloom to be heated in crucibles for long period of time.

There are basically two methods of steel production which are the Basic Oxygen Furnace/Blast Furnace (BOF/BF) and the Electric Arc Furnace/Direct Reduction (EAF/DR). For the purpose of this article, the process of steel making using the Basic Oxygen Furnace/Blast Furnace (BOF/BF) method will be discussed because that is the method that was designed for the Ajaokuta Steel Plant. The work therefore focuses on the process of making steel, the structure and operation of the Ajaokuta Complex, It went further to discuss the various units of the plant and the impact of the industry on Air and water quality as well as on solid waste generation and the impacts on the immediate environment and the carbon foot print in general.

II. OVERVIEW OF STEEL PRODUCTION SYSTEMS

Steelmaking in integrated plants is a complex of at least five industrial units related vertically to each other which are referred to as the primary plants. There are also a number of supportive facilities not directly involved in the production of steel but which are essential to the plant’s operations. These supportive facilities are referred to as the secondary plants. A typical steel plant makes use of four basic raw materials, namely: coal, iron ore, fluxes and scrap. It also makes use of a number of other essential inputs like refractories, water and electric power. (Sato, 2009; AGM 2012; Deshpande 2008)

The first stage in steel production begins with good quality coal or coking coal being fed into the coke ovens, which is the first major unit of a steel plant. In addition to the coke produced from the coke ovens, important by-products such as coal tar and coke oven gas are also produced which may be sold or used as fuel by the plant itself. The second stage is the preparation of iron ore concentrates, limestone combined with the processed coke and fed into the Blast Furnace which is the second major unit of a steel plant. The blast furnace produces molten iron either by smelting lump ore or artificial iron bearing materials such as sinter and pellets. The Coke serves as a reducing agent, its carbon forms a chemical union with the oxygen in ore. Fluxes are a third essential input of the blast furnace. It facilitates the separation of metal from impurities in iron ore. The most commonly used fluxes are limestone and dolomite. The desired combination of iron bearing materials, coke and fluxes is known as the *charge*.

The third stage is the transfer of the principal product of the blast furnace which is hot metal to the iron making shop which is the third major unit. The hot metal will then be cast into pig iron and sold. It could also be formed and molded into several shapes of iron depending on the future use of such iron. Some steel making plants by passes this stage with the recent technology and transports the hot metal directly to the steel melt shop which is the fourth major unit of a steel plant.

The steel melt shop as earlier stated is the fourth stage of a steel plant. It receives hot metal or pig iron and adjusts the composition of carbon and other impurities to form steel. A most important part of any steel plant that uses the blast furnace method of production is the converter. This is usually a pear-like shaped vessel with a spherical bottom, cylindrical middle portion and a conical top. It is lined in the interior with basic refractories usually tar-bonded unburnt dolomite, magnesite, and magnesite - chromite bricks. The converter is solely used to effect the conversion of molten pig iron into steel without the use of fuel for heating the metal. This is achieved by blowing a current of air (oxygen or other gaseous matter capable of evolving oxygen) to the molten pig iron contained in the converter.

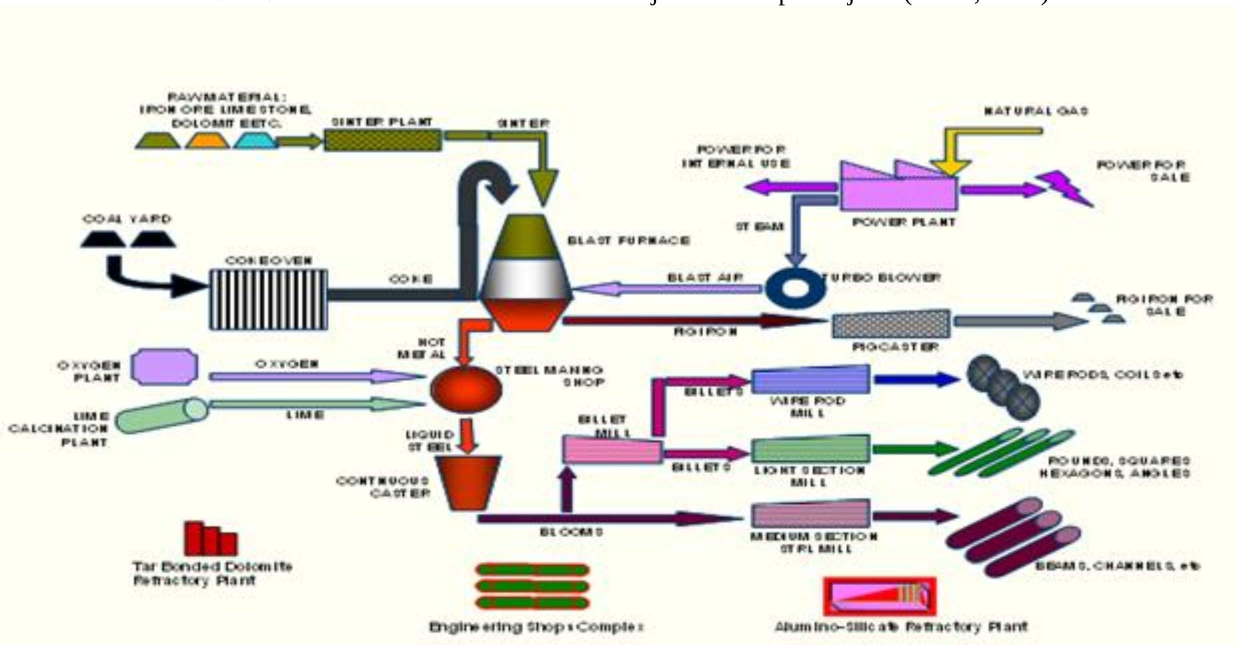
The fifth stage is the movement of the steel produced in the steel melt shop to the fifth major unit of an integrated steel plant which are the rolling mills. Only a relatively small amount of additional rolling is necessary to produce bars, structurals, rails and plates. To produce sheets, slabs may first be rolled into strips, then, finished in a cold rolling mill, and in some plants, galvanized, tinned, or corrugated. It is germane to note that steelmaking has had a long history that included constant improvements in the techniques of making and using steel products.

III. THE AJAOKUTA STEEL PLANT

The Ajaokuta Steel Project was designed to produce long products like iron bars, wire rods, angles, squares, channels, beams, and structures in its first phase. Most of the products were expected to be used in the civil engineering and construction industry. The structure and operation of the Ajaokuta steel plant has no spectacular difference with other steel plants around the world using the blast furnace method of steel production. The primary and secondary plants of Ajaokuta steel plant have reached about 98% stage of completion.

The Ajaokuta Integrated Iron and Steel plant is based on the Blast Furnace /Basic Oxygen Furnace (BF-BOF) process of iron making. This process, often referred to as the conventional method has been acknowledged by steel experts to be the most versatile means of producing crude steel. The method accounted for over 70% of steel production in the world. The Ajaokuta Steel Plant has a raw materials preparation unit, a sintering plant, Coke-oven unit, the iron making plant, steel making plant and the rolling mills known as the primary plants. The Ajaokuta steel was built in its conception with four rolling mills. These are 150mm Wire Rod Mill, 320mm Light Section and Bar Mill, 700mm Medium Section and Structural Mill and 900/630 semi-continuous Billet Mill.[20] Two of these mills, the light section and Wire Rod mills were originally supposed to be the priority rolling mills. This meant that these priority rolling mills was accorded accelerated speed in their construction so as to produce steel with imported billets and scraps while the blast furnace and other components of the steel plant were on going. These priority mills were actually completed and commissioned between 1983 and early 1994 and production started with imported billets (Agbu, 2006, Audu 1992; Easter et al 2009)

FIG 1: AJAOKUTA STEEL PLANT PROCESS CHART
Source: Initiative for the actualization of Ajaokuta/Itakpe Projects (IAAP, 2011)



3.1 RAW MATERIALS PREPARATION UNIT:

This is the unit of the Steel Project that is responsible for the handling of unprocessed or partially processed material used as inputs for processing operation. This unit receives about 2.135 million tons of iron ore in concentrated form annually. Other raw inputs handled by this unit includes coking coal which is about 1.32 million tons in a year, limestone whose supply is about 669 million tons in a year. The unit also receives 250 million tons of dolomite and 85 million tons of manganese ore annually. This unit over time especially in the early 1980's received some of these raw materials but not up to half of the expected capacity due to the non completion of the blast furnace and other infrastructural facilities like the warri – Portharcourt- Onne railroad.

3.2 SINTERING PLANT AND COKE OVEN UNIT:

The Sintering Plant comprises of a sinter machine with a sintering area of $360m^2$ & one straight cooler having cooling area of $420m^{2,}$ The capacity of the plant is 600 t/h of sinter. The sintering plant removes some of the impurities of artificial iron bearing materials such as sinter and pellets.
The coke oven unit is a rectangular shaped room of about 10-15 meters long, 3-7 meters in height and a volume of 30.3 cubic meters. It is closed at each end by a removable cast iron or steel door. This unit primarily handles the blending of coking coals. The unit is built in such a flexible manner that it is able to blend coking coals from different local and external sources. (Ajasteel, 1981, Audu 1992; Halliday et al 2009)

3.3 BLAST FURNACE AND IRON MAKING PLANT:

The blast furnace has been regarded as the heart of the steel plant. Ajaokuta has a proposal for two blast furnaces in the first phase. The construction of the blast furnaces began in 1982 and by 1987, one of the furnaces was 100% completed, the other is about 15% complete as at 1994 when the Soviet company, TPE's contract was determined. A single blast furnace has a capacity of 2000 cubic meters capable of producing 1.35 million tons of hot metal annually. This furnace is designed to function under high pressure. About 1.2 million tons of molted iron are expected to be produced in a year and passed to the steel making shop for further processing while about 150,000 tons of molted iron remaining in the iron making plant are cast in the pig casting machine for the provision of pig iron used in local foundries. It should be noted that the blast furnace has never been put to use since its construction because according to the Assistant General Manager, Blast Furnace, if the blast furnace is lit, it cannot be put off until after ten years. The implication is that, the blast furnace will be working twenty four hours producing hot metals which Ajaokuta steel plant has not made adequate preparation for. But with the completion of the steel project, and all units working, the availability of raw material that can sustain the blast furnace, the blast furnace will be put to maximum use.

The iron making plant is one of the principal units of the Ajaokuta Steel Project. It is essentially a vertical cylindrical steel shell. It has an average height of 33 meters and a diameter of 8.4 meters. The shell acts as a container through which iron ore descends and 90% of these iron ore is reduced to pig iron through the blast furnace process of iron making.

3.4 Steel Making Unit And Rolling Mills:

This is often called the steel making shop. It is the place where various processes for steel making from pig iron take place. The unit is of two top blown oxygen converters of 135 tons each. The converters require rich oxygen injection for the refinement of hot metal to steel. The major products of this unit are blooms which are sent to the rolling mills within the plant.

Rolling mills is the unit in which the iron product is fed past spring loaded rollers that apply force against the side of a revolving bowl. It is actually a grinding mill. This unit consists of the wire rod mill (WRM), the billet mill (BM), the medium section and structural mill (MSSM) and the light section mill (LSM). The wire rod mill has the capacity of producing 130,000 tons of wire rod coils with 5,000 tons of scrap sent to the scrap processing unit annually.( )

The billet mill has the capacity of producing 295 million tons of saleable billets. 150,000 tons of billets used in the medium section and structural mill and 40,000 tons of scrap for the scrap processing unit. The medium section and structural mill has the capacity of producing about 560,000 tons of medium section and structural steel and 65,000 tons of scrap for use in the scrap processing unit. The light section mill has the capacity of producing about 400,000 tons of scrap that is sent to the scrap processing unit.

3.5 The Thermal Power Plant

The Thermal Power Plant (TPP) which is a Captive Power Plant has two turbo-generators of 55MW each with a full capacity of 110MW. It supplies electricity to the steel plant and the steel township. The Steel plant cannot do without constant power supply due to the equipments which needs cooling to maintain its lifespan. The blast furnace uses electricity and as earlier discussed, if lit, it will remain on for about ten years and it needs this power to keep it on. The Ajaokuta Steel Plant cannot exhaust the 110 MW produced. It actually consumes about 65MW. At a time, the excess was sold to the national grid but due to non maintenance and lack of gas, the plants do not supply to the national grid any longer. (Sato, 2009, Ajasteel 1983; IAAP,2011)

IV. Environmental Issues And Solution In The Ajoakuta Plant

As already mentioned the manufacture of steel from ore involves a large number of operations covering large scale usage of mineral resources and high levels of energy consumption. While the large integrated steel plants based on the BF-BOF route (with associated coke ovens & sinter plants) are highly polluting, the EAF and EIF route using scrap and DRI are relatively less polluting due to lower scales of operations. The coal based DRI of the Ajaokuta complex units also are often criticized for not adopting/operating pollution control facilities. The environmental issues associated with the Ajaokuta complex can be treated under the following topics;

4.1 Air Environment:

The environmental concern with respect to air pollution by the industry arises mainly due to particulate emissions (dust) from process and non process operations. The emissions of volatile matter associated with coke oven and dioxins from sinter plant operations also have serious health implications. Other gaseous pollutants like oxides of sulphur and nitrogen are another cause of worry wherever the Integrated Steel plants are large and are located in the vicinity of large thermal power plants as the in the case of Ajaokuta complex.

The specific emissions of air pollutants like dust, oxides of sulphur and nitrogen in the steel plants are still above 1.0 kg per ton of steel as compared to less than 0.5 kg per ton of steel in developed countries. A substantial reduction in specific air emissions may be possible with introduction of larger capacity units like sinter plants, blast furnaces, taller coke ovens, increased size of steel converter etc, by reducing the number of process operations. But given the very high operational costs linked to air pollution control, the introduction of state of the art pollution control facilities in smaller units, though technically feasible, may not be economically viable to the Ajaokuta Industry. There is a need to limit the capacity of the processing units to a threshold level.

As regards high dust emissions from the sponge iron units based on coal, this has attracted adverse opinion leading to suspension of operations of some of the units. The high emissions are mainly due to inadequate design of pollution control systems to handle widely varying type of raw materials in the kilns. Since this route is the main supplier of raw material for secondary steel production, there is an urgent need to share the best practices for environment control by developing a Best Available Technology (BAT) document for the secondary steel sector.

Over the years, there has been substantial improvement in particulate control technologies like scrubbers, bag filters and electrostatic precipitators. Bag houses (bag filters) have now emerged as the main technology for dust control in steel plants with capabilities to meet extremely stringent emission standards at marginally high cost. The efficiency of installed dust control equipment in some of the steel plants however continues to be poor, due to improper design of hoods and mismatch of estimated and installed ventilation volumes. Considering the very high energy cost of operation, there is an urgency to introduce improved practices for design of control equipment for effective capture and control at lower cost. The use of mathematical models like Computational Fluid Dynamics (CFD) can be very useful in this respect.

The control of fugitive dust emissions from non process operations is another major concern in the Ajaokuta steel plants and some of the available technologies for their control are as given below:

Table 1: Suggested Technologies to Control Dust Emissions

Area	Control systems
1. Raw material handling	Bag filters, Dust suppression, Enclosures
2. Raw material storage	Wind nets, Covering by tarpaulins, Chemical spray, Green belt
3. Raw material movement	Tyre washing, Covering of material, Speed control
4. Sinter/pellet plant	Large capacity ESP or bag filter
5. Coke ovens	
Coal charging emissions in coke ovens	Efficient aspiration of COG in top charge batteries. Dedusting car or charge gas transfer car in stamp charged batteries.
Coal carbonization	Good oven doors, Water sealed AP caps, good operational practices
Coke pushing emissions	Stationary bag filters
6. Blast furnace	Bag filters for stock house and Cast house dedusting.
7. Hot metal pretreatment	Bag filters for secondary emissions
8. Secondary dust emissions from BOF, EAF, Furnaces	Large capacity Bag filters

As may be noted, the major contributory factors to air pollution by the industry are on account of the quality of raw materials, operational practices, process controls etc.

Al these factors may separately or else jointly be responsible for fugitive emissions and need to be addressed accordingly.(Jones et al 1988)

In integrated steel plants, sinter plant and thermal power plants are the major sources of emission of SOx and NOx. Several technologies for control of sulphur dioxide and nitric oxides from waste gases have been developed in other countries, though at very high costs. The use of low sulphur coal in coke ovens and desulphurization of coke oven gas can lead to reduction of more than 80% of SO2 emissions from the steel plants and is recommended for SO2 control. Further reductions can be made by introducing desulphurisation of waste gases from sinter plants, though at extremely high capital and operating costs. Similarly NOx emissions in the plants can be controlled by use of staged burners, suitable selection of fuels etc. Further reductions can be made by introducing denitrification of waste gases from sinter plants, though at extremely high capital and operating costs.

The state of the art technologies available for emissions control in various areas of the steel plant are given below:

Table 2: New Available Technologies for Control of Emissions

Area	Technology
Coke Ovens	Induced aspiration of leaking gases by HPAL or steam. Forced aspiration by ID fans Individual oven pressure control during coal charging Coke pushing emission control with stationary bag filters
Sinter Plant	Dust :Air fine system(VAI) ESP: Pulse energisation (Coromax); Movable electrode (Mitsuibishi) Gas & dust conditioning DeSOx & DeNOx : Lime injection ; wet scrubbing after ESP ; Activated carbon Dioxin removal by high efficiency particulate control
Blast furnaces	Secondary emission control during charging. Dry gas cleaning using bag filters. Cast house fume extraction systems,
Steel melting	BOF: Dry type ESP for gas cleaning

4 . 2 WATER ENVIRONMENT:

The steel making process involving high temperature operations also uses a large volume of water in cooling and cleaning operations. Over the years, the fresh water consumption for steel production has been brought down from 12-15m3/tcs to less than 5 m3/tcs, with some integrated steel plants operating at volumes less than 3.0 m3/tcs, against a norm of 5m3/tcs for flat and 8 m3/tcs for long products.

Total water management audits will help in identification of potential areas for improvement and ensuring transition to zero discharge. Some of the techniques/technologies considered necessary to ensure zero discharge by the steel industry may include the following:

Table 3: Recommended Techniques/ Technologies for Water Management

Area of water usage	Measures
Water storage	Use of chemicals to reduce evaporation from large ponds
Fresh Water treatment	Use of slurry dewatering equipment; Control of TDS in fresh water by suitable mixing
Water usage in cooling Towers	Continuous Blow down control; use of chemicals; Fin-Fan heat exchangers; Improved COC; leakage control; High recycle rates aiming at >98% recycling
Water cascading	Blow down from one unit to be used as make up of another unit, after assessing water chemistry
Water reuse	In less critical applications like ore washing, slag and coke quenching; gardening, spray on raw material yards and roads etc
Reverse osmosis	Recovery of good water from blow down water
Evaporation of RO rejects	In evaporators using steam/electricity.

The existing technology for water treatment systems in Ajaokuta steel plants are at par with the best available for the industry and the performance of steel plants in terms of meeting compliance to wastewater discharges has also been satisfactory except for coke ovens, with respect to presence of cyanides. Further, several modifications and upgrades of the coke oven wastewater treatment are also necessary in the steel plants to improve the performance. Another area of concern is the usage of treated wastewater from coke ovens after the introduction of coke dry quenching technology in coke ovens and this aspect needs to be taken into account while planning installation of CDQ facilities.

4.3 SOLID WASTES

During the iron and steel making process, the impurities present in the raw materials like iron ore, lime stone and coal are normally removed as slag. Further, the operations of air and water pollution control equipment generate dusts and sludge. Currently this volume of solid wastes generated in the Ajaokuta plants is relatively high at 600-800 kg per ton of steel as compared to 400-500 kg in developed countries. This is mainly due to higher impurity levels in the raw materials. The steel industry has been successfully converting these wastes into useful byproducts for recycling or else for use as a raw material in other industries, but that is not the case in the Ajaokuta Plants

The limited use of steel slag from BOF and EAF in Indian steel plants (less than 30%, mainly used in sinter plant as lime substitute, and use of recovered metallic in steel making) remains a matter of concern. In contrast in developed countries, the steel making slag is used as construction material ensuring 100% utilization. The main reason for the lower domestic slag utilization may be attributed to the presence of free lime, which makes it unfit for construction industry due to its hydration and expansion after aging. Reportedly steel slag (with less than 5% free lime and a maximum 5% expansion during steam testing) can be effectively used as a construction material. This can be achieved by weathering of slag; granulation by air or water. JSW Steel has introduced a BOF slag granulation facility using water (BSSF technology) which is reported to reduce free lime content in the slag to less than 5%.

Steel slag can be effectively used as a material for construction, substituting other natural resources like aggregates and sand, first by developing a product standard for steel slag by the steel plants and later mandating its use in construction as has been done in case of fly ash. Steel slag after removal of metallic's can also be used as soil conditioner for conditioning acidic soils and also to some extent in cement making. The use of slag generated in hot metal pretreatment and secondary metallurgy is another potential area of use to be studied by the industry.(Oribe 1978; Rai 2006)

Dusts and sludge collected from air and water pollution control equipment is extremely fine and is currently recycled through sinter making. However, in case of larger units, the recycling of large volumes of micro fine dusts is problematic, as it hinders the productivity of sinter plant. Many of our integrated steel plants elsewhere in the world have evolved innovative means of recycling dust and sludge and this need to be adopted by the Ajaokuta steel plant. Some of the practices followed are as given below;

Table 4: Global Best Practices in handling Sludge and Dust

Process dusts/sludge	**Interim usage**	**Preferred usage**
ESP dust from sinter/pellet plants	Recycle in sinter plant	Micro pellets
Flue dust from Blast furnaces	Sinter plant depending on alkali loading	Micro pellets
Dust from bag filters of coke ovens	Power plants	Micro pellets
Sludge from gas cleaning plant of blast furnaces	Disposed	Micro pellets after dewatering
Dust from secondary fume extraction system(ESP or bag filter)	Sinter plant/ BOF Converters	Micro pellets for use in sinter plant/briquettingfor use n
Sludge from gas cleaning plant	Sinter plant/BOF Converters	Micro pellets for use in sinter plant/briquettingfor use n converters after dewatering
Mill scales from caster and Mills	Sinter plant, depending on oil content	Briquetting for use in BOF Converters.

Steel plant operations also generate hazardous wastes and the relevant global best practices in effective management of this hazardous waste cover the following:

Table 5: Global Best Practice in the Management of Hazardous Wastes

Area	**Hazardous waste**	**Usage/Disposal**
Coke ovens	Decanter sludge, BOD plant sludge, Tar sludge	Used in coke ovens
	Still bottoms	Incineration / Cement plant
Blast furnace	High zinc containing flue dust	Hazardous waste disposal or sale
Others	Acidic, alkaline sludge, sludge from water treatment,	Hazardous waste disposal
	Waste and used oils, electric wastes.	Sale to authorized agencies for recycling

It is to be noted that the management of dusts and sludge depends on the steel plant configuration and requires innovative solutions (Singhal 2009; Shah 2003 and Skrotzki 2002). There is therefore a need for the Ajaokuta Plant to obtain the experience of successful recycling schemes from other steel plants.

V. CONCLUSION

The Ajaokuta integrated Steel Plant and its thermal power plant were a product of an efficient design this then latest technological and environmental considerations in place. However, Forty years since that design several things have change in the steel making technology and the environmental/waste control and management. These changes were haven not incorporated in the Ajaokuta Complex.

Similarly, the various challenges encountered by the project in the construction and assemblage of the plants, which culminated into the change of Contractors and Engineers for five times have also confused the configuration process and is certainly affecting the environmental quality of the ecosystem.

It is therefore imperative for the Ajaokuta Steel Complex to be overhauled with the suggested environmentally friendly technologies that are recommended in this article. Further, a comprehensive environmental audit of the steel complex and the township is urgently necessary in order to determine the toxicity states of the various media, so that the ecosystem integrity and sustainability of the entire Ajaokuta region is assured.

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