



RESEARCH ARTICLE

Energy Efficiency Alternatives in the Ajoakuta Steel Project of Nigeria

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Abstract

This work is an attempt to generating a collective understanding for all relevant stakeholders in steel industrial production and policy in appreciating the complex nature of steel production and its high burden on energy demand. This was achieved through breaking down the complex steel making process of the Ajoakuta plant into simple and comprehensible knowledge that is absorbable to non-engineering personnel. Each of the plant in the production line was diagnosed to expose the entire processes involved and how it becomes highly dependent on energy supply and utilization. This gave a sound background for discussing the various challenges associated with high energy demand and how it translate into a burden to environmental sustainability the Ajoakuta ecosystem. This was successfully achieved through establishing the carbon foot print of the industrial process. Important energy conservation technologies and processes were identified and discussed with particular reference to waste heat recovery and the potentials of each reduction process. In the end, various devices were recommended for recovering heat through pressure regulation process.

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1. Introduction

Currently steel industries are the largest energy consuming sector in the world, accounting for 15% of world's industrial energy consumption. Steel industries all across the globe are highly energy intensive. Of the total cost of producing steel, 20% is spent on energy. The increasing cost of energy and even its current and future availability shows the need to refocus attention on energy conservation in steel production.

Steel is 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 (Agbu,2006; Skrotzic, 2002;). 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 through the crucible technique (AGM 2012; Shah 2003). The crucible technique was 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 Ajoakuta Steel Plant. This work focuses on the process of making steel, the structure and operation of the Ajoakuta Steel Plant. It goes further to discuss the various units of the plant which include the primary and secondary plants. This was made in order to bring out the various energy concerns associated with the industrial plant. At the end of which various alternatives for either conservation or conversion of energy from lower and inefficient levels to that of highly efficient one.

2.0 Overview of Steel Production System.

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 (Rai, 2006; AISI 2005; Halliday 2006).

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* (Easter, 2009; Singhal 2009).

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 (Oribe, 1978; Jones et al,1978).

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 (Oribe, 1978;). 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.

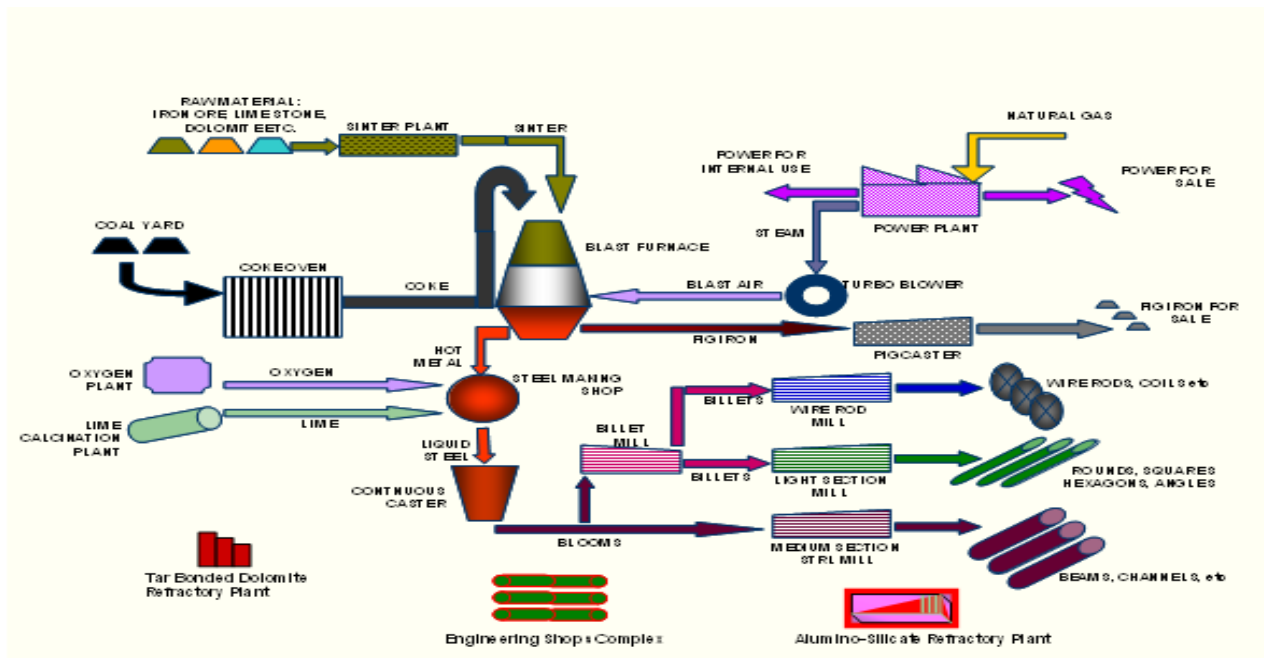
3.0 The Ajaokuta Steel Plant

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 (Ajasteel, 1981). 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 (Audu 1992). Two of these mills, the light section and Wire Rod mills were originally supposed to be the priority rolling mills (Banerjee, 2002; IAAP, 2011). 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.

FIG 1: AJAOKUTA STEEL PLANT PROCESS CHART



Source: Initiative for the Actualization of Ajaokuta/Itakpe Projects (IAAP, 2011)

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 (Oyebanjo and Oluwole 1988). 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 (Dethloff, 1979; DCM 2002 and AGM 2012). 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.

Sintering Plant and Coke Oven Unit:

The Sintering Plant comprises of a sinter machine with a sintering area of 360m² & one straight cooler having cooling area of 420m². 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 1983).

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 molten 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 molten iron remaining in the iron making plant are cast in the pig casting machine for the provision of pig iron used in local foundries (Shah 2003; Jones et al 1988). 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.

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 (Singhal,2009; Shah,2003; Deshpande,2008). 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.

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 (Ajasteel,1981)

4.0 Energy Concerns in the Ajaokuta Plant.

Over the years the domestic steel industry has updated its technology and maintenance systems and many of the new units coming up have also opted for adoption of state of -the -art technology to ensure quality, productivity and efficiency of operations. But globally we are far behind our competitors not only in terms of productivity or quality but also the energy consumption levels and introduction of sustainable production techniques. Locally steel making industry is normally perceived to be large; old; dirty and polluting by civil society and environmentalists and this has often come in the way of obtaining clearances for setting up of new production capacities. So despite the industry's contribution towards providing large value added products

and services the environmental concerns linked to the sector and its associated mining industry has become a serious matter to be addressed on a priority basis (Skrotzki and Vopat,2002).

Our per capita consumption levels of steel is expected to go up in the coming years and this implies increased investment in large scale expansion of existing facilities and of setting up of new capacities.. This would also imply increased extraction of natural resources and their processing .So unless there are reduction in the existing consumption norms as well as specific emission intensities it may be difficult to achieve a balance between increased production and minimum possible damage to the environment by the industry .

Energy Efficiency and Carbon intensity

Given the various process combination of steel making from iron ore, there exist substantial differences in the specific energy consumption & carbon emissions levels or intensities. The Electric Arc Furnace (EAF) route using steel scrap involves the lowest energy intensities as it is required only to melt the scrap. On the other hand the BF-BOF route which obtains in Ajaokuta produces steel from iron ore through many intermediate operations generally involves higher energy consumption and associated carbon emissions. The energy and carbon intensity of steel production from iron ore is the lowest for Gas based DRI-EAF route, followed by BF-BOF route and with the Coal DRI- EAF/IF route being the highest (Oribe et al 1978)

Over the years, the energy intensity in integrated steel plants has been brought down substantially by improvements in raw material quality, processes and operational practices to current level of 6.0-6.7 GCal/tcs. This is still higher than the 4.5-5.5 Gcal/tcs levels achieved by steel plants in other countries. With gradual reduction in energy intensity of steel plants, the carbon intensities have also been.

The differences in the energy consumption levels may be explained by factors such as economies of scale, the level of waste energy recovery , the quality of raw materials used, operational know how and quality control standards adopted .

With higher cost of energy and introduction of regulatory and voluntary initiatives, the steel industry worldwide is being gradually modernized and renovated to adopt energy efficient and environment friendly technologies. Newer facilities are also being set up with clean and green, state-of –the - art technologies. However, due to technological and space constraints diffusion of energy efficient technologies has remained relatively lower in the case of old/existing units in the Ajaokutas Plants (AISI, 2005; Agbu, 2006; Singhal, 2009; DCM 2012)

Given below are some of the important energy conservation technologies that can be harnessed to improve the energy intensity of the steel industry in Nigeria.

Table 1: Important Energy Conservation Technologies Useable in Ajaokuta

Technology	Potential reduction
1 Sinter cooler-waste heat recovery	500-550 MCal/ton of sinter
2 Coke dry quenching	200-280 Mcal/ton of coke
3 Coal moisture control in coke ovens	70 Mcal/ton of coal
4 Top gas recovery turbine in BF	40-60 KWH/TON OF IRON
5 Waste heat recovery from stove waste gases of Blast furnace	18-20 Mcal/ton of iron
6 OG boiler in BOF	80 Mcal/ton of steel
7 Regenerative burners	10-15 Mcal/ton of steel

Of the above mentioned technologies, the Top gas recovery turbine in BF (TRT) can be adopted by several plants Coke Dry Quenching (CDQ) can also be adopted. Sinter cooler waste heat recovery can be adopted. While other technologies are yet to be fully harnessed,, technologies like TRT and CDQ, waste heat recovery from stoves and sinter cooler can be introduced as part of the expansion programmes of several processes.

With a number of large new steel making capacities being added based on the BF-BOF route, the share of this segment is expected to increase in future leading to reduction in the overall carbon intensity. As regards the secondary steel producers, supply constraints of natural gas, good quality scrap, high grade ore for sponge iron making, along with the compulsions to adhere to energy reforms and reduced energy intensity/carbon emissions may put pressure on them to improve productivity, energy efficiency and environmental sustainability. This can not be avoided, if they are to ensure their survival.

Similarly, tax benefits can be provided to promote implementation of energy conservation measures. It is imperative that all the steel units to exploit this opportunity for conserving energy and also to reduce costs of operation. Since it is the secondary steel makers that need to catch up urgently in terms of energy efficiency, a separate scheme to benefit them must be adopted.

About 40% of crude steel is produced by the mini steel plants comprising of Electric Arc Furnace (EAF) and Electric Induction Furnace (EIF) units. Besides more than 60% of long steel products are also produced by the Secondary Steel Sector i.e., the EAF, EIF as well as the Re-rolling Mills. The Re-rolling Mills in Jos and Katsina normally source their inputs, viz., pencil ingots and continuously cast billets, mostly from the EAF and EIF units of the Ajaokuta. All these units are characterized by high levels of energy consumption and Green House Gas (CHG) emissions. Therefore, adoption of clean, green and energy efficient technology by them has become over the years a subject requiring special attention both from the point of view of improving their productivity as well as for ensuring environment protection (Sato,2009; IAAP, 2011)

As regards policy implementation for ensuring energy efficiency, the Steel industry is also required to conduct at regular intervals an energy audit by certified Ajaokuta energy auditors and Energy efficiency labeling for the entire equipment.

5.0 Proposed Energy Saving Technology for Ajaokuta

The proposed technology relates to a method and an apparatus for recovering waste heat from EAF whose exhaust gases have high dust content. The recovery of waste heat has been very difficult with conventional techniques. This paper improves and expands upon similar technology that has already been proposed and patented

Various devices have been proposed for recovering waste heat from EAF. In these methods, the internal pressure of the recovery device is kept higher than atmospheric pressure in order to increase the quantity of useful heat recovered. But proper maintenance and management for safe operation is required. Another difficulty is that the dust contained in exhaust gases is generally very liable to adhere to the structure and because this dust has poor heat conductivity, the size of the heat recovery area must be enlarged, thereby resulting in increased size of the apparatus as a whole. The present technology is free from the aforementioned disadvantages, and is capable of recovering useful heat without reducing the production capacity of the EAF itself.

5.1 Working of the System for the Ajaokuta Plants

Water is pumped through an ion exchange where impurities are removed to prevent water hardening. This purified water is then stored in feed water tank. The heat recovery system takes place in two parts: the Primary heat recovery section, and the secondary heat recovery section.

The water from the feed water tank is fed into the primary heat recovery section by a pumping system and flow controller. Here the water cools the overheating apparatus of the electric arc furnace. The heat emanating from the EAF components is recovered by controlling the temperature of the cooling liquid circulating through the furnace apparatus in such a way that the maximum temperature of the coolant remains below its boiling point, under normal atmospheric pressure. In the secondary heat recovery section, a stream of dust-laden gas leaves the EAF under the action of the induced draft fan. This stream of gas is passed through the internal tubes of the heat exchanger, which are made of heat-proof steel and have a circular shape so as to minimize adhesion of dust and to allow easy removal of dust if it does accumulate.

Simultaneously a stream of hot water is flowed by a pump, as a heat exchange medium, along the outer side (shell side) of the heat exchanger. The water is heated in the heat exchanger to a high temperature and is converted into steam. This steam is then collected in a steam drum.

The stream of EAF discharge gas is lowered to a temperature level at which the filter can be operated effectively. The discharged fume gases are filtered and finally released to the atmosphere through the chimney, having less energy than before.

The steam from the steam drum and hot water from the feed water tank are accumulated in a steam accumulator. A steam accumulator is an insulated pressure tank containing hot water and steam under pressure. It is a type of energy storage device which is used to smooth out peaks and troughs in demand for steam. This steam generated can be used for driving vacuum pumps at the VD plant, or for driving a single strand steam turbine to generate electricity. Both ways a high saving of fossil fuel can be achieved and the carbon emission can be reduced significantly.

Similarly. Some steel plants in Ajaokuta use VD system full time, some of them use it sparingly and some don't use it at all. Though it's more efficient to use the generated steam in a VD boiler, it can also be used to run a steam turbine to produce electricity when a VD is not in use. The 75kWh of recovered energy could power a turbine and produce electricity with an overall efficiency of 50%, yielding approximately 40 kWh of electric energy (Easter and Siemag, 2009)

6.0 Conclusion

Changing the energy footprint of the Ajaokuta steel industry is a daunting task, but the rewards could be huge. Retrofitting the above discussed system in an already running plant can be difficult, and would impede the working of the plant during installation. But for a steel plant that is yet to be commissioned, this system can be installed with minimum difficulties and great advantage. There is a good chance to undertake these stated reformatings in Ajaokuta before the Arc Furnace is finally switched on; which will demand its continuous running for at least ten years non-stop

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