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The Midrex Process and the Nigerian Steel Industry

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Abstract

The goal of producing steel in Nigeria from iron ore was made possible through the Midrex Process based Direct Reduction plant at the Delta Steel Company. The iron ore was originally imported from Liberia and its parameters formed the basis of the design of the plant. Following the difficulty in obtaining this ore, the Brazilian ores later became the source of raw materials. The difficulty in maintaining this supply led to the need of looking inwards at the substantially available local iron ore at Itakpe in the middle belt region of the country. This ore with an as-mined total iron content of less than 50% and after beneficiation a total iron content of about 63% and a gangue content of about 4% was unsuitable for use in the direct reduction process. The re-beneficiated ore of about 66% total iron was pelletized and reduced in the direct reduction plant yielding a degree of metallization of about 92% and a carbon content of about 2% after careful adjustment and application of the operating parameters to produce direct reduced iron suitable for steel production in the electric arc furnaces.

Keywords: Midrex process

Introduction

The importance of iron and steel as a basis for technological development is common knowledge and all industrialized nations have multiple iron and steel plants, some of which are integrated.

In her bid to promote technological growth, and to also join the league of industrialized nations, Nigeria in the early 1960s conceived a vibrant economy with the steel industry as the foundation for industrial development.

At the request of the Nigerian Government, feasibility studies were conducted by Western Nations who turned in reports, which claimed that it was not feasible to establish iron and steel industries based on the then available raw materials.

In 1967 the Nigerian Government commissioned experts from the then Soviet Union (USSR) to carry out further studies. Encouraged by the recommendations of the Soviet experts, the Federal Government promulgated Decree No.19 of 1971 establishing the Nigerian Steel Development Authority (NSDA) which was given responsibilities and necessary powers to develop the steel sector through exploration, opening up of mines, carrying out research on steel plants, manpower training, steel plant design and the development of metallurgical processes and raw materials sourcing with the iron ore concentrate being increased to about 65%.

Following this and under the auspices of the NSDA, Nigerian and Soviet geologists and technologists were able to determine the resources and suitable local raw materials required to set up an integrated iron and steel plant at Ajaokuta in Kogi State.

Although the main contract for the establishment of the conventional Blast Furnace – Basic Oxygen Furnace route to steel production was signed in 1979, global recession, poor funding and the installation of massive infrastructural facilities had stood on the way of the completion and full commissioning of Africa's largest steel making Plant.

Due to this delay, and convinced by the well-advertised advantages of the Direct Reduction – Electric Arc Furnace route to Steel production which include:

a. Efficient use of the abundant natural gas in Nigeria.
b. Independence from coke imports.
c. Capacity sized to meet needs rather than economy of scale.
d. Electric arc furnaces can be rapidly started and stopped, allowing the steel mill to vary production according to demand.

e.   Lower capital cost per ton of product.
f.   Shorter construction time (Less than 4 years),

the Federal Government of Nigeria signed an agreement with a consortium of 10 Austro-German companies on 3rd October, 1977, to set up a DIRECT REDUCTION – ELECTRIC ARC FURNACE Integrated Steel Plant of a capacity of one million tonnes per year of liquid steel at Ovwian-Aladja in Delta State.

Therefore the decision by the Federal Government to adopt the direct reduction process was hinged on the abundant natural gas in the Niger Delta region of the country thereby making the import of coal which was an essential ingredient for the conventional blast furnace process unnecessary. Also, investment cost was lower and flexibility of operation with respect to variation of operating parameters with regard to different iron ore qualities was plausible. (Madagua, 2013).

Direct reduced iron and specifically that produced through the Midrex process is a highly metallized type of direct reduced iron with known and controlled chemical characteristics and helps in meeting the demand for the production of quality steel from the Electric Arc Furnaces.

This is because, the effect of DRI on the physical properties of steel can increase productivity and yield in the rolling mills and downstream of the manufacturing facilities.

At Delta Steel Company, the quantity of DRI charged to the melting furnace ranges from 70 – 80 % which necessitates the need to produce optimum quality DRI. The Lamco Liberian/Guinean ore based on which the Direct Reduction plant at Delta Steel was designed, was successfully reduced with Performance Guarantee Test values meeting the designed values.
The Delta Steel project was officially commissioned in January 1982. The installed steel melting capacity is 1 million tonnes per annum achievable through the electric arc furnace steel making route using the in-house DRI produced through the Midrex process, from pelletized iron ore. Production rose from 9% in that year to about 24% in 1985 and this corresponded with the natural learning curve.

The full annual production of Delta Steel would have resulted in 960,000 tonnes of billets, and designed to be consumed jointly at the rate of 320,000 tonnes per annum within the in-house rolling mill at Delta Steel,

and 210,000 tonnes apiece by each of the three Inland Rolling Mills at Katsina, Oshogbo, and Jos. These mills all produce long products; wires and reinforcing bars, in the case of the Inland Rolling Mills, and reinforcing bars and light sections in the case of Delta Steel. (Mohammed, 2002)

The Delta Steel Company was established primarily to meet these needs and also to put Nigeria on the map of the world as a major steel producer, against the backdrop of the delay in the completion and commission the Ajaokuta Steel Project.

Upon commissioning of the Delta Steel Company and subsequent commercial production of steel, the Liberian/Guinean ore mines from where the Lamco iron ore used as feedstock for the Direct Reduction Plant at Delta Steel, and on the basis of which the plant was designed, was depleted within 3 years of commissioning.

This led to the necessity to seek other sources of raw materials. The next alternatives were the Brazilian Compania Vale do Rio Doce (CVRD) and Feijaio Ores which apart from the peculiarity in their operational characteristics were not readily available due to scarce foreign exchange. These ores were used sparingly between 1989 and 1993.

It therefore became imperative to seek other sources of iron ore. This led to the need to investigate the possibility of utilizing at Delta Steel Company, the locally available iron ore in Itakpe in Kogi state of Nigeria, which was originally conceived for use at the Blast Furnace plant in Ajaokuta. This plant was built to accommodate sinter grade of 63 to 64% total iron content. The silica was in excess of 4% and the ore was not suitable for the Direct Reduction process at DSC. (Ola et al., 2009).

The most important import substitution therefore was the successful utilization of the Itakpe iron ore concentrate in the Direct Reduction Plant and the Steel Melt Shop for the production of truly indigenized steel. (Madagua, 2013)
The beneficiation of Itakpe iron ore, making it suitable for production of Direct Reduced Iron from the MIDREX based Direct Reduction Plant at Delta Steel Company, marked a major turning point in the historical quest for the production of iron and steel from locally available iron oxide raw material in Nigeria.

Direct reduction technology

Direct reduction technologies have been developing since the early 19th century, as an attempt by steelmakers to produce iron directly from iron ore, avoiding high temperatures needed to melt iron. More recently, the search for better quality iron units in the production of steel in mini-mills, as well as problems with price volatility of scrap has led to a renewed interest in the development of direct reduced iron, also called sponge iron.

'Reduced iron' derives its name from the chemical change that iron ore undergoes when it is heated in a furnace at high temperatures in the presence of hydrocarbon-rich gases.

'Direct reduction' refers to processes which reduce iron oxides to metallic iron below the melting point of iron. The product of such solid state processes are called direct reduced iron (DRI). It can be produced either in lump, pellet or fines as a porous product which retains the original size and shape of the pellet and lump feed. (Grobler and Minnitt, 1999)

The Direct Reduction process regarded as the heart of the Midrex technology for production of iron has enjoyed increased usage as against the older traditional use of the Blast Furnace route.

Although the blast furnace process is still the predominant method for primary iron production, the disadvantages inherent in the process led to the development of alternative processes which includes the direct reduction process and which has reached tangible level of commercial applications and is considered to be the most developed alternative iron making route. One major advantage over the blast furnace is that it is coke-less and environmentally friendlier.

Furthermore, there is increased need for various grades of steel products which are easier to obtain through the DR route, and which require flexibility of operation and the need for lower energy consumption.

Various routes are applied to produce steel. These routes can be divided into two major categories namely, "from ore to steel" and "from scrap to steel". Although the latter is more advantageous because only melting energy is needed as far as energy requirement is concerned, and was used for many years, the demand for higher value steel led to the demand for the former.
In this regard, the direct reduction route took the lead with some more added advantages in the use of DRI which include:

i.   Low content of impurities (residual elements, sulphur and phosphorous).
ii. Permits dilution with low-cost scrap.
iii. Easy to handle, store and transfer.
iv. Permits automatic continuous charging into the electric arc furnace.
v.   Stable electric power input.
vi. Stable steel bath surface which reduces possibility of electrode breakage.

Another major advantage of direct reduced iron is that it has a well-defined chemical composition when compared with steel scrap and has efficient melting properties in the electric arc furnace. (Anameric and Kawatra, 2007)

Consequently, there has been a great increase in the demand for direct reduced iron in electric arc steel making. These attractive features have led to an increase in worldwide production of direct reduced iron as shown in Figure 1.
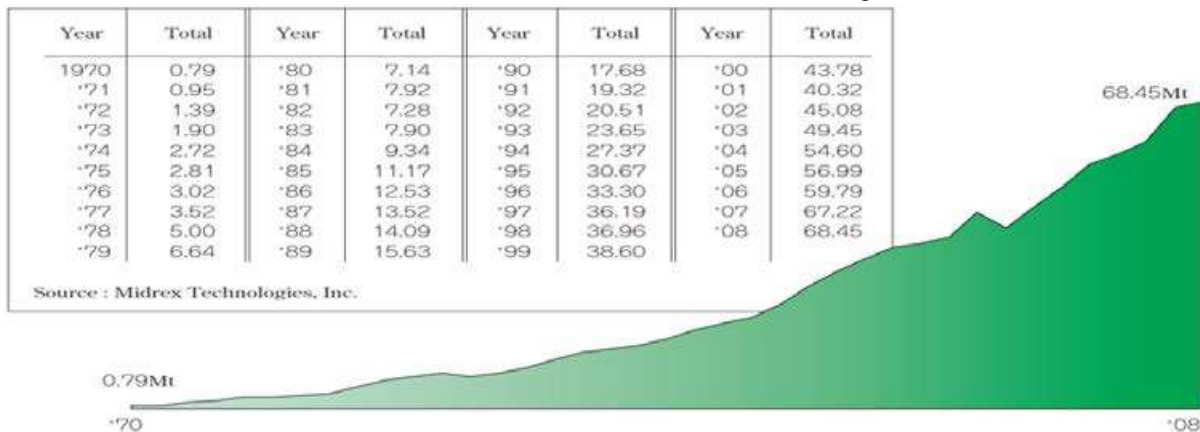

Year	Total	Year	Total	Year	Total	Year	Total
1970	0.79	'80	7.14	'90	17.68	'00	43.78
'71	0.95	'81	7.92	'91	19.32	'01	40.32
'72	1.39	'82	7.28	'92	20.51	'02	45.08
'73	1.90	'83	7.90	'93	23.65	'03	49.45
'74	2.72	'84	9.34	'94	27.37	'04	54.60
'75	2.81	'85	11.17	'95	30.67	'05	56.99
'76	3.02	'86	12.53	'96	33.30	'06	59.79
'77	3.52	'87	13.52	'97	36.19	'07	67.22
'78	5.00	'88	14.09	'98	36.96	'08	68.45
'79	6.64	'89	15.63	'99	38.60		

Source : Midrex Technologies, Inc.

68.45Mt

0.79Mt

'70   '08

FIG 1: World production of DRI. (DRI Midrex Statistics worldwide, 2008). Retrieved from www.midrex.com)

The reducing gases produced from natural gas or coal, is a mixture mainly of hydrogen (H_2) and carbon monoxide (CO) which acts as the reducing agents. This process of directly reducing the iron ore in solid form by reducing gases is called direct reduction. They include:
o Midrex direct reduction
o HYL direct reduction
o SL/RN direct reduction

Midrex direct reduction: This is a more common method of iron reduction and the furnace has two main stages which are the reduction zone and the cooling zone. The process is based on natural gas.

HYL direct reduction: The HYL direct reduction method, is less common than Midrex, but the source for HYL is the same as for Midrex. In the HYL process, the reducing includes four reactors. The reduction of the charged material takes place in the main reduction stage and other three stages which are used for cooling, carburization, and the final regulation of metallization. The operating conditions in the HYL process are based on a reducing gas composition rich in Hydrogen (70 – 87%), elevated pressure (>5.5 Kg/cm^2) and high reduction temperature (> 920°C). (Morales, 2000)

SL/RN direct reduction: This is a coal-based rotary kiln reduction process. It is used mainly in India and South Africa. In this method the feed is preheated up to 1800°F by counter flowing gas, which usually contains ore, coal, recycle char and flux, if sulphur is to be removed from the coal. In order to increase kiln efficiency, the preheat zone should be 40 to 50% of total kiln length. Reduction is started when temperature reaches roughly 1650°F. Then, the solids are discharged from the rotary cooler, which is cooling by spray water to the cooler shell and the temperature brought down to about 200°F. The cooled material is separated by screen and magnetic separator. The fines are briquetted to be used later with the DRI.

(Iron and Steel Engineer, 1995. Retrieved from www.heattreatconsortium.com
Table 1 shows the major differences between DR and HYL processes.
TABLE 1: Differences between DR and HYL Processes. (Source: Tata Steel)

Difference between Midrex & HYL

Sl. No.	Item	Midrex	HyL III
1.	Type of process	Continuous shaft furnace	Continuous shaft furnace
2.	Type of reductant	Natural gas	Natural gas
3.	Type of oxide feed	Pellets and sized ore	Pellets and sized ore
4.	Type of reformer	Catalytic reformer	Heater in place of reformer
5.	Type of reforming	Catalytic reforming(CH4 react with Top gas (H2 + CO$_2$) & some amount of insitu reforming	Partial oxidation & Steam reforming & insitu reforming
6.	Furnace operating pressure	Operates at slightly above atmospheric pressure(1.5 bar max)	Operates at 4-5 bar (g)
7.	Furnace operating temperature, ^{0}C	~950	~1000

Classification of direct reduction processes

Direct Reduction Processes can be classified according to the Reducing agents in use and the Reactor types. These are shown in Figures 2 and 3 (Anameric and Kawatra, 2007) and also according to their operational modes as shown in Table 2 (Udofot, 2008).
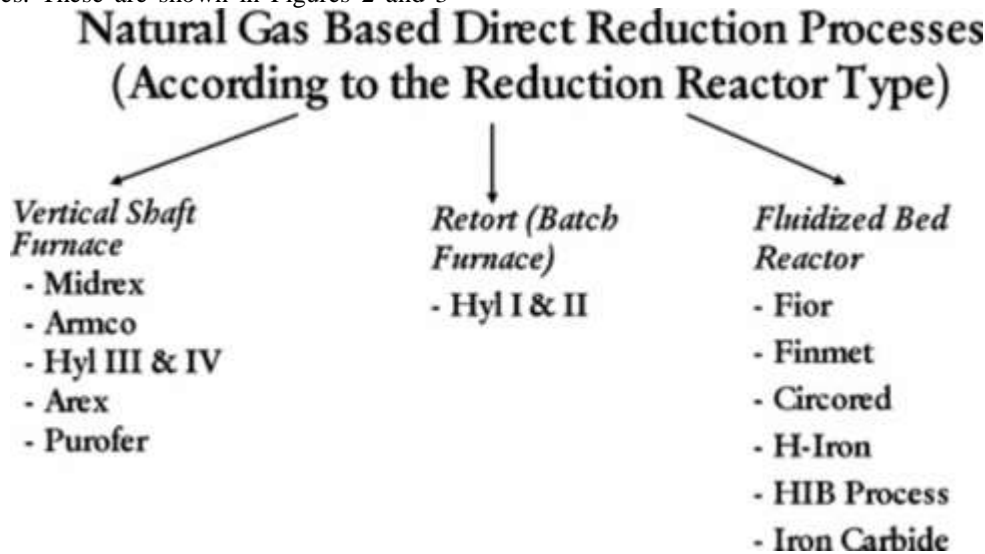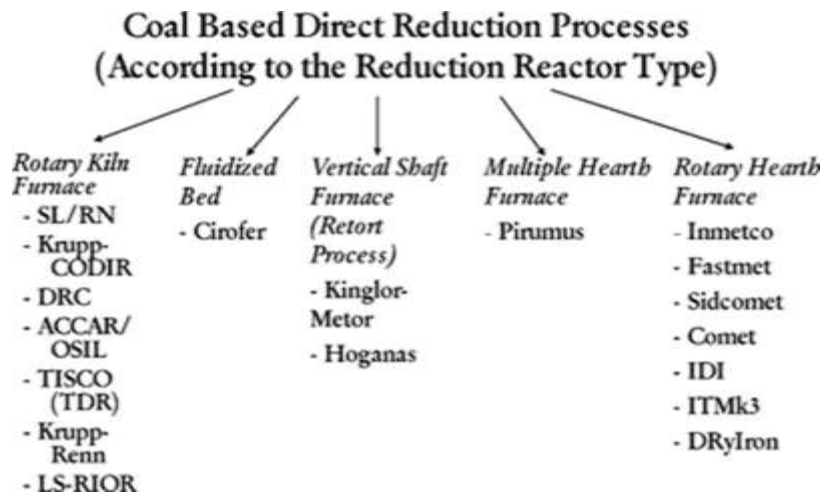
Natural Gas Based Direct Reduction Processes
(According to the Reduction Reactor Type)

Vertical Shaft Furnace
- Midrex
- Armco
- Hyl III & IV
- Arex
- Purofer

Retort (Batch Furnace)
- Hyl I & II

Fluidized Bed Reactor
- Fior
- Finmet
- Circored
- H-Iron
- HIB Process
- Iron Carbide

FIG 2: Natural Gas based Direct Reduction Processes.

Coal Based Direct Reduction Processes
(According to the Reduction Reactor Type)

Rotary Kiln Furnace
- SL/RN
- Krupp-CODIR
- DRC
- ACCAR/OSIL
- TISCO (TDR)
- Krupp-Renn
- LS-RIOR

Fluidized Bed
- Cirofer

Vertical Shaft Furnace (Retort Process)
- Kinglor-Metor
- Hoganas

Multiple Hearth Furnace
- Pirumus

Rotary Hearth Furnace
- Inmetco
- Fastmet
- Sidcomet
- Comet
- IDI
- ITMk3
- DRyIron

FIG 3: Coal based Direct Reduction Process

TABLE 2: Direct Reduction processes [Udofot, 2008)

DR PROCESSES	FURNACE TYPE	MATERIAL P=PELET, S=SINTER, L=LUMP	OPERATION BATCH/CONTINUOUS
1.**REFORMED NATURAL GAS** PROCESSES			
a) Midrex	Shaft	P & L	Continuous
b) Armco	Shaft	P, L & S	Continuous
c) Purofer	Shaft	P, L & S	Continuous
d) HYL	Static bed	''	Batch
e) Fior	Fluidized bed	P,L & S	Continuous
f) HIB	Fluidized bed	S	Continuous

2. COAL-BASED SOLID REDUCTANTS PROCESSES			
a) SL/RN	Rotary kiln	P & L	Continuous
b) Krupp (Codir)	' '	"	Continuous
(c) DRC	' '	"	Continuous
d) Kawasaki	' '	P of waste dust & residue	Continuous
e) SDR	' '	from Steel plant.	Continuous
3. **2ND GENERATION COAL BASED PROCESSES**			
a) ACCAR	Rotary kiln	P	Continuous
b)Hot-gas desulphurization	Shaft	P or L	Continuous
c)Improved SL/RN	Rotary kiln	P or L	Continuous
d) SALEM	Rotary kiln	P or L	Continuous
e) SPM	Rotary kiln	P	Continuous
4. **COKE OVEN GAS DRI**			
HYL	As in 1 (d)		Batch
Midrex	As in 1 (a)	-	-

However, by far the most popular type of Reactor in use is the Vertical Shaft Furnace Reactors utilized in (Anameric and-Kawatra, 2007):

i) **Natural Gas**-based direct reduction processes: **Midrex, Armco, Hyl III & IV, Arex, Purofer**, and

ii) **Coal**-based Direct Reduction processes: **Kinglor- Metor, Hoganas**.   The flow of gases and solids in the vertical shaft furnace are shown in Figures 4 and 5.
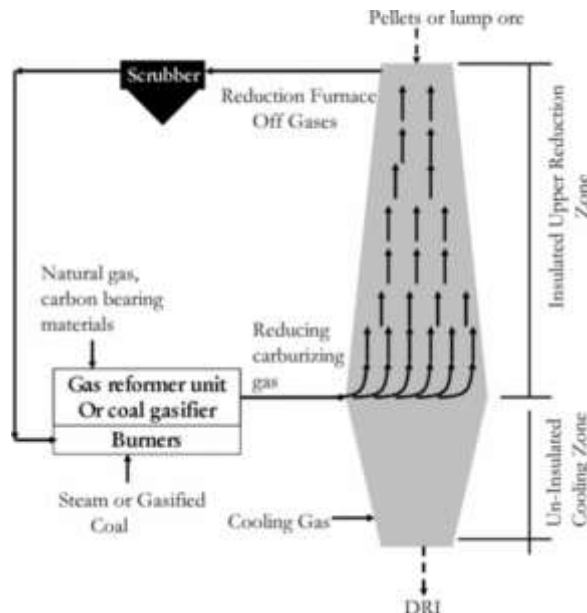
FIG 4: Direct reduction vertical shaft furnace showing Gas and Solid movement. (Anameric and Kawatra, 2007)
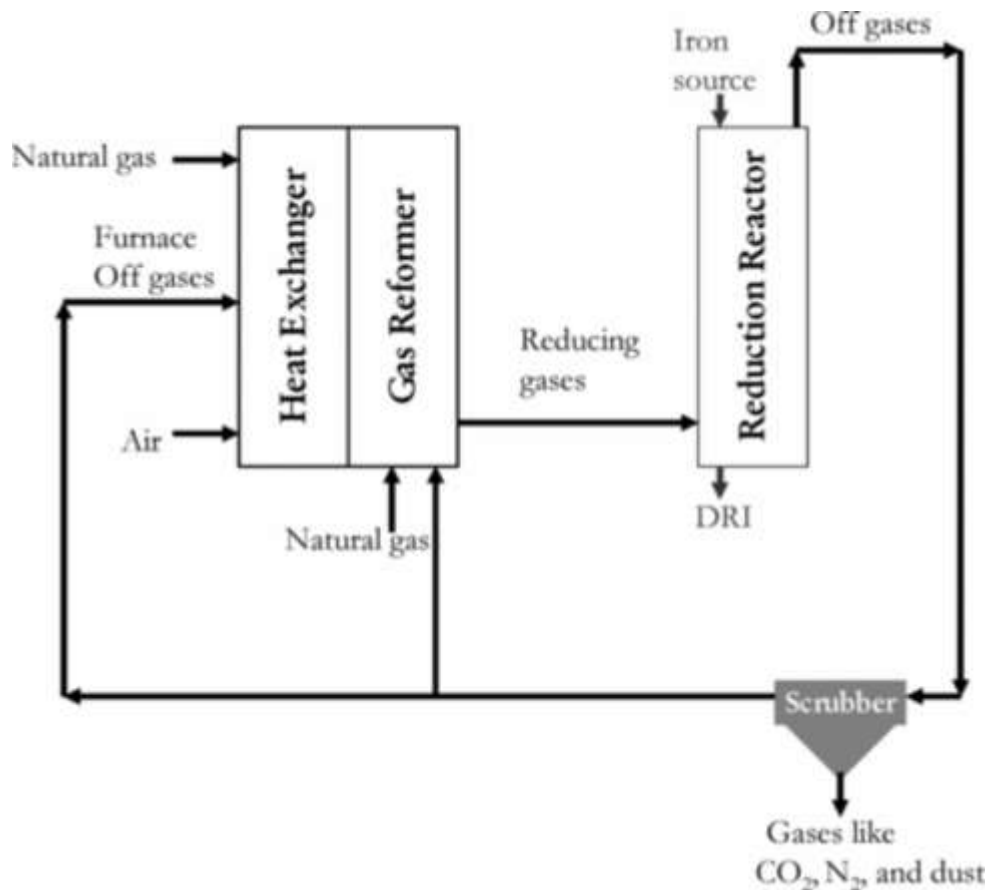
FIG 5: Schematic flowsheet of the natural gas-based direct reduction process utilizing off gases from the reduction reactor for reducing gas production.

Figure 6 shows the comparison of the direct reduced iron production methods and Figure 7, the 2011 ratio in the use of Midrex and other Processes.
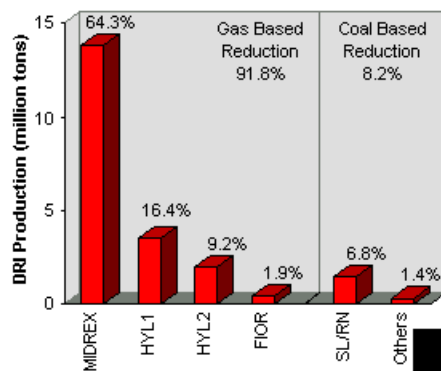

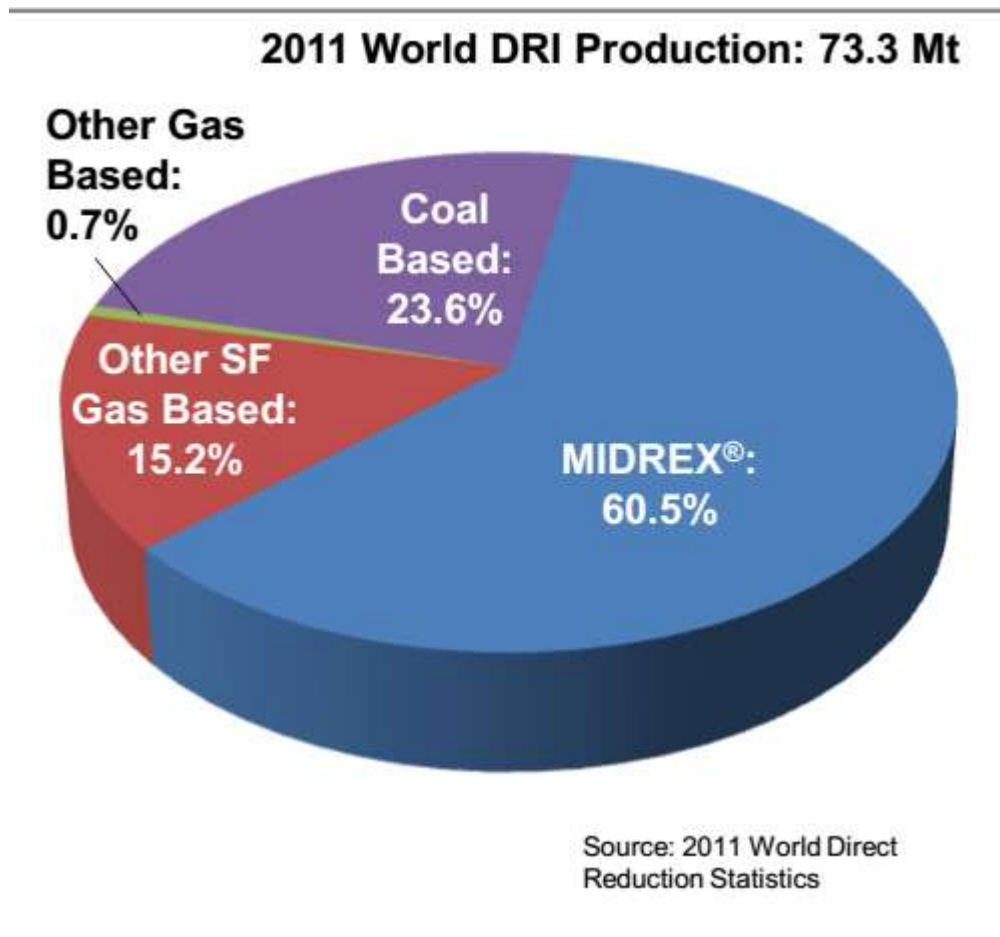*FIG 6: Comparison of Direct Reduced Iron production methods (Energy and Fuels, 2001)*

FIG 7: 2011 World DRI production. (Source: Midrex Technologies, 2012)

The midrex process

MIDREX direct reduction iron making also known as the MIDREX process, reduces iron ore using reforming gas produced from natural gas. The original process was developed by the Midland-Ross Co., which later became MIDREX Technologies, Inc., a wholly owned subsidiary of Kobe Steel. A pilot plant was built in Toledo, Ohio in 1967. The first commercial plant, having a production capacity of 150 thousand tonnes/year, was built in Portland, Oregon, in 1969.

The key components of a MIDREX Plant are a shaft furnace, a reformer as well as systems for gas cleaning and heat recovery as shown in Figure 8.
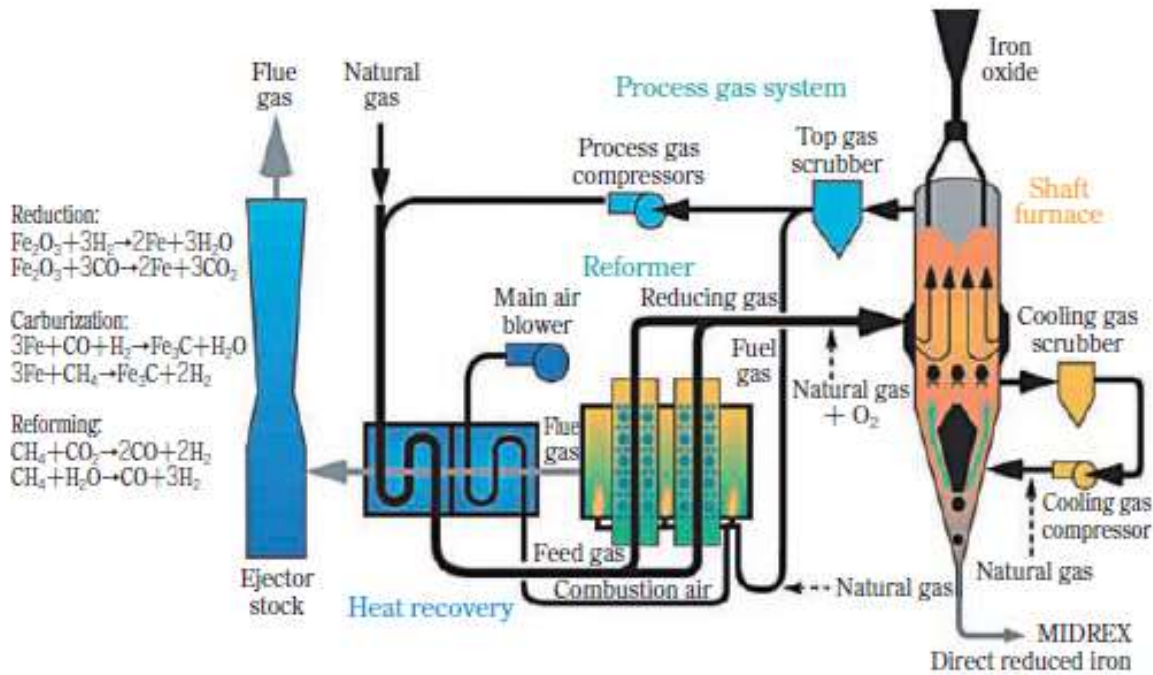
FIG 8: Midrex Direct Reduction flowsheet. (Atsushi et. al, 2010)

Since iron occurs in nature in the form of oxide compounds, the goal of the MIDREX process
is to reduce the iron ore (that is, remove oxygen). This is done in a countercurrent process using natural gas as the reducing agent.

The MIDREX process produces direct reduced iron (DRI). The DRI produced by the MIDREX Process features high metallurgical iron content, but almost no nonferrous metal impurities which are undesired in steel. Highly demanding steel grades can be produced by this route.
(Kempken et.al, 2008).

The Product variations of direct reduced iron include, Cold DRI, Hot Briquetted
Iron and Hot DRI (Direct From Midrex, 2012).

Cold DRI
Of the 75 million tons per year of DRI currently being produced, more than 60 million tons per year are made as CDRI. CDRI is made by cooling the iron immediately after it is reduced to the metallic form and before it is exposed to the atmosphere.
CDRI has been used for almost every form of steel that is produced. Even though its use is often associated with the production of high grade, low residual metal, low nitrogen products, most of it is

actually applied to the making of the common grades of long products, reinforcing bar and light structurals.

FIG 9: Cold Direct Reduced Iron

Hot Briquetted Iron (HBI)
HBI was first developed for a DR process in South America.

Chemically, it is the same as CDRI and is compacted from the DRI just as it is discharged from the reduction furnace while it is still hot. For it to qualify as HBI within the guidelines of the International

Maritime Organization, HBI must be compacted to at least 5.0 grams per cc and the operation must be done using DRI that is at least 650°C as it enters the briquetting dies. MIDREX HBI now accounts for more than 90% of all HBI involved in transcontinental trade.

FIG 10: Hot Briquetted Iron

Hot DRI (HDRI)
The ability to transport DRI from the reduction furnace to the steelmaking furnace while still hot was developed during the latter 1990's. The reasoning for doing so is obvious.
Sensible heat contained within the DRI after reduction represents a large share of the heat needed for melting.
By conserving this heat, not only are there significant energy savings, but also time savings.

The DRI is used mainly as the raw material for electric arc furnaces (EAFs), as a clean iron source substitute for scrap iron. However, there are applications for DRI outside the EAF steelmaking industry. Today, more than ten percent of the HBI that is involved in intercontinental shipment is bound for use in blast furnaces; the original purpose for developing direct reduction (Direct From Midrex, 2012).

The shaft furnace is continuously charged with iron ore which moves from the top downwards while a reducing gas, consisting mostly of hydrogen and carbon monoxide, flows in opposite direction, i.e. from the bottom upwards.

The shaft furnace
The MIDREX Shaft Furnace operates at low pressure, which provides a number of benefits, including easy charging and discharging and the ability to use burden feeders to facilitate material flow. These features have enabled MIDREX Plants to use a wide variety of iron ores, including lump ores. (Direct From Midrex, 2004)

The maximum production capacity in 1984, when Kobe Steel became affiliated with MIDREX Technologies, was 600 thousand tonnes/year. In 2007, the scale reached 1.8 million tonnes/year, which is comparable to that of a small blast furnace.

There was an urgent need to upsize the shaft furnace in response to the market need for an increased production capacity. To achieve this, Kobe Steel and MIDREX Technologies began development by conducting analyses using the three-dimensional finite element method, conducting two-dimensional model experiments for verification and improving raw material characteristics on the basis of reduction/pulverization tests.

As a result, the shaft furnace diameter was increased to 5.5m and then to 6.5m (MEGAMOD shaft furnace). This has increased the production capacity from the previous maximum of less than 400 thousand tonnes/year, first to 800 thousand tonnes/year, and then to 1.5 million tonnes/year). Figure 11 shows the changes in the diameter of the shaft furnace and the corresponding annual production capacity.
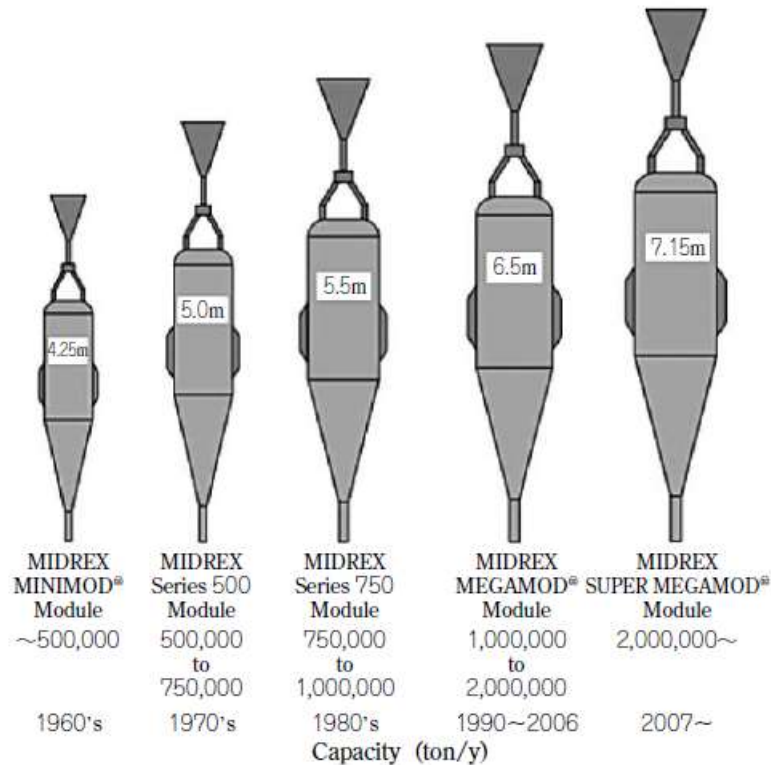
FIG 11: Changes in shaft furnace diameter and annual production (Atsushi et. al, 2010).

A technology was devised to raise the temperature of reducing gas (bustle gas) by coating the raw material with lime hydrate which has a melting point higher than that of DRI. This has raised the reducing gas temperature to about 900℃ and improved shaft furnace productivity by more than 10%. This is shown in Figure 12. This technology was utilized in Delta Steel Company during a reduction campaign in the use of local Nigerian Itakpe iron ore. The reduction temperature was however maintained at $870^{O}C$.
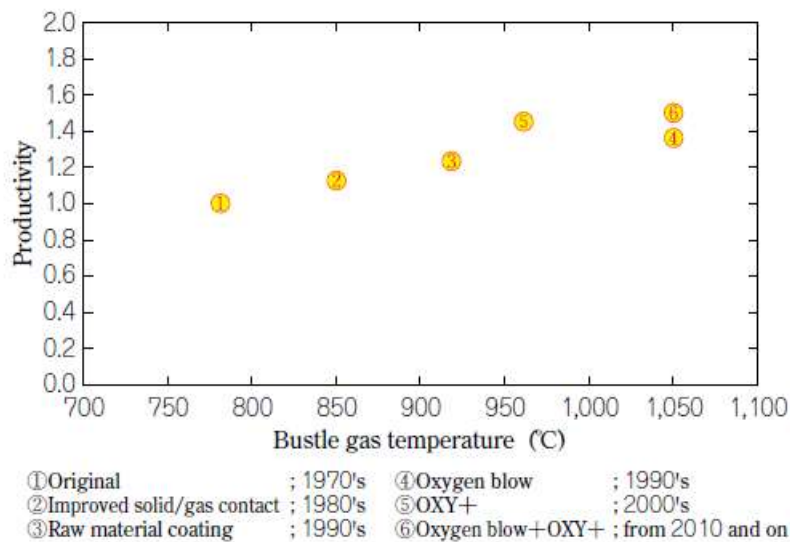
FIG 12: Changes in productivity of MIDREX shaft furnace (Atsushi et. al, 2010).

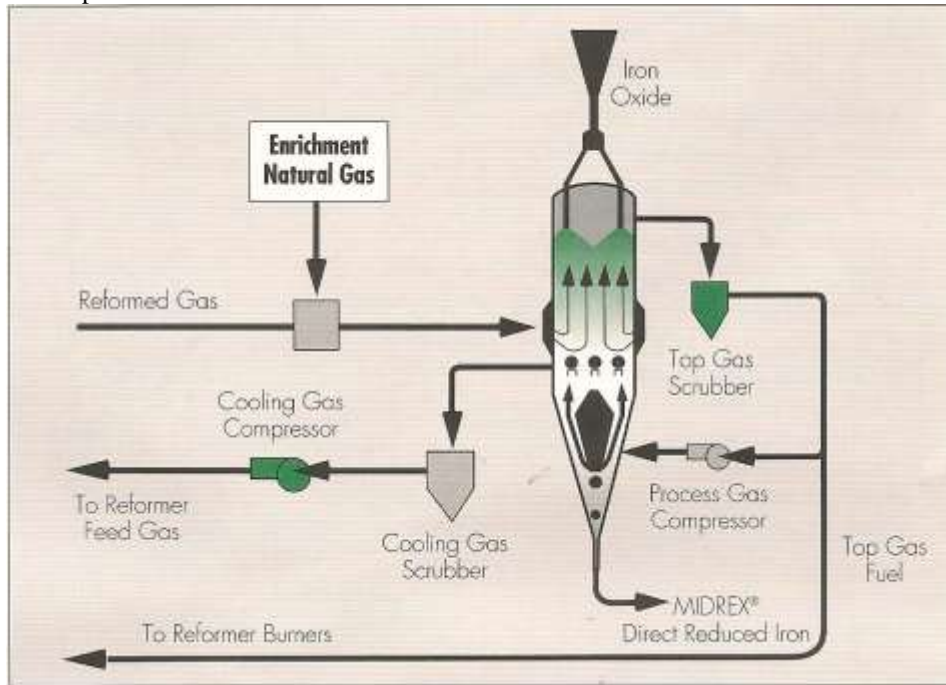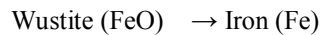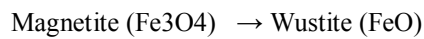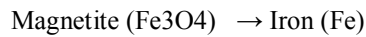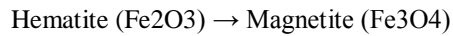Figure 13 shows the process flow sheet of the shaft furnace.

FIG 13: Shaft Furnace process flow. (Source: Direct From Midrex, 2000)
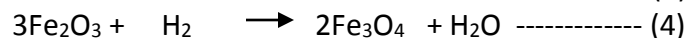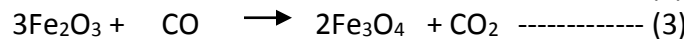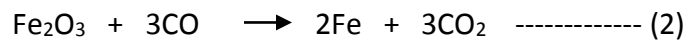
Reduction reactions

The reduction of iron oxide involves one or more of the following steps:

Hematite (Fe2O3) → Magnetite (Fe3O4)

Magnetite (Fe3O4) → Iron (Fe)

Magnetite (Fe3O4) → Wustite (FeO)

Wustite (FeO)   → Iron (Fe)

$$Fe_2O_3 \longrightarrow Fe_3O_4 \longrightarrow FeO \longrightarrow Fe \text{ -------------------------- (1)}$$
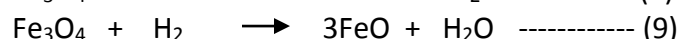
The detailed steps in the reaction sequence are shown below (Direct From Midrex, 1993)
Hematite Reduction,

$$Fe_2O_3 + 3CO \longrightarrow 2Fe + 3CO_2 \text{ ------------- (2)}$$
$$3Fe_2O_3 + CO \longrightarrow 2Fe_3O_4 + CO_2 \text{ ------------- (3)}$$
$$3Fe_2O_3 + H_2 \longrightarrow 2Fe_3O_4 + H_2O \text{ ------------ (4)}$$
$$Fe_2O_3 + 3H_2 \longrightarrow 2Fe + 3H_2O \text{ ------------- (5)}$$
$$3Fe_2O_3 + C \longrightarrow 2Fe_3O_4 + CO \text{ ----------- (6)}$$

For Magnetite Conversion,

$$Fe_3O_4 + C \longrightarrow 3FeO + CO \text{ ------------- (7)}$$
$$Fe_3O_4 + CO \longrightarrow 3FeO + CO_2 \text{ ------------- (8)}$$
$$Fe_3O_4 + H_2 \longrightarrow 3FeO + H_2O \text{ ----------- (9)}$$

$$Fe_3O_4 + 4CO \longrightarrow 3Fe + 4CO_2 \text{ ------------- (10)}$$

$$Fe_3O_4 + 4H_2 \longrightarrow 3Fe + 4H_2O \text{ ----------- (11)}$$

For Wustite Conversion,

$$FeO + C \longrightarrow Fe + CO \text{ --------------------- (12)}$$

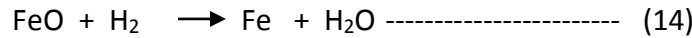$$FeO + CO \longrightarrow Fe + CO_2 \text{ ----------------------- (13)}$$

$$FeO + H_2 \longrightarrow Fe + H_2O \text{ ----------------------- (14)}$$
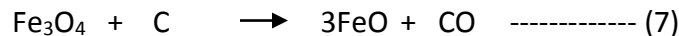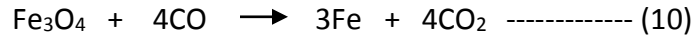
(wustite is stable only at temperatures above 570°C)   (Direct From Midrex, 1992)

DRI is usually produced from the furnace in the carburized form. The carburization reactions are as follows:

$$3Fe + CH_4 \longrightarrow Fe_3C + 2H_2 \text{ --------------- (15)}$$

$$3Fe + 2CO \longrightarrow Fe_3C + CO_2 \text{ --------------- (16)}$$

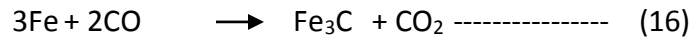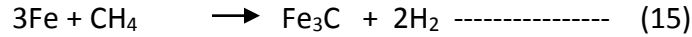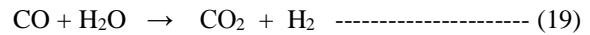$$3Fe + CO + H_2 \longrightarrow Fe_3C + H_2O \text{ -------------- (17)}$$

$$Fe + CO + H_2 \longrightarrow FeC + H_2O \text{ ------------- (18)}$$

An investigation into the internal reduction of hematite ore in hydrogen and carbon monoxide was carried out by Turkdogen and Vinters (1971). They discovered that the rate of reduction in H_2 – CO mixtures is in accord with that derived from the rate constant for the reduction in CO and H_2 even though the iron formed by reduction of dense wustite is similar to that formed by hematite.

The thermodynamic equilibria for these reactions are well established for these two major reducing agents used, viz., hydrogen and carbon monoxide (Direct From Midrex, 2000).

Now, reduction by carbon monoxide or by hydrogen is reversible.
In reduction by carbon monoxide the reactions listed above are nearly isenthalpic except for the reduction of hematite to magnetite, which is exothermic.

Reduction by hydrogen is endothermic. In addition, they found out that the rate of reduction of hematite increases with increasing pore surface area of the reduced oxide.

  Three important points are to be noted here:
  1) The kinetics of the above reactions are first order and the reaction rates are proportional to gas concentration.

  2) Concentration changes in the solid phase are proportional to the concentration change in the reactant gases.

  3) The Water Gas Shift Reaction (WGSR) is a very important part of the kinetics and linearly dependent with respect to the 2 main reactions above.

The WGSR is Reaction 1 minus Reaction 2 and is presented as follows:

$$CO + H_2O \rightarrow CO_2 + H_2 \text{ ---------------------- (19)}$$

Midrex reformer

Midrex designed and built the world's first commercial high temperature stoichiometric reformer. The concept is unique to the MIDREX Process and enables the production of a high quality reformed gas that can be fed directly to the direct reduction furnace.

The reformer converts recycled off gas from the MIDREX Shaft Furnace plus fresh natural gas into hydrogen (H_2) and carbon monoxide (CO). Unique to the process specifically due to the MIDREX Reformer is the recycle of waste CO_2 from the reduction furnace creating an additional reaction as follows (Midrex Solution for Steel Makers, 2012).

$$CH_4 + CO_2 = 2H_2 + 2CO \text{ ---------------- (20)}$$

This above reaction in the reformer, takes place when the cleaned process gas of the furnace is blended with fresh natural gas, then heated and converted to hydrogen and carbon monoxide by means of a catalytic reaction. The hot reformed gas is sent directly to the shaft furnace (Kempken et. al., 2008).

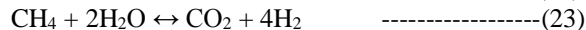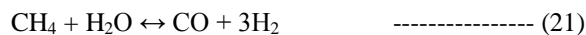A Midrex reformer differs from the conventional steam reformers in several ways:
• A typical steam-reformer operates at pressures of 20 to 40 bar, but the Midrex reformer operates at pressures of 2 to 3 bar. Shorter tube length and larger tube diameter in a Midrex reformer impose less pressure drop compared with the conventional steam-reformers.

• At high mass velocities in conventional steam reformers (G_M = 10 to 23 kg/m2/sec), the radial diffusivity will be too high to allow the development of significant radial concentration. However, in a Midrex reformer, mass velocities are considerably lower (G_M = 2 to 5 kg/m^2/sec), and significant radial gradients may develop inside the tubes. This, in turn, increases residence time and hence, the risk of carbon formation is amplified.

• In a Midrex process, design specifications necessitate that the reformer feed gas be a mixture of the off gas stream from the moving bed reactor and fresh natural gas. Since hydrogen and carbon-oxide comprise more than half of the off gas stream, the reformer feed gas is far above the equilibrium condition. As a result, at typical feed temperatures of about 400^OC – 500^OC, set by process economics, the reforming reactions cannot proceed, whereas the carbon formation reactions have a high potential of stepping up. Moreover, this relatively low temperature of feed gas results in a very large gradient between the furnace gas temperature and process gas temperature at the reactor inlet zone, which consequently develops a large gradient inside the tubes.

• The carbon dioxide content of feed gas in a Midrex reformer is significantly higher than most conventional steam reformers.
This specification, together with a low content of steam, dictated by design specifications, entails a greater risk of carbon deposits, which must be balanced by selecting appropriate operating reaction parameters and catalysts (Vakhshouri and Hashemi, 2007).

Other reactions which occur in the reformer include:

$CH_4 + H_2O \leftrightarrow CO + 3H_2$ --------------- (21)
$CO + H_2O \leftrightarrow CO_2 + H_2$ ----------------(22)
$CH_4 + 2H_2O \leftrightarrow CO_2 + 4H_2$ -----------------(23)

Quality of direct reduced iron
DEFINITION OF DRI QUALITY

DRI quality is defined by the following factors:
- The amount of fines. This affects the energy efficiency of the electric arc furnace operation and may cause contaminations of the electrical parts. It also causes problems in handling and loading the DRI.

- The amount of carbon. The amount of carbon in the DRI is controlled between 1-2.5 wt %. It has been reported that more than 90% of the carbon present is utilized for the following reactions, if sufficient oxygen is supplied:
  a. Endothermic Reaction, where iron oxide and carbon reacts to form iron:
  More than 90 wt % of the FeO present in the DRI gets reduced by this reaction. It was reported that for each 1.0% Fe in the form of FeO present in the DRI theoretically requires wt 0.215% C to reduce it.
  b. Endothermic Reaction 40, generation of carbon monoxide to increase iron
   recovery by reduction of FeO present.
  c. Exothermic Reaction, oxidation of carbon:
  This oxidation reaction replaces a considerable amount of electric energy required for melting in the electric arc furnace with chemical energy. If the carbon in DRI is in the form of iron carbide, more chemical energy can be obtained by its oxidation. In addition, oxidation of carbon produces CO, which provides stirring and slag foaming in the electric arc furnace bath. Slag foaming in the electric arc furnace increases the thermal efficiency, protects the furnace walls and roof from the intense electric arcs, and prevents nitrogen and hydrogen from being exposed to the arc where it can dissolve in to the steel. Stirring of the bath improves the reaction kinetics by renewing the slag/metal reaction interfaces.
- The amount of iron oxide and metallic iron. The amount of iron oxide present determines the amount of extra energy required for reduction. It is reported that if the metallization is not completed in the direct reduction process, theoretically 41 MJ/ton of energy is required to reduce 1% Fe present as wustite (FeO) into metallic iron in an electric arc furnace (when metallizaton

is between 91-95%). Thus, the higher the metallization of the DRI, the lower the energy required to reduce wustite (FeO) present in the structure.

- The amount of slag. This amount determines the extra amount of energy and residence time required to melt it. However, its presence also substitutes for slag-building agents in the electric arc furnace burden (Poveromo and Swanson 1999).

Measurement of Dri quality
The quality of direct reduced iron is measured based on two major parameters i.e.
. etallization
. arbon content.

Metallization.
Metallization represents the extent of the reduction reactions in Equations (13) and (14). Iron oxide that has not been exposed to reducing conditions has zero percent metallization i.e., none of the iron is present as Fe so the reduction reaction is zero percent complete.

On the other hand, iron oxide that has been exposed to gas having a quality greater than two, for a period of time will have a percent metallization greater than zero E.g. 90 % metallization means that 90 percent of the iron is present as Fe and 10 % as iron oxide.

By definition therefore, metallization is the ratio of metallic iron to total iron. There are several factors that determine or affect metallization (Turkdogan et. al 1971).
These include:
urden temperature.

The burden temperature will determine the equilibrium conditions for the reduction reactions at a given Bustle (reducing) gas quality since the bustle temperature affects the burden temperature and reaction kinetics are favoured by higher temperatures.

The reaction in Equation 13 is exothermic while that in Equation 14 is endothermic. Now FeO reduction by H_2 is faster than FeO reduction by CO.

An increase in the H_2/CO and increase in temperature favours the kinetics for both reduction reactions. Table 3 shows the ranges of the H_2/CO ratio for the various Midrex processes. The DSC plant was always operated with ratios of between 1.5 and 1.7%.

TABLE 3: Reducing gas ratio for Midrex Plants (Source: Midrex Technologies, 2012).

Energy Source	Midrex Plant Reference	Reducing Gas Train	Reducing Gas H_2/CO	Start-up
Corex offgas	Arcelor Mittal South Africa	CO_2 Removal + Heater	0.3 to 0.4	1999
Corex offgas	JSW Projects Limited	CO_2 Removal + Heater	0.5 to 0.6	construction
Coal Gasifier	JSPL Angul I	CO_2 Removal + Heater	2.0	construction
Natural Gas	Numerous - 60 modules in operation	Midrex Reformer	1.5 to 1.7	since 1969
Natural Gas	FMO (formerly OPCO)	Steam Reformer + Midrex Reformer	3.2 to 3.9	1990

Bustle gas composition and flow.

The bustle gas composition with respect to equilibrium, determines the driving force for the reduction reactions.
In general, more H_2 or CO will increase metallization. An increased bustle gas flow per tonne will ensure that the gas contacting the ore is further from equilibrium, and therefore, metallization will increase.

Residence time in the reduction zone.

The residence time in the reduction zone, for proper metallization to occur is usually between 3 – 5 hours. Given uniform mass flow, the rate – limiting diffusion steps would take place during this period.

Product Discharge rate.

For each 1 percent increase in metallization percentage, there is a 2.5 percent decrease in production. This is shown in Figure 14.
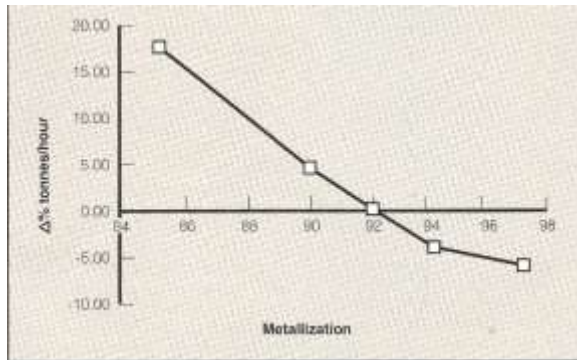
FIG 14: Effect of change in Production on Metallization.
(Source: Direct From Midrex, 1992)

Type of ore.

It is known that reaction rates are determined largely by diffusion rates and surface area available for reaction. The pore diameter, porosity, external surface – to – volume ratio, pellet diameter and other physical properties associated with a particular ore, will determine the rate and extent of metallization.
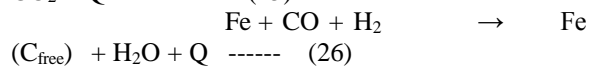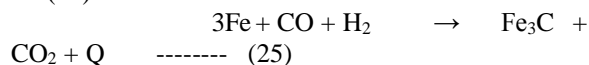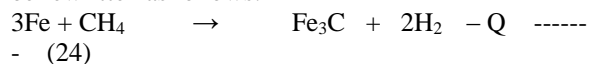
Carbon Content

DRI usually exits the furnace as iron carbide as seen in Equations 15 – 18.

The importance of carbon in DRI has gained more prominence as a result of the need for improved productivity in steel manufacture. This has led to increased oxygen consumption so as to obtain additional energy input from oxidation reactions.

In order to minimize iron oxidation and avoid excessive yield loss, some form of carbon is normally used as a fuel source. The traditional method of adding carbon is as coke/coal which is either batch charged or injected. Today one of the easiest means of doing this is through DRI or iron carbide. A carbon content of about 1.5 – 1.8 % in the DRI, is optimal for steel producers. (Yu and Gillis, 1981).

Total carbon is the carbon content of the direct reduced iron. About two thirds of the iron is present as iron carbide and the balance is deposited as carbon black or free carbon.

The carburization reactions in Equations 15 – 18 can be rewritten as follows:

$$3Fe + CH_4 \rightarrow Fe_3C + 2H_2 - Q \ ------ (24)$$

$$3Fe + CO + H_2 \rightarrow Fe_3C + CO_2 + Q \ -------- (25)$$

$$Fe + CO + H_2 \rightarrow Fe (C_{free}) + H_2O + Q \ ------ (26)$$

where Q is heat.

From Equation 24, hot iron cracks methane which is added either to the reformed gas or the cooling gas. Equation 25 shows high temperature H_2 reduction. Equation 26 shows the production of free carbon or carbon black which is obtained by lower temperature H_2 reduction.

Since the inauguration of the first commercial plant in 1969, seventy-two MIDREX plants have been built in twenty-one countries so far. The MIDREX process occupies a market share of about 60% among DRI making plants. This is a result of the improved reliability of the MIDREX process, as well as improved process efficiency, which is widely recognized and highly evaluated. (Atutshi et. al., 2010)

The nigerian steel industry

By the current estimate, the annual per capita consumption of Steel in Nigeria is about 10 kg while the corresponding world average is 130 kg. In terms of Apparent Steel Consumption (ASC), Nigeria is lagging behind when compared with countries like Algeria with 42 kg/capita, Egypt with 38kg/capita, and Zimbabwe with 25 kg/capita. This is an indication that Nigeria which is the most populous country in Africa has a large room and huge potential domestic market that can sustain rapid growth in the metals and related product sector. (Federal Ministry of Mines and Steel 2006 - 2012)

As a result the National Steel Policy was formulated and which among other things include:
- To increase the present per capita consumption of steel products from about 10 kg to about 100 kg within a few years,
- To become a regional and global producer of steel with a target of 12 million tonnes by the year 2020.
- To attain private investment and expand value-adding downstream industries.
- To accelerate the growth of export of value-added metals and related products through increased processing of metals and metal products,

The first steel plant in Nigeria (a mini steel plant) was established at Emene, near Enugu, in 1962 by the then Eastern Nigerian Government. Two similar plants were established in Lagos in 1968 and 1970 through private initiative. (Federal Ministry of Mines and Steel 2006 - 2012)

Under the auspices of the NSDA, Nigerian and Soviet geologists and technologists were able to determine the resources and suitable local raw materials required to set up an integrated iron and steel plant at Ajaokuta in Kogi State. Table 4 shows the availability and location of iron ore deposits in Nigeria.

TABLE 4: Location of iron ore deposits in Nigeria.

STATE	LOCATION	ESTIMATED RESERVE (tonnes)	Wt % Fe
Kogi	Agbaja	1 billion	45-54
	Itakpe	200-300 million	38-45
	Ajabanoko	60 million	40
	Koton-Karfe	2 million	43-53
	Choko-choko	10 million	35
	Agbado-Okudu	70 million	37-43
	Kakun	-	40-55
	Bassa Nge	40million	43-49
	Fatti	37	46
Enugu	Nsude Hills	60 million	37.43
Nasarawa	Muro Hills	Not available	35
Kebbi	Dakingari	Not available	27-30
Bauchi	Rishi	Not available	14-19
	Gamawa	Not available	40-45
Borno	Karfa	Not available	34-45
Kaduna	Tajimi,	Not available	22-52
	Ayaba	Not available	27.5
Benue	Egenerja	Not available	34-45
Anambra	Nsude	43-50 million	43-45
Zamfara	Maraba Hill	Not available	-

Sources: Raw Materials Sourcing for Manufacturing in Nigeria,
Inventory of Nigeria Minerals and Mines.
Journals of Minerals and Metallurgical Processing.
NIOMCO

The ajaokuta steel plant

The Ajaokuta Steel Company, was established as an integrated industrial complex from conception and has its own port on the Niger River, a railroad for transporting ore from nearby National Iron Ore Mining Company (NIOMCO) at Itakpe which was charged with the responsibility of mining and processing iron ore by means of its Beneficiation plant consisting of three lines, was to make available concentrate of about 63% total iron and earmarked to supply a total of 2.155 million tonnes per year iron ore requirement of the Ajaokuta Steel Project which

upon completion was expected to jump-start the country's industrialization.

According to the plan, the first phase would produce 1.3 million tonnes of liquid steel per annum. The second phase would expand production to 2.6 million tonnes per annum, while the third and final phase would push up capacity to 5.2 million tonnes per annum. This production capacity of the company was expected to drastically meet Nigeria's dependence on imported steel.
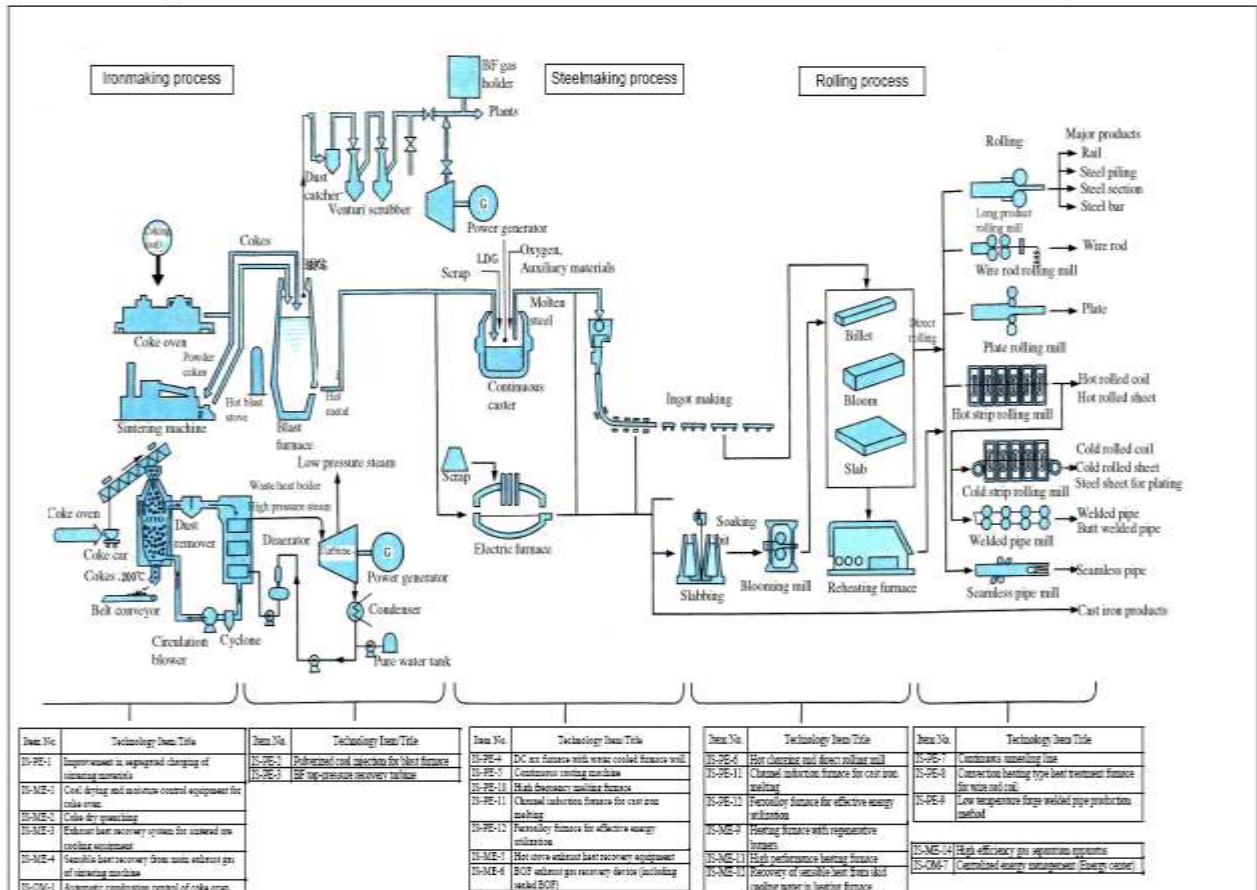

FIG 15 : SCHEMATICS OF AJAOKUTA IRON AND STEEL COMPLEX. (Aderibigbe, 2011)

The Plant is made up of basically five (5) stages in the iron and steel processing operations by which raw materials are to be converted to finished steel products. These are:

(i) Raw materials preparation and Coke making.
(ii) Iron Making.
(iii) Steel Making.
(iv) Continuous Casting or Continuous Rolling.
(v) Finishing Operations.

The major raw materials required for the steel production are Iron Ore, Limestone and Coking coal.

One major challenge with the Ajaokuta plant is the supply of coking coal.

Coking coal has not been found in Nigeria in both quality and quantity. Therefore about 1.3 million tonnes of coking coal which would be required per year for the Phase 1 of the project must be imported to produce metallurgical grade coke for the operation of its Blast furnace.

Another challenge associated with the operation of both the Coke Oven Plant and the Iron Blast Furnace was that they require continuous operations (24 hours per day) for at least five (5) years (i.e. one campaign life of the Furnace). Any shut down within this period (as a result of unsustainable production) will result in the destruction of the two facilities.

Also the storage life of coking coal is very short with deterioration in properties common within four months of storage. On the other hand, availability of metallurgical coke is very scarce in the world market. As a result adequate foreign exchange has to be

available to ensure uninterrupted supply of coke. [Aderibigbe, 2011)

A third challenge stemmed from observing the three basic functions of metallurgical coke in an iron blast furnace namely;

   i.   Fuel to provide the heat for melting;
   ii.   Source of reducing agent and
   iii.   The provision of a permeable support bed for the charge and molten metal.

The implication of these functions is that the amount of metallurgical coke required for the operations of the Blast Furnace is not dependent on the capacity utilization for iron ore sinter feed for the production of molten pig iron. Therefore, it may reasonably seen that whether the furnace operates at 10 %, 30 %, 60 % or 100 % capacity utilization, the amount of metallurgical coke required may be about the same for all practical purposes. (Aderibigbe, 2011).

Although the main contract for the establishment of the conventional Blast Furnace – Basic Oxygen Furnace route to steel production was signed in 1979, global recession, poor funding and the installation of massive infrastructural facilities stood on the way of the completion and full commissioning of Africa's largest steel making Plant.

Due to this delay, and convinced by its well-advertised advantages which include:

   a) Efficient use of the abundant Natural Gas
   b)   Independence from Coke imports
   c) Capacity sized to meet needs rather than economy of scale
   d) Electric Arc Furnaces can be rapidly started and stopped, allowing the steel mill to vary production according to demand.
   e) Lower capital cost per ton of Product
   f) Shorter construction time (Less than 4 years),

the Federal Government of Nigeria signed an agreement with a consortium of 10 Austro-German companies on 3rd October, 1977, to set up a Direct Reduction – Electric Arc Furnace integrated Steel Plant with a capacity of One million tonnes per year of liquid steel at Ovwian-Aladja in Delta State, starting from the iron ore stage to the final liquid steel. This gave birth to the Delta Steel Company (DSC).

Delta steel company
The plant was officially commissioned on the 29th of January 1982 to supply two thirds of its billets to the inland Rolling mills at Oshogbo, Katsina and Jos. (Raw Materials Research and Development Council, 2010)
Production at DSC rose from 9% in that year to about 24% in 1985.

The major units of the plant are:

Pelletizing plant
Direct reduction plant
Steel melting shop
Continuous casting plant
Rolling mills

Delta Steel Company Direct Reduction Plant
The Direct Reduction Plant is made up of two Midrex based 600 Series modules with a total installed capacity of 1.2 million tonnes of cold direct reduced iron. They were put into commercial operation in 1983, after successful Performance Guarantee Tests (PGT).

The two major units of the plant are:
   1) The gas reformer
   2) The shaft furnace.

Other features include:
   a.   Oxide (Day) Bin
   b.   Top Gas Scrubber
   c.   Gas Recuperator
   d.   Reformed Gas cooler
   e.   Cooling Gas scrubber
   f.   Process and Cooling Gas Compressors
   g.   Combustion system
   h.   Seal Gas system.

The gas reformer
The Reformer of the DR Plant at Delta Steel Company utilizes the off Gas Reforming technology.

The fresh natural gas feed and reduction furnace off gases are mixed and preheated in the heat exchanger unit (Recuperator). These mixed gases are reformed primarily according to the reactions in equations 20 and 21.

These two reforming reactions are highly endothermic and require high temperatures in order to obtain high hydrogen productivity.

This process by which rich reductants are generated for use in the reduction furnace, uses the supply of heat from the burning of the reduction furnace off gases, and additional fuel which is usually added.

The Gas Reformer itself generates about 50 % of the reductants required in the reduction furnace. The other 50 % is obtained through the recycling of the 2/3 portion of the Top Gas that is scrubbed and the mist removed, to form the process Gas.

The schematics of the gas reforming system at DSC is shown in Figure 16.
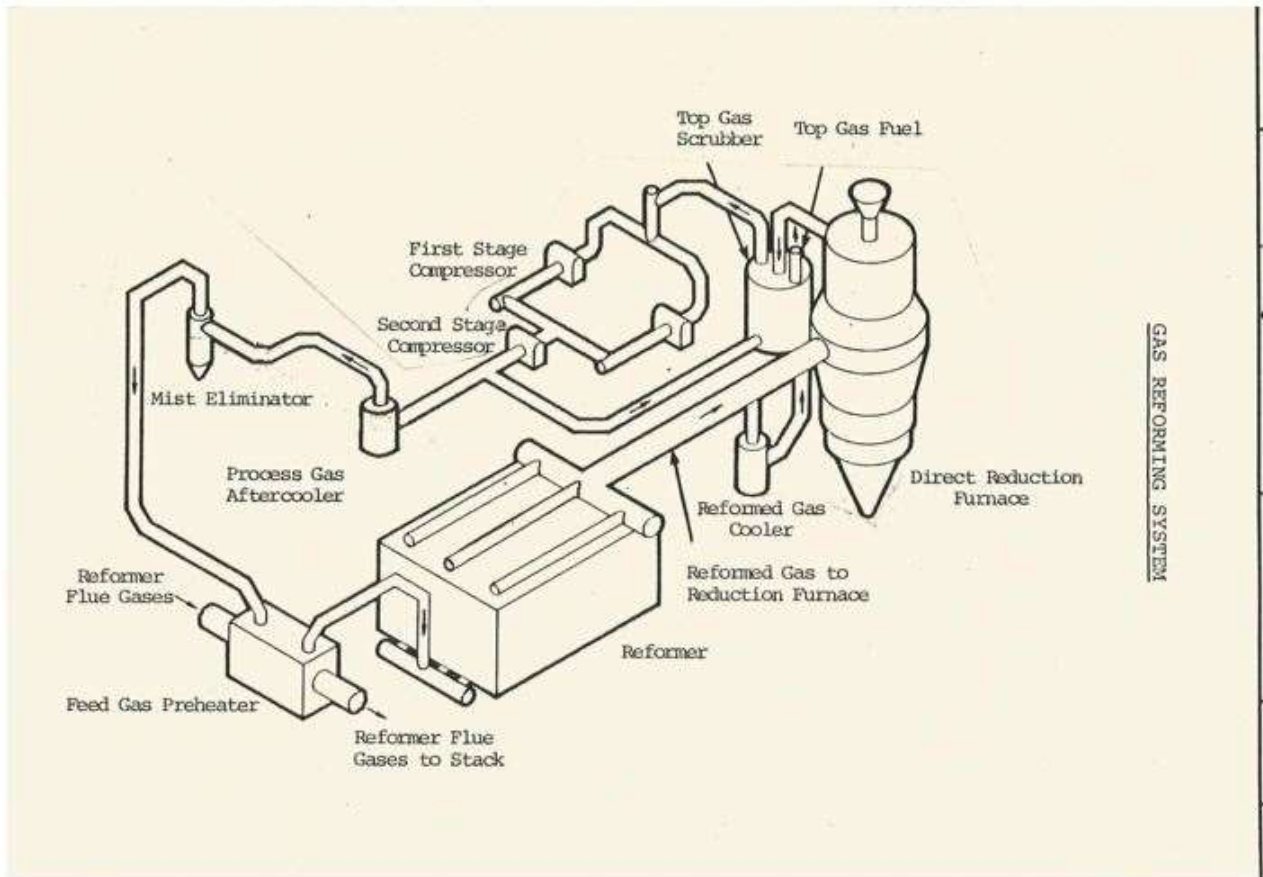
FIG 16: Gas Reforming System. (Source: Direct Reduction Plant Operating Manual, 1981)

Preheated natural gas is added to the stream to form the feed gas, which is passed through the heat exchanger (Recuperator) to the reformer

The reformer contains 360 alloy tubes which hold the proprietary high-activity, commercial and conventional nickel-based catalyst supported on a refractory base, alumina, which is utilized for the gas reforming reactions in these processes.

The Reduction Shaft Furnace
The reduction shaft furnace at Delta Steel Company is the 600 Series with a diameter of 5.5 meters. The structure is shown in Figure 17.
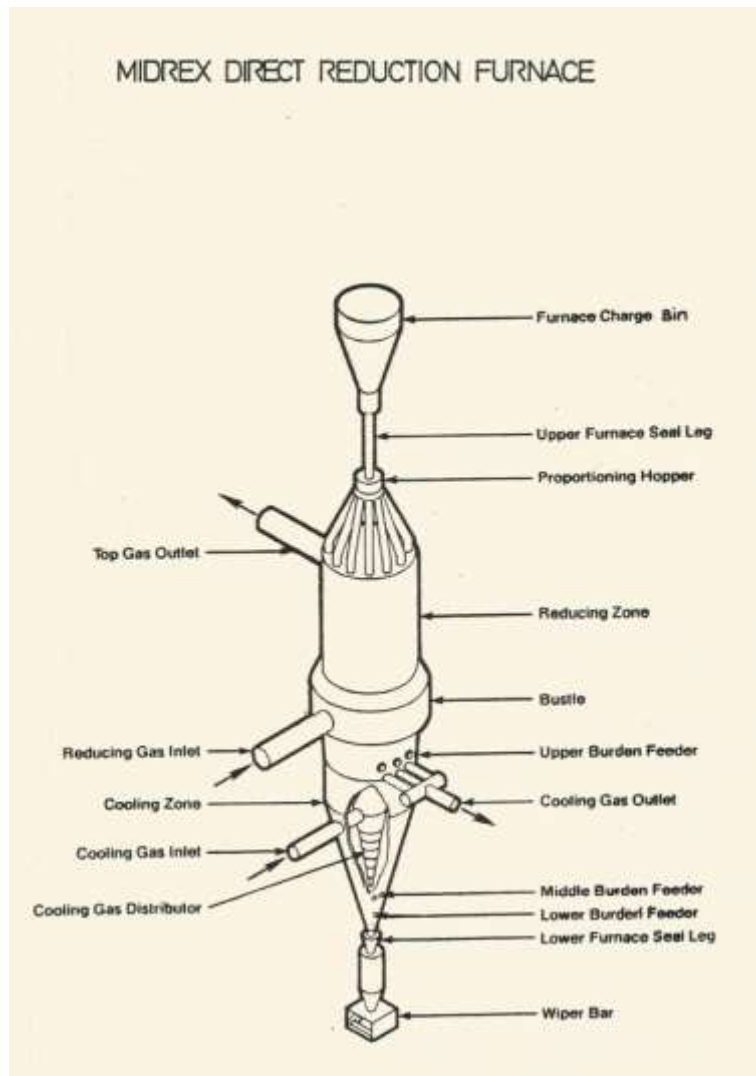
FIG 17: Reduction Shaft Furnace. (Source: Direct Reduction Plant Operating Manual, 1981)

The furnace is designed to optimize process efficiency and metallization while preserving existing environmental standards.

The Furnace is divided into two major parts with a transition zone between them.
These are namely:
1. The Reduction zone at the top end of the furnace, and
2. The Cooling zone at the bottom end.

In the Furnace, the Iron Oxide feed material comes in contact with a countercurrent flow of hot reducing gases and is reduced to metallic iron.
The Furnace zones are shown in Figure 18.

FIG 18: Direct Reduction Furnace zones. (Source: Direct From Midrex, 1992)

The reduction zone is made up of the upper half of the furnace, extending from the feed stock line down to the reformed gas inlet (Bustle). It is here the oxide is heated to the process operating temperature and reduced to metallic iron.

The reducing gas enters the furnace as shown and exits as Top gas after contact with the oxide pellets and completion of the reduction process.

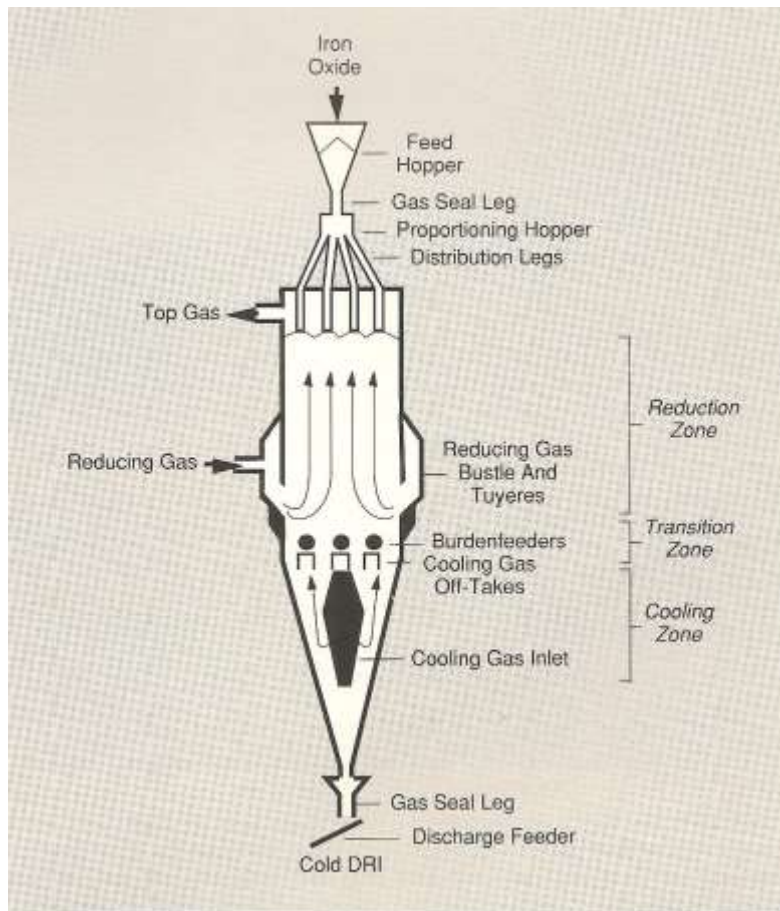The reduced iron (Sponge Iron) is discharged from the lower part of the furnace at temperatures between 40 -55˚C.
Below the reduction zone, is the cooling zone, the conical shaped region where a flow of gas cools the product prior to its discharge from the furnace.

At the bottom of the furnace, is a second (Bottom) Seal leg and product discharge mechanism.

The furnace charge bin is the container at the top of the furnace that receives iron oxide from the Flexowell conveyor (oxide feed belt). The bin is designed with adequate storage capacity to permit safe, short-term operation of the furnace. If an interruption in the material feeding system should occur. It is furthermore equipped with level control and alarm devices.

The reduction furnace top seal connects the furnace charge bin with the proportioning hopper and provides a free flowing, unrestricted path for descending oxide material while maintaining a gas seal between the reduction furnace and the outside atmosphere.

The seal is accomplished by introducing seal gas at the base of the seal leg and utilizing the resistance of the gas flow to the atmosphere provided by the material contained within the leg to maintain a pressure slightly greater than the furnace gas pressure.

At the lower end of the seal leg is a distribution manifold through which the iron oxide is charged into the furnace via feed legs.

The distribution manifold and the attached feed legs are designed to prevent segregation of material and to uniformly distribute the incoming material in the reduction furnace.

Each feed leg receives an equal quantity of oxide. This distribution and feeding system has been proven to be extremely effective in ensuring a uniform particle size distribution.

Near the bottom of the reduction zone, reducing gas from the reformer enters a circumferential chamber called the Bustle that distributes the gas uniformly around the periphery of the furnace. The reducing gas enters the furnace on a trajectory through uniformly spaced bustle ports.

The gas flows upwards through the burden, heating the oxide and reducing it to metallic iron. The partially spent reducing gas then leaves the furnace through the Top gas outlet and goes to the top gas scrubber.

Directly underneath the reduction zone are Burden Feeders which promote uniform burden descent through the furnace. The upper burden feeder lies just below the bustle area. At this elevation, the reduction process has been completed, and the reduced iron moves into the cooling zone.

The cooling of the reduced material is accomplished in the conically shaped lower half of the reduction zone. Here a cooling gas is introduced into the moving bed through a gas distributor located in the center of the cooling zone. Figure 19 shows the cooling gas circuit
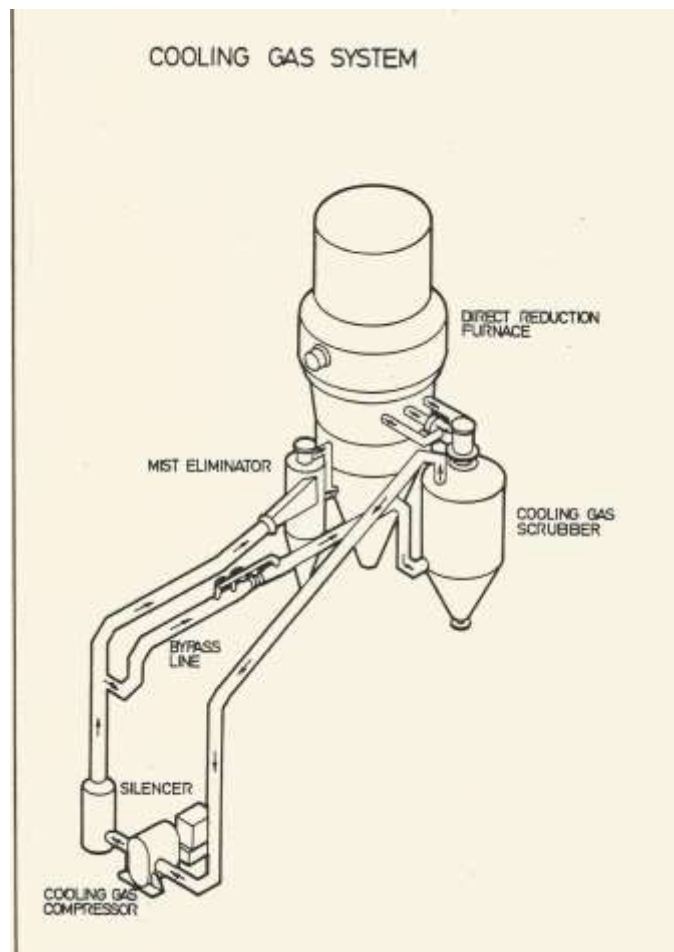

FIG 19: Cooling Circuit of the Direct Reduction Furnace. (Source: Direct Reduction Plant Operating Manual, 1981)

The cooling gas flows upwards through the bed, and is withdrawn from the furnace through offtakes located just below the upper burden feeders

The cooling zone gas is sufficiently low in both oxidants and reductants to be essentially inert. Its primary function is cooling, which is strictly a heat transfer operation.

In the lower part of the cooling zone are two additional burden feeder systems to maintain uniform material flow.

Located below the cooling zone is the Bottom Seal Leg, which contains the cooling zone gases within

the furnace. As with the top seal leg, the bottom seal leg seals combustible gases within the furnace, without impeding the movement of the direct reduced iron.

The reduction furnace discharge mechanism is called the Wiper Bar. It is a positive displacement volumetric feeder that regulates the rate at which metalized product is discharged from the furnace.

The metalized product, the Cold DRI, is transported via conveyor belts to inertized silos for storage prior to utilization for steel making in the in-house Electric Arc Furnaces.

Iron Ore Feed Types Utilized In DSC.
The following iron ore feeds were utilized in DSC in order to keep the plant in production:

Oxide Feed Material	Year
Lamco ore from Liberia (100%)	1982 – 1983
Feijaio ore from Brazil (100%)	1983 – 1985
CVRD ore from Brazil (100%)	1986 – 1987
CVRD with recycled material blend	1987
Lamco with recycled material blend	1988
Lamco with oxide/metallized fines blend	1988 – 1989
Itakpe ore (100%)	1995

NOTE: Recycled material blend consisted of Feijaio and CVRD ores.

TABLE 5: Physical Properties of Ores processed at the Direct Reduction plant

PHYSICAL PROPERTIES	UNIT	LAMCO ORE	FEIJAIO ORE	CVRD ORE	ITAKPE ORE	STANDARD
Tumble Index (+6.3mm)	%	95.34	95.33	97.33	94.51	93.0 (Min)
Abrasion (- 1mm)	%	2.0	2.67	2.0	3.93	5.0 (Max)
Compression Strength	N/P	4420	4540	4850	4561	2000 (Min)
Screen Analysis 6.3mm – 16mm Fines (-6.3mm)	%	97.25 2.75	98.22 1.78	96.49 3.51	96.24 3.76	96.0 (Min) 2.5 (Max)
Bulk Density	T/M^3	2.22	2.32	2.49	2.51	2.1 – 2.2

TABLE 6: Chemical Properties of ores processed at the DR plant

CHEMICAL PROPERTIES	UNIT	LAMCO ORE	FEIJAIO ORE	CVRD ORE	ITAKPE ORE	STANDARD
Fe_{total}	%	65.7	65.9	65.9	65.8	67 (Min)
Fe_2O_3	%	94.0	94.2	94.2	94.1	95 (Min)
CaO	%	1.87	1.93	0.84	0.13	2.5 (Max)
Al_2O_3	%	0.25	0.80	0.36	0.80	0.7 (Max)
SiO_2	%	2.45	2.05	2.30	3.93	2.0 (Max)
MgO	%	-	0.05	-	-	1.0 (Max)
H_2O	%	0.03	-	0.34	0.56	-
P	%	-	0.029	0.005	-	0.03 (Max)
S	%	-	0.003	0.011	-	0.015 (Max)
TiO_2	%	-	-	-	-	0.3 (Max)

TABLE 7: Physical Properties of DRI derived from Itakpe ore

PARAMETER (WT %)	DSC SPECIFICATION	ITAKPE
Compression Strength (N/P)	700 min	970
Grain size (9.5 – 16mm)	90 min	89.5
Tumble Index (6.3 – 16mm)	80 min	83,33
Abrasion Index (-1mm)	6.0 min	6.67
Fines level (%)	6.0 min	6.70

TABLE 8: Chemical Properties 0f DRI derived from Itakpe ore

PARAMETER	DSC SPECIFICATION	ITAKPE
Degree of Metallization	88 min	92
Fe_{total}	90 min	88
Fe_{met}	82 min	81
FeO	2.2 – 9.4	9.1
CaO	0.04 – 2.5	1.22
$SiO_2 + Al_2O_3$	3.6 max	5.42
C	1.1 – 2.0	2.06
MgO	0.04 max	Trace
P	0.03 max	-
S	0.03 max	0.006
Reduction Temperature ^{O}C	760 – 850	760

TABLE 9: Average Specific consumption figures per tonne of Product

PARAMETERS	STANDARD VALUES	IMPORTED ORES	ITAKPE ORE
Iron oxide	1.45	1.50	1.46
Natural gas (net Gcal)	2.25	2.25	2.36
Electricity	95	115	125
Oxygen	0 – 15	10	10
Nitrogen	-	20	25
Water (m^3)	1.0	4.5	3.5

TABLE 10: Typical composition of Reformer Gases

	FEED GAS (%)			REFORMED GAS (%)		
	Standard	Imported ore	Itakpe ore	Standard	Imported ore	Itakpe ore
H_2	35	35	36	55	55	54
CO	19	18	18	35	34	35
CO_2	15	13	14	2	2.5	2
H_2O	13	15	14	4	4	4.5

CH_4	17	17	16	1	2.5	2.5
N_2	1	2	2	1	2	2
Temp (^{O}C)	580	450	450	980	930	930

Conclusion

The development of the local steel industry is imperative if Nigeria is to join the league of industrialized nations and attain the Vision 20 - 20 - 20 goal.

The Ajaokuta Steel Company, established in 1979 as an integrated industrial complex upon completion was expected to jump-start the country's industrialization and drastically reduce Nigeria's dependence on imported steel. However, more than 33 years after the project was conceived, the dream of achieving self-sufficiency in steel production, as well as exporting steel and steel products to other countries remains largely unrealized from this source. Having successfully produced steel from imported raw materials and later from local raw materials at The Delta Steel Company, through the Midrex based direct reduction plant, the stage seems set for the achievement of the National Policy on Steel which among other things includes, increasing the present per capita consumption of steel products from about 10 kg to about 100 kg within a few years and ensuring Nigeria becomes a regional and global producer of steel with a target of 12 million tonnes by the year 2020.

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