REMODIFICATION IN THE OXIDE FEED SYSTEM FOR MIDREX DIRECT REDUCTION SHAFT FURNACE OF THE DELTA STEEL COMPANY

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Abstract

The oxide pellets feed from the day-bin goes to charge-bin (top of the furnace) through the flexowell conveyor belt. A mesh at the inlet to the furnace prevents direct entry of the oversize into the furnace. These oversized materials accumulate occasionally cause blockage hence impeding material flow. Accumulated oversized materials spill out from the 65m platform of the shaft furnace. Also oversize pellets entering the furnace through the by-pass chute from the charge bin create channeling, bridging and excessive fines. Persistent bridging can lead to uneven burden temperature distribution that can result in hot spots and clusters within the furnace which can have dire consequences on the entire production campaign. Wet materials during monsoon season create blockages at the transfer chute of the oxide feed system impeding free flow of oxide pellets to the charge bin from the flexowell. Modifications were carried out in the oxide material handling system so as to forestall any incidences that may lead to bridging or channeling that could result in downtimes or plant shut downs.

Introduction

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.

Now 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 DR 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.

MIDREX direct reduction iron making reduces iron ore using 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 150000 tonnes/year, was built in Portland, Oregon, in 1969. The process was immature in 1978, when Kobe Steel began the construction of a plant with a production capacity of 400000 tonnes/year in the State of Qatar. Kobe Steel significantly modified the design, exploiting the company's technologies developed through blast furnace operation, and stabilized the then new process. On the other hand, MIDREX Technologies also carried out various improvements to the plants they built in various countries. These were all integrated in the early 1980s, making the process nearly complete. The maximum production capacity in 1984, when Kobe Steel became affiliated with MIDREX Technologies, was 600000 tonnes/year. Later improvements, made by Kobe Steel in collaboration with MIDREX Technologies, have dramatically increased the production capacity. In 2007, the scale reached 1.8 million tonnes/year, which is comparable to that of a small blast furnace (Atsushi et. al., 2010).

The MIDREX process either lump ore, or pellets prepared for direct reduction iron making, are charged as raw material from the top of a shaft furnace. The ore is reduced inside the furnace and the reduced iron is discharged from the bottom of the furnace. Reductant gas blown in from about the middle of the shaft furnace reduces the raw material above the nozzle and escapes from the top of the furnace. The cooling gas, which circulates in the lower portion of the furnace, cools the DRI. Both the charging and discharging ports are dynamically sealed by a sealing gas, allowing the continuous charging of raw material and discharging of DRI. (Atsushi et. al., 2010).

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However, the economic viability of a DRI project depends, not just on the urgent need for good, low-residual iron units, but on strategic economic determinants. The most important strategic factor is the location of DRI plants, as this translates into all the other important inputs. The positioning should be made in such a way that advantage can be taken of the proximity of good quality, low cost iron ore, as well as natural gas (or coal). Additionally, the plant should not be too far from the market or point of off-set as the transport cost can easily absorb the competitive advantage or profit made by such a project. (Grobler and Minnitt, 1999)

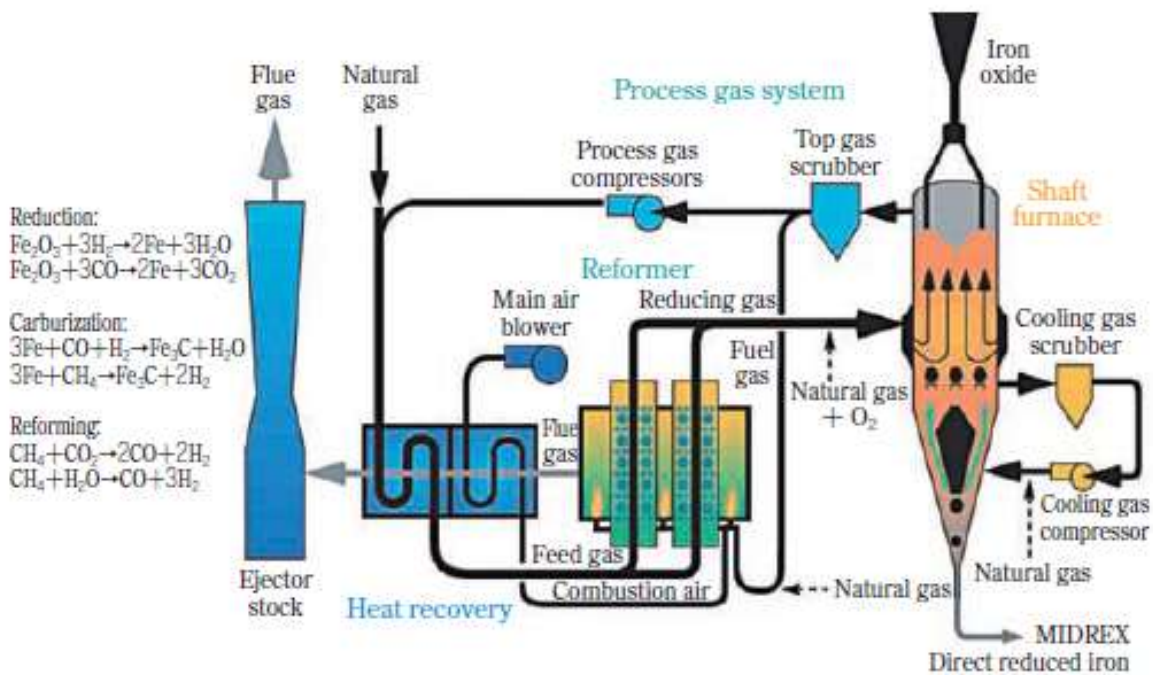The typical Midrex direct reduction plant is shown in Figure 1.

FIG 1: Flow sheet of the Midrex Direct Reduction Plant (Atsushi et. al., 2010).

The DELTA STEEL COMPANY Direct Reduction Plant comprises of two Midrex based 510,000 tonne capacity direct reduction modules. Each module comprises a Natural Gas Reformer which produces the reducing gases, CO and H2, to reduce Iron Oxide to Iron (specifically Iron Carbide, also known as Cementite, Fe3C) in a Shaft Furnace.
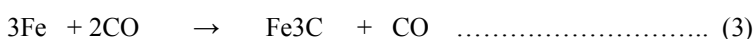
The reduction shaft furnace

The direct reduction plant shaft furnace is a 65m high structure designed to optimize process efficiency and metallization while preserving existing environmental standards.

On the top of the furnace is the oxide feed charging system and top Seal leg. 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 primary reactions taking place in the reduction zone are:

Reduction reactions:-

$Fe2O3 + 3H2 \quad \rightarrow \quad 2Fe + 3H2O$ ……………………….. (1)

$Fe2O3 + 3CO \quad \rightarrow \quad 2Fe + 3CO2$ ………..…………….. (2)
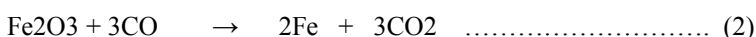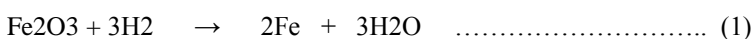
Carburization reaction:-

$3Fe + 2CO \quad \rightarrow \quad Fe3C + CO$ ……….…………….. (3)

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.

![Logo] Global Journal of Engineering Science and Research Management

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.
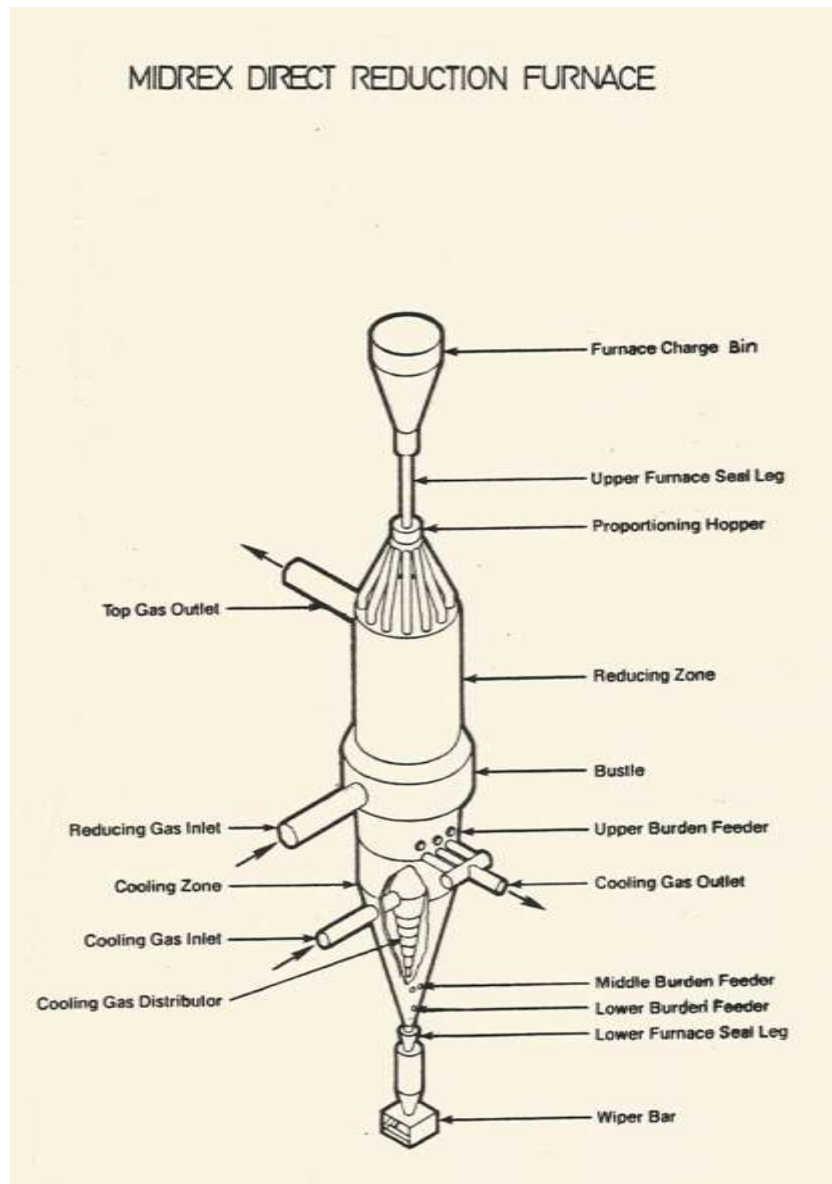

FIG 2: Reduction Shaft Furnace. (Source: Delta Steel Company Operations Manual, Vol 1. 1981)

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.

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The distribution manifold and 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. As shown in Figure 2, 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

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 gasses 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, or Sponge Iron (DRI), is transported via conveyor belts to inertized silos for storage prior to utilization for steel making.

The reformer
The reformer is a refractory lined, gas tight, welded steel structure containing 360 reformer tubes arranged in six rows. These 200mm I.D. tubes which have approximately 8 meters of heated length are anchored in the roof of the reformer and extend downward through the reformer casing. The reformer roof is insulated with light weight ceramic material while the walls are lined with ceramic block insulation. The reformer is constructed nearly air-tight hence resulting in combustion efficiency.

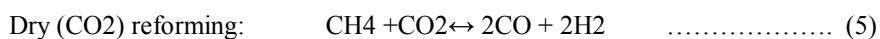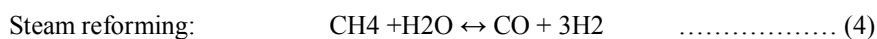A sketch of the reformer is shown in Figure 3

FIG 3: Natural gas reformer including the Recuperator. (Source: Delta Steel Company Operations Manual, Vol. 1. 1981)

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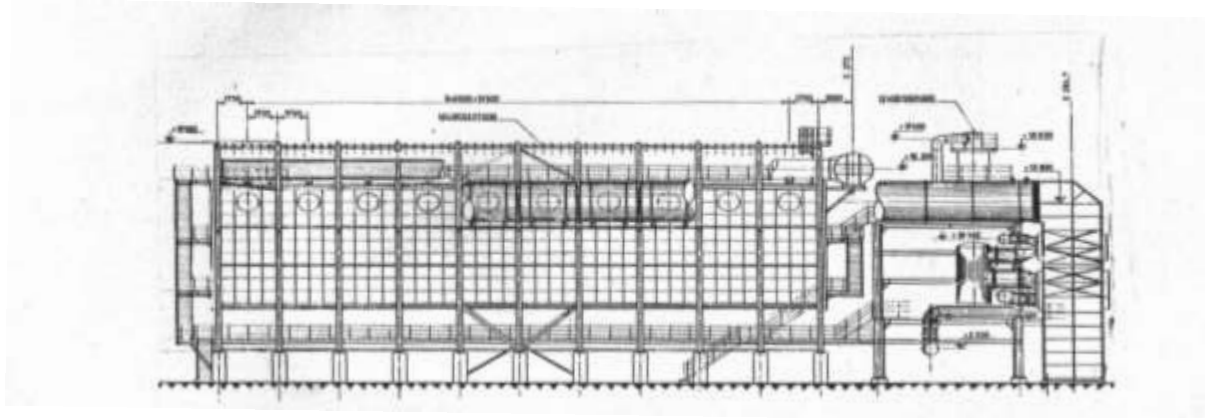
The efficiency of the reforming cycle is improved by recycling up to two-thirds of the process gas through the reformer. Since the scrubbed top gas from the shaft furnace still contains up to 70% of reductants, it is economically attractive to recycle this gas.

The preheated feed gas, consisting of recycled process gas and preheated natural gas, enters the bottom of the reformer tubes and flows upward through the catalyst bed.

The reforming reactions are as follows:

Steam reforming: $CH_4 + H_2O \leftrightarrow CO + 3H_2$ ……………… (4)

Dry (CO2) reforming: $CH_4 + CO_2 \leftrightarrow 2CO + 2H_2$ ………………. (5)

The combustion system is located between the tube rows in the middle of the reformer box. Preheated air is combined with surplus process gas plus some additional fuel and burned to provide the required heat input for the reformer.

About 15-30% of the natural gas consumed in the process is used to heat the reformer. Flue gas exits through two headers located on either side of the reformer. Since th oxygen concentration in the flue gas is low, flue gas is a suitable source of inert gas for the process requirements.

Close temperature uniformity from end to end of the reformer is achieved through even distribution of combustion gases. The flue gas leaves the reformer at a temperature of about 1100OC and is used to preheat combustion air, natural gas and feed gas.

Three reformed gas headers, one each for two rows of reformer tubes, collect the reformed gas. These headers discharge into a main header that transports the reformed gas into the reduction furnace for the reduction of the oxide material.

Oxide material handling system

The oxide material handling system enables the operation of either one or both direct reduction modules. The oxide material usually in the size range of 5-25mm diameter, from the oxide stock pile or the in-house Pellet plant, travels by conveyor belt to a screening station and then to a two-way transfer chute at the top of the oxide Day bins. The oxide material is fed into the two oxide bins each with a capacity of 1100 tonnes. Each bin is equipped with load cells and a discharge slide gate.

The material is extracted from the oxide bins by belt conveyors to the Flexowell conveyors. These conveyors elevate the oxide material to the charge hopper on the top of each reduction furnace.

A single idler belt weigher is installed in each of the conveyor systems for measuring the total quantity of oxide feed.

The furnace charge hoppers are equipped with level control devices that regulate the flow of material into the hopper. (Delta Steel Company Operations Manual, 1981)

Oxide feed material

The final chemical composition and physical form of the DRI is dependent on the raw materials used. High-quality direct reduced iron can be produced by the utilization of high-quality iron oxide feed stocks. Thus, the levels of gangue minerals and the

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percentage of oxide minerals present in the direct reduced iron can be adjusted with the quality of the iron oxide feed stocks materials utilized.

The direct reduced iron-producing reactions are solid state reactions (see Figure 1); the physical size distribution of the iron oxide feed stocks used as raw materials does not change (unless there are sticking and degradation problems) throughout the process (since only oxygen is removed from the structure). Accordingly, the physical size distribution of the iron oxide feed stocks utilized (pellets, lumps, sinters, green balls, briquettes, and fine ore) dictate the size distribution of the DRI produced. This determines whether there is a need for the briquetting of DRI produced, in order to reduce the surface area, to ease handling, shipping, transportation, and loading to the consequent operational reactor (electric arc furnace, blast furnace, foundry cupola, basic oxygen furnace).

Additionally, reducibility characteristics of the iron oxide feed stocks can be used to promote the efficiency and yield of the direct reduction processes. Iron oxide feed stocks with good reducibility, low sticking, degradation, and swelling properties are preferred. For example, if highly reducible iron oxide feed stocks are utilized, it is more likely to produce highly metallized DRI. (Anameric and Kawatra, 2007)

Shaft furnaces utilize iron ore pellets, lumps, briquettes, and sinters as iron oxide feed material for direct reduced iron production. The efficiency and yield of the shaft furnace operation is highly affected by the following properties of the feed materials:

1. **Size distribution**. The feed should have narrow size distribution for the formation of a permeable furnace bed to allow maximum reducing gas flow. This increases productivity and decreases the reducing agent consumption. Oversized feed material should not be introduced to the furnace, since due to the heat transfer properties, it would adversely affect the operation. Fine feed material also should not be introduced to the furnace, since it would decrease the furnace bed permeability, cause sticking problems, and reduce the furnace efficiency and yield.
2. **Mechanical strength**. The feed should have enough strength to support the weight of the furnace bed. This provides consistency on the permeability of the furnace bed and reduces cave-ins.
3. **Physical degradation properties**. Fragmentation of the feed should be decreased for promotion of the shaft furnace performance. The fine material formation during handling, shipping, and transportation; dropping to the furnace; and heating (thermal shock) should be minimized. The fines generated would either end up in the furnace gas system or would be converted to DRI fines, which might re-oxidize or get lost during transportation to the electric arc furnace (Poveromo and Swanson 1999). Additionally, the fines in the shaft furnace might cause sticking and buildup problems and reduce performance.
4. **Particle and bulk densities**. The weight of the furnace bed to be supported is directly proportional to the particle and bulk densities of the feed materials.

Operational parameters which can be adjusted with the physical characteristics of the iron oxide feed stocks include (Anameric and Kawatra, 2007):

1) Adequate bed permeability for reduction gases.
2) Adequate mechanical strength to support the weight of the bed.
3) Feed should not disintegrate when being fed to the reactor or when subjected to the thermal shock to reduce the amount of fines produced.

Use of lower grades of iron ore

One development that is being forced upon the iron making industry by simple Malthusian force is the use of lower grades of iron ore for making steel. To date, mankind has made approximately 35 billion tons of iron, using well over 50 billion tons of ore in the process. The rate of iron making has been   rapidly growing. Over half of the 35 billion tons were made within the last 30 years. The other 'less than half' was made in the preceding three thousand years.

As one might expect miners are always trying to take the least costly, highest quality ores. After taking 50+ billion tons to date, much of the truly high quality ore has already been used.

As so, necessity demands that we adjust to using lower grades.

The Midrex Process can easily reduce lower grade ores, but the issue is that costs increase in steelmaking by using these ores. Midrex Technologies, Inc. is actively working with partners to develop new melting practices, techniques and equipment to

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accommodate the lesser grade ores of the future. In fact, lower quality ores are often used in Midrex Plants depending on the cost of the raw materials and the impact of downstream steelmaking operations (Direct From Midrex, 2012)

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 – 2007
Lump ore	2007

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

The physical and chemical properties of the oxide pellets derived from these ores are shown in the following tables:

TABLE 1: 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	%	97.25	98.22	96.49	96.24	96.0 (Min)
Fines (-6.3mm)		2.75	1.78	3.51	3.76	2.5 (Max)
Bulk Density	T/M^3	2.22	2.32	2.49	2.51	2.1 – 2.2

TABLE 2: 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)

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Modification modalities

Normally the oxide feed system to the reduction furnace is designed to be problem free. However, bridging may occur in the top seal leg and in the feed legs when relatively large size materials or excessive undersize materials are fed into the furnace. The results of bridging include:

- a decrease in the top gas fuel due to loss of effective sealing of the top seal
- a decrease in the top gas CO_2
- an increase in the top gas temperature
- a rapid change in the seal leg differential pressure.

Persistent bridging can lead to uneven burden temperature distribution that can result in hot spots and clusters within the furnace. These can have dire consequences on the entire production campaign.

These modifications were done to eliminate any incidences of bridging that may result from the oxide material handling system. They were carried out during the utilization of the lump ore for direct reduced iron production.

Dosing belt discharge chute

Figure 4 shows the original design of the dosing belt-to-charge hopper arrangement.
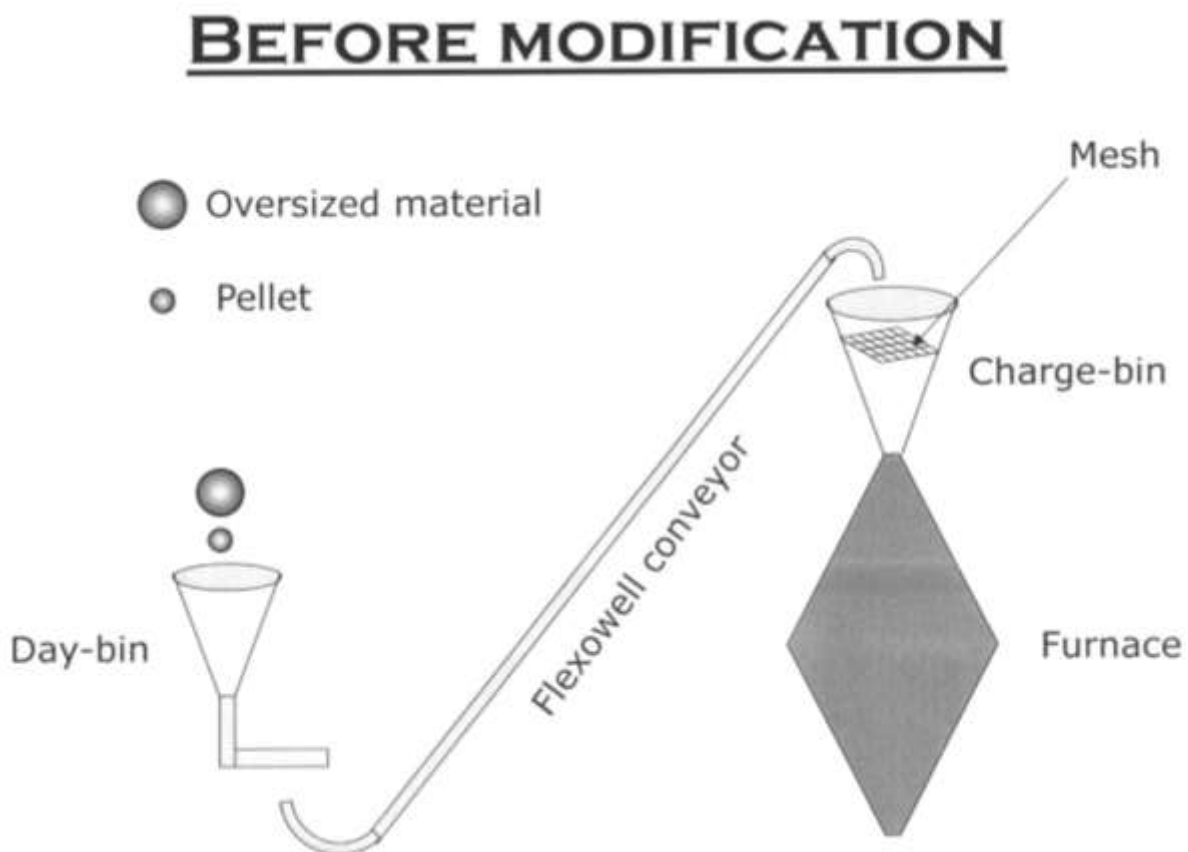

FIG 4: Oxide feed supply system from Day bin.

The pellets from the day-bin go into the charge-bin (top of the furnace) through flexowell conveyor belt. At the charge bin assembly an installed mesh ensures separation of the oversized materials. The preponderance of oversize materials was encountered during the Itakpe production campaign.

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These oversized materials resulted in accumulation in the oversize box and blockage of the mesh. The result was frequent spillage of material from the top of the furnace.

The evacuation of the oversize box was normally carried out manually. The modification executed is shown in Figure 5.

A mesh was provided below the day-bin to facilitate safe evacuation as against carrying out the same exercise in the gas endangered areas at the furnace top.
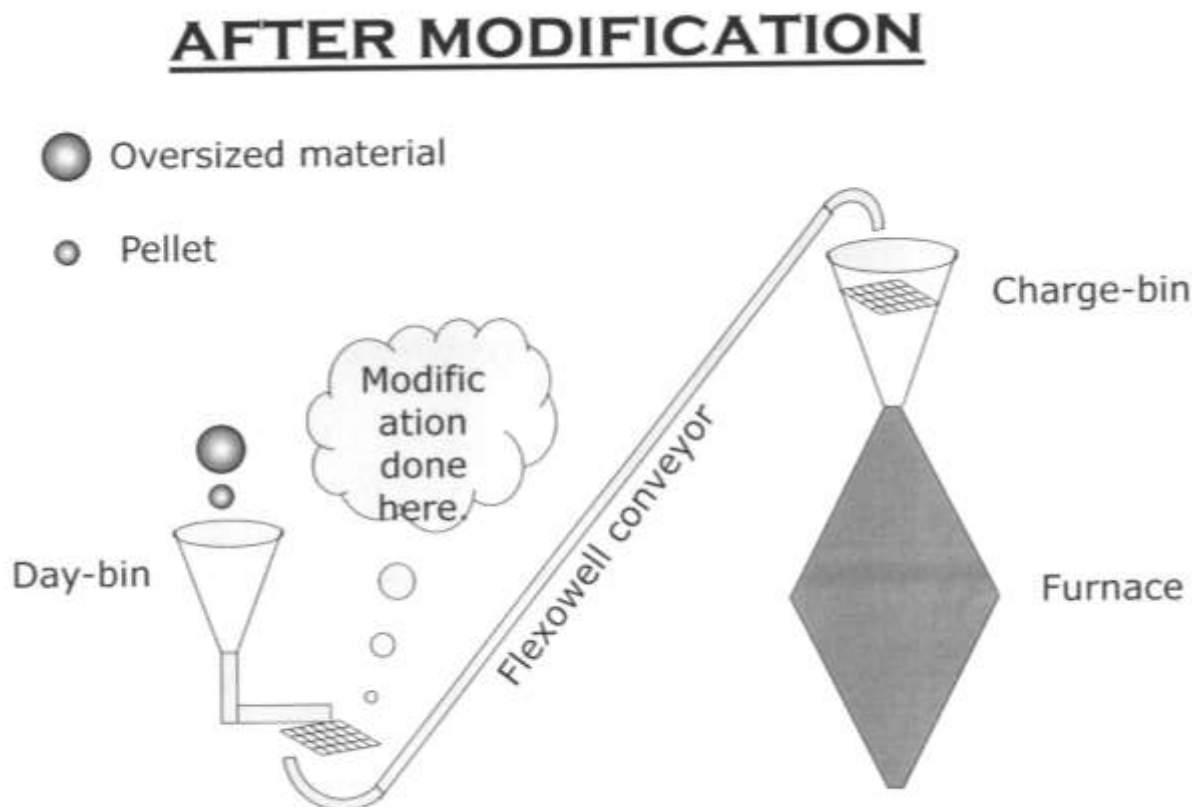

FIG 5: Modification in the oxide feed supply system from the Day bin.

Flexowell transfer chute

By the original design of the chute, shown in Figure 6 fines blockage at the chute was common particularly during wet season. Free flow of oxide pellets to the charge bin through the flexowell was then interrupted leading to production stoppage. This was usually corrected by shutting down the plant in order to avoid furnace seal loss which could lead to dangerous ingress of air into the furnace or equally dangerous egress of combustibles into the atmosphere. The transfer chute covers are dismantled, blockages cleared, and reinstalled. The exercise took about 2 hours.

Figure 7 shows the modification that was carried out. A man - hole was constructed in the oxide conveyor 2105 discharge chute. Clearing took maximum of 15mins as it was no longer required to completely dismantle the transfer chute box. Shut down and production slowdown was eliminated. A minimum of 300tons of DRI production time was saved
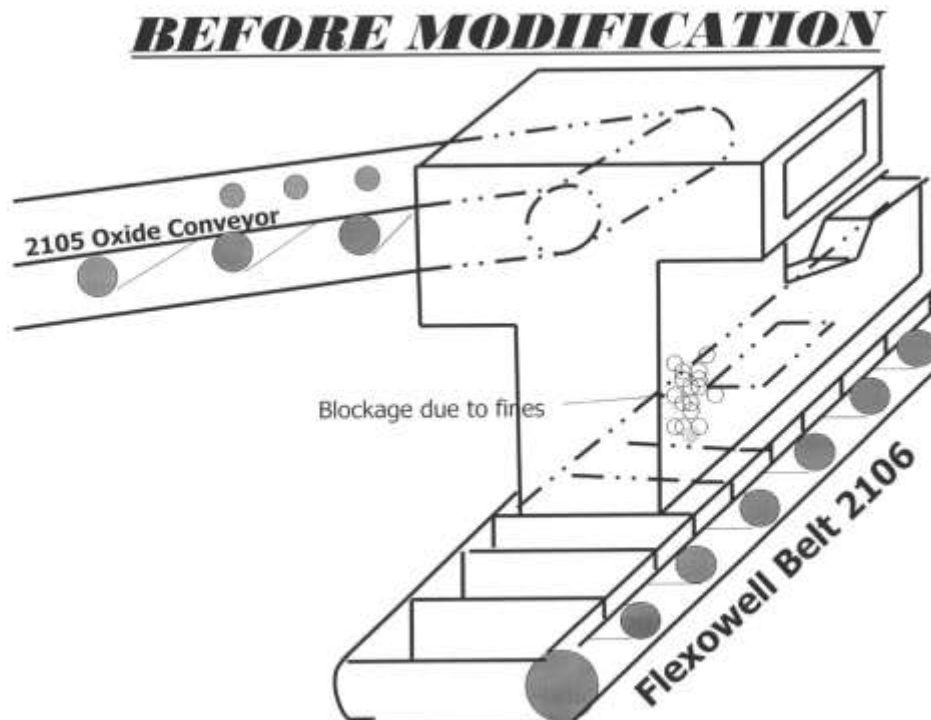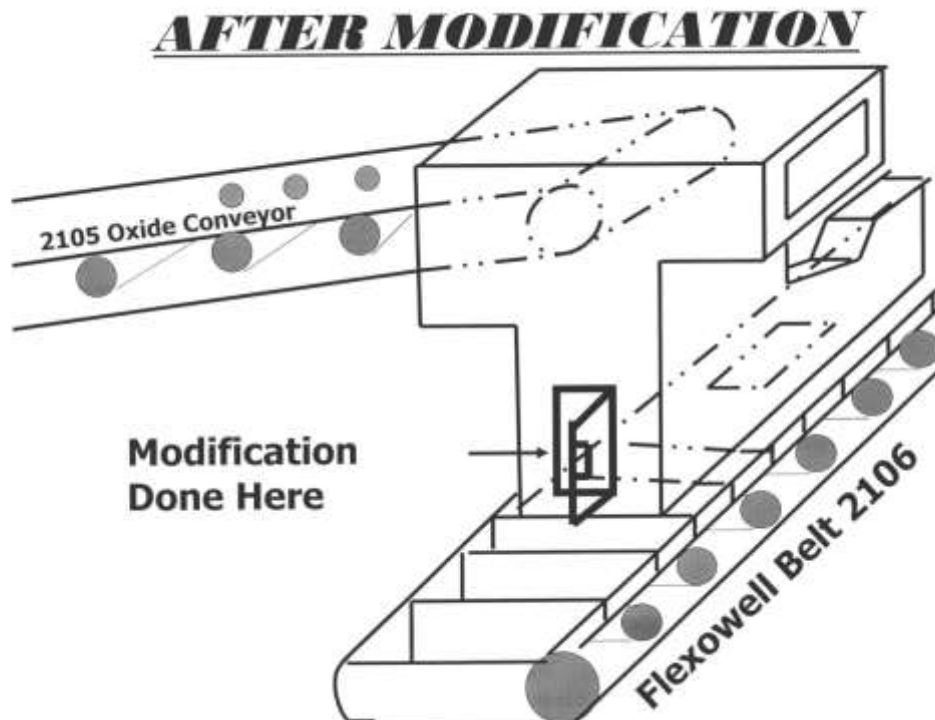
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FIG 6: Transfer chute assembly before modification.

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FIG 7: Transfer chute assembly after modification.

Conclusion

The modifications in the oxide pellets feed system from the day-bin to the charge-bin through the flexowell conveyor belt in both modules, by means of an entrapment mesh exit of the dosing belt ensured a secondary screening of the oxide feed, the primary screening having been done at the material handling screening station which is outside the battery limit of the direct reduction plant. The accumulation of oversize materials occasionally caused blockages hence impeding material flow. In addition, these materials spill out from the 65m platform of the shaft furnace. Also oversize pellets entering the furnace through the by-pass chute from the charge bin created channeling, bridging and excessive fines which can result to clusters and hot spots in the furnace. These problems were mitigated by this modification. Wet oxide materials resulting from the monsoon season created blockages at the transfer chute of the oxide feed system of module 4 impeding free flow of oxide pellets to the charge bin from the flexowell. The introduction of a sized aperture in the transfer chute eliminated wet fines and pellet accumulation at the chutes resulting in the elimination of downtime.

Acknowledgements

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