# Gas Based Direct Reduction Process

## Future of DRI Making

- Damodar Mittal

**Damodar Mittal** presently working as Executive Vice President-Projects in Jindal Steel & Power Ltd., Angul, ODISHA. He is a Business Unit Head of Iron & Steel consisting of DRI, SMS, Slab Caster, Billet Caster, Oxygen Plant, Lime Dolo Plant and Coal Handling Plant. He is also a Factory Manager of JSPL, Angul Plant.

The production of direct reduced iron (DRI), a basic raw material for making steel, is concentrated in a few countries in the Middle East and Latin America. One primary reason is that natural gas, the main fuel source for most DRI processes, is too costly in many of the steel making regions of the world. However, coupling a coal or petroleum refining by-products gasification unit with a DRI plant will be economically attractive. This paper has been prepared based on explored possibilities of combining a gasification unit with the Direct Reduction Process.

### Reduction Process

The following is a brief discussion of some of the fundamentals of the direct reduction of iron ores in the DRI process.

Iron oxide lump ore and pellets utilized in direct reduction contain about 30.0% oxygen by weight. In direct reduction, the oxygen in iron oxide reacts with carbon monoxide (CO) and hydrogen (H2) at elevated temperatures leaving metallic iron, carbon dioxide (CO2), and water vapor (H2O). The CO and H2 reduce iron oxide to metalized iron and are known as reductants. The CO2 and H2O oxidize iron and are known as oxidants.

The reducing potential of the gas used for reduction is related to the percentage of CO plus H2 in the gas divided by the percentage of CO2 plus H2O in the gas. This is known as the reductant-to-oxidant ratio of the gas, or "gas quality," denoted by R in the following equation:

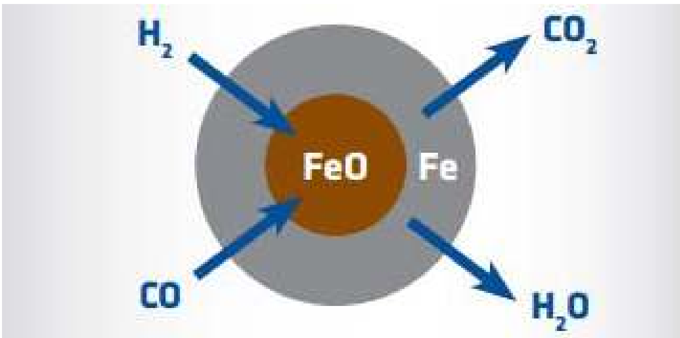
$$R = \frac{CO + H2}{CO2 + H2O}$$

To reduce iron oxide to metallic iron, the reductant-to-oxidant ratio must be greater than 2 (preferably in a range of 10-12) for fresh, hot reducing gas. To achieve the most complete reduction, the reducing gas flow per unit of iron must be great enough so the spent reducing gas leaving the reduction zone of the furnace has a reductant-to-oxidant ratio of at least 2.0.

The Coal Gasification based Direct Reduction Process utilizes a continuous flow of reducing gas to chemically extract oxygen from iron ore. The reducing gas (primarily carbon monoxide and hydrogen) is produced in the nearby coal gasification plant. It is mixed with recycled gas from the furnace that was treated in a CO2 removal system, heated in the process gas heater and introduced into the Shaft Furnace at a controlled concentration and temperature.

The upper portion of the furnace is called the reduction zone. The primary chemical reactions occurring in the reduction zone are:

$$Fe2O3 + 3\ CO \rightarrow 2\ Fe + 3\ CO2$$
$$Fe2O3 + 3\ H2 \rightarrow 2\ Fe + 3\ H2O$$




Carbon Dioxide (CO2) and Water Vapor (H2O) are byproducts of the Iron Oxide Reduction Reactions.

The reducing gas flows upwards, countercurrent to the descending ore, heats and reduces it to the desired metallization and initiates the carburization of the product. As the gas moves upwards towards the stock line, the carbon monoxide and hydrogen are converted into carbon dioxide and water vapor, and as the feed material descends the furnace, it is reduced to metallic iron.

The rate at which these reactions occur determines the residence time needed to metalize the product (typically 4-6 hours) and establishes the size of the equipment required to achieve the target production rate.

The reaction time within the reduction zone must be sufficient to reduce the iron oxide feed to uniform metallization levels of 92.0% or greater.

Spent reducing gases (top gas) exits the top of the furnace at about 350-450°C. The top gas then goes to the top gas scrubber, where the gas is cooled and scrubbed of entrained dust before being recycled to the process. The hot direct reduced iron (HDRI) exits the reduction furnace into an external product cooler, where it is cooled prior to storage in product silos, and/or fed directly to the Melt shop via a Product Discharge Chamber, Rotary Feeder and Hot Transport Conveyor.

### Carburization

Carburizing is the process of increasing the carbon content of the metalized product while inside the reduction furnace. The carbon content of the DRI is a key consideration in determining its viability as steel mill charge material.

Carburization can be achieved by one or more of the following reactions :

$$3Fe^{o} + CH_4 \; Fe_3C + 2H_2$$
$$3Fe^{o} + 2CO \; Fe_3C + CO_2$$
$$3Fe^{o} + CO + H_2 \; Fe_3C + H_2O$$

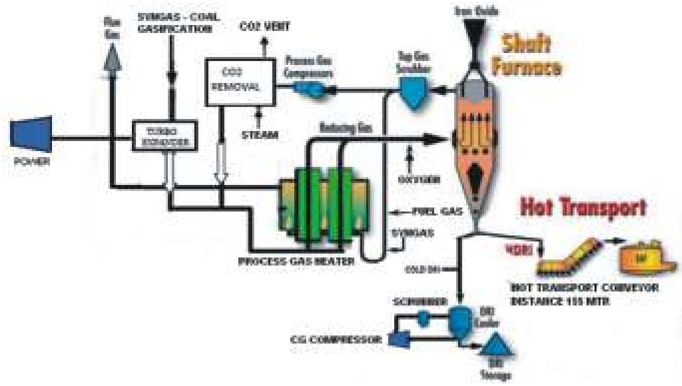
All direct reduction processes carburize by one or more of the above reactions. Carburization in this Process is achieved by introducing syngas into the furnace through the transition zone. Some methane is present in the syngas injected into the reducing gas through the feed gas mixer and becomes a constituent of the bustle gas. Syngas is added to the transition zone of the reduction furnace through nozzles in the periphery located below the upper burden feeders.

The syngas added to the transition zone is not preheated.

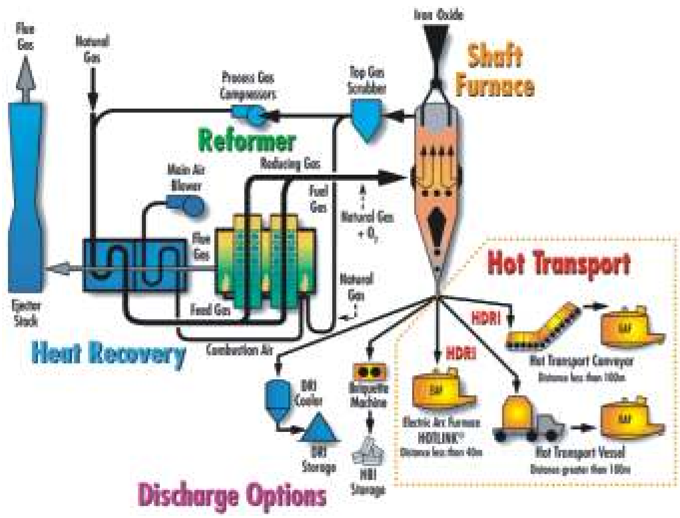
### Direct Reduction Flow Sheet

The DRI Process performs the iron ore reduction activities inside a tall vertical reactor called the Shaft Furnace. This is accomplished as the continuously fed iron oxide, which is similar in size and shape to marbles, flows downward through the Shaft Furnace by gravity, countercurrent to the hot reducing gases which are rising up through the Shaft Furnace. The hot reducing gases react with the iron oxide, stripping away the chemically bound oxygen.

**DR-1 AT JSPL, ANGUL**




Syngas Based DRI Plant at JSPL, Angul




Conventional MIDREX DRI Plant at JSPL, Angul

### Parameters of DRI Process

### Reducing Gas

The reducing gas used in the DR Furnace is produced by re-circulating a portion of the top gas from the furnace. This gas is first cleaned by the top gas scrubber, compressed, conditioned in a Carbon Dioxide removal system, mixed with fresh Syngas and heated in a reducing gas heater to operating temperature.

### Syngas Quality

| Syngas Characteristics | Requirement |
|---|---|
| CO2 Content | 2.0 – 3.0 % |
| Gas Quality* | ≥10 |
| Gas Requirement | ~ 2.35 net Gcal / t DRI |
| Pressure | > 3.5 barg |
| H2 / CO Ratio | 1.6 |
| Sulfur Content | ~ 50 ppm |
| N2 + Ar Content | < 0.5 % |

* Gas Quality is defined as (% H2 + % CO) / (% H2O + % Co2)

### Specific Consumption

| Inputs | Units | Quantity Per t /DRI |
|---|---|---|
| Iron Ore | t | 1.42 |
| Synthesis Gas | Nm3 | 700 |
| Oxygen | Nm3 | 20 |
| Nitrogen | Nm3 | 20 |
| Power | kWH | 120 |
| L. P. Steam | t | 0.2 |
| M. P. Steam | t | 0.4 |
| Water | M3 | 1.5 |

### Emissions

| | PM10 Mg/Nm$^3$ | $SO_2$ Mg/Nm$^3$ | NOx Mg/Nm$^3$ | $CO_2$ Kg/t DRI |
|---|---|---|---|---|
| Reheater | < 20 | < 15 | < 200 | 218.9 |
| CO2 Acid Gas Stacks | | | | |
| DR Plant | < 20 | Trace | < 320 | 306.1 |
| Coal Gas Island | < 20 | Trace | < 320 | 374.8 |
| Aux. Boiler | < 20 | 150 | < 700 | 265.9 |
| | | (90% FGD) | (0.5 lb/10^6 Btu's) | |

### Technological Advantages of Syngas Based DRI Plant

Our JSPL Angul DRI plant is a MIDREX designed DRI plant (1.8 MMTPA capacity) which is first ever in the world paired with commercially available gasification technology to produce DRI for use in melt shop applications.

This technology is the future of the coal based DRI production because it allows all the benefits, quality and reliability of the DRI process but using coal as the primary energy source rather than natural gas. With larger shaft furnace sizes, technology allows for greater competitiveness for steel makers by providing further fuel options for the DRI process. As energy costs rise, gasification also enables the use of lower quality coals or waste products to produce energy. The shaft furnace used in JSPL, Angul is nearly identical to the one used in natural gas based MIDREX plants. The main difference between the traditional MIDREX flow sheet and this new combination is that it uses a coal based synthesis gas source rather than a natural gas reformer. Options include: Coal gasifier synthesis gas, Coke oven gas and BOF gas. JSPL DRI plant is designed with greater flexibility for production of Hot and Cold DRI.

Benefits/Savings of using Hot DRI in Electric Arc Furnace are figured out below:

### HDRI Vs CDRI in EAF

| Operating Data | Units | CDRI | HDRI |
|---|---|---|---|
| Electrode Consumption | Kg/t | 2 | 1.8 |
| Oxygen Consumption | Nm$^3$/t | 32 | 32 |
| Energy Consumption | kWh/t | 640 | 520 |
| Tap to Tap Time | Minutes | 82 | 68 |
| Productivity | t/h | 184 | 221 |

The core plant consists of the following facilities/units:

- Shaft Furnace • Product Cooler • Process Gas System
- Cooling Gas System • Scrubbers • CO2 Removal System
- Reducing Gas Heater • Hot DRI Conveyor System
- Turbo Expander (Generator) • Instrument and Plant Air Systems
- Seal Gas and Purge Gas Systems
- Machinery Cooling and Process Water Systems
- Dust collection systems
- Raw Material and Product Handling System
- Raw Material Screening

### Advantages of Syn Gas Based DRI Process

(1) The Syngas based DRI Process is an inherently high metallization process because of:

- The counter-flow of reducing gas and oxide in the reduction furnace.
- A furnace burden residence time of 4-6 hours in the reduction zone.
- The uniform distribution of reducing gas.
- The uniform descent of the burden in the reduction zone.

(2) Lower metallization and reduced fuel and power consumption, if required, are achieved by increasing the production rate relative to the flow of reducing gas to the furnace bustle.

(3) Syngas based DRI Plant has a turndown ratio of 3:1 from rated capacity with no significant loss of efficiency in the process. The plant can be idled for extended periods and returned to full production in a few hours.

(4) Most EAF steelmakers want DRI with 92.0-95.0% metallization and 1.4 - 1.8% carbon. With the Syngas based DRI Process, carbon can be controlled at any desired level in the range of 1.0-2.0%. The day-to-day variation is about ± 0.1 - 0.2% from the desired level.

(5) Potential to use coal Syngases from other sources such as coke oven gas or BOF gas.

(6) Produces DRI with quality comparable to natural gas based DRI plant.

(7) Lower air emissions.

### Unique Features of DRI Plant at JSPL, Angul

(1) This is first ever in the world of this kind of DRI plant combined with Coal Gasification plant to produce DRI with the Synthesis Gas.

(2) Super Mega DRI module with Annual Rated Production Capacity of 18,00,000 t (High volume production of 225 t/h)

(3) High grade DRI production with 93% metallization and 1.8 % Carbon in the product.

(4) Charging of Hot DRI directly to Steel Melt Shop to reduce the power consumption substantially with increase in the productivity at Melt shop.

(5) 10.4 MW Power Generations by Syn Gas Turbine Generator.

(6) Unique kind of set up with the system involved as Co2 Removal and Reducing Gas Heater which is first ever combination with Midrex Technology

(7) Fully automated process control System supplied by Honeywell, C300 DCS with redundant controllers and servers with firewall system first time in the world being used for DRI plant approx 4000 I/os and ML 200 PLCs for Utility and Material handling system having approx 2500 I/os

(8) Smart Positioners used for control valves and all field instruments are HART enabled.