

## **PROCESS TECHNOLOGY FOLLOWED FOR SPONGE IRON**

This chapter describes the various process technologies adopted at present all over the world for production of Direct Reduced Iron (DRI).

In order to understand the process technology in a comprehensive manner it is necessary to understand the various terms used in DRI production as well as desired DRI quality for use in steel making.

### **Type of Process Technology**

Sponge iron, also known as "Direct Reduced Iron" (DRI) and its variant Hot Briquetted Iron (HBI) have emerged as prime feed stock which can replace steel scrap in EAF/IF as well as in other steel-making processes. It is the resulting product (with a metallization degree greater than 82%) of solid state reduction of iron ores or agglomerates (generally of high grade), the principal constituents of which are metallic iron, residual iron oxides, carbon and impurities such as phosphorus, sulphur and gangue (principally silica and alumina). The final product can be in the form of fines, lumps, briquettes or pellets. Sponge iron when briquetted in hot condition at elevated temperature is called hot briquetted iron (HBI).

Direct reduction processes available can be broadly grouped under two categories based on the type of reductant used. These are:

- Solid based processes
- Gas based processes

### **Solid Based Processes**

From amongst various solid based processes, only a few have attained commercial significance. Most of the processes such as SL/RN, KRUPP-CODIR, DRC, TDR, SIIL, JINDAL, OSIL, Popuri utilise rotary kiln for reduction whereas Kinglor Metor process utilises an externally heated vertical retort.

### **Process Technology**

Generally in any sponge iron process, reduction is conducted in a refractory lined rotary kiln. The kiln of suitable size, generally inclined at 2.5 % slope rest on two-four support stations, depending on the kiln size. The transport rate of materials through the kiln can be controlled by varying its slope and speed of rotation. There are inlet and outlet cones at opposite ends of the kiln that are cooled by individual fans. The kiln shell is provided with small sampling ports, as well as large ports for rapid removal of the contents in case of emergency

or for lining repairs. The longitudinal positioning of the kiln on its riding rings is controlled hydraulically.

The coal and iron ore are metered into the high end of the inclined kiln. A portion of the coal is also injected pneumatically from the discharge end of the kiln. The burden first passes through a pre-heating zone where coal devolatilization takes place and iron ore is heated to pre-heating temperature for reduction.

Temperature and process control in the kiln are carried out by installing suitable no. of air injection tubes made of heat-resistant steel spaced evenly along the kiln length and countercurrent to the flow of iron ore. Tips of the air tubes are equipped with special internal swirlers to improve uniformity of combustion.

A central burner located at the kiln discharge end is used with LDO for heating the cold kiln. After initial heating, the fuel supply is turned off and the burner is used to inject air for coal combustion.

The kiln temperatures are measured with fixed thermocouples and Quick Response Thermocouples (QRT). Fixed thermocouples are located along the length of the kiln so that temperatures at various sections of the kiln can be monitored. Fixed thermocouples, at times may give erratic readings in case they get coated with ash, ore or accretion. In such cases QRT are used for monitoring the kiln temperatures.

The product (DRI) is discharged from the kiln at about 1000°C. An enclosed chute at the kiln discharge end equipped with a lump separator and an access door for removing lumps transfers the hot DRI to a rotary cooler. The cooler is a horizontal revolving cylinder of appropriate size. The DRI is cooled indirectly by water spray on the cooler upper surface. The cooling water is collected in troughs below the cooler and pumped to the cooling tower for recycling alongwith make-up water.

Solids discharged to the cooler through an enclosed chute are cooled to about 100°C. without air contact. A grizzly in the chute removes accretions that are large to plug up or damage the cooler discharge mechanisms. The product is screened to remove the plus 30mm DRI. The undersize – a mix of DRI, dolo char and coal ash are screened into +/- 3mm fractions. Each fraction passes through a magnetic separator. The non-magnetic portion of the plus 3mm fraction is mostly char and can be recycled to the kiln if desired. The non-magnetic portion of – 3mm fraction mostly spent lime, ash and fine char is discarded. The magnetic portion of each fraction is DRI. The plus 3mm fraction can be used directly for steel making and the finer fraction can be briquetted / collected in bags.

The kiln waste gases at about 850-900°C pass through a dust settling chamber where heavier dust particles settle down due to sudden decrease in velocity of gases. The flue gases then pass through an after burning chamber

where un-burnt combustibles are burnt by blowing excess air. The temperature of the after burner chamber, at times, is controlled by water sprays. The burnt gases then pass through a down duct into a evaporation cooler where the temperature is brought down and through a pollution control equipment namely ESP / Bag filter/ scrubber where balance dust particles are separated. Then the gas is let off into the atmosphere through stack via ID fan.

In certain coal based large plant in India is equipped with waste heat recovery system, the flue gases after the after burning chamber pass through an elbow duct to waste heat boiler where sensible heat of the gases is extracted. The gas is then let off into the atmosphere after passing through pollution control equipment like ESP, ID fan and stack.

In solid based processes, the non-coking coal and iron ore which are at intimate contact start reacting at the prevailing temperature.

### Reaction mechanism

There are two major temperature zones in the kiln. The first pre-heat zone is where the charge is heated to 900 – 1000°C. The second metallization zone is held fairly constant at 1000-1050°C.

The charge into the kiln consists of a mixture of iron oxide lump, fluxes such as limestone and/or dolomite (amount depending of sulfur content of the coal) and medium volatile non-coking coal. In the pre-heating zone, the moisture is driven off first, and then the hydrocarbons and hydrogen evolve by thermal decomposition of the coal.

As the combustible gases rise from the bed of solid material, a portion of the gases is burnt in the free board above the bed by controlled quantities of air introduced through the air tubes. As the kiln rotates, the primary mode of heat transfer is by radiation to the tumbling charge and subsequently by internal solids mixing and renewal of the exposed bed surface.

In the pre-heat zone, the reduction of iron oxide proceeds only to ferrous oxide (FeO) (Equation I).



Final reduction to metallic iron occurs in the metallization zone by reaction of CO with FeO to form CO<sub>2</sub> and metallic iron (Equation II).



Most of the CO<sub>2</sub> reacts with the excess solid fuel in the kiln and is converted to CO according to the Boudouard reaction (Equation III).



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(III)

Coals with higher reactivity are preferred as they provide rapid conversion of  $\text{CO}_2$  to  $\text{CO}$ , thereby maintaining reducing conditions in the kiln metallization zone. The highly endothermic reaction of coal with  $\text{CO}_2$  prevents the bed from over heating and attaining high temperature that could lead to melting or sticking of the charge.

High coal reactivity decreases the reduction zone bed temperature but increases the relative capacity. Desired bed and gas temperature in the freeboard can be achieved with high reactivity fuels even with very high throughput rates.

Air admitted to the ports below the bed in the pre-heat zone will burn some of the gases that otherwise leave the kiln unburnt to improve fuel consumption

### **Available Module Size**

Coal based plants are available in module sizes in the range of 50 tpd (15000 tpa), 100 tpd ( 30,000 tpa), 300/350 tpd (100,000/120,000 tpa) and 500 tpd (150,000 tpa).

### **Preferred Raw Material Characteristics**

The principal burden material used for production of steel making grade DRI in the sponge making process is iron oxide lump ore, non-coking coal and lime stone/dolomite. The iron ore should be preferably high in Fe content (>65% Fe) and non-decrepitating type. Coals with a high reactivity and high fusion temperature are preferred. The coal should also be non-coking. A low ash fusion temperature is undesirable as it promotes formation of accretions in the kiln. The coal ash composition is also important as a siliceous ash might react with ferrous oxide to form low melting ferrous silicate and interfere with the reduction to metallic iron.

### **TYPICAL RAW MATERIAL CHARACTERISTICS**

|  |                             |
|--|-----------------------------|
| <b>i)</b>                              | <b><u>Iron ore lump</u></b> |
| Fe                                     | : 65 % (min.)               |
| $\text{SiO}_2 + \text{Al}_2\text{O}_3$ | : 3.5 % (max.)              |
| S                                      | : 0.02 %(max.)              |
| P                                      | : 0.035%(max.)              |
| Size                                   | : 5-20 mm                   |

**ii) Coal (dry basis)**

|              |                         |
|--------------|-------------------------|
| Fixed C      | : 42.5 % (min.)         |
| Ash          | : 27.5 % (max.)         |
| VM           | : 30 %                  |
| S            | : 1.0 % (max.)          |
| Moisture     | : 7 % (Max.)            |
| Reactivity   | : 1.75 cc of CO/gmC/sec |
| Caking index | : 3 max.                |
| Size         | : 0 - 20 mm             |

**iii) Limestone**

|                  |               |
|------------------|---------------|
| SiO <sub>2</sub> | : 8 % (max.)  |
| CaO              | : 46 % (min.) |
| MgO              | : 8-10 %      |

**iv) Dolomite**

|                  |               |
|------------------|---------------|
| SiO <sub>2</sub> | : 5 % (max.)  |
| CaO              | : 28 % (min.) |
| MgO              | : 20 %        |

**Typical Product Characteristics**

The typical sponge iron (coal based) characteristics are as follows:

|                              |                  |
|------------------------------|------------------|
| Fe (total)                   | : 92 % (min.)    |
| Fe (Met.)                    | : 83 % (min.)    |
| Metallization                | : 90 % (min.)    |
| Carbon                       | : 0.25 % (max.)  |
| S                            | : 0.025 % (max.) |
| P                            | : 0.06 % (max.)  |
| Re-oxidation characteristics | : Non-pyrophoric |

**Major Facilities of Coal Based DR Plant**

- a) Reactor
- b) Cooler
- c) Off gas handling
- d) Reactor feed system
- e) Product processing
- f) Briquetting (Optional)
- g) Instrumentation & control

- h) Electrics
- i) Dust collection and disposal system
- j) Water system
- k) Compressed air system
- l) Fuel oil facility
- m) Fire fighting
- n) Air-conditioning & ventilation
- o) Emergency DG set
- p) Raw material, product storage and handling
- q) Repair shop and store
- r) Laboratory

## **Technology Options for Coal Based Plants**

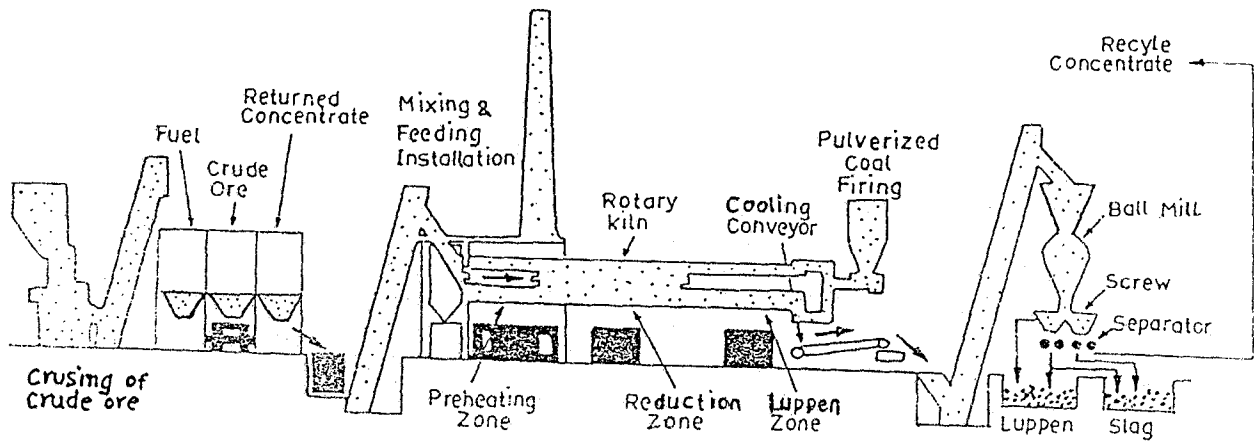
### **Krupp Renn process**

An annual production of 450000 metric ton (500000 net ton) of DRI has been achieved by using the Krupp Renn process. The Krupp –Renn process was developed in the 1930's to treat high silica ore with a basicity ratio as low as 0.2 to 0.3, with the addition of limestone. In this process a mixture of minus 64 mm (2.5 inch) ore and fine grained carboneous reducing agent (coke breeze or bituminous coal fines) is fed continuously in rotary kiln.

The maximum temperature of kiln is kept at 1230 to 1260°C (2250 to 2300°F), which is sufficient to convert the gangue in the ore to a very viscous high silica sludge and also to effect coalescence the sponge iron obtained from the reduction of the iron ore. The reduced iron welds into nodule called “luppen” which become embedded in the pasty sludge. This product is discharged from the kiln. After cooling it is crushed and luppen are magnetically separated from the sludge. Recovery of iron in the luppen varies between 94% to 97.5%.

High Titania ore can also be used in this process and iron can be separated from titanium since the latter is not reduced. Almost any solid carboneous fuel can be use as a reducing agent. Since a large part of the sulphur contained in the reducing agent goes in the luppen, the sulfur content of the metal becomes high and difficult for economically conversion of the luppen into steel by the conventional steel making practices. In some places, the process is used to concentrate low grade iron ores containing up to 30% silica, and the luppen been fed in to blast furnaces.

The process flow diagram of Krupp Renn process is shown in **Figure 3.1**.



**Fig. 3.1 : Krupp-RENN Process Flow Diagram**

### **Krupp – CODIR process**

The Krupp – CODIR process of Krupp Industries, West Germany, seems similar to original Krupp – Renn process. The process operates at a lower temperature than the Krupp – Renn thus producing a standard DRI product. Furthermore, limestone or dolomite in the furnace charge absorb a substantial part of the sulfur introduced with fuel.

A Krupp CODIR plant designed for a facility of 150000 metric ton (165000 net tons) started operation 1973 at the Dunswart Iron and Steel Works Ltd. at Benoni, Republic of South Africa. The reduction kiln in this plant is about 4.0 meter (13 feet) inside diameter and 74 meters (243 feet) long. The energy consumption is about 15.9 million kilojoules per metric ton (13.7 million BTU per net ton) of DRI when low volatile anthracite is used for the reduction coal. As mentioned previously, the gross energy requirement increases when high volatile matter coals are used.

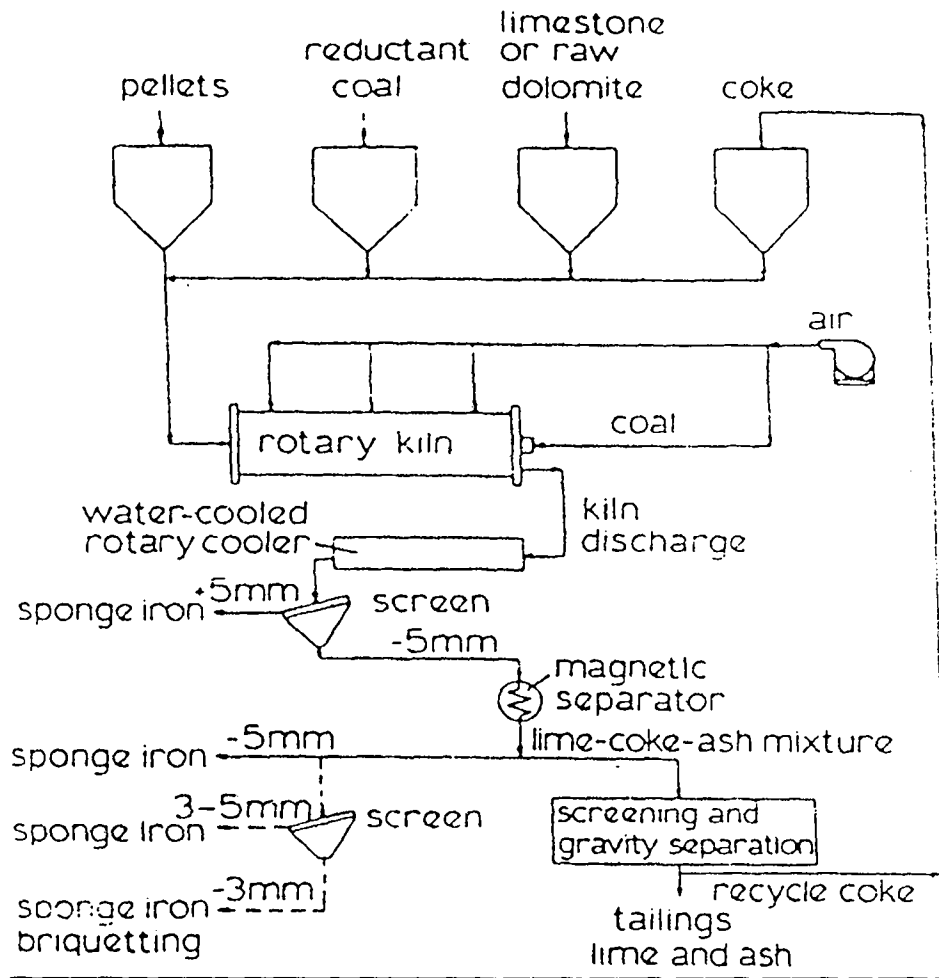
In this process lump ore or oxide pellets, solid reductant, dolomite or limestone as flux is needed. The feed size of the solids is closely controlled to expedite separation. Typically, the preheating zone extends from 25% to 40% along the CODIR process kiln.

Primary heat is supplied to the kiln by the combustion of pulverized coal injected at the solids discharge end of the kiln. Secondary heat is supplied by injecting air into the kiln gas space through tubes spaced along the entire length of the kiln. The secondary air is introduced axially (along the kiln's centre line). In this way, a uniform charge temperature profile between 950 and 1050°C (1740 and 1925°F) is achieved in the reaction zone of the kiln.

The DRI, char, coal ash and spent flux are discharged via an enclosed chute from the rotary kiln burner hood into a shield rotary cooler. Cooling is accomplished by spraying a controlled amount of water directly into the hot solids and by spraying additional water on the outside of the cooler shell. The cooled solids are discharged over a 5 mm screen. The minus 5 mm

fraction is processed through further screening at 3 mm and magnetic separation to separate the final DRI from recycled char, spent flux and coal ash. Minus 3 mm DRI is separated as cold briquettes and 5-3 mm DRI is combined with plus 5 mm fraction. Char is separated by gravity for return to the kiln feed, and ash and spent flux are separated for disposal.

The process flow diagram of Krupp CODIR process is shown in **Figure 3.2**



**Fig. 3.2 : Krupp-CODIR Process Flow Diagram**

### SL / RN Process (Outcompu)

A forerunner to the SL / RN process, RN process (for Republic Steel Company and Nations Lead Corporation) was developed originally in Norway, primarily to recover  $TiO_2$  from titanium bearing ore for the production of paint pigments. However, further development showed that

other iron bearing ores could also be treated successfully to produce iron. Subsequently, a pilot plant is built in the United State, and in 1964 Lurgi Chemie acquired the RN patents and developed the technology further with the Steel Company of Canada Ltd. (Stelco) to the SL/RN process.

The SL/RN process flow typically rotary kiln operation described earlier. The largest commercial SL/RN plant, design to produce 360000 metric ton (400,000 net ton) of DRI per year was installed by Stelco at Griffith Mine in Ontario, Canada and began operating in 1975. The reduction kiln in this plant is 6 meters (19.7 feet) inside diameter and 125 meters (410 feet) long. The energy consumption at this plant is about 22 million kilojoules per metric ton (19 million BTU per ton) of product when the process is operated with high volatile sub-bituminous coal. This relatively high consumption occurs because most of the volatile matter in the reductant coal leaves the kiln and is not recovered.

Other commercial installations based on the SL / RN process include one installed in 1970 by New Zealand Steel Ltd. in Glenbrook, Auckland, New Zealand for recovery of iron from native iron sands and another plant installed at the Fukuyama Works of Nippon Steel in Japan in 1974. The New Zealand Steel Limited plant was subsequently modified to included a multiple hearth furnace for reheating the iron sand feed and charging the reduction coal. The Fukuyama plant was designed to process waste oxides generates at the Fukuyama Works. Other plants have been constructed the more recent plant are operating or under construction in Peru, and South Africa.

The SL / RN process consists of lump ore or pellets, coal, recycle char, and flux need to scavenge sulphur from the coal. In the kiln preheat zone, the charge is heated to about 980°C (1800°F) by counter flowing hot freeboard gases. For high kiln efficiency the reheated zone is made as short as possible usually 40 to 50% of kiln length. Reduction begins when the charge reaches temperature in excess of 900°C (1650°F) when the carbon gassification reaction starts generating carbon monoxide. To maintain a uniform reduction zone temperature by burning combustibles released form the bed, air is blown by shell, mounted fans, feed air into the freeboard gas stream, through burner tube space uniformly along the length of the kiln. Air is introduced axially in to the kiln and additional

combustion air is blown into the kiln through a central airport of the discharge end.

The solids are discharged from the rotary kiln via transfer chute into a sealed rotary cooler. Water sprays on the cooler shell reduces the temperature of solids to about 95°C (200°F) in a non-oxidizing atmosphere. External lifter aids heat transfer in the cooler discharge material that are continuously separated into DRI, DRI fines, non magnetic by a system of screen and magnetic separation. Char is separated from the waste by gravity separation.

The SL /RN process kilns are now equipped with nozzles for under-bed injection of about 25% of the process air in the preheating zone of kiln. The air is available for combustion of the volatile matter in the coal within the bed in the preheating zone. As a result, the length of preheating zone of the kiln is reduced because of improved heat transfer and fuel utilization. More of the kiln length can therefore be used as a reduction zone.

The process flow of SL/RN process is shown in **Figure 3.3**

### **ACCAR Process**

The Allis Chalmers Controlled Atmosphere Reactor (ACCAR) produces highly metallized DRI in a rotary kiln. Liquid, solid and gaseous fuels singly or in combination are used directly in the kiln with an external reformer or gasifying plant. The ACCAR kiln is equipped with an intricate port system and with valves arranged radially around the circumference of the kiln and spaced uniformly along its length, for liquid or gases fuel injection. Versatility in the use of fuel is claimed as an advantage for this process as it permits use of the most economical fuels available.

The original ACCAR development work started in the late 1960 and was based on hydrocarbon gases and liquids. Work was started in a 0.6 meter (2 feet) diameter by 7 meter (23 feet) long pilot plant at Milwaukee and continued in a 2.5 meter (8 feet) diameter by 45 meter (148 feet) long demonstration plant at Niagara Fall, Ontario, Canada.























































