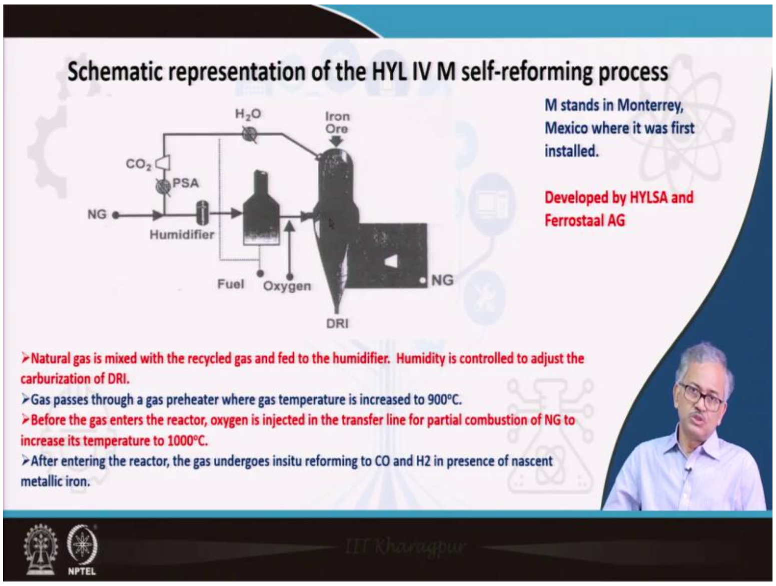
Iron Making and Steel Making
Prof. Gour Gopal Roy
Department of Metallurgical and Materials Engineering
Indian Institute of Technology, Kharagpur

Module – 11
Lecture – 56
Gas Based DR Processes (continued)

In this lecture we will discuss the remaining two important gas based DR processes like HYL-IV and Midrex processes.

(Refer Slide Time: 02:16)



HYL IV process is the 4th generation of HYL process and the most modern one. The unique feature of this process is that this process does not require any separate reformer and natural gas is get reformed inside the reduction unit itself. So, the reactor here act as a dual reactor where in-situ reforming and reduction take place simultaneously. That is why this process sometimes is also called HYL ZR (zero reforming) process.

The process flow sheet for HYL-IV process is shown in the Figure 56.1. Some features of this process is noted below.

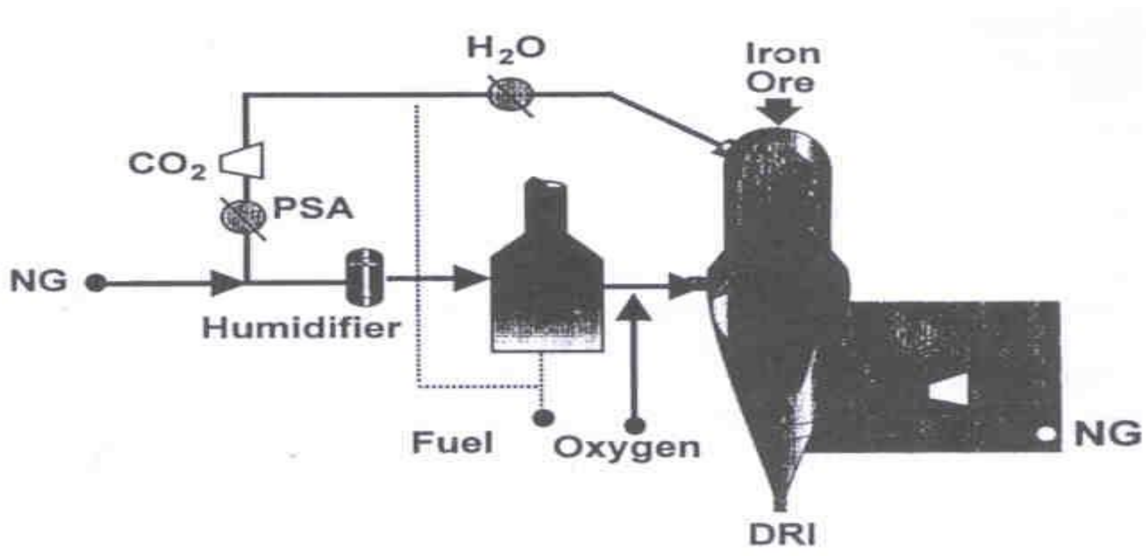
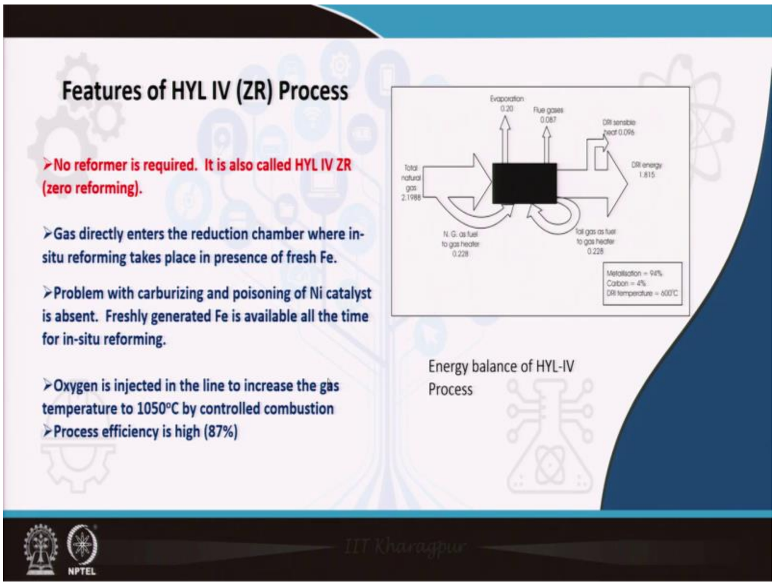


Figure 56.1 Schematics of HYL-IV process [2]

Natural gas is mixed with the recycled gas after cleaning dust, and scrubbing moisture and CO_2. Finally the mixed gas is humidified in a controlled manner to adjust the carburization of DRI. Gas passes through a gas preheater where gas temperature is increased to 900^{o}C. Subsequently, oxygen is injected in line to carry out partial combustion of methane to raise temperature of the gas in excess to 1000°C before it enters the reduction chamber. Such high temperature will support both reforming and reduction in the reduction chamber.

After entering the shaft reactor the methane undergoes in situ reforming to CO and H_2 in presence of nascent metallic iron. Therefore, the process eliminates the requirement of a separate reforming unit leading to process integration, saving energy. Secondly, Nickel catalyst that was required for separate steam reforming unit, is not required any more, it saves money. Besides, hassles of frequent replacement of costly nickel catalyst because of carbon poisoning is also eliminated. During reforming cracking of methane forms carbon shoots which deposits on nickel.

(Refer Slide Time: 07:56)



The energy balance of HYL-IV is shown in the Figure 56.2.

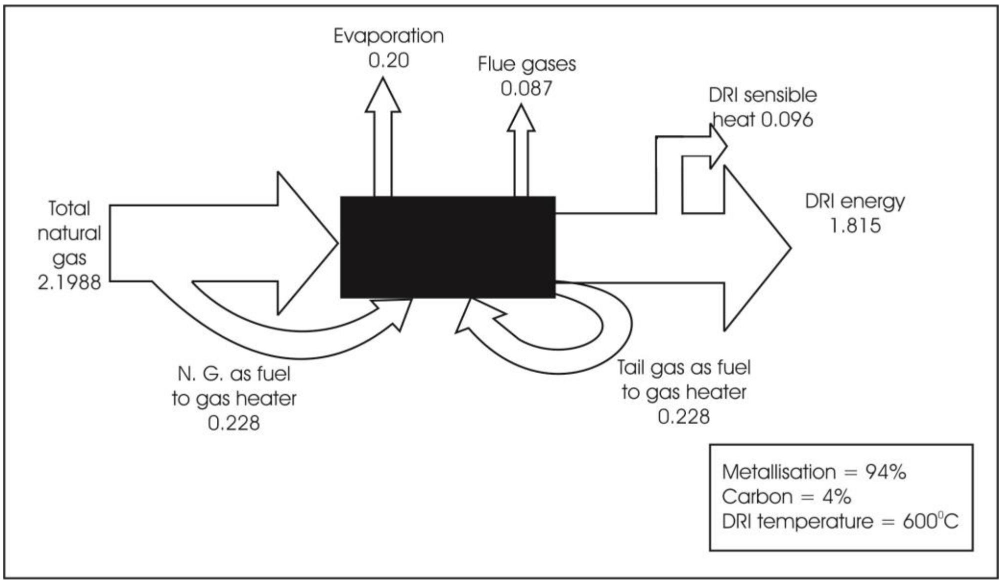
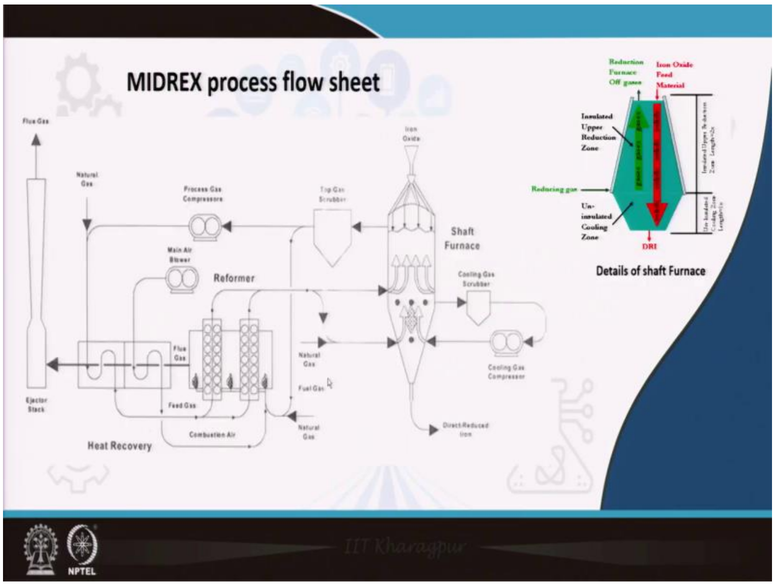


Figure 56.2: Energy balance of HYL-IV process [2]

Energy input through natural gas is approximately 2.2 Gcal/ton of DRI produced. A part of the natural gas along with cleaned and CO_2 scrubbed off gas is used for gas heating; total 0.46 Gcal/ton, sharing equally between NG and off gas). Evaporation loss is 0.2 Gcal and flue gas 0.087 Gcal/ton. Total energy required for iron ore decomposition to DRI and associated reaction is 1.815 and sensible heat of DRI is 0.096 Gcal. So, process efficiency is 82% without considering sensible heat of DRI in case of cold charge. It is around 87% considering sensible heat of DRI in case of hot charging.

(Refer Slide Time: 12:08)



Now let us discuss the MIDREX process. The flow sheet of MIDREX process is given in Figure 56.3.

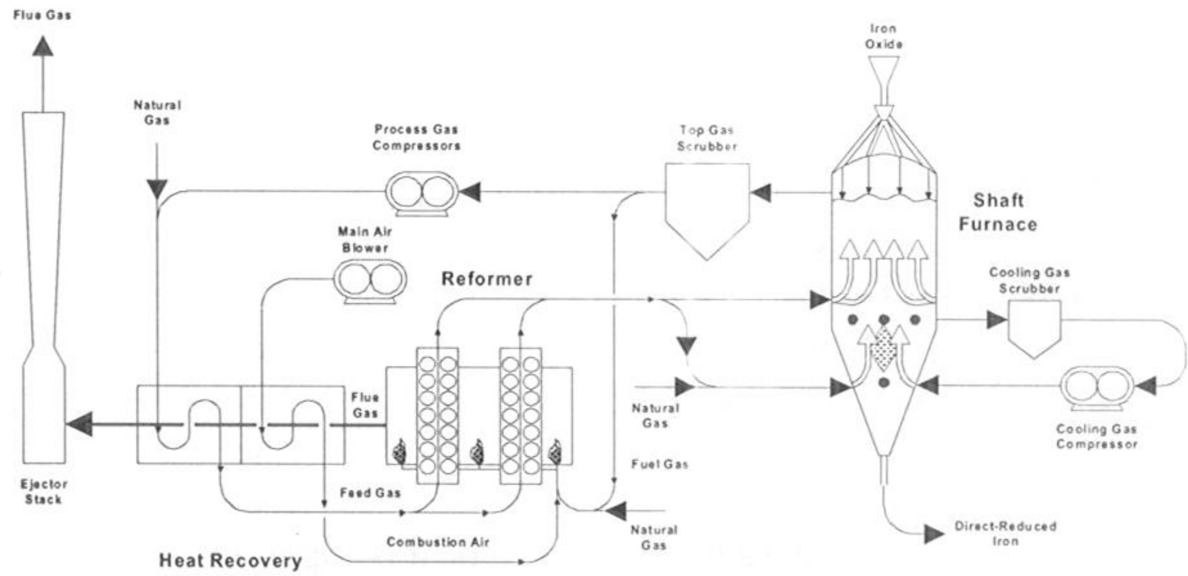


Figure 56.3: Process flow sheet of MIDREX Process [3].

The unique feature of MIDREX process is that off gas is recycled through the reformer that is the off gas is used to reform the natural gas. Here unlike in HYL process, CO_2 reforming of natural gas is done here; not the steam reforming. Off gas after cleaning and dehumidification containing CO_2, CO, H_2 is mixed with natural gas and sent to reformer and reforming is carried out in presence of nickel catalyst. All the off gas is not required for reforming. A part of the off gas (40%) is used for heating purpose for reformer as well as gas preheater.

The reactor consists of two parts: (i) upper cylindrical part where reduction of ore takes place in presence of reformed gas, called the reduction chamber, (ii) lower conical part where the cooling of DRI takes place by passing natural gas. Reformed gas directly enters the reduction chamber. A part of the reformed gas mixed with fresh natural gas and enters the lower part of the reactor, the cooling zone, where DRI gets cooled and also cracking of methane carburize the freshly produced iron. The off gas from lower part is recirculated through lower part after dehumidification. The details of the reactor is shown in the figure 56.4.

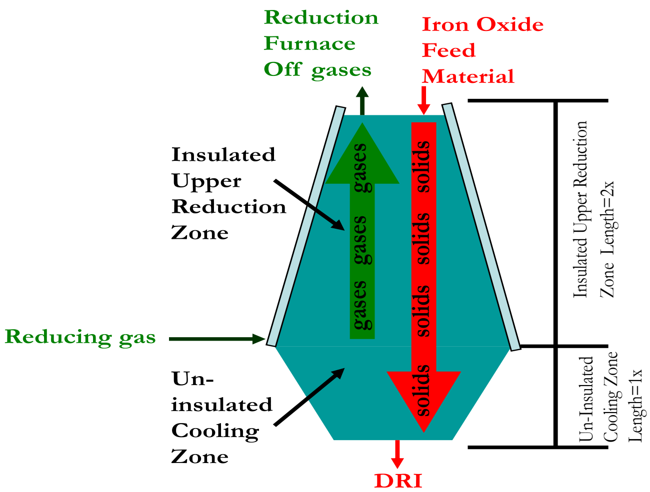
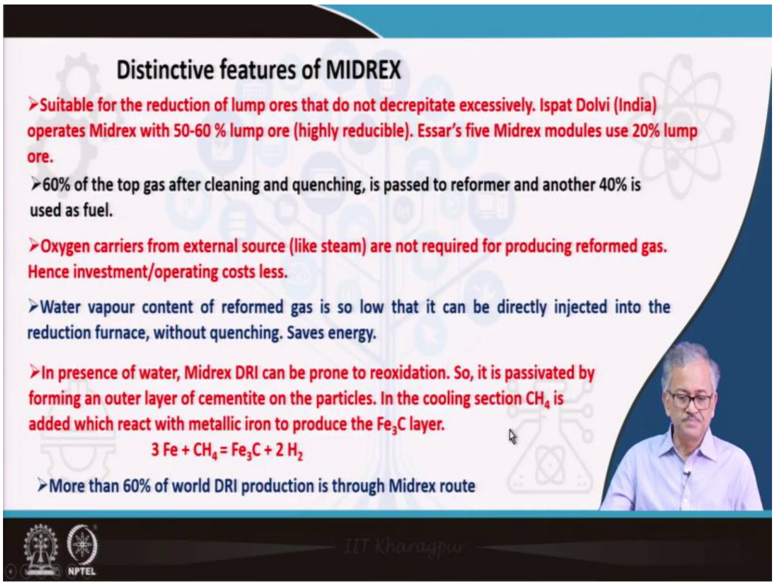


Figure 56.4 Details of the shaft reactor containing top reduction zone and bottom cooling zone.

It may be noted that upper reduction zone is insulated to preserve the heat to maximum extent to assist reduction. While the lower part or cooling zone is not insulated to assist cooling of the DRI at faster rate. Natural gas is used as a cooling agent and also carburizing agent.

(Refer Slide Time: 16:24)



Suitable for the reduction of lump ores that do not decrepitate excessively. Ispat Dolvi (India) operates Midrex with 50-60 % lump ore (highly reducible). Essar's five Midrex modules use 20% lump ore. Rest is pellets.

Oxygen carriers from external source (like steam) are not required for producing reformed gas. Hence investment/operating costs less. Off gas CO2 is used for reforming, which enhances the carbon efficiency of the process.

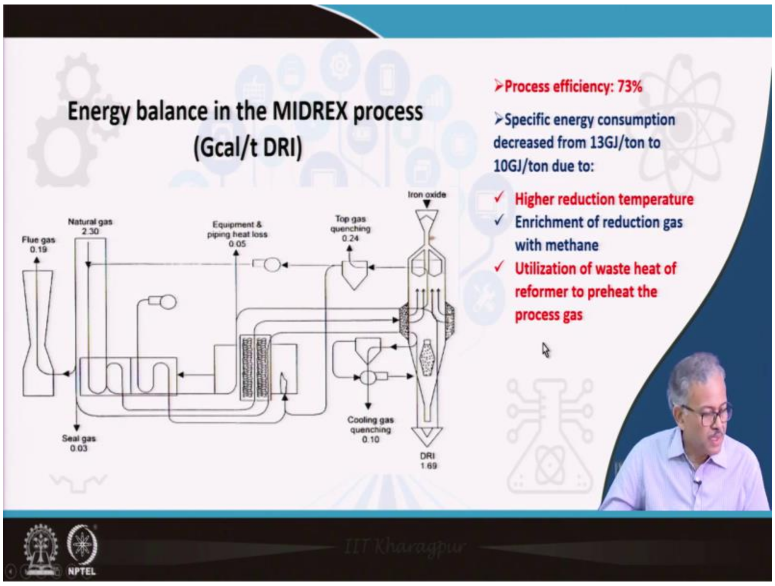
Since the NG is not steam reformed, water vapor content of reformed gas is so low such that it can be directly injected into the reduction furnace without quenching, which saves energy.

Midrex DRI is porous and prone to re-oxidation, even at low temperature in presence of moisture. Therefore, it is passivated by forming a dense outer layer of cementite on iron particles. In the cooling section methane is added which react with metallic iron to produce the Fe_3C layer.

$$3\,Fe + CH_4 = Fe_3C + 2\,H_2$$

MIDREX is the most popular gas based DR process and today more than 60 percent of world DRI is produced by the MIDREX route.

(Refer Slide Time: 20:07)



The flow sheet of energy balance for MIDREX process is given in the Figure 56.5.

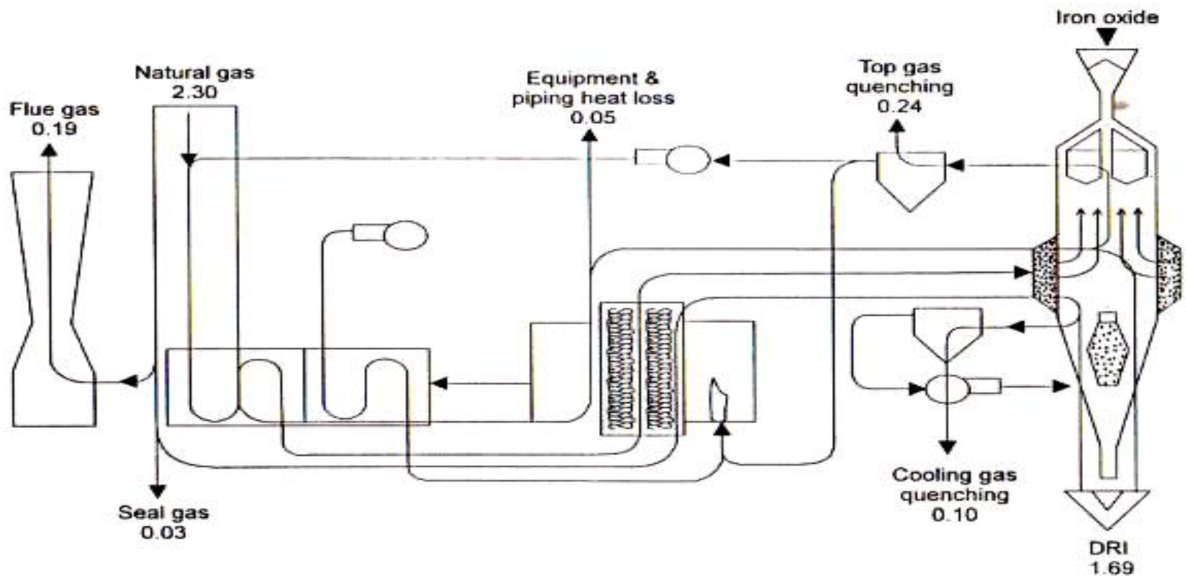
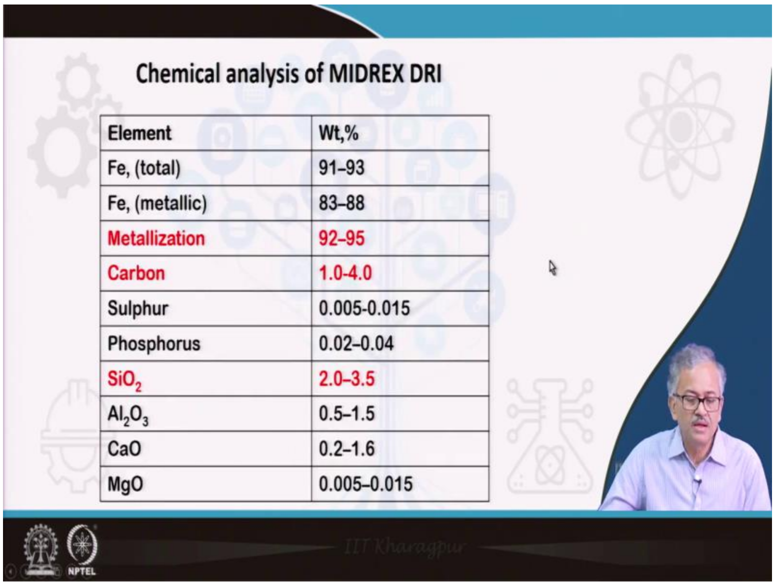


Figure 56.5: Flow sheet of energy balance in MIDREX

Input energy through natural gas only (2.3 Gcal/ton). Process energy for DRI production is 1.69 Gcal/ton. Various other losses counts to 0.61 Gcal/ton. So, process efficiency is 73%.

And, specific energy consumption is decreased from 3 Gcal/ton to 2.3Gcal/ton, which is attributed to off gas utilization for gas preheating.

(Refer Slide Time: 22:03)



The chemical analysis of the MIDREX DRI is given in Table 56.1.

Table 56.1: Typical composition of MIDREX DRI

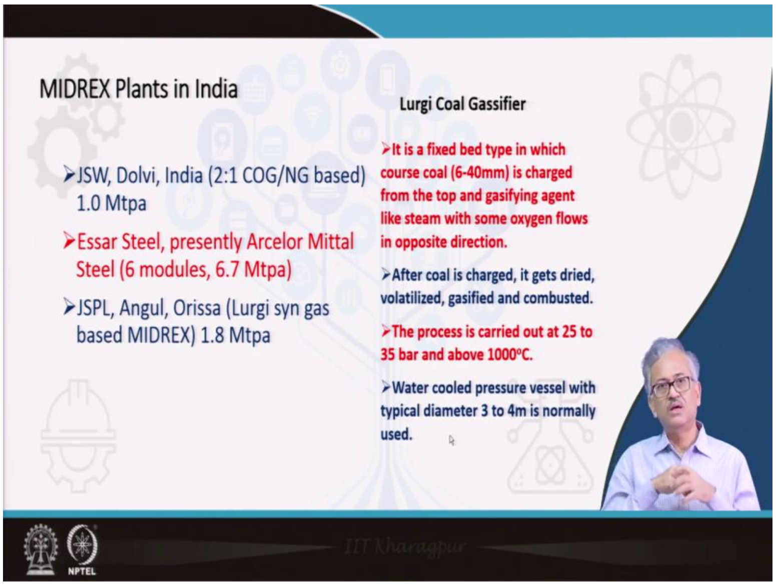
Element	Wt,%
Fe, (total)	91–93
Fe, (metallic)	83–88
Metallization	92–95
Carbon	1.0-4.0
Sulphur	0.005-0.015
Phosphorus	0.02–0.04
SiO_2	2.0–3.5
Al_2O_3	0.5–1.5
CaO	0.2–1.6
MgO	0.005–0.015

Total iron in MIDREX DRI is 91 to 93, indicating grade of iron ore used in MIDREX process quite high. Because grade of sponge as indicated by total iron depends on the grade of iron ore used. Metallization defined as the ratio of metallic iron to total iron converted to percentage, is an index of process efficiency. Metallization of 92-95% indicates a very good process efficiency indicating only 5 to 8% of iron is associated with oxygen and rest of the iron has been liberated from oxygen to metallic iron.

Carbon in DRI is quite high 1 to 4 % compared to coal based DRI, which hardly exceeds 0.2%. Such high carbon reduces its liquidus and requires less energy for its melting. High carbon in DRI is produced through special decarburization technique in the cooling zone through cracking of natural gas.

Sulphur is quite low because in gas based process, major source of sulphur, coal is not used. And then phosphorous 0.02 to 0.04. SiO_2, Al_2O_3, CaO and MgO in DRI are all sourced from ore gangue and depends on the quality of ore.

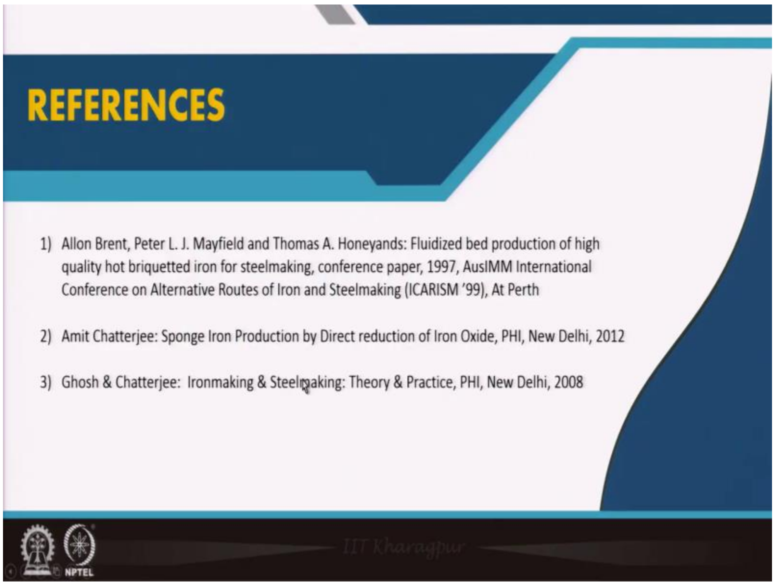
(Refer Slide Time: 23:41)



There are several MIDREX plants in India. JSW, Dolvi plant in India. It has around 1 million tonne capacity MIDREX plant and it uses mixed coke oven and natural gas in the ratio of 2:1 for reduction. Coke oven gas is used to supplement the limited and costly natural gas.

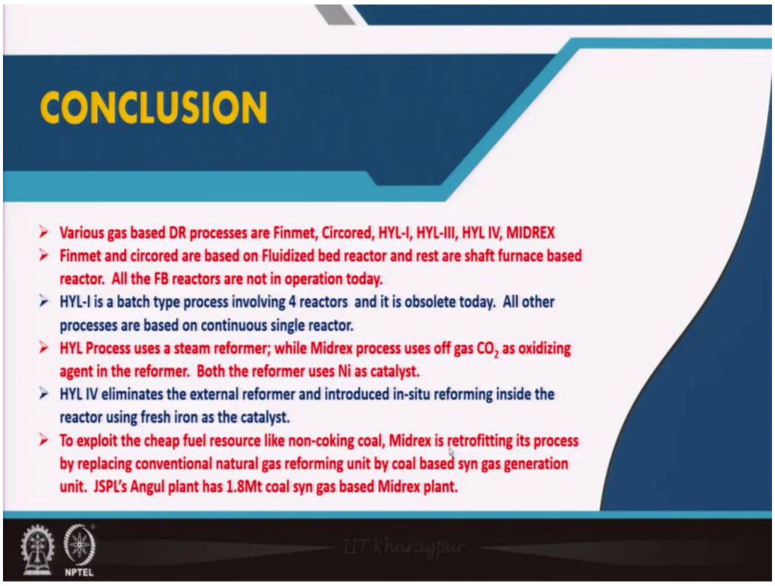
Essar Steel presently Arcelor Mittal, has 6 modules with total capacity of 6.7 million tonne. JSW, Angul, Orissa has set up 1.8 million tonne per annum in MIDREX plant. But, it is very unique because this MIDREX plant is designed to run on synthetic gas produced through gasification of coal. So, it is coal based MIDREX. It uses Lurgi coal gasifier, which is a fixed bed type. Course coal (6 to 40 mm) are charged from the top and gasifying agent like oxygen and steam flows in the opposite direction from the bottom. The process is carried out in a water cooled pressure vessel (3-4 m in diameter) at high pressure (25-35 bar) and temperature (above 1000^{o}C).

(Refer Slide Time: 26:55)



References: as listed above.

(Refer Slide Time: 26:57)



Conclusion:

- Various gas based DR processes are Finmet, Circored, HYL-I, HYL-III, HYL IV, MIDREX
- Finmet and circored are based on Fluidized bed (FB) reactor and rest are shaft furnace based reactor. FB reactors did not became popular due to maintenance of high pressure in the reactor.
- HYL-I was a batch type process involving 4 reactors and it is obsolete today. The third generation HYL, the HYL-III was designed based on a single continuous shaft reactor with wide acceptance. HYL Process used steam reformer with Ni-catalyst.
- The most popular gas based DR process is Midrex process, which uses off gas CO_2 as oxidizing agent in the reformer. Input energy is around 9-10 Gcal/ton, similar to HYL-II process and with a process efficiency of 73%.
- HYL IV eliminates the external reformer and introduced in-situ reforming inside the reactor using fresh iron as the catalyst.
- To exploit the cheap fuel resource like non-coking coal, Midrex is retrofitting its process by replacing conventional natural gas reforming unit by coal based synthetic gas generation unit. JSPL's Angul plant has 1.8Mt coal synthetic gas based Midrex plant.