Iron Making and Steel Making
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Module - 07
Lecture - 34
Hybrid Processes

In this lecture, we will discuss about the Hybrid Processes. Hybrid process, as the name suggest, it is an amalgamation of two, or more processes in a single reactor.

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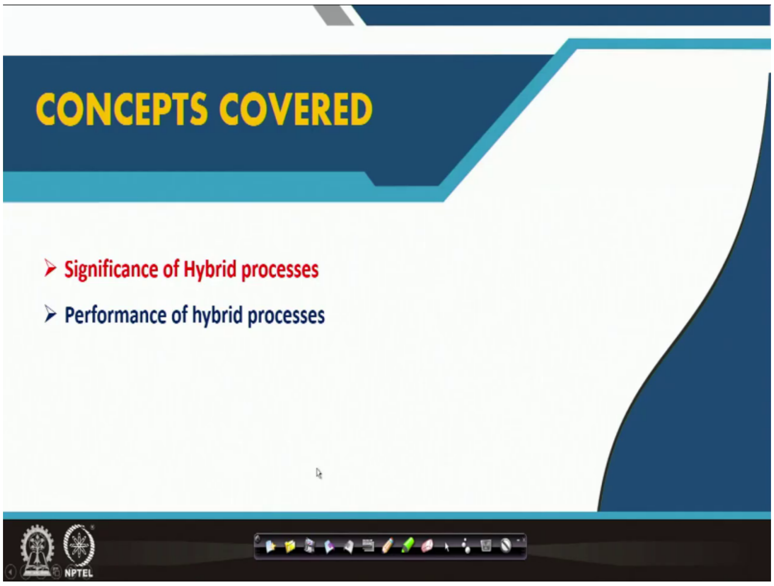

Topics cover will include the significance of the hybrid process and then, the performance of the hybrid processes.

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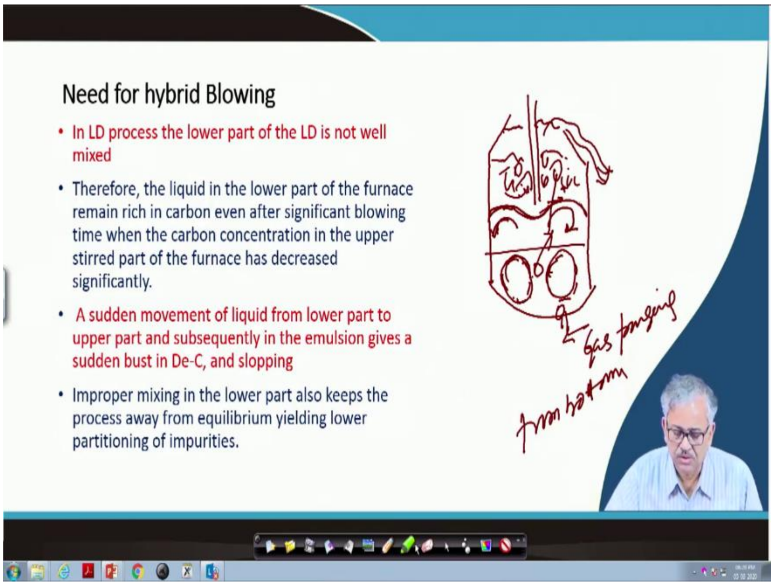

Hybrid, or combined blowing is an example of a hybrid process. In LD furnace the bath stirring is not uniform. Since the bath is stirred from the top; a clear stratification between upper and lower layers takes place with respect to heat, mass and momentum transfer. There exists a steep gradient in terms of velocity, concentration and temperature between two layers as shown schematically in Figure 34.1.

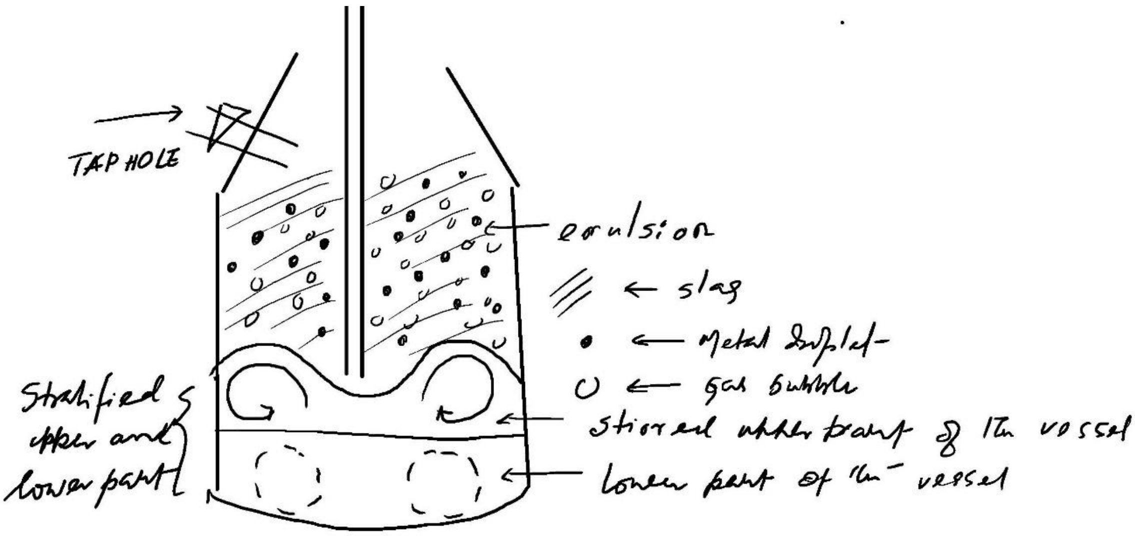

Figure 34.1: Schematics of LD showing stratification between upper and lower layers

So, upper part liquid is strongly stirred while the lower part liquid is weakly stirred (shown by dotted circles). While the upper part regularly interacts with emulsion and its impurity concentration decreases progressively; the lower part rarely interact with emulsion phase and remain rich in impurities. So, when a packet of impurity rich liquid from the lower part of the furnace joins the upper part and subsequently join the emulsion phase, there could be a sudden brust of decarburization; causing foam and emulsion height to rise suddenly and leading to slopping.

An improper mixing in the lower part of the furnace also keeps the process away from the equilibrium; consequently, the partitioning of the impurity, and yield of the process remains low. So, the process will not be very efficient. So, two problems are there in conventional LD namely, the irregularity like slopping, and poor partitioning of impurities and lower yield due to improper mixing of the lower parts of the furnace.

So, inert gas purging from the bottom, alleviates this problem by mixing the lower part of the furnace; and thus giving birth to the process of combined blowing, or hybrid blowing. Thus in hybrid blowing, in addition to conventional oxygen lancing from the top in LD, inert gas is also purged from the bottom.

There are several other variants of hybrid processes. Table 34.1 presents various existing hybrid processes.

Table 34.1 Classifications of various hybrid processes [3]

Process Class	*Representative process*
1. Classical LD with only top blowing and lumpy charge from top	LD
2. LDAC/OLP process with top oxygen and lime powder from top	LDAC/OLP
3. LD with additional bottom gas purging	LBE/LD-AB/LD-KG
4. Oxygen blowing from top and bottom	BSC-BAP/LD-OB
5. Oxygen blowing from top and bottom with lime powder from top	LD-HC/STB-P
6. Oxygen blowing from top and bottom and lime powder from bottom	K-BOP

7.	Oxygen and lime powder from bottom only	OBM-P
8.	Oxygen and protective hydrocarbon (classical OBM)	OBM
9.	Oxygen bottom blown plus oil/gas injection for preheating	KMS-KS/OBM-S
10.	Oxygen and inert gas from top only	LD-GTL/AOB/AOD
11.	Oxygen from top only but with jet pulse	LD-PJ
12.	Oxygen from top only with circular motion of the lance	LD-CL

After classical LD, the second process in the table is called the LDAC, or OLP (oxygen Lime Powder), where lime powder is blown with oxygen from top. Lime powder is added to enhance the lime dissolution rate and to form the basic slag early to treat high phosphorus hot metal.

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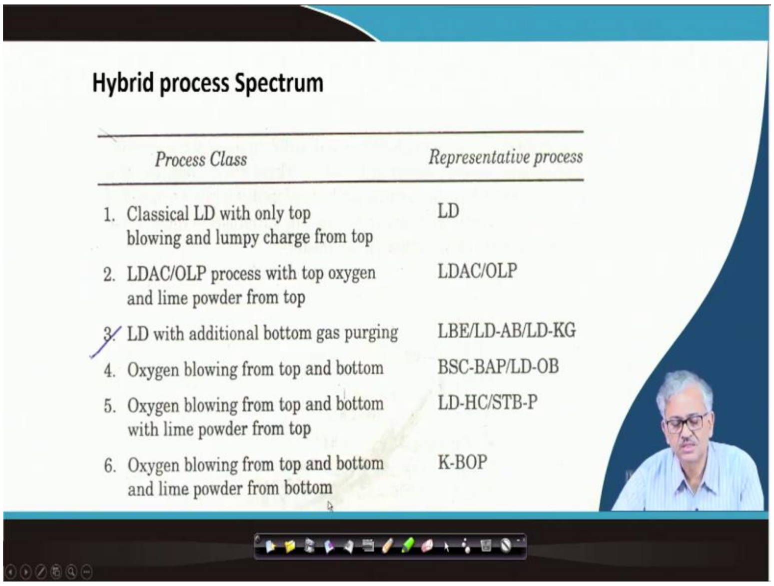
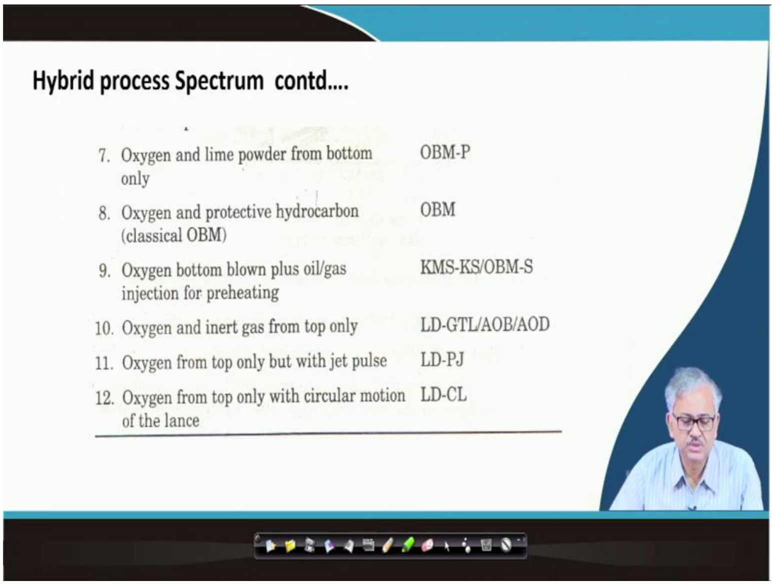


And then, LD with additional bottom gas purging, i.e., the hybrid blowing. One of the variant of hybrid blowing is called the LBE (ladle bubbling equilibrium) process; here inert gas is purged from the bottom at a moderate rate to eliminate the stratification at the lower part of the LD furnace. And the process in the vessel move closer toward the equilibrium, improving the partition coefficient.

Then, LD-AB LD-KG, are the other process variants of the LD with the additional inert gas purging from the bottom.

In some hybrid process oxidizing gas (oxygen/Air) is blown along with or without inert gas from the bottom. There some process variants like LD-OB, BAS_BAP.

There are some processes where oxygen is purged both from top and bottom, along with lime powder either from top or from bottom. Depending on that some process variants are there; like LD-HC, STB-P for lime injection from top and K-BOP for lime injection from bottom. (Refer Slide Time: 11:08)



When 100 percent oxygen is blown from the bottom; that is called the classical OBM (oxygen bottom blowing method). Oxygen blowing from the bottom has been found to be very good from the mixing point of view and the process is also very close to equilibrium, with a minimum iron loss, maximum yield and with maximum impurity partitioning. But the major problem is the nozzle maintenance. When oxygen is purged from the bottom, the impurity oxidation takes place at the nozzle tip leading to its rapid erosion, especially when large amount of oxygen is purged. Such nozzle is designed to pass hydrocarbon gas through annular section and when the hydrocarbon exposed to liquid steel it leads to endothermic cracking, giving a partial protection from excess heat generation at the nozzle tip. Such protection might be okay for moderate oxygen purging like 20% along with other inert gases. When full load of oxygen is purged from the bottom, like in OBM, hydrocarbon protection is not sufficient and nozzle has to be replaced at regular interval, which makes the process cumbersome and costly. This is the reason, in-spite of very good impurity partitioning and yield, the process could not compete with LD with moderate bottom purging.

And then there exists a variant of the OBM process, where oxygen and lime powder are injected from the bottom, called OBM-P.

Then, there are process where oxygen and inert gas are purged from the top only. LB-GTL/AOB/AOD processes. Although AOD is not a competitor to LD and it is used for making ultra low carbon steel out of crude mild steel produced in LD.

Oxygen from top only, but with a jet pulse (LD-JP); then, oxygen from top only with circular motion of the lance (LD-CL).

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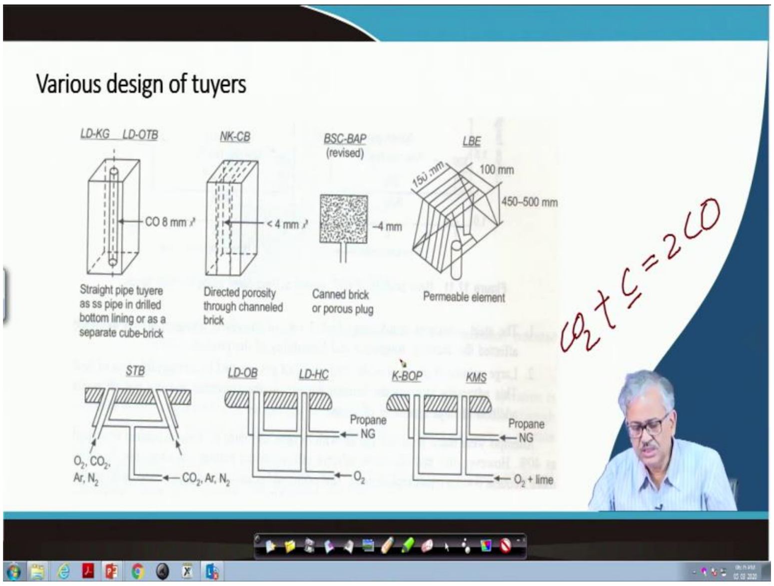

Various process variants have also emerged based on nozzle design. Figure 34.2 depicts the various process variant based on nozzle design. You can have a straight pipe nozzle as in LD-KG, LD-OTB. There are directed porosity through the channel bricks, NK-CB process. Other designs are porous plug in BSC-BAP, permeable membrane as in LBE. The process where oxidizing gases are introduced from the bottom have slight variations in nozzle design or, process could vary in terms of combination of gas and solid powder injection. In STB process, oxidizing CO_2 is purged along with air and nitrogen both through central as well as annular section of the nozzle. CO_2 serves both the purpose of oxidation as well as cooling. It oxidize carbon through an endothermic solution loss reaction (Equation 34.1) that helps in reducing the temperature near the nozzle.

$$C + CO_2 = 2CO \tag{34.1}$$

In case of LDHC and LD-OB process, oxygen is purged through central tube with a protective hydrocarbon through annular section as in OBM process. In case of K-BOP and KMS process, they have similar nozzle design but lime powder also accompany oxygen from the bottom.

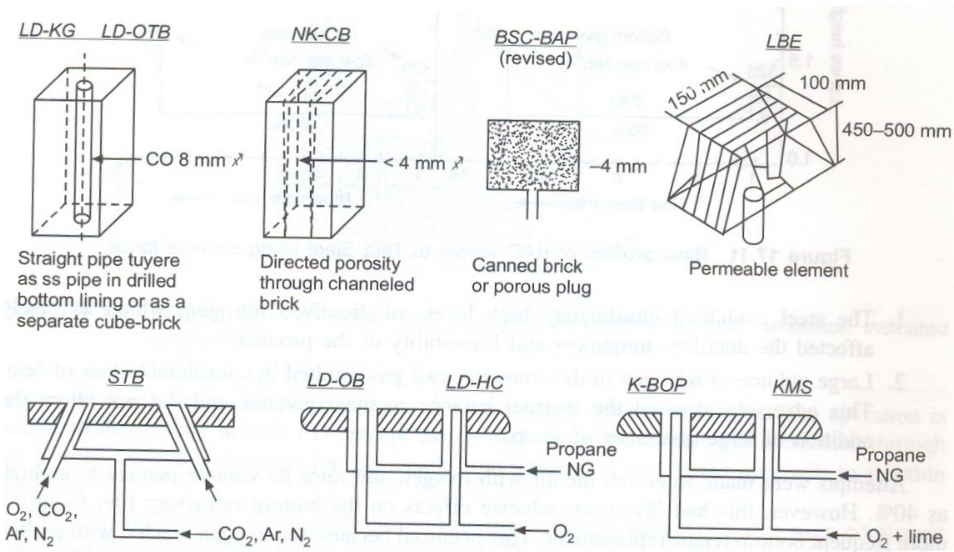

Figure 34.2 Various process based on nozzle design [1]

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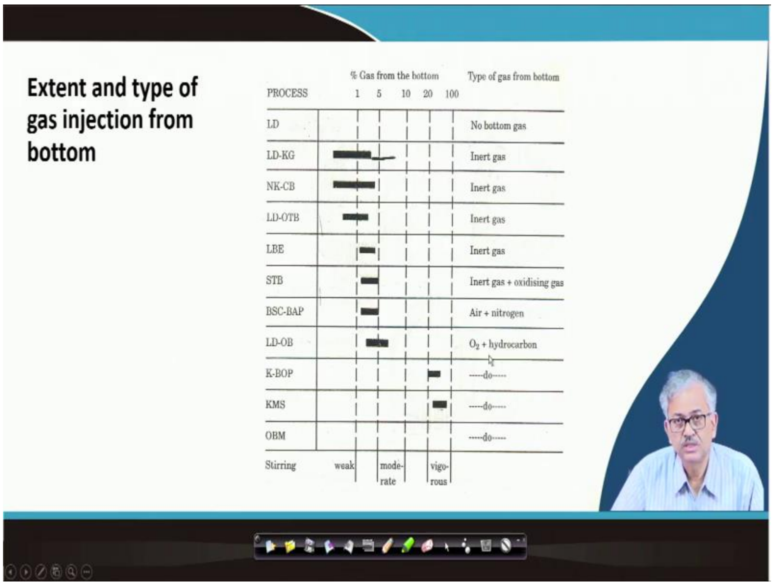

Various process originated from the intensity of bottom stirring. Figure 34.3 shows the extent and type of gas injection from the bottom for various processes.

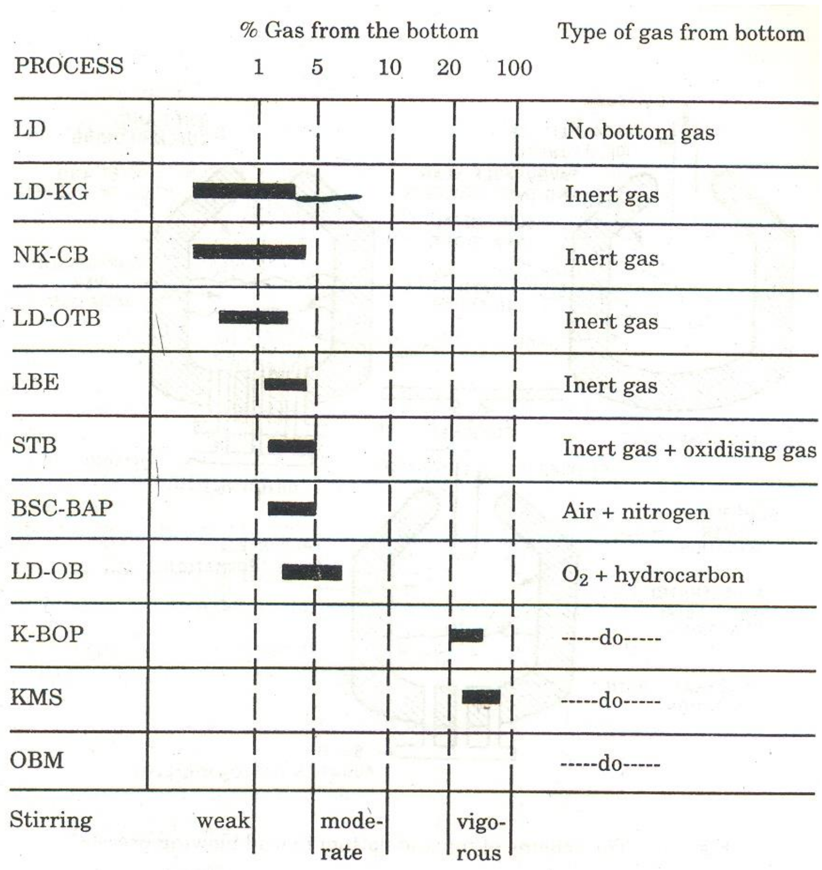

Figure 34.3 Extent and type of gas injection for various processes[3].

There exists three regimes of gas injection from the bottom. When the gas injection from bottom is less than 1 percentage of the total gas (including oxidizing and inert) charged in the vessel, bottom stirring may be characterized as weak. 1 to 5% gas injection from the bottom may be considered as standard, because several hybrid process operate in this regime. When the gas purged from the bottom ranges between 5 to 10%, stirring may be characterized as moderate and when more than 20% gas injection may be termed as vigorous. We can find LD-OB in the moderate regime and K-BOP and KPS in vigorous regime. In moderate and vigorous regime oxygen from bottom is purged with hydrocarbon protection. Most of the standard processes including LBE (the most popular method) only purge inert gas from the bottom in the range 1 to 5%. STB, BSC-BAP, which inject oxidizing gases like air and CO_2 along with inert gas also operate in this regime (1-5%).

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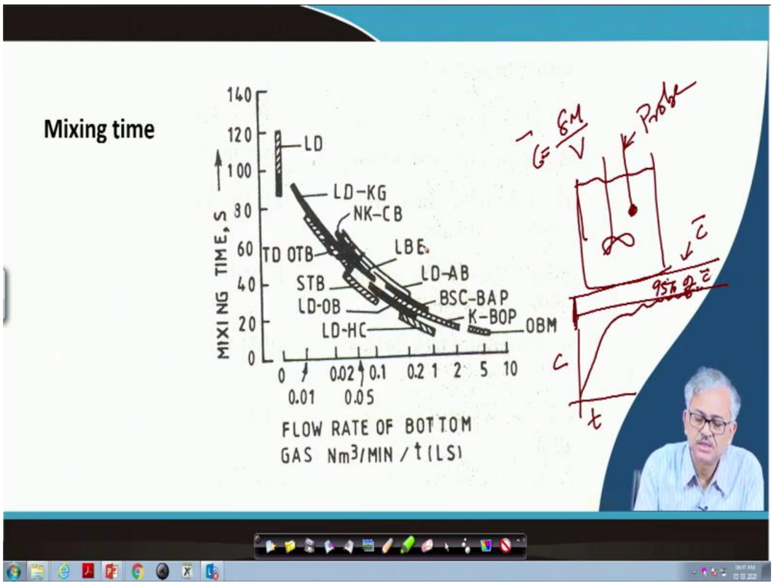

In hybrid blowing, mixing rate is decreased significantly compared to conventional LD process. Mixing time provides an estimate of the time required to homogenize the bath. Average time required to attain the 95% of the average concentration in the bath, is defined as the mixing time. It is measured by introducing a trace in the bath and monitoring the temporal evolution of concentration in the bath using a suitable probe. Since mixing time will also depends on the locations, mixing time could be measured in some representative location; or it could be measured at several locations and their average could be taken. Figure 34.5 shows the spectrum of mixing time for different processes.

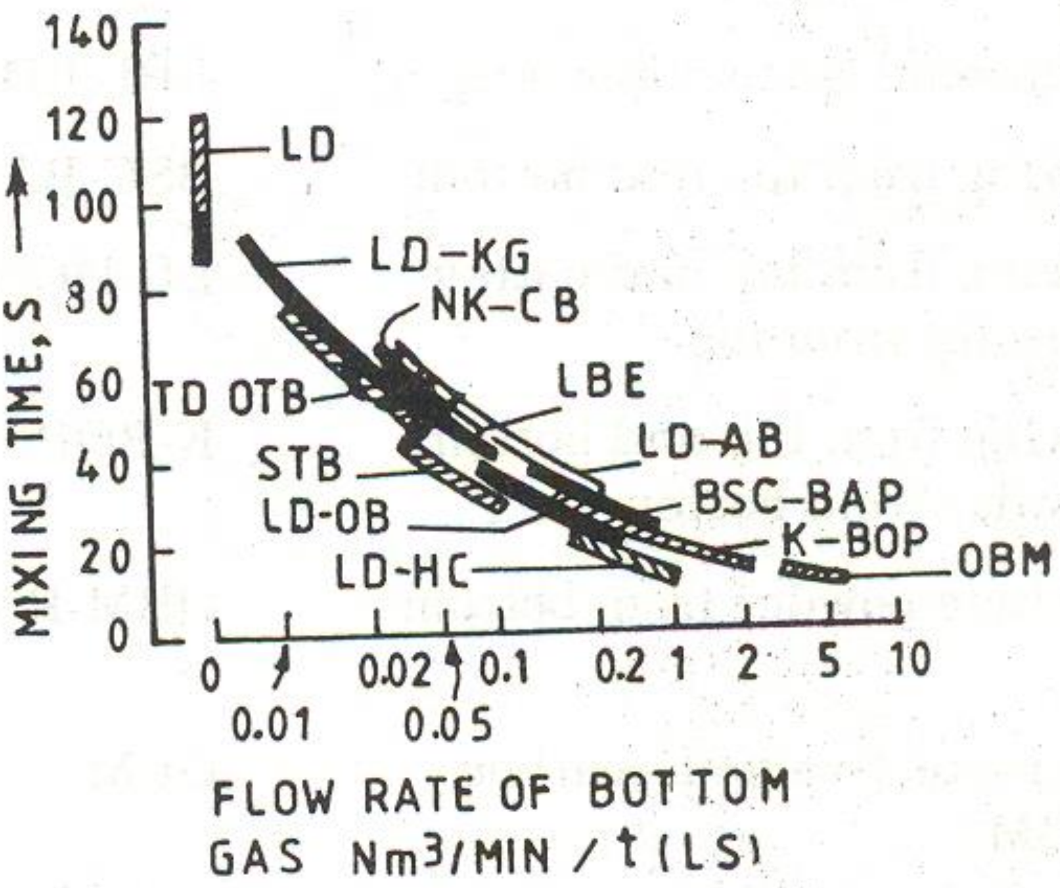

Figure 34.4: Spectrum of mixing time for various processes[3]

Now, from the Figure 34.4, it may be observed that in case of the LD, the mixing time is maximum; you can find it ranges from 100-120 seconds; while it is less than 20 seconds for OBM process where mixing is fastest among the hybrid processes. In case of LBE, it is around 50 secs. So, some amount of gas purging from the bottom always help in increasing the mixing time.

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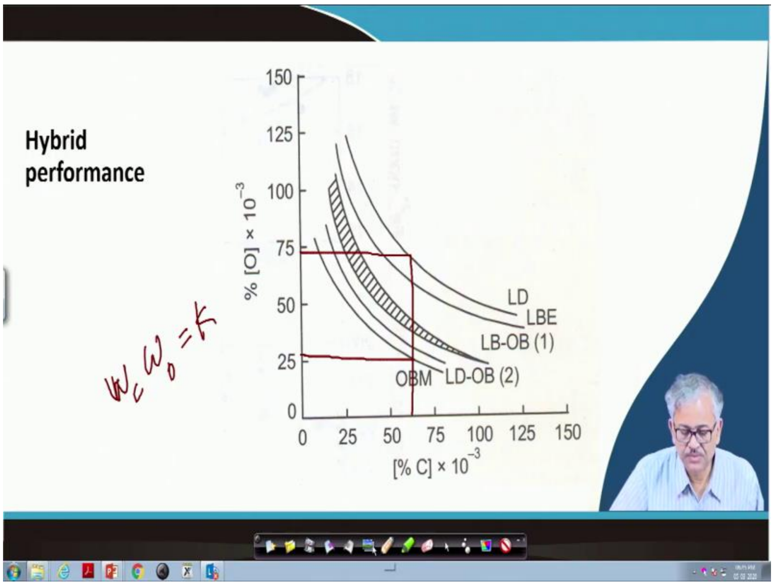

The performance of hybrid process can be assessed based of residual dissolved oxygen in the bath, and the iron loss through slag (Figure 34.6).

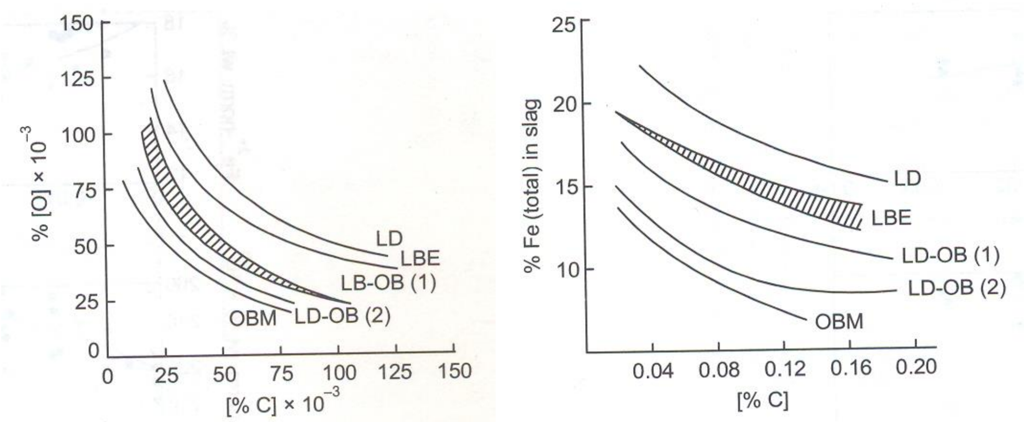

Figure 34.6: (a) residual dissolved oxygen and (b) extent of iron loss through slag for various processes[1]

You can find that for a certain dissolved carbon in the bath, residual dissolve oxygen in tapped steel is maximum in the LD process and it is minimum in the OBM process. The OBM line is very close to the equilibrium line defining the solubility product of dissolved carbon and oxygen at 1 atmospheric pressure and at 1600^{o}C. That means, for a particular amount of the carbon, this oxygen amount in case of OBM is very close to the saturation oxygen level in the bath.

In Figure 34.6(b), it is also see that iron loss is also maximum in LD and minimum in OBM. Because of lower mixing in the bath, the slag in LD get over oxidized, which keeps the bath as well as slag at higher level of oxygen.

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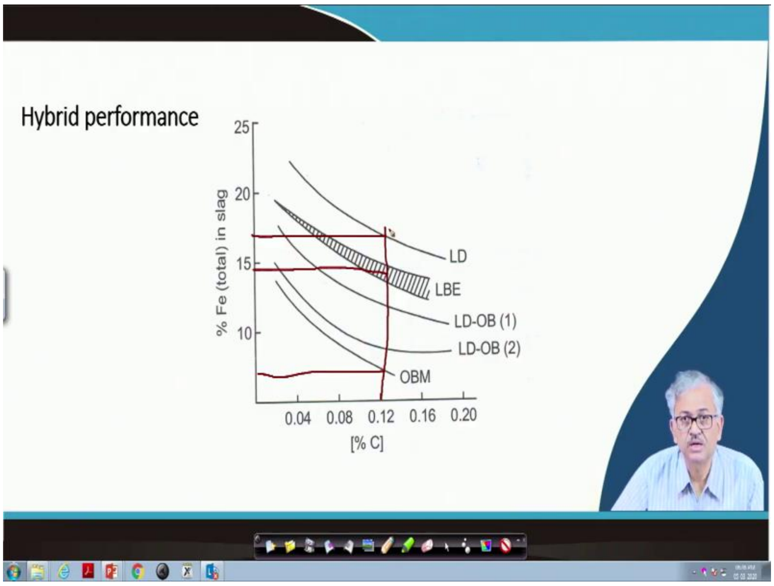

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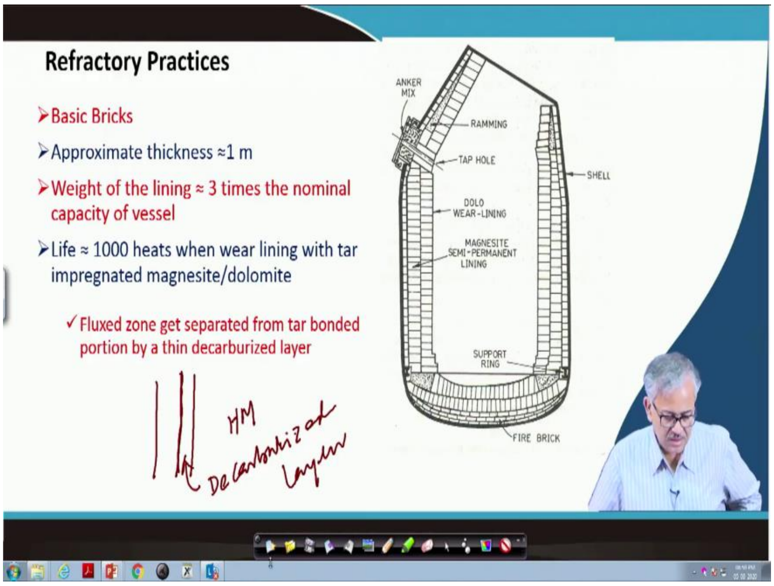

Now I will end this lecture by touching upon the refractory in LD furnace. LD furnace has a basic refractory lining and first I will give some interesting facts. Approximately thickness of the refractory lining is around 1 meter and weight of the lining is around 3 times the nominal capacity of the vessel.

Converter is lined with a permanent lining and above it there is a wear lining. Permanent lining thickness may vary from 100mm to 120mm and is made of chrome-magnesite bricks, which is given on the full height of the converter. Above the permanent lining, wear lining is constructed. The cylindrical portion of the converter is lined with tar impregnated dolomite bricks, and or, the ramming mass of tar dolomite. The detachable bottom is constructed by using mica, fireclay, chrome-magnesite and Mag-chrome bricks

Using tar bonded dolomite wear lining, the life of the refractory becomes 1000 heats. What happens is that when the refractory comes in contact with the hot metal, then wear lining in contact with hot metal is decarburized, and forms a decarburized layer ahead of hot metal. Decarburized layer contains lots of non wettable micro pores, which separates the wear lining from the direct contact with the liquid.

Another technique that is used to enhance the refractory life further to more than 2000 heats is called the slag wash or slag splashing.

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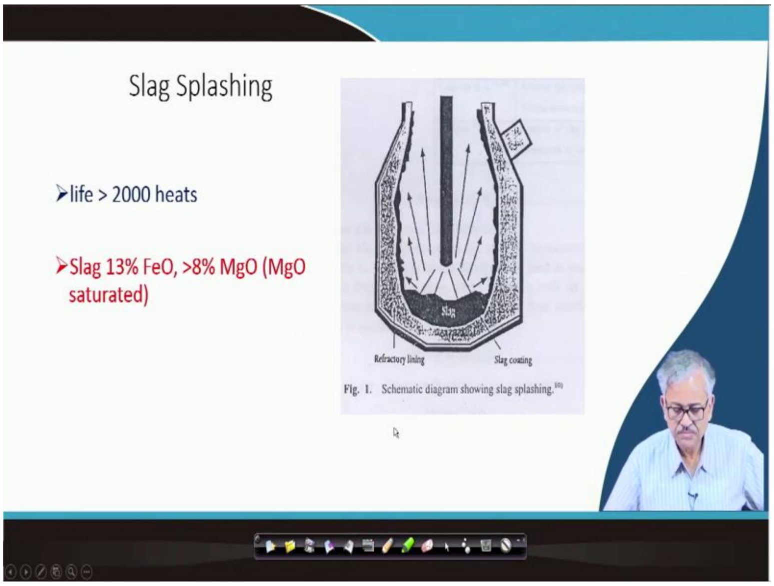

Here, the composition of the left out slag in the vessel is modified and splashed pneumatically to the refractory wall to give a protective coating. The slag composition is adjusted to 13 percent FeO and more than 8 percent MgO in the slag. FeO provides required fluidity to adhere to the wall. 8% MgO is the saturation level of MgO in the slag. MgO provides the protection to the refractory wall.

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Reference 3. R. H. Tupkary: Modern steelmaking, Khanna publishers

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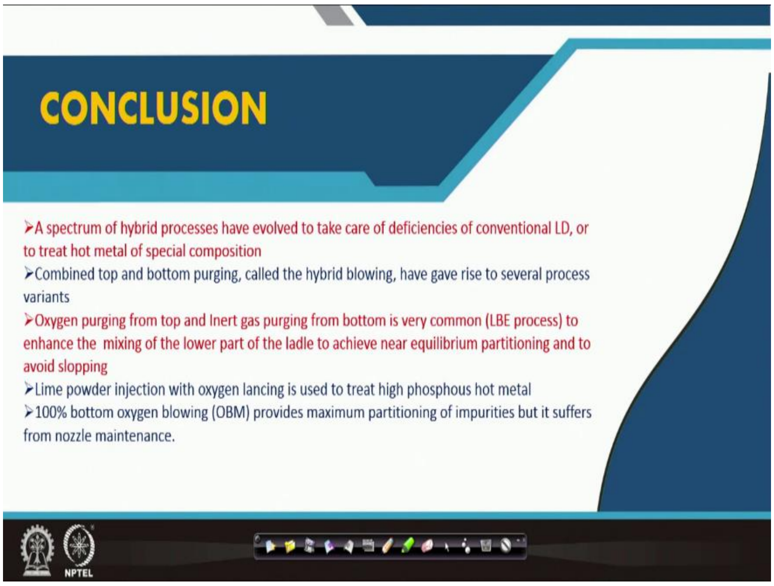

Conclusion: A wide range of hybrid process have evolved to take care of deficiencies of conventional LD furnace.

Several processes have emerged with hybrid blowing, where in addition to the conventional top lancing of oxygen, inert and oxidizing gases are also injected from the bottom with different intensity. In most popular LBE process, inert gas is charged from the bottom with mild intensity (at a level of around 1-5% of the total gas charged in the furnace). Such gas purging from the bottom remove the stratification between the top and bottom layer in the furnace and brings the process closer to equilibrium improving the impurity partitioning and yield. It also minimize the phenomenon of slopping in the LD furnace.

The process where 100% oxygen is charged from the bottom is called the OBM process, which is characterized by excellent mixing and maximum yield and impurity partitioning. However, it is crippled with regular replacement of nozzle, in-spite of hydrocarbon protection of the nozzle. Hydrocarbon is passed through the annular portion of the nozzle and its endothermic cracking in presence of hot liquid iron helps to cool the nozzle.

In some innovative process (STB), CO_2 is used as an oxidizing agent for carbon deriving both the benefit of oxidation and nozzle cooling by endothermic solution loss reaction.

The refractory of LD vessel consists of two layers: Chrome-magnesite permanent brick lining followed by tar impregnated dolomite wear lining. Total lining thickness could be 1 meter and weight of the lining could be three times the nominal capacity of the vessel.

Tar impregnated dolomite wear lining improves the corrosion resistance by forming a porous decarburized layer ahead of liquid iron.

Slag wash is another technique to improve the lining life by more than 2000 heats. Here a slag of desired composition (by adjusting the left over slag) is given as a coating on the refractory lining by pneumatic means.