Iron Making and Steel Making
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Lecture – 03
The Iron Blast Furnace

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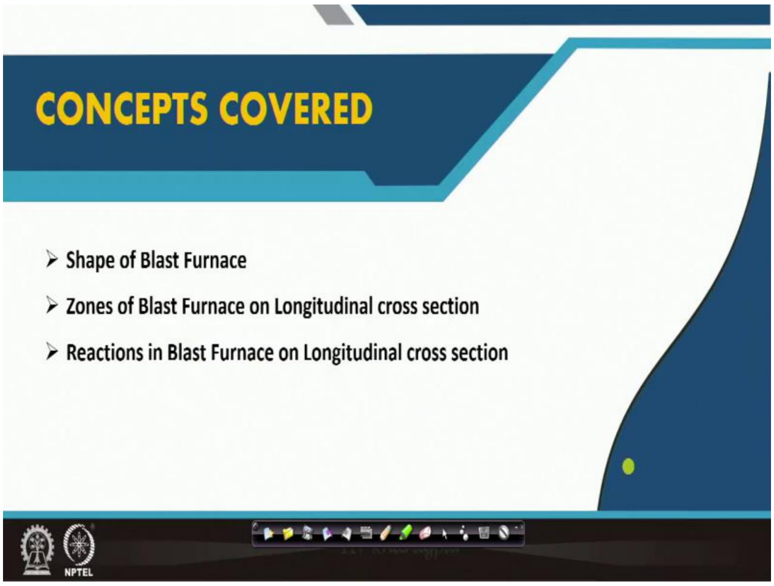

So, very good morning. And today, I will start the Iron Blast Furnace. The concept that will be covered, actually the shape of the blast furnace, how does the blast furnace look like, and why the shape is like that. And then we will talk about the various zones in the blast furnace, on longitudinal cross section and various reaction in the blast furnace.

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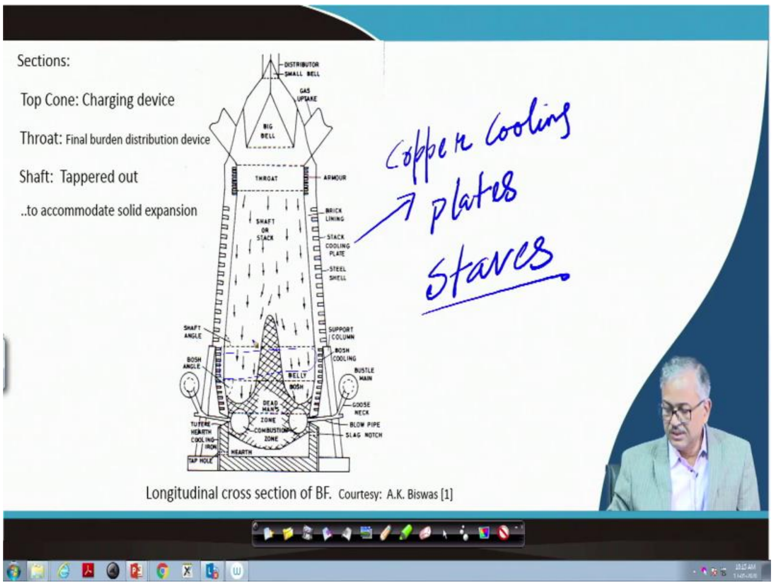

So, this is a very nice picture and taken from the book of A K Biswas. This is the blast furnace on a longitudinal cross section, as it look like. Now, let us start with the different section. At the top we can find there is a charging device, placed in a top cone. The device shown is conventional two bell charging and the most recent charging system is the bell less charging. Next to the charging region is a cylindrical section, called the throat. Throat section is used for the final burden distribution over the stockline. Wall of the throat is also used to project armour for deflecting the charge material away from the wall.

After throat comes the shaft. This is a very important region in the blast furnace where most of the solid state reduction takes place through counter current gas-solid interaction. It is the longest portion of the furnace and maintenance of good permeability across section in this region is a challenging task. Also you can find that stack is little tappered out. It is not perfectly cylindrical, and it is basically a cone. This tapering out is to accommodate the expansion of the solid as it get heated up during its course of descent and heat exchange with the ascending hot gas.

Another thing you can find on the shaft wall- is a cooling arrangement. In the course of heat exchange with the hot ascending gas, refractory as well as the wall get heated up. Unless this heat is extracted out there could be heat accumulation and increase in refractory temperature, which is not good for the refractory lining and its life-period.

Since blast furnace is a continuous reactor it is not economic for intermittent shutdown and replacement of refractory. Therefore adequate cooling arrangement on the wall is required to drive out the excess heat. Cooling is done using some water cooled copper plates placed on the shaft wall, called the copper staves. In copper staves, there are arrangement for cold water going in and hot water coming out.

Now, after the shaft we have another cylindrical section, called the belly region.

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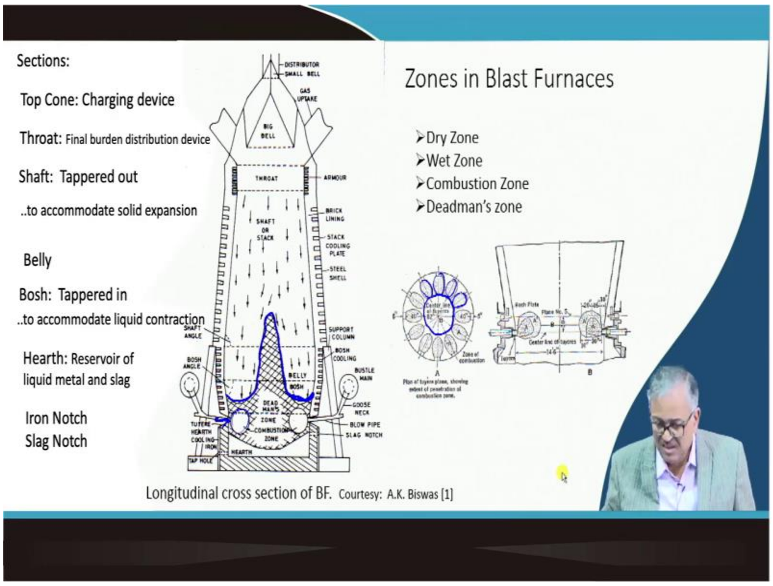

Softening of solid burden (except coke) starts here. And just below the belly you have another conical region with tapering in, is called the bosh. Again, why it is tappered in? Here, the solid become liquid and it shrink in volume. So, some tapering is required such that shrinking volume is accommodated inside to restrict creation of voids and charge slips etc

And just below the bosh, you have the hearth. This is basically the reservoir for liquid metal and slag. Near the top of the hearth, there is a slag notch to take out the lighter slag floating over the liquid iron. An iron notch is there near the bottom of the hearth to tap out the hot metal.

So, these are the different longitudinal section in blast furnace and below that it has the foundation. And now let us see different internal zones in a blast furnace. Blast furnace is a complicated reactor which separates two regions-dry and wet regions separated by an interface, called the cohesive zone. In cohesive zone softening of solid burden starts and everything is liquid (except coke) below the cohesive zone. So, in dry zone (shaft region) burden remains solid, and in the wet zone (belly, bosh region) burden becomes liquid. Gas moves up against solid coke and liquid iron and slag in wet zone and against solid in the dry zone. The cohesive zone has a shape of inverted V, following the solid isotherm inside the furnace.

Then comes the combustion zone, the heart of heat generation in the furnace. Here preheated air blast after entering through tuyers combusts the coke particles around it- called the raceway What are the reaction you can expect? First carbon is burned with oxygen in air forming CO_2 and then CO_2 reacts with carbon to form CO, forming a CO rich gas in the raceway. Because, thermodynamically CO_2 is not stable in presence of carbon at high temperature. In the slide above you can find two regions in the raceway, A and A-prime. In region A, carbon get oxidized to CO_2, which subsequently gasify carbon to CO in the A-prime region.

In combustion zone there are several tuyers across the periphery of the lower part of the bosh region, with gas being sourced from a bustle pipe. You can see only two tuyeres on the longitudinal cross section and on a plan view you can see all the tuyers, as shown in the slide. Each ballon shaped region at the tip of tuyere is called the raceway. Carbon burning takes place only in the raceway. Beyond raceway, oxygen does not reach. So, there exists a coke region in the central region, which remains inactive, called the Deadman’s coke. It is shown by the central circular region in the plan view and in longitudinal cross section by an inverted V shape. This is the steady state shape of the deadman’s zone in blast furnace. This is a very important zone because this is the only solid burden at the bottom of the furnace which holds the over burden. The deanman’s coke might be seating on the hearth bottom (seating deadman) or it might be floating on the liquid iron (floating deadman).

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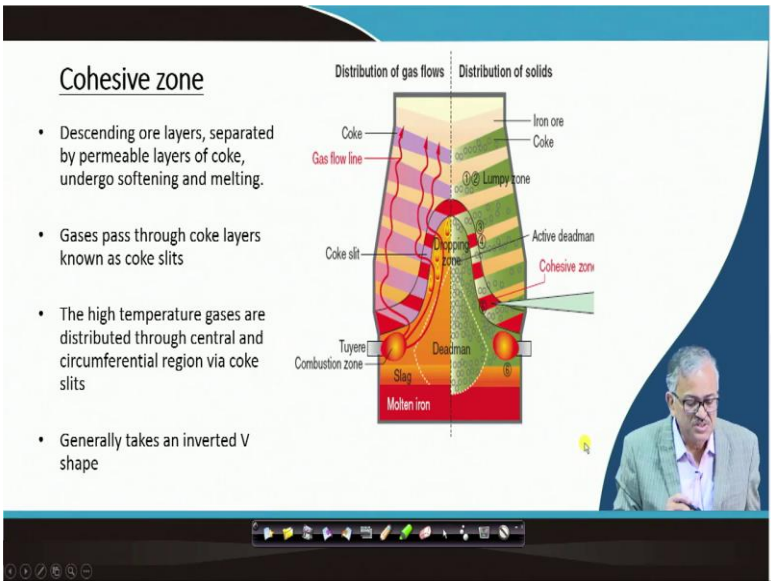

Now, let us talk about cohesive zone, which I have mentioned as an interface separating the dry and wet zone in the blast furnace. In blast furnace, solid-liquid transition does not takes place along a particular horizontal line, that is, above that line everything is solid and blow it liquid.

In the blast furnace, the cohesive zone takes the shape of an inverted V-shape. It basically follow the shape of the isotherm of the solid burden. The thickness of the cohesive zone is defined by two lines-start of softening and end of softening defined by the solidus and liquidus isotherm of the slag. It is to be noted that coke does not melt in the blast furnace and as a result coke in the cohesive zone offers the path gas to pass, called the coke slits. In the figure shown in the slide, coke slits are shown in purple color, and the fused mass of iron and slag in red. So, alternate layers of fused mass and coke slits may be observed. Now, if you follow the ore layer from periphery to the center, you can find that the ore layer when it approach near the center in cohesive zone, it has become red, means it has softened. So, ore was solid away from cohesive zone and gets softened in cohesive zone. You may also note that no such transition has taken place for coke as indicated by no change in color.

Let us explain temperature profile and shape of cohesive zone. Usually blast furnace is dominated by central flow and therefore more amount of gas passes through the central region maintaining temperature of the central region higher than the region near wall.

Now consider the stock profile. It is usually V shapped because burden moves through the central region at faster speed than that near the wall due to resistance offered by the wall. So, alternate softened region and coke slit appears in the cohesive zone. Gas passes through these coke slits, which distribute the gas both in the peripheral (through coke slits placed near wall region) and central region (through coke slits near central region).

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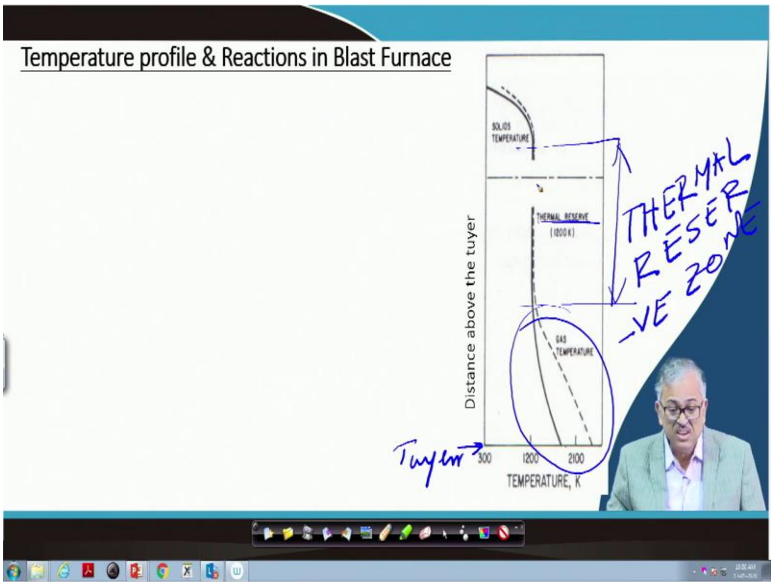

Now, come to the temperature profile and reaction in the blast furnace across the longitudinal cross section above tuyere location. Gas temperature is shown by dotted line; while solid temperature is represented by the solid line. We can see that there exists an isothermal zone in the middle part of the blast furnace, where temperature of the gas and solid are same (may be taken as 1200K) and no heat exchange takes place. It also indicates that heat balance in the lower and upper part of the furnace is maintained separately. In lower part of the furnace gas temperature decreases from 2200K to 1200K (a decrease by 1000K), while the solid is heated from 1200K to 1600K (a rise by 400K). It obviously indicates much higher heat capacity of solid compared to that of the gas and large heat capacity of the solid may be attributed to several endothermic reactions in the lower part of the furnace. In contrast, in the upper part of the furnace solid is heated from 300K to 1200K (an increase by 900K) and the gas is cooled from 1200K to say 500K (a decrease by 700K), indicating sufficient heat capacity of gas to preheat the solid.

At the upper part of the thermal reserve zone there exists a zone called the chemical reserve zone, where iron-wustite equilibrium is achieved.

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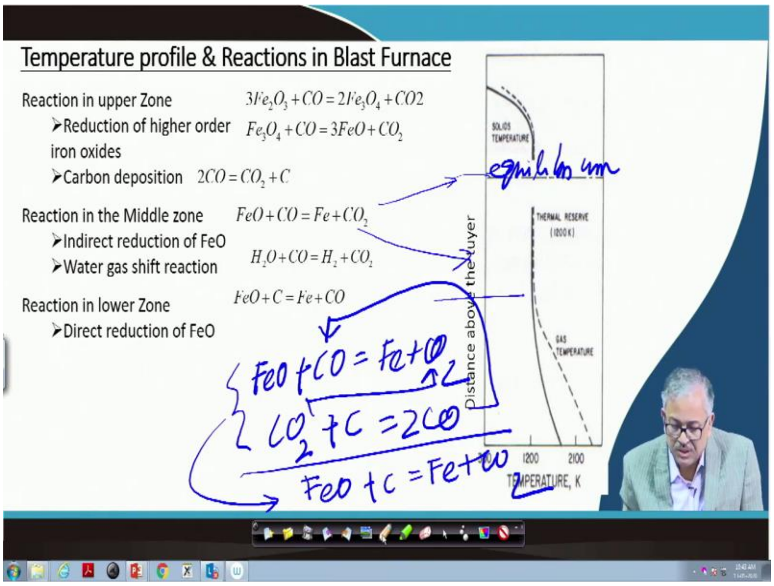

Now, let us see the major reactions that takes place across the longitudinal section of the furnace. In the upper part of the furnace the reduction of higher order oxides takes place, namely hematite to magnetite and magnetite to wustite by indirect reduction. It is called indirect reduction because the CO generated by carbon gasification at the lower part of the furnace is used for these reduction. Carbon does not take part in the reduction through its gasification at comparatively lower temperature.

$3Fe_2O_3+CO=2Fe_3O_4+CO_2$

$Fe_3O_4+CO=3FeO+CO_2$

Wustite reduction takes place at comparatively lower part of the furnace. Wustite undergoes both the direct and indirect reduction; indirect reduction at comparatively upper zone and direct reduction at comparatively lower zone, where carbon directly participate in the reaction through in-situ carbon gasification takes place.

$FeO+CO=Fe+CO_2$ - indirect reduction

$FeO+C=Fe+CO$ - direct reduction

The direct reduction is a misnomer-direct reduction takes place through gaseous intermediates. Carbon takes part in the reaction through carbon gasification reaction 9endothermic reaction), which takes place only if the temperature is high. Therefore direct reduction takes place only in the lower part of the furnace where temperature above 1200K.

The direct reduction of wustite can pictorially be represented as:

$$FeO + C = Fe + CO$$

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$$FeO + CO = Fe + CO_2$$

$$CO_2 + C = 2CO$$

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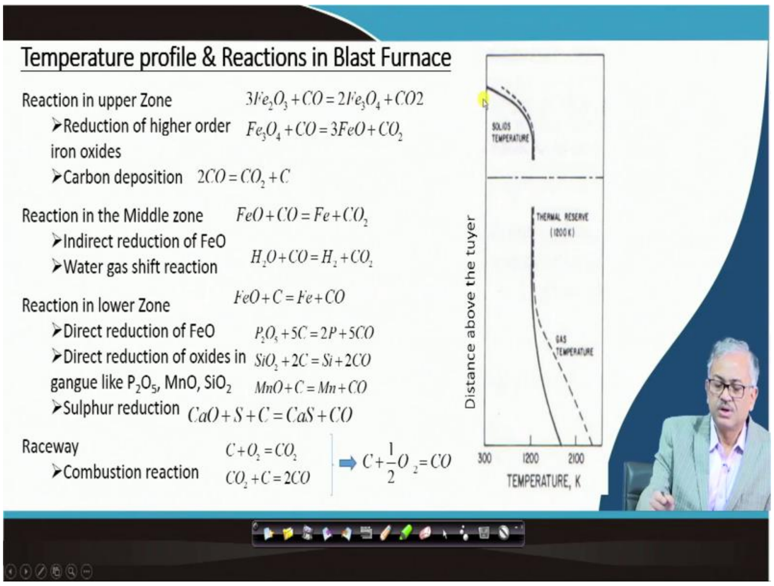

All other direct reductions (direct reduction of P_2O_5, MnO, SiO_2) also take place in the lower part of the furnace, as indicated in the slide.

Final sulphur reaction takes place at the slag metal interface through the reaction:

$CaO + S + C = CaS + CO$

Here, Sulphur get reduced to CaS. Therefore it is favoured under blast furnace reducing atmosphere.

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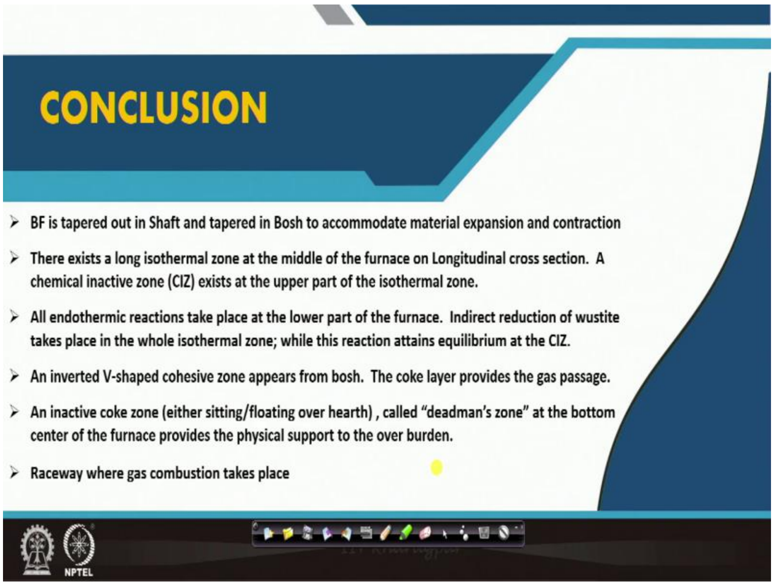

In this lecture, what we have discussed different sections of blast furnace across the longitudinal direction, namely upper cone with charging device, cylindrical throat, truncated conical shaft with tapered out, cylindrical belly, truncated conical bosh with tapering in, and cylindrical hearth from top to bottom. Blast furnace is tapered out at shaft and tapered in at bosh to accommodate the material expansion and contraction. And there exists a long isothermal zone in the middle of the longitudinal section and a Chemical Inactive Zone exists in the upper part of the isothermal zone. The dry and wet zone in a blast furnace is interfaced by a cohesive zone, which has a shape of inverted shape and here the solid softening takes place. The coke provides the path for ascending gas in the cohesive zone. Combustion of carbon takes place in the balloon shapped raceway originating from tuyere-tip. Oxygen cannot penetrate beyond raceway and in the central region the coke remains inactive-called the deadman's coke. The deadman zone extends from hearth upto cohesive zone and it can either seat at the bottom of the hearth or float over the liquid in the hearth.

Higher order oxides are reduced by indirect reduction in the upper part of the furnace. Indirect reduction of wustite attains equilibrium in the chemical reserve zone. All direct reductions takes place at the lower part of the furnace including the direct reduction of wustite. In direct reduction carbon directly participate in the reaction through in-situ gasification reaction, which is only possible at higher temperature at the lower part of the furnace.

Thank you.