Iron Making and Steel Making

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Lecture - 14
Coke rate and fuel efficiency in Blast Furnace

Welcome. In this lecture we will discuss the Coke rate and fuel efficiency in Blast Furnace because coke rate is also to some extent is correlated to aerodynamics.

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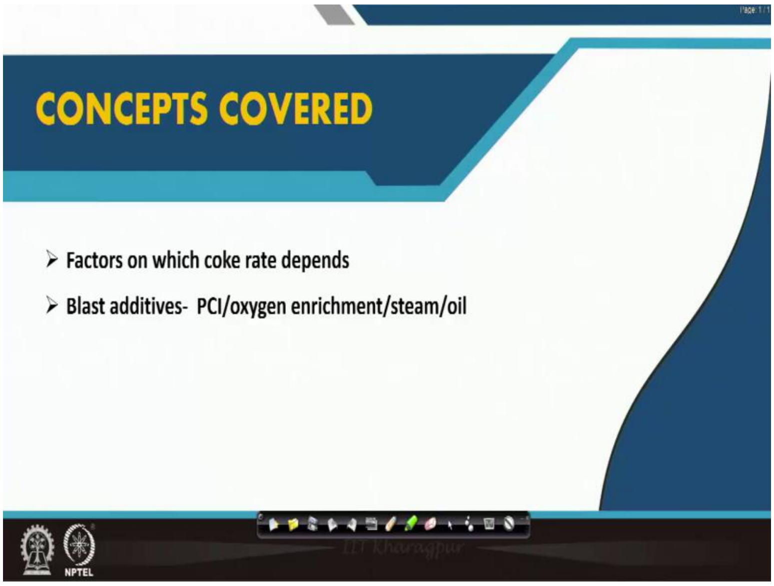

The concept that will be covered are the factors on which the coke rate or the fuel rate in the blast furnace depends and the various blast additives like PCI, oxygen enrichment, steam and oil.

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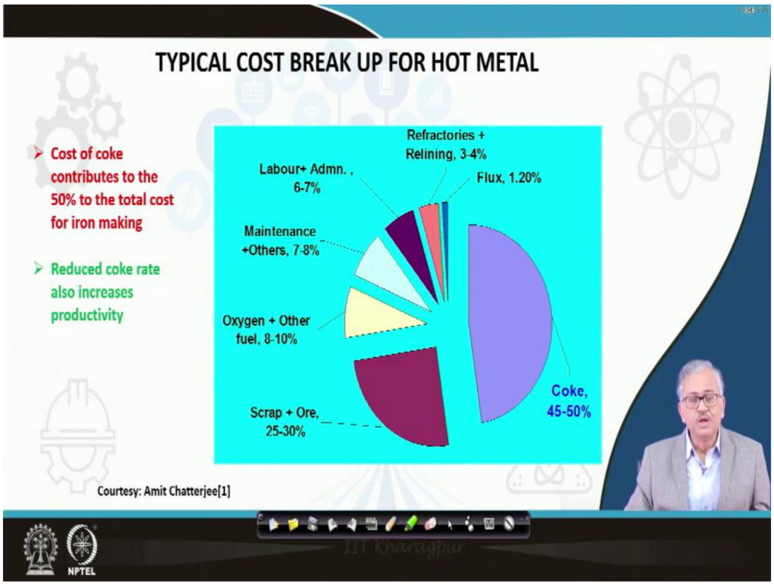

Typical cost break up for the hot metal is shown in the pie diagram. From this pie diagram, we can see that around 50 percent of the cost of the hot metal is contributed by the cost of the coke only. Therefore, the cost of the coke is the major part of the iron making because the coke is made from a special grade and rare coal type called the coking coal. In the world, only very few places are there where the coking coal reserves exist. In India it is a very rare and only in the Ranigunj and Jharia area you have certain amount of coking coal; that too contain comparatively higher ash. Most of the low ash coking coal is imported from Australia.

That is why the cost of coke contributes significantly to liquid iron production, especially in India. And several efforts have been made to reduce the coke rate in the blast furnace and coke rate has been significantly reduced over the years. However, blast furnace cannot operate without a minimum amount of coke. A certain amount of coke is required to physically hold the overburden in the blast furnace as well as to maintain the required bed permeability both in the dry and wet zone.

Let us see the methods of reducing the coke rate in blast furnace. Here the aim is to supplement two major functions of coke, namely heat generation and reduction potential of the gas. Today coke rate has decreased significantly at 350 kg per ton of hot metal, with additional 200 kg of pulverized coal injection. Reduction in coke rate increases the productivity.

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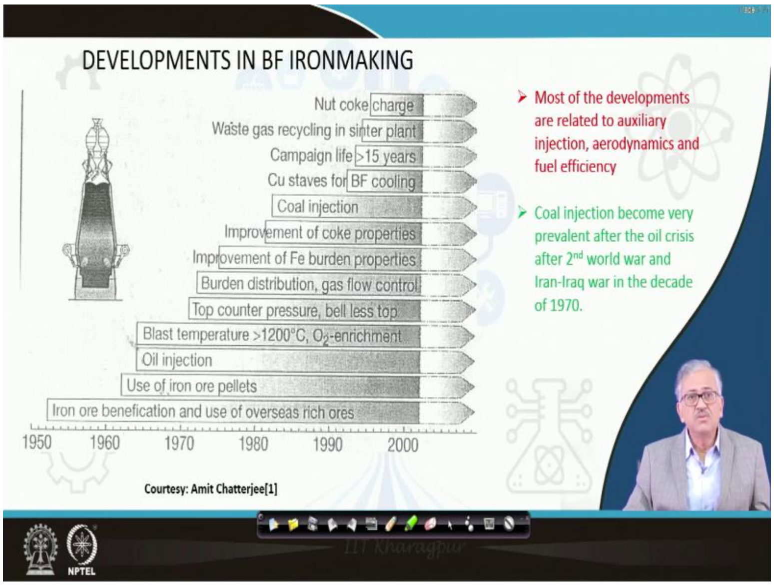

So, let us see the development in blast furnace over the years that have reduced the coke rates. The first step in this direction was iron ore beneficiation, or use of high grade overseas ore. Blast furnace is very sensitive to the raw material and the raw material quality has to be good. Basically iron ore should have sufficient strength, abrasion resistant, impact strength such that when those are descending from top, those should not generate much fines that can reduce the bed permeability. Besides, the gangue content of the ore should be low that does not produce large volume of slag and disturb the bed permeability in the wet zone of blast furnace.

Subsequently, came the usage of agglomerated iron ore in the form of iron ore pellets. Iron ore pellets could be made from beneficiated iron ore fines and might be very rich in iron. Because of its higher strength, it may be transported from overseas countries. Pellets with its higher strength and reactivity are considered very good iron ore burden for blast furnace. Later another form of agglomerated iron ore burden called the sinter appeared. But due to its comparatively lower strength it could not be transported long distance and has to be made within the plant itself. Besides, pellets are costly compared to sinter and therefore sinter gets an edge over pellets and now-a-days most of the plants are equipped with sinter plant in the plant itself. Sinter also provide a means of utilizing iron bearing solid waste from the plant and comparatively coarser particles could be sintered, which are not amenable for pellet making.

Then oil injection as blast additive appeared in blast furnace. Oil injection came as additive to decrease coke rate and increase productivity. It can supplement the heat and the reduction potential of the coke. Besides, oil being hydrocarbon, it produces hydrogen that is a better reductant than CO gas both thermodynamically and kinetically and promotes indirect reduction in the blast furnace and reduces coke rate.

Then came preheating of air blast. By preheating air blast, heat input in the blast furnace increases in the form of sensible heat that reduces coke rate.

Subsequently, bell less top charging increased the efficiency of burden charging mechanism, enhancing bed permeability and promoting indirect reduction, and enabling the dynamic control of bed permeability. Application of high top pressure also become easier. With high top pressure, pressure drop in the furnace could be reduced even at high blast rate, producing more.

Then attention was put towards the improvement of burden qualities through by improving the design and operating parameters of agglomeration units. Quality of blended coke was improved by stamp charging by increasing the bulk density of the raw coke mix.

Finally, a very significant milestone in terms of pulverized coal injection (PCI) appeared. Coal injection came as a substitute for oil injection during oil crisis in 1970s. First coke injection plant came in Japan in 1981 and after that PCI injection increased steadily. Nowadays most of the plant are equipped with the pulverized coal injection, and today's benchmark for PCI is more than 200 kg per ton of hot metal.

Finally attention was given to proper cooling of the blast furnace to enhance the refractory life and campaign life of blast furnace. Copper staves are water cooled copper plates which effectively extracts the heat from refractory wall avoiding overheating and premature refractory failure. Copper stave cooling enhanced the campaign life of blast furnace greater than 15 years.

Thus these are the improvements in blast furnace that has come over the years and most of these developments are related to the auxiliary injection, aerodynamics and the fuel efficiency.

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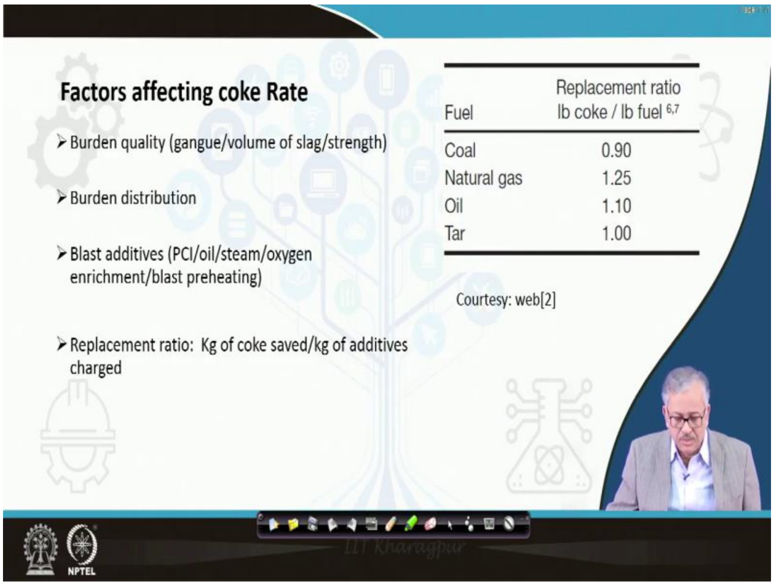

Now, let us discuss the factors affecting the coke rate. One important factor is the burden quality, which includes strength, gangue content. Strength of the burden should be high such that it does not generate fines during its descend and reduces bed permeability. The burden should not have much of gangue constituents such that slag volume produced will be less, which does not promote flooding.

Secondly, the burden distribution has a great role to play. Basically the evolution of gas flow dynamics through the bed depends extensively on the burden distribution. With bell loss top it is possible to dynamically control the burden distribution by charging the permeable charge in the locations of higher pressure drop as mapped through under-burden probes. With proper burden distribution we can ensure more or less uniform gas flow through the cross section of the blast furnace leading to extensive gas solid interaction, gas utilization, indirect reduction, and finally coke savings.

The blast additive reduces coke rate by supplementing its function of heating and reducing gas generation, and even supplying hydrogen that promotes indirect reduction. Blast additive includes pulverized coal injection, oil injection, steam injection, blast preheating and oxygen enrichment. So, by using blast additives we can save certain amount of coke and the ratio of kg of coke saved per kg of additives used is called the replacement ratio. For high rank coal the replacement ratio of PCI may be 0.9. Similarly natural gas has a replacement ratio of 1.25, oil has 1.1 and tar has 1.

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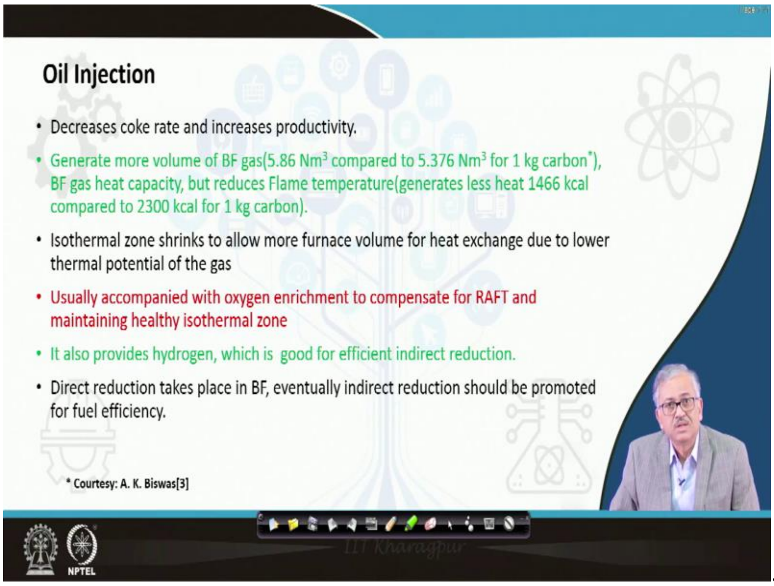

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Now, discuss oil injection in details. Oil generates more volume of blast furnace gas compared to coke. On burning, one kg of coke (assuming pure carbon) provides 5.376 Nm^3 of gas, while 1 kg of oil provides 5.86 Nm^3 of gas. So, oil generates more volume compared to carbon. So, blast furnace gas heat capacity increases due to more volume generation. But it reduces the flame temperature because more gas volume is generated and at the same time oil also generates less amount of heat compared to carbon. 1 kg oil generates 1466 kcal compared to 2300 kcal when 1 kg of carbon is burned. If the flame temperature is less, then heat exchange potential of the gas becomes less. With low flame temperature and higher gas volume, the heat balance in the lower part of the furnace is maintained at the cost of higher furnace working volume and as a result the isothermal zone is shifted upwards. It may be noted that isothermal zone exists in the middle part of the ballast furnace, which allows independent heat balance in the lower and upper part of the blast furnace and make the furnace to run efficiently. With oil injection isothermal zone shifted upwards; or in other words, isothermal zone in the blast furnace shrinks. So larger injection of oil may leads to a situation where isothermal zone may not exist at all leading to escape of large amount of unutilized gas. So, higher heat capacity with lower flame temperature is a problem with oil injection, which could be compensated with oxygen enrichment of air blast. Because oxygen enrichment does the reverse effect, i.e., it increases flame temperature with reduction of gas volume, mainly due to partial removal of nitrogen from air blast. Again, too much decrease in heat capacity of the gas is also not suitable as it might lead to insufficient heat content of gas in upper part of the furnace leading to thermal imbalance and inappropriately heated burden material may descend to the lower part of the furnace leading to furnace irregularities. So oxygen enrichment with oil injection complement each other.

Another thing is that oil injection provides hydrogen which is good for efficient indirect reduction. Direct reduction in blast furnace eventually takes place because in the lower part of the furnace temperature is very high that is suitable for direct reduction in presence of carbon. However, unlike direct reduction where gas mass transfer is not a problem due to in-situ gas generation, in case of indirect reduction gas transport at the gas solid interface is a major problem unless bed permeability is ensured to an appropriate level. There are various measures to maintain proper bed permeability like better burden and its distribution. Hydrogen is also one such measures to promote indirect reduction because hydrogen is a better reductant both thermodynamically as well as kinetically.

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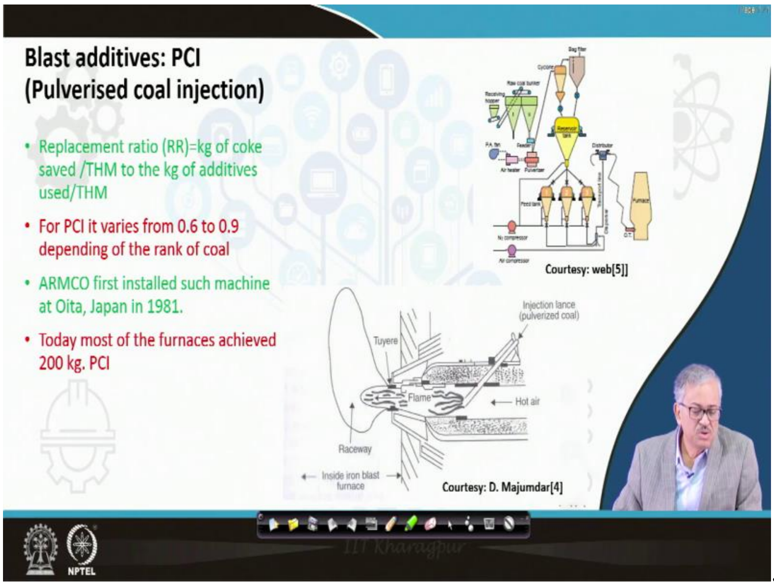

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Next we come to Pulverized coal injection (PCI). PCI today is the major blast additive. Its replacement ratio can vary between 0.6 to 0.9 depending on the rank of coal. So, ARMCO first installs such machine in Oita, Japan in 1981 and the schematics is given in the Figure 14.1.

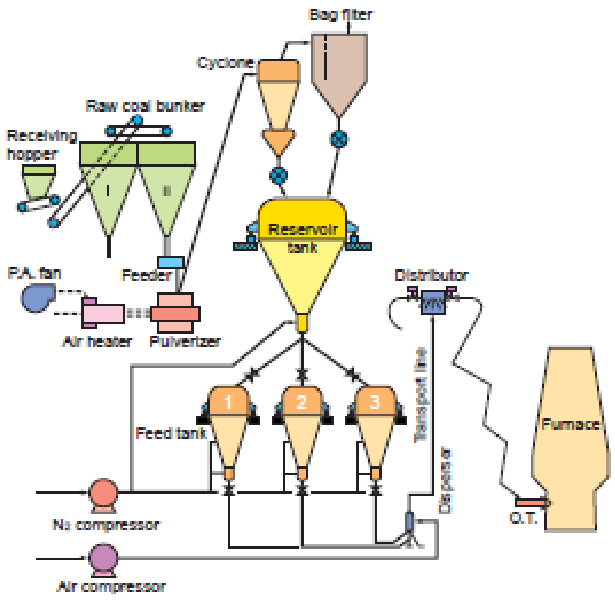

Fig 14.1 Schematics of PCI injection

Coal is stored in bunkers from where those proceeds to the pulverizer, and then air dryer to remove physical moisture to enhance its flowability and combustion kinetics. Subsequently, dried coal is taken to the cyclone separator to take out the powdery fines mass, presence of which hampers the flowability of powder. Finally, coal feeds are stored in feed tanks. Finally coal is feed in the furnace along with air as carrier gas. The final lance for coal injection in the furnace is shown in a bigger sketch (Fig. 14.2).

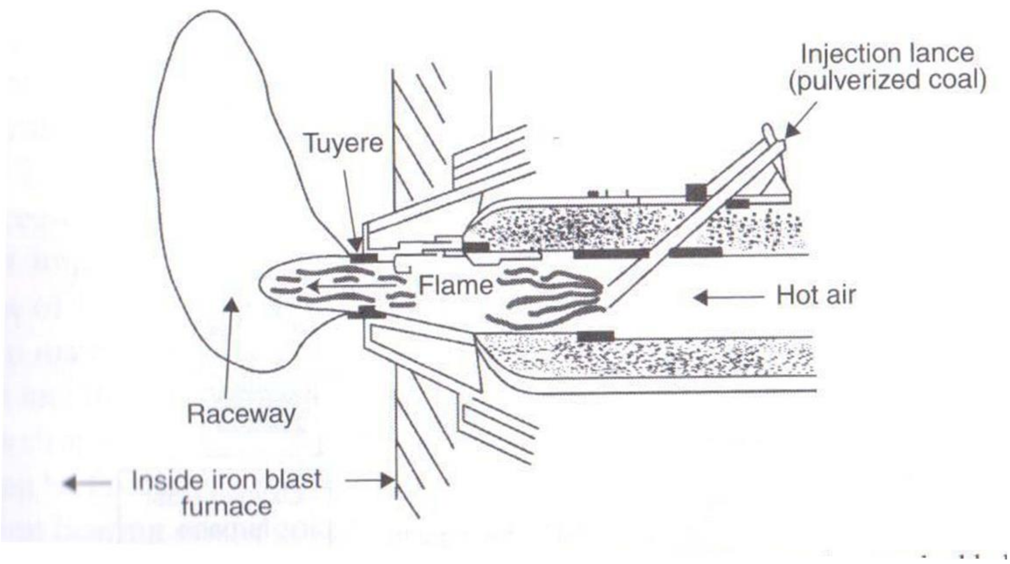

Fig. 14.2 Schematics of PCI

Pulverized coal with carrier gas enters from the side of the tuyere where it interacts with the hot air blast. So, before entering to the raceway, hot air blast is mixed up with pulverized coal.

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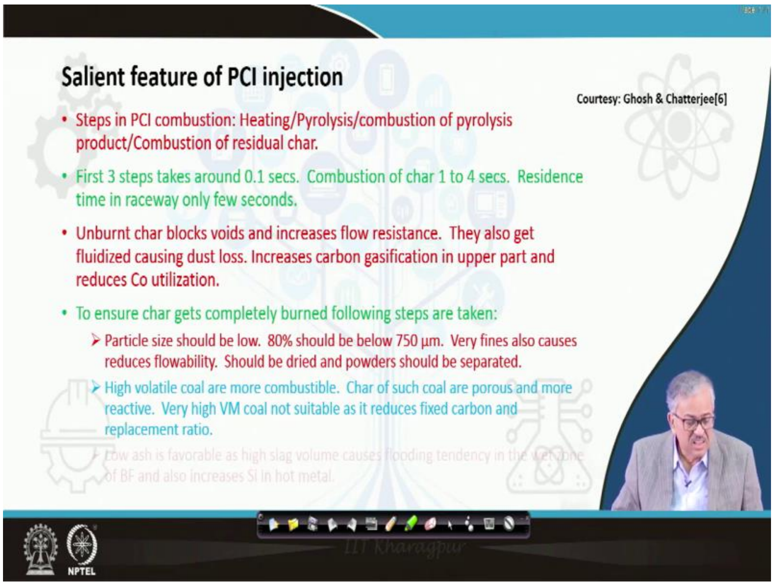

The salient features of the PCI injection is discussed in this slide. As soon as PCI comes in contact with hot air blast it is preheated and pyrolysed. During pyrolysis coal volatile is released which subsequently burns in the raceway. Finally the solid product of coal pyrolysis, i.e the coal char has to be combusted completely in the raceway. The steps involved in heating, pyrolysis, and combustion of the pyrolysis gaseous product, take only 0.1 second. So, it does not take too much time; but major time is taken by that char combustion. Combustion of the char take around 1 to 4 seconds; but the residence time in the race way is not very high. It is very short duration may be 3-4 seconds,. So, basically the combustion of the char has to be completed in 4 second or in less time. If char is not completely combusted, they makes a lot of problem. Unburned char can block the voids in coke bed in wet zone increasing the pressure drop. Otherwise those can be carried away in the upper part of the furnace and might be blown away from furnace causing energy loss, or those are being very reactive can enhance carbon gasification at the upper part and relieving unutilized CO to the atmosphere.

So, to ensure that char gets completely burned in the raceway, following steps are taken. The first thing to ensure is to maintain proper size distribution of the coal particles. As mentioned powdery fines should to excluded to increase its flow-ability but coal particles should remain fine enough that offers significant surface area to favour combustion kinetics. Therefore, it is optimized that 80 percent of coal particles should be below the 750 micrometer such that it have sufficient surface area for burning.

Secondly, it has been found that high volatile coal are combusted better; because char produced from the high volatile coal is very porous, reactive, and burn faster. So, high volatile coal is good, but too much of volatile is also not good. Too much volatile reduces the fixed carbon. In the PCI if you reduce the fixed carbon, then you may not make up the required replacement ratio.

Thirdly, coal should have low ash. High ash means sulphur and silica, which burn in the raceway and get into hot metal. Besides, high ash in coal increases slag volume that promotes flooding in the wet zone.

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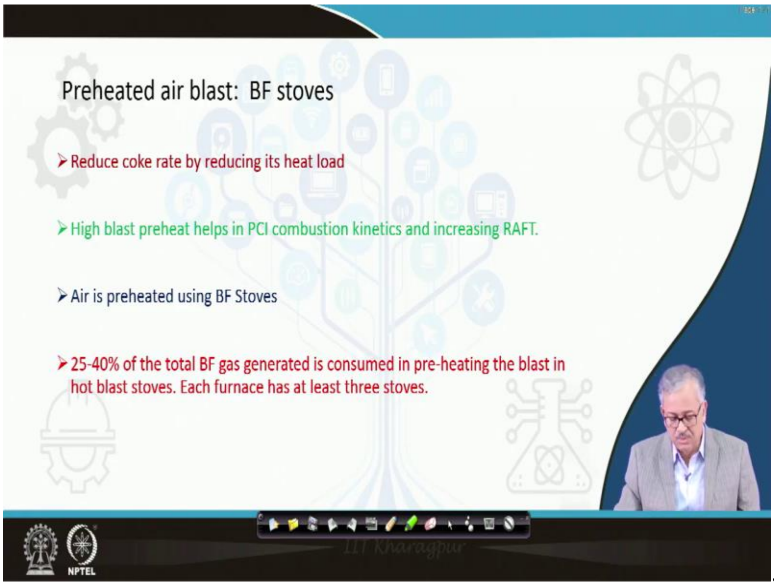

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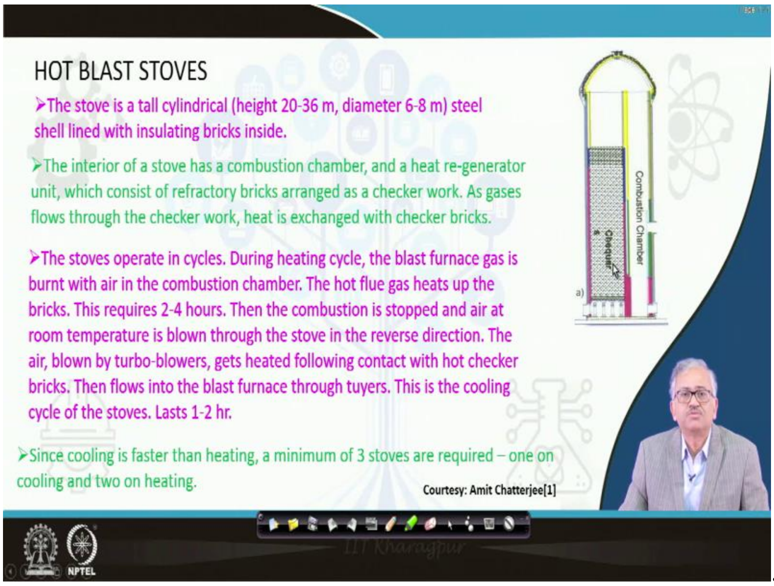
Next come to the preheated air blast. Preheated air carries some sensible heat along with it and supplements some of the heat generation by the coke. As a result coke rate can be reduced. Blast preheat not only reduces the coke rate; but nowadays the blast preheat of 1200^{o}C is essential when you are injecting pulverized coal through tuyere. Hot air blast ensures faster heating, pyrolysis of coal, combustion pyrolysis gaseous product and char. High air blast preheat temperature also increases the heat transfer potential of the air blast, meaning faster delivery of heat.

Air is preheated in the blast furnace stoves. Around 25 to 40 percent of the blast furnace gas is used for blast preheating.

Blast furnace gas has significant sensible heat. Typically around 1400 Nm^3 of BF gas is produced per ton of hot metal at 100 to 200^{o}C. Blast furnace gas also contain 15 to 20% CO as a source of chemical heat. So, around 25 to 40 percent of the blast furnace gas is used for the heating of air blast in the blast furnace stoves and rest another 60 percent goes for the downstream application. (Refer Slide Time: 26:16)



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Blast furnace stove are tall cylindrical unit as shown in the figure 14.3.

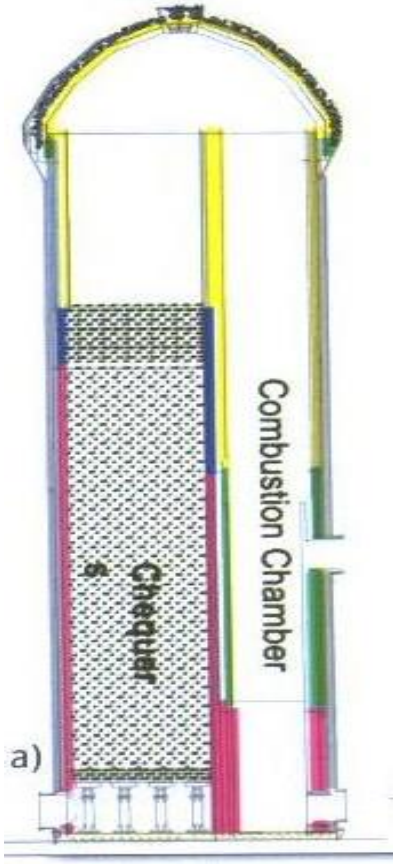

Figure 14.3 Schematics of Blast Furnace Stove

It is around 20 to 36 meter high with diameter 6 to 8 m. It is the steel cell lined with insulating bricks. You can find that it has two chambers; one is combustion chamber, another is the checker brick walls. This checker brick walls means a brick pattern with lot of surface area for heat exchange with gas.

In the first cycle blast furnace gas is burned in presence of oxygen and heat is exchanged with these checker brick walls and because of large surface area, it quickly heats up by heat of combustion. It takes around 2 to 4 hours for heating up. In the next cycle air blast is passed through the checker bricks and air gets heated up by taking the heat from the checker bricks. Cooling of bricks takes smaller time around 1-2 hr. Since the cooling of the checker bricks is faster than heating a minimum of 3 stoves are required; one on cooling and two always on heating.

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Above slide shows the reference used in this lecture.

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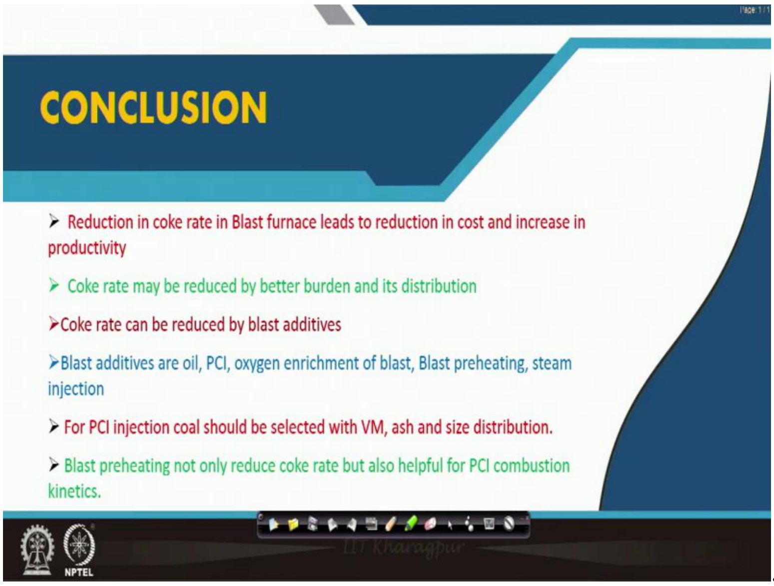

Conclusion of this lecture is summarized in the slide above.

Blast additives are used to reduce the coke rate in blast furnace. Among the blast additives discussed PCI is the most prominent today. Bench mark of PCI today is more than 200 kg/ton of hot metal produced. For PCI injection, coal should be selected with optimum volatile and low ash and optimum size distribution.

Thank you and then in the next lecture, I will discuss about the Oxygen enrichment and the Steam injection.