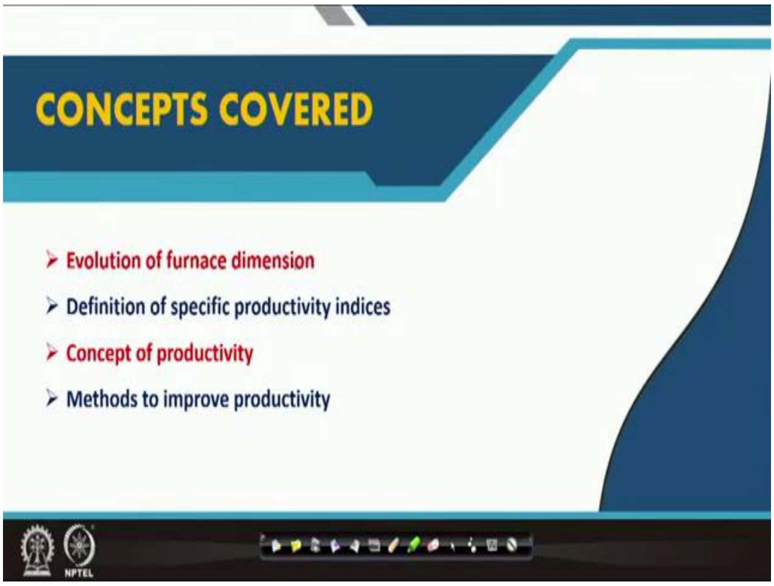
Iron Making and Steel Making
Prof. Gour Gopal Roy
Department of Metallurgical and Materials Engineering
Indian Institute of Technology, Kharagpur

Module - 05
Lecture – 23
Blast Furnace Productivity

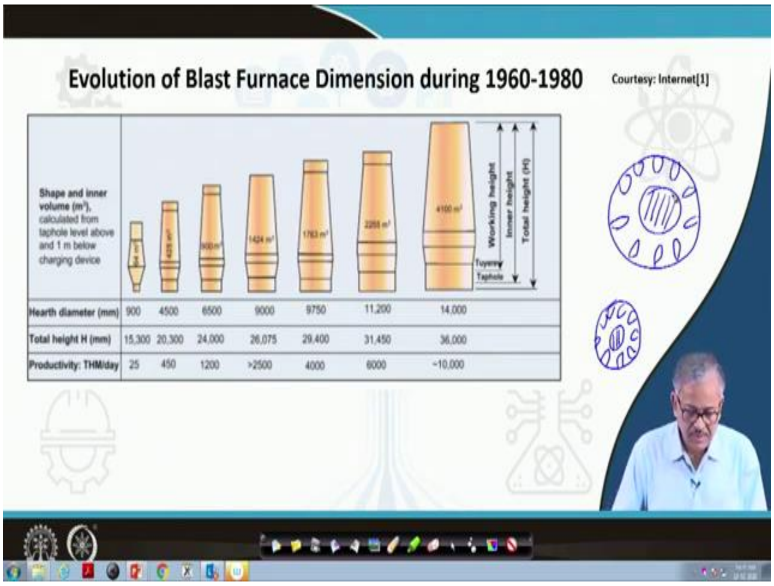
In this lecture, I will talk about the Blast Furnace Productivity.

(Refer Slide Time: 00:32)



Topics to be covered in this lecture is indicated above.

(Refer Slide Time: 01:24)



Now, let us see the evolution of the blast furnace dimension over 1960 to 80s, because during that time there has been significant increase in the blast furnace dimensions. Blast furnace has grown to 4000 meter cube by 1980 only; and after that it has increased up to around 6000 meter cube, but limited to few blast furnaces only. Moreover, you may note that blast furnace has increased in size, not only axially but significantly in lateral direction also (Figure 23.1); hearth diameter has increased from 0.9 meter to 14 meter. Height has increased from 15 to 36 meter. Consequently, the productivity has also increased from 25 ton hot metal (THM) per day to 10,000 THM per day.

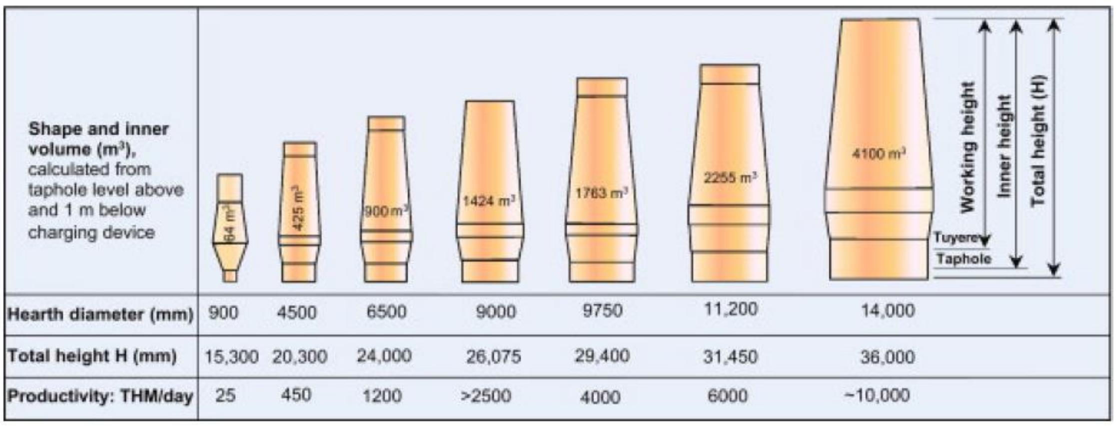
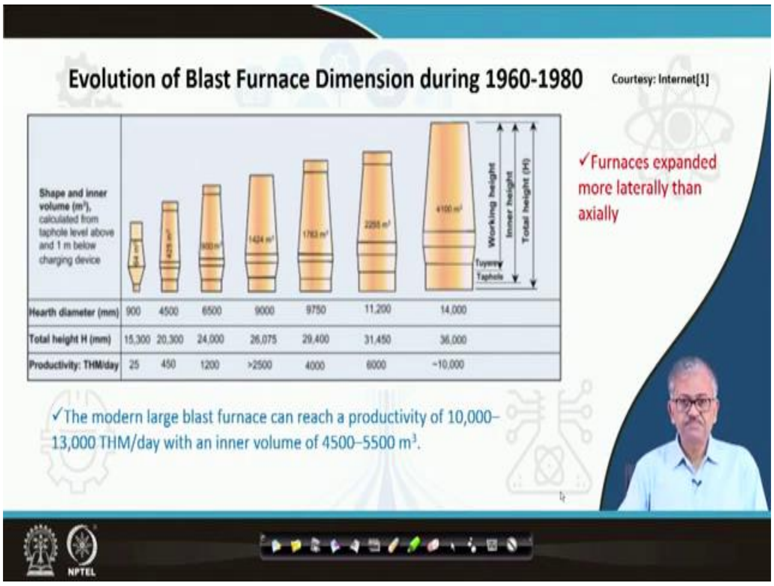


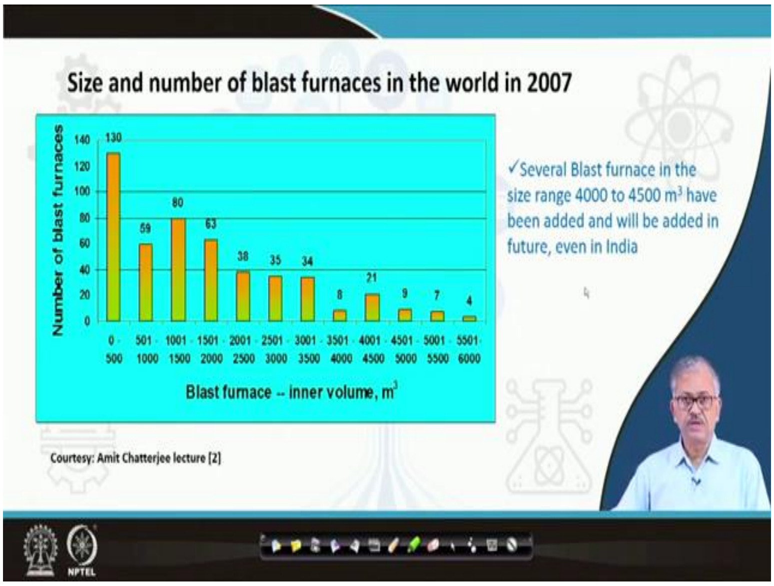
Figure 23.1:Evolution of blast furnace volume[1]

Both axial and lateral increase in size is due to the fact that if furnace is increased along height only, then overburden on the blast furnace will increases significantly; consequently burden will have to withstand more overhead pressure and burden also has to move a longer distance. When the burden moves longer distance under pressure, materials undergo prolonged abrasion under enhanced pressure, resulting in more fine generation; and maintaining the bed permeability becomes very difficult unless supported by excellent burden material. And already all resources for improving burden materials have been exploited. So, very tall furnace might be fraught with danger of collapsing the burden in the furnace. Therefore, while increasing the size of the furnace, lateral increase of the furnace was also taken into account. But, there is also problem of increasing the hearth diameter. The raceway can not penetrate the coke beyond a certain distance in radial direction, increasing the inactive coke zone, or the dead man coke zone. So, fraction of unutilized hearth area increases with increase in hearth diameter; and coke throughput cannot be increased proportionally with increase in hearth diameter and intended productivity. Increase in hearth diameter also increases the heat loss from the furnace. This sets the limitation of increasing in hearth diameter beyond a certain hearth diameter.

(Refer Slide Time: 06:08)



(Refer Slide Time: 07:24)



Let us see the size and number of the blast furnace in the world according to 2007 data (Figure 23.2).

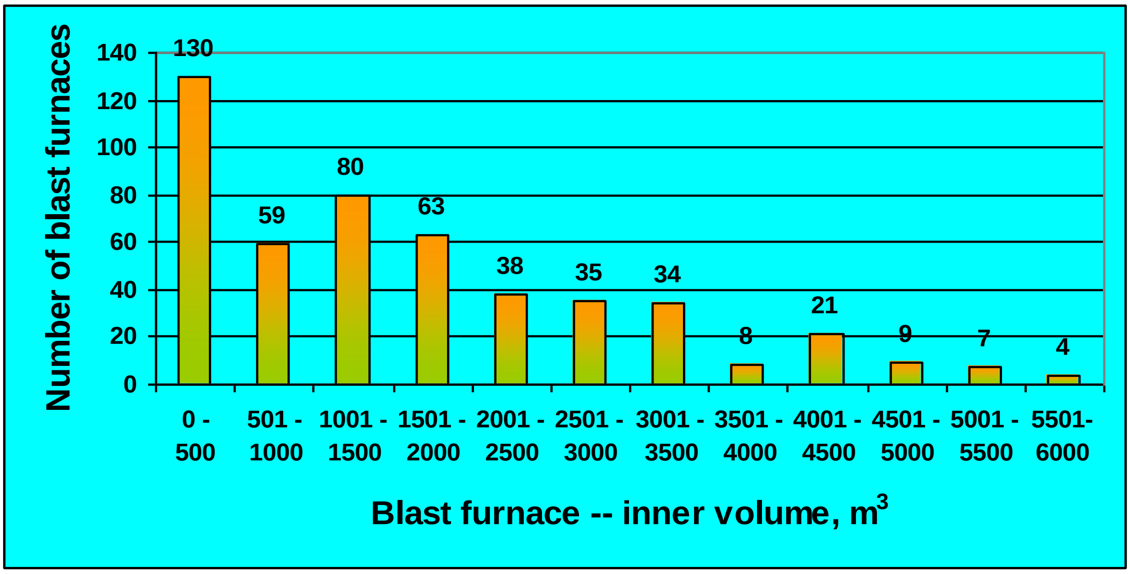
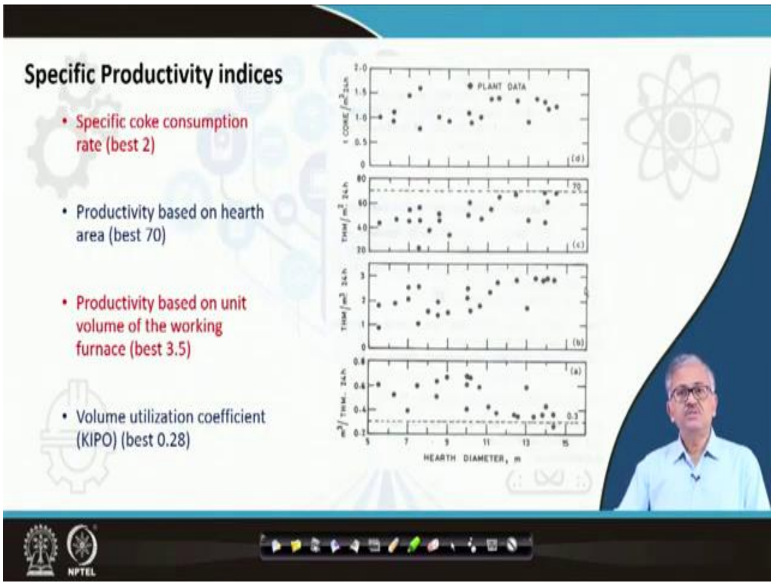


Figure 23.2: Evolution in number of furnaces against their sizes[2].

WE can see smaller blast furnaces upto 500 meter cube was the maximum at 130 numbers in 2007. And, bigger furnaces were less in numbers compared to smaller furnaces; especially very large furnaces of the sizes 5501 to 6000 m^3 were limited to 4 only. Furnaces in the range 501 to 2000 m^3, were also significant. Since quality of burden material can be compromised to some extent in smaller furnaces, those were popular.

Bigger furnaces are limited due to stringent raw material requirement. And, nowadays furnaces in the size range 4000 to 5000, are coming up even in India.. Several blast furnace in the size range 4000 to 4500 meter cube have been added, and will be added in future even in India. In China lot of 4000 meter cube furnace have come; but by China's large productivity not only due to very big furnaces, but they have several small size furnace to meet up the productivity.

(Refer Slide Time: 09:19)



Performance of blast furnaces can be compared with respect to specific productivity indices irrespective of size. First and most popular productivity index is ton of hot metal produced per meter cube per day, THM/m^3-day and the benchmark for this value is 3.5. The next popular productivity index is ton of hot metal produced per unit hearth area per day (THM/m^2-day) and its bench mark value is 70. There are other two productivity indices which are not so frequently used and one of those is the volume utilization coefficient KIPO. It is defined as the useful volume of the blast furnace required to produce ton of hot metal per day and its benchmark value is around 0.3. The other definition is the specific coke consumption rate, defined as the amount of coke consumed in tons) per unit volume (m^3) of the blast furnace per day and its benchmark is around 2. All four productivity indices as a function of hearth diameter is shown in the figure 11.3.

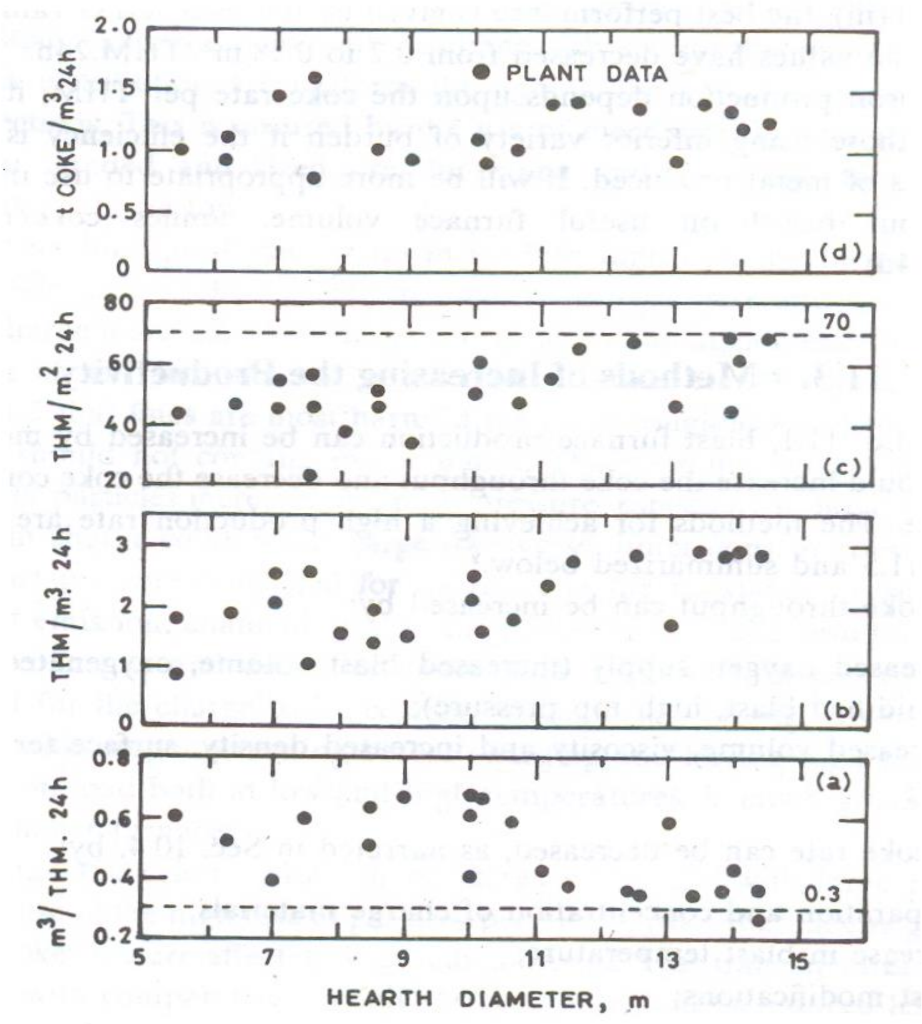
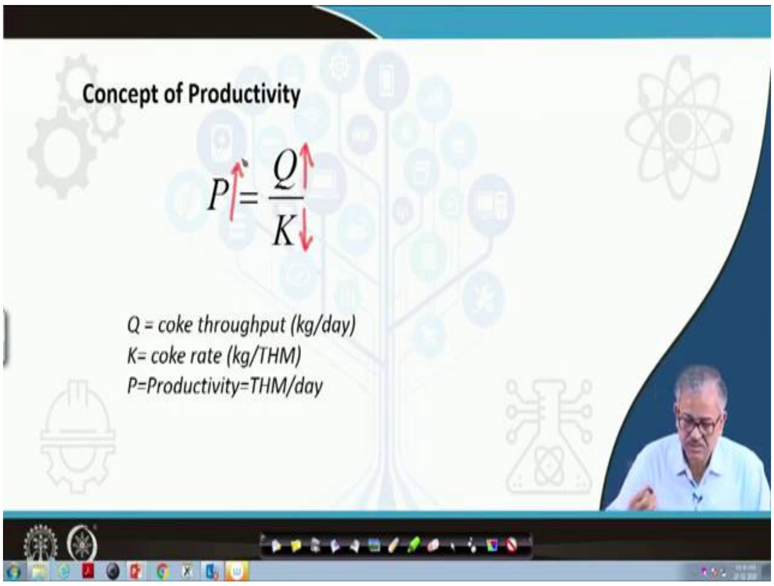


Figure 11.3: Specific productivity indices as a function of hearth diameter[3]3.

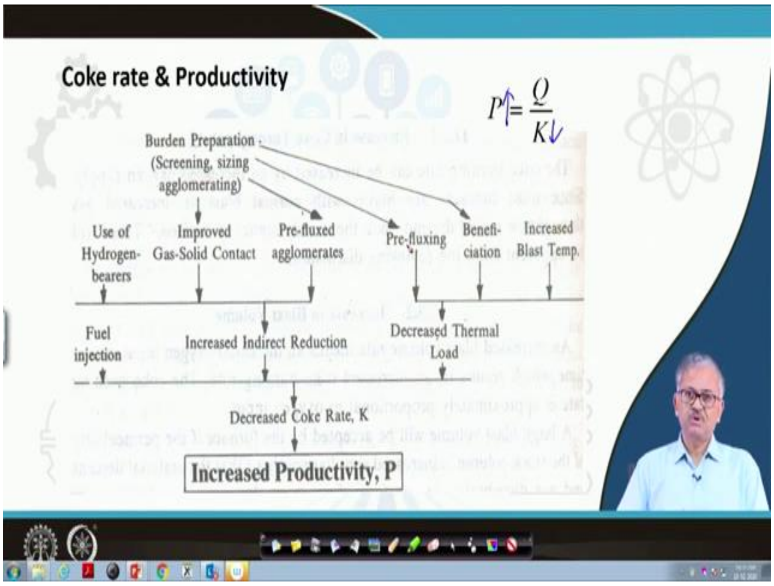
(Refer Slide Time: 12:37)



Productivity can be defined as Q/ K, where, the numerator, Q is called the coke throughput that is the kg of coke burned per day, and the denominator, K is the coke rate, which is defined as the kg of coke consumed to produce one ton of hot metal. The ratio gives ton of hot metal produced per day, the unit of productivity. According to this definition, the productivity cab be increased either by increasing the Q or decreasing K. To understand physically: increasing Q means burning more coke per unit time, which will in turn melt more iron per unit time yielding higher productivity, provided favourable conditions in blast furnace and quality burden material supports for high coke throughput. Similarly, lower coke rate will make more space for iron burden leading to higher productivity, provided favourable conditions and quality burden material increases coke utilization in the furnace.

Now, let us see the parameters that affects the coke throughput (Q), and the coke rate (K) in the blast furnace.

(Refer Slide Time: 14:35)



Coke rate can be decreased by reducing the thermal load of the furnace, i.e., amount of heat generation per ton of hot metal produced. Coke rate can also be reduced by promoting indirect reduction that increases the CO utilization and the carbon utilization efficiency. Fuel injection through tuyer also can supplement the function of coke like heat generation and production of reducing gases and consequently reduces coke rate. Figure 11.4 pictorially depicts it.

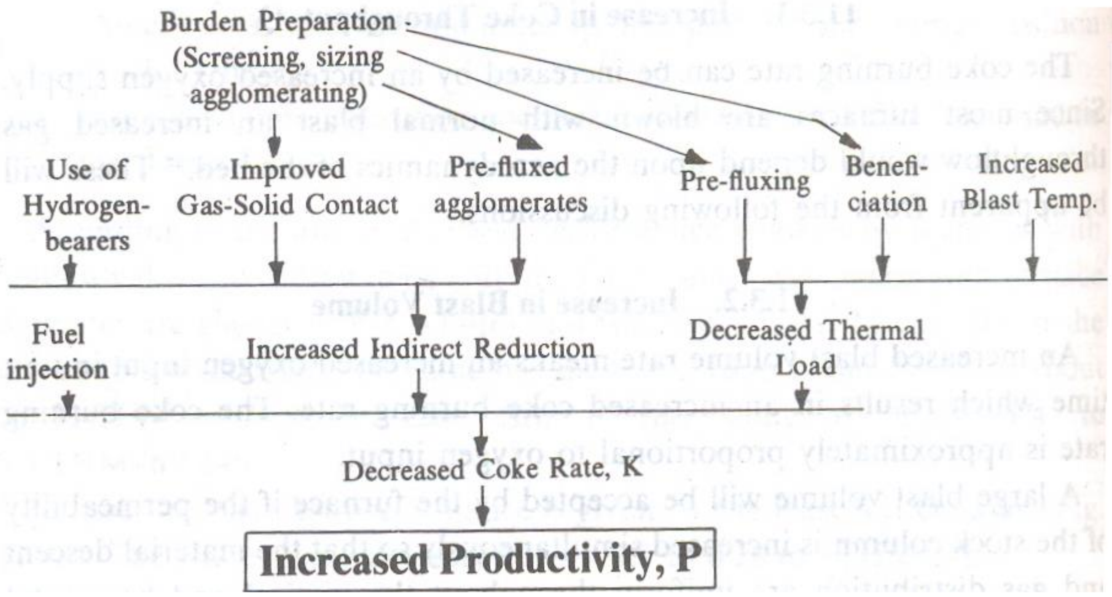


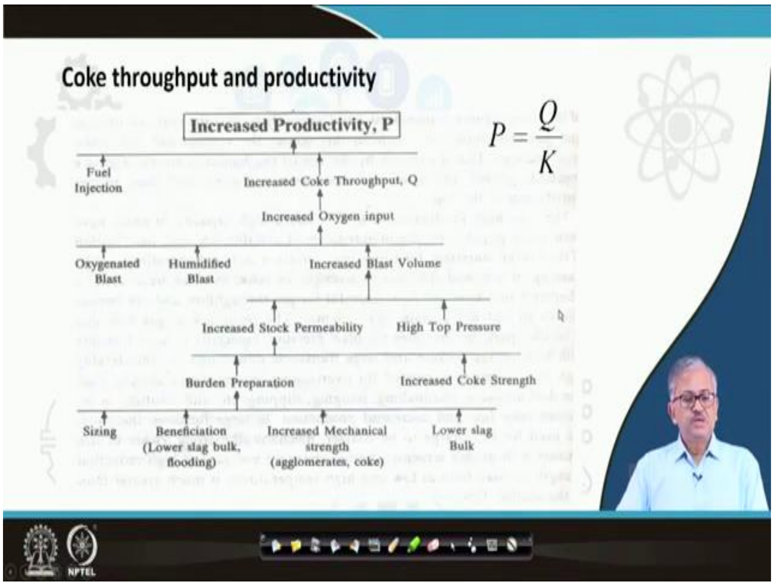
Figure 11.4 Pictorial representation showing how coke rate can be reduced through injection and proper burden preparation [3]

Burden preparation plays a great role to reduce the coke rate through reducing thermal load of the blast furnace and promoting indirect reduction. Burden preparation involves beneficiation, pre-fluxing and agglomeration giving proper shape, size and strength of the prepared burden. Beneficiation allow us to decrease the gangue constituents in the burden that reduces slag volume, and associated sensible and latent heat that reduces the thermal load of the blast furnace. Through pre-fluxing we can produce self and super-fluxed sinter that avoids adding limestone separately with the feed and avoid thermal decomposition and associated thermal load of the blast furnace. Thermal load of the blast furnace may also be reduced by blast preheating; because preheated blast brings in lot of sensible heat that supplements the heat generation in the furnace by carbon burning and helps to reduce the coke rate.

So, we see that through burden preparation we can reduce the thermal load of the furnace that decreases the coke rate. Similarly, if you can increase the indirect reduction, then also you can improve CO utilization and consequently carbon utilization and reduce the coke rate. As I have mentioned that direct reduction in the blast furnace eventually takes place at high temperature in the lower part of the furnace; but promoting indirect reduction is a challenge due to difficulty in maintaining proper bed permeability across the cross section to ensure whole cross section gas-solid heat and mass exchange. We have also seen that 46% indirect reduction produced the maximum efficiency (maximum CO utilization, or coke utilization) of the furnace. Excellent bed permeability is required to ensure such high extent of indirect reduction; and bed permeability can be enhanced by stronger burden that does not generate much fines during their descent through impact and abrasion. Stronger agglomerated burden like sinter and pellets help in attaining higher bed permeability. Narrow size and shape distribution of spherical pellets also ensures excellent bed permeability.

Pre-fluxed burden also changes the sinter morphology from glassy structure to porous and strong crystalline calcium ferrite that increases the reducibility of the sinter, promoting indirect reduction.

So, there also burden preparation has a great role to play in reducing coke rate. Auxiliary injection of hydrogen bearer through tuyer can also promote indirect reduction. Because hydrogen is a much better reductant than CO both thermodynamically and kinetically; and reducibility of ore can be increased by around 4 to 5 times if hydrogen is used as an reductant compared to CO. So, if we can introduce some amount of hydrogen into the blast furnace, obviously indirect reduction will improve. Hydrogen may be injected in the form of steam, oil through tuyer. (Refer Slide Time: 22:27)



Now, let us see how we can increase the coke throughput. Coke burning rate can be enhanced by increasing air blast rate, by supplying additional oxygen through tuyer in terms of oxygen enrichment of air blast, or humidification of air blast. High blast rate can be ensured by good stock permeability and high top pressure. Stock permeability can be improved through burden preparation and enhanced coke strength. Burden preparation includes beneficiation, agglomeration that results in sized, stronger burden material. Beneficiation also makes iron rich burden with lower slag volume that narrows down the wet zone decreasing the pressure drop in the wet zone. Higher strength of the burden produces lesser amount of dust and maintain higher permeability in the dry zone of blast furnace. Proper sizing of the burden also narrows down the size range, which is also helpful in maintaining better bed permeability. Enhanced coke strength, which can be ensured by appropriate raw coal mix, or stamp charging, also enhance the bed permeability by improving CSR. In addition to improved burden quality, high top pressure also assists in high blast rate and coke throughput. High top pressure reduces the pressure drop under high blast rate. The figure 11.5 pictorially depicts how coke throughput can be enhanced by proper burden preparation, high top pressure and auxiliary injections.

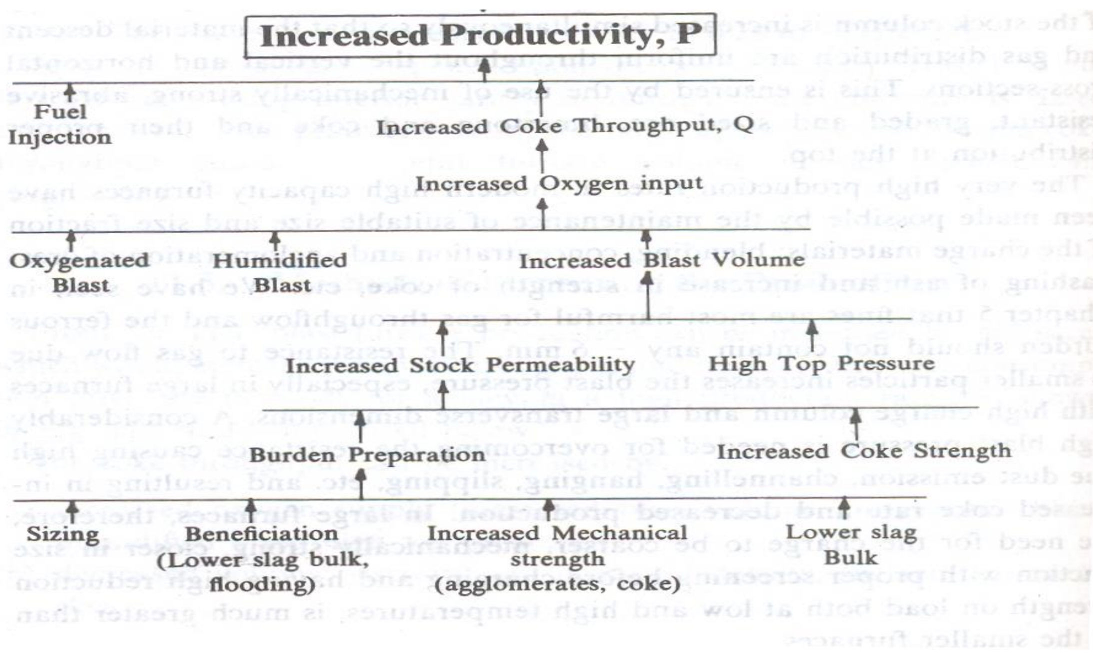
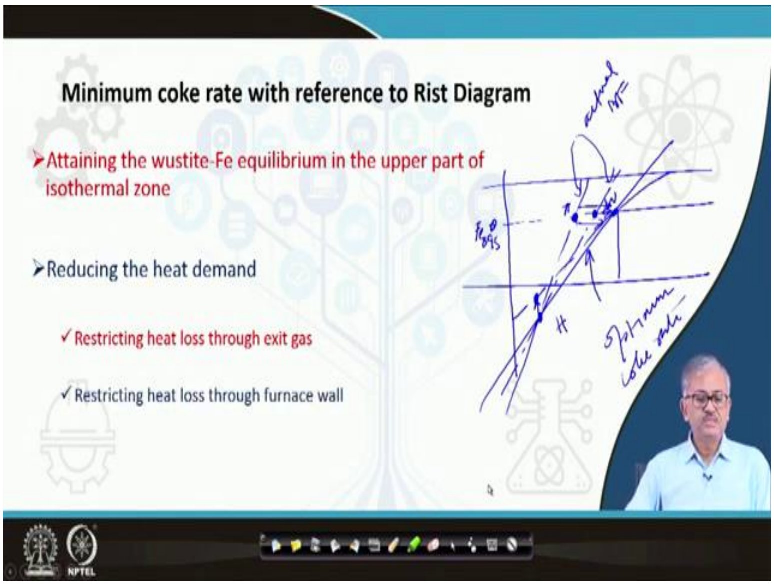


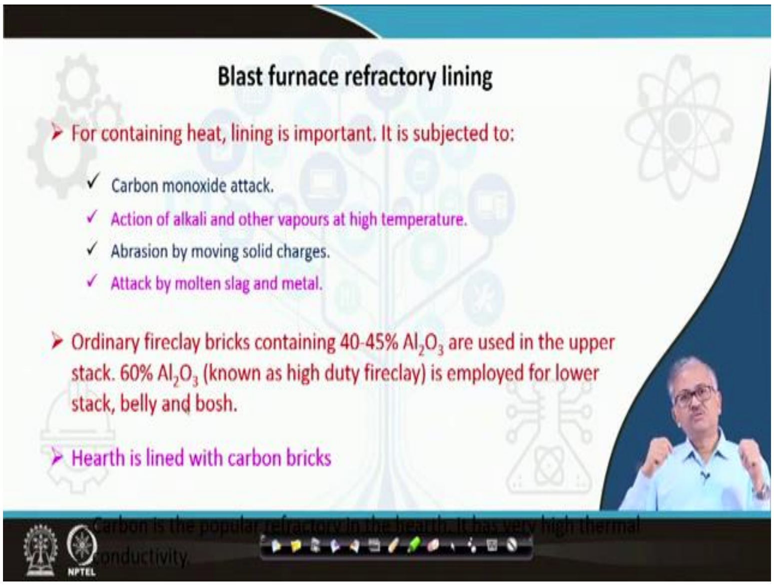
Figure 11.5: Pictorial representation showing how coke throughput can be increased by burden preparation, high top pressure and additional oxygen injection through tuyer

(Refer Slide Time: 29:01)



During discussion of Rist diagram, we have seen that minimum coke rate in blast furnace can be achieved when wustite-Fe equilibrium is attained in the upper part of the isothermal zone for a fixed heat demand. Coke rate can further be lowered by reducing the heat demand of the blast furnace. Heat demand can be reduced using dry, pre-fluxed burden with lower gangue and undesirable impurities, preheated air blast, and restricting heat loss through exit gas (better heat exchange between gas and solid), and through hearth wall, which can be ensured by using proper refractory material.

(Refer Slide Time: 34:22)

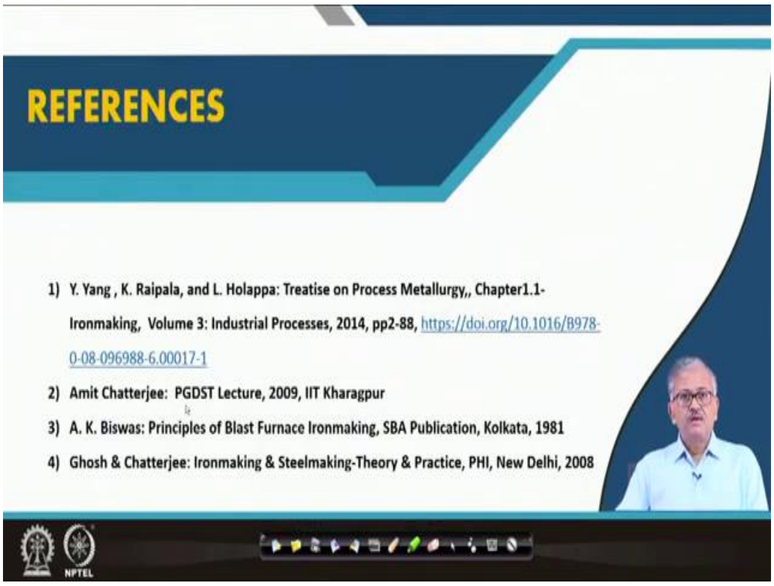


Now let us talk about the refractory bricks in the blast furnace. The main purpose of refractory brick is to contain the heat. It is also used to protect the outer steel shell against the carbon monoxide attack, action of the alkali and vapours at high temperature, abrasion by moving solid charge, and attack by the molten slag and metal in the hearth area.

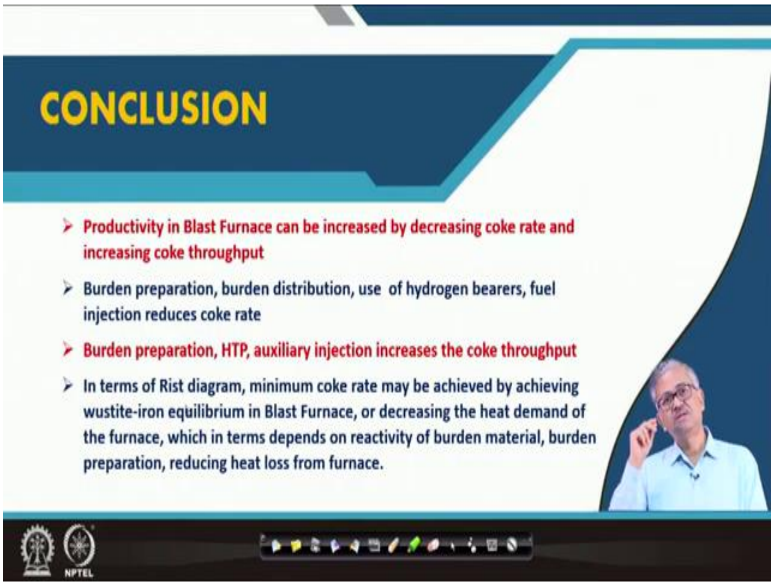
Fireclay bricks containing 40 to 45 percent alumina used in the upper stack, and heavy duty fireclay brick continuing more percentage of alumina (around 60 percent) is used in the lower part like stack, belly, and the bosh region.

And carbon lining is used normally into the hearth region. Erosion of hearth lining under the action of hot metal and slag is an important issue. When the hearth lining erodes away, then lot of heat can escape through the furnace, and heat demand will increase, and obviously the coke rate will increase,and productivity will decrease. Erosion of hearth lining is a major concern. Since it is difficult to monitor the erosion of hearth lining directly, mathematical model with thermocouple temperature measurements in the refractory has been developed to map the erosion profile of the refractory surface at the refractory metal interface.

(Refer Slide Time: 35:51)



(Refer Slide Time: 35:55)



Conclusion:

1) Productivity in the blast furnace can be expressed by four specific productivity indices; the most popular being the ton of hot metal produced per m^3 per day, which has a bench mark value of 3.5.
2) Productivity in the blast furnace can be increased by decreasing the coke rate, and increasing the coke throughput. Burden preparation, preheated air blast, and injection of hydrogen bearers through tuyer, and fuel injection can reduce the coke

rate. Burden preparation, high top pressure, oxygen enrichment, steam injection can increase the coke throughput.

3) Minimum coke rate can be achieved by maintaining the wustite-Fe equilibrium in the upper part of the isothermal zone for a fixed heat demand of the furnace. The coke rate may further be reduced by reducing the heat demand using quality burden and restricting heat loss using proper refractories.
4) Refractory are used in the furnace to restrict the heat loss from the furnace and to protect the outer steel shell of the furnace from chemical attack of corrosive gas and liquid. Usually fire brick (silica with 40% alumina) are used in the upper part of the furnace and heavy duty fire bricks (60% alumina brick) are used in the lower part namely, belly, bosh. Carbon bricks are used in the hearth region. Erosion of carbon bricks is an important concern as significant heat loss can take place across the hearth.