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

Module – 03
Lecture – 15
Oxygen enrichment of blast

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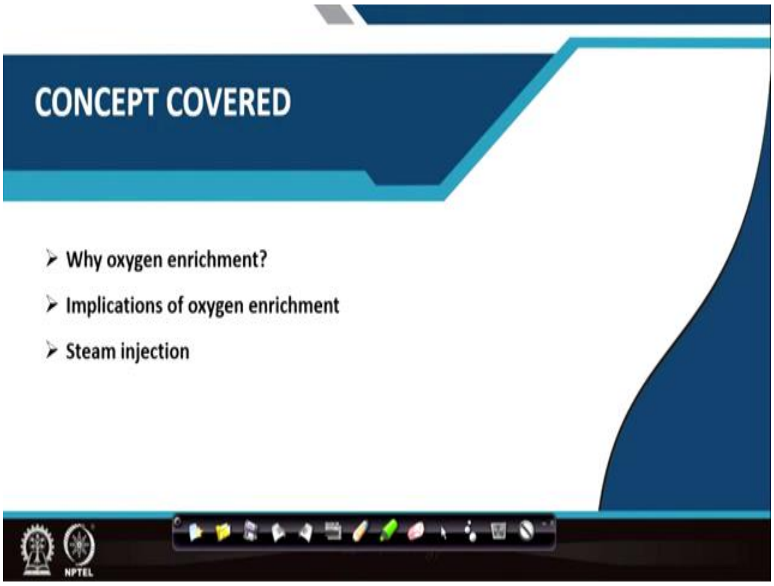

Welcome. In this lecture, we will discuss the Oxygen enrichment of blast. Now, the concepts that will be covered in this lecture are why actually oxygen enrichment is required and what are the implication of oxygen enrichment; mainly what are the pros and cons of oxygen enrichment because oxygen enrichment also has some disadvantages that will also be discussed. And, along with it steam injection will also be in the same lecture.

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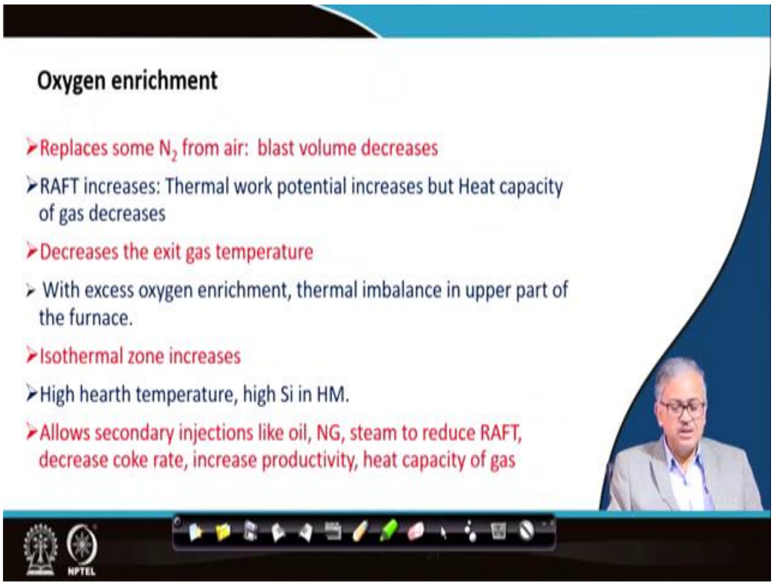

Now, oxygen enrichment, what does it mean? Oxygen enrichment means you are replacing a part of the nitrogen from the air. For example, in the normal air blast you have 21 by volume percent oxygen and 79 volume percent of nitrogen. By oxygen enrichment what we can do; for example we can make the oxygen percentage in the air blast at 23 percent and nitrogen percentage will be reduced by 2 percent it will become 77 percent nitrogen by volume.

So, oxygen enrichment means partial replacement of nitrogen by oxygen. Therefore, for the same amount of oxygen supply, lesser amount of air blast is required. Subsequently, the blast volume also decreases due to reduction of nitrogen in air. This results in decrease in heat capacity of the gas. Since same amount of carbon is burned at a certain productivity level, heat generation remains constant irrespective of oxygen enrichment. Reduction in blast furnace gas volume at same heat generation level, results in higher raceway adiabatic flame temperature (RAFT).

As the raft increases its thermal work potential increases; obviously, raft increase means temperature gradient between gas and solid also increases. So, as a result its efficiency of transferring heat (work potential) increases. But heat capacity of the gas decreases because of partial absence of nitrogen, which otherwise could hold some sensible heat. Since the volume, heat capacity, and heat content of the gas decreases; in the upper part of the furnace the heat content of gas surpass the heat content of the solid marginally, resulting in lower exit gas temperature. However, with too much oxygen enrichment, heat content of the gas in the upper part of the furnace may fall short of whatever required by the solid. This leads to a situation of thermal imbalance where solid may not be preheated sufficiently before those descend to the lower part of the furnace, leading to chilling of hearth.

As we know presence of isothermal zone in the middle of the blast furnace ensures independent heat balance in the upper and lower part of the furnace. With oxygen enrichment isothermal zone increases as the zone shift downwards in the furnace. With oxygen blast furnace gas volume decreases with higher RAFT that require less working volume to complete the heat exchange in the lower part of the furnace. So, as a result the isothermal zone will shift downward; in otherwords it will start early in the lower part of the furnace. Higher RAFT increases hot metal temperature that favours higher silicon in hot metal. Because silicon is removed into the slag by forming oxide,which is an exothermic reaction. So, if your temperature increases then obviously, this reaction will be retarded, as a result silicon will prefer to stay into the metal phase. Oxygen enrichment also allows the secondary auxiliary injection like oil, steam or the PCI. When you do auxiliary injection RAFT decreases due to lower heat generation and increase in gas volume. Heat capacity of the gas also increases due to higher volume generation. Oxygen enrichment can adjust this; because oxygen enrichment increases the RAFT and RAFT may be kept intact by adjusting oxygen enrichment with auxiliary injection. At the same time oxygen enrichment can assist in decreasing gas volume by partial elimination of nitrogen from blast furnace gas. Because higher heat capacity of the gas is also not good for a healthy blast furnace operation. Higher volume of gas with comparatively lower RAF requires larger working volume to complete lower part heat balance that shifts the isothermal zone upward and the isothermal zone shrinks. Too much of heat capacity of gas can vanish the isothermal zone when independent heat balance in the upper and lower part of the furnace may not be maintained leading to inefficient heat and mass exchange and gas will escape the furnace with large unutilized thermal and chemical potential of the gas. Oxygen enrichment therefore can adjust the RAF and voleue of the gas when applied along with auxiliary injection. As we have mentioned oxygen enrichment alone at higher level is also not good as it may lead to thermal imbalance in the upper part of the furnace; therefore, oxygen enrichment and auxiliary are complementary to each other. By coupled inject we can derive the advantages of auxiliary injection.

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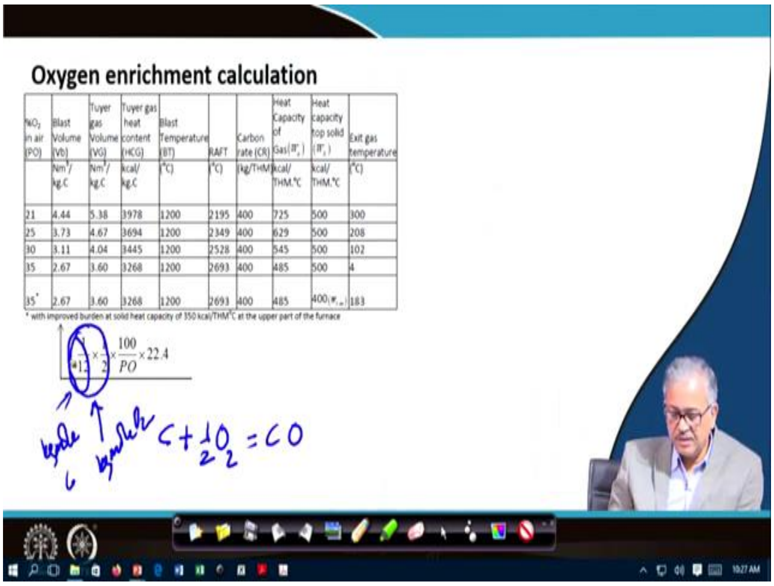

Here we show some calculations depicting how variation of oxygen enrichment changes the blast furnace gas volume, tuyere gas heat content, RAFT and exit gas temperature. Oxygen percentage in air has been varied 21, 25, 30, 35.

The basis of following calculation is 1 kg of carbon and the carbon burning equation considered is given by equation (15.1). The blast volume may be calculated using the following formula that uses simple stoichiometry of the reaction (15.1):

$$2C + O_2 + \left(\frac{100 - PO}{PO}\right) N_2 = 2CO + \left(\frac{100 - PO}{PO}\right) N_2 \qquad (15.1)$$

It is to be mentioned at high temperature CO_2 is unstable and it converts to CO through carbon gasification reaction. Therefore, although initially CO_2 might form but finally the product gas is CO. From the above equation it is seen that to burn 1 kg mole of carbon, oxygen required is ½ kg-mole. Therefore to burn 1kg of carbon the volume of air blast required can be given by the following expression:

$$\frac{1}{12} \times \frac{1}{2} \times \frac{100}{PO} \times 22.4$$

Here PO represent the volume percentage of oxygen in air.

Blast volume may be calculated using the following expression. Because from equation (15.1), it may be seen that one kg mole of oxygen produces two kg-mole of CO and moles of nitrogen that enters through air blast as par the volume ratio with respect to oxygen.

$$\frac{1}{12}\times\frac{1}{2}\times\left(2+\frac{(100-PO)}{PO}\right)\times 22.4$$

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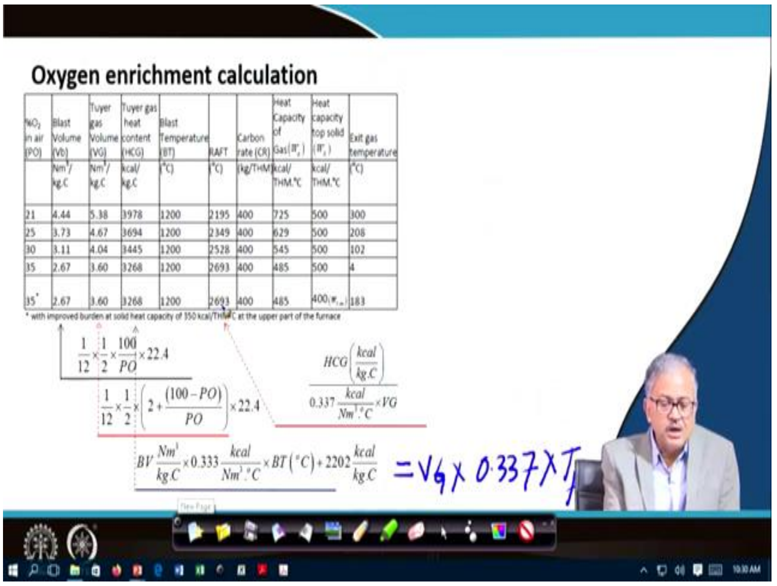

Tuyer gas heat content has two components – one is the sensible heat of the blast another is the heat of reaction because you are burning carbon to CO, which is represented mathematically by the following expression:

$$BV\,\frac{Nm^3}{kg.C}\times 0.333\,\frac{kcal}{Nm^3.^oC}\times BT\left(^oC\right)+2202\,\frac{kcal}{kg.C}$$

.

BV represent the blast volume. BT represent the blast preheat temperature.2202 is heat of reaction for carbon oxidation, i.e., heat released by burning 1 kg of carbon.   .

RAFT can be calculated using the following expression:

$$\frac{HCG\left(\dfrac{kcal}{kg.C}\right)}{0.337\,\dfrac{kcal}{Nm^3.^oC}\times VG}$$

Where, HCG represent the tuyer gas heat content. VG represent the volume of blast furnace gas.

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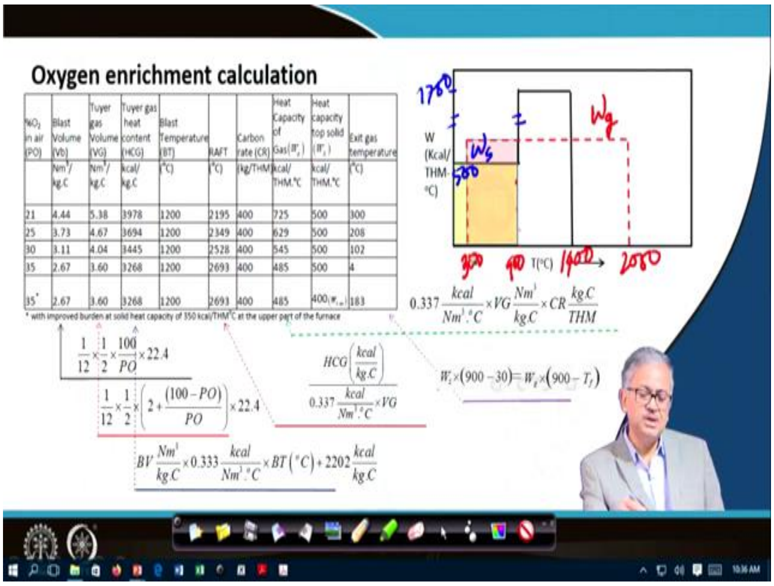

Heat capacity of the gas per ton of hot metal produced may be calculated from volumetric heat capacity by the following expression:

$$0.337 \frac{kcal}{Nm^3.^oC} \times VG \frac{Nm^3}{kg.C} \times CR \frac{kg.C}{THM}$$

Where, CR is the carbon rate (assumed to be 400 kg/THM, which is a rather adventurous estimate).

The exit gas temperature can be calculated by upper part heat balance assuming a typical solid heat capacity as 500 kcal/THM-^{o}C, using the following expression. It may be noted that such solid heat capacity might be responsible for moisture removal, decomposition reactions, and solid preheating. It may further be mentioned that isothermal zone temperature is 900^{o}C. So solid is heated from 30 to 900^{o}C and gas cools from 900^{o}C to exit gas temperature in the upper part of the furnace.

$$\frac{W_s \times (900 - 30)}{W_g \times (900 - T_f)}$$

It is to be mentioned that in the lower part of the furnace typical heat capacity might be as high as 1700 kcal/THM-°C Such high heat capacity of solid is responsible for several endothermic reduction reactions, sensible and latent heat of iron and slag. So, finally the variation of different parameters as a function of oxygen enrichment is produced in the following Table 15.1.

Table 15.1: Variation various relevant parameters with variation of oxygen enrichment

%O_2 in air (PO)	Blast Volume (Vb)	Tuyer gas Volume (VG)	Tuyer gas heat content (HCG)	Blast Temperature (BT)	RAFT	Carbon rate (CR)	Heat Capacity of Gas(W_g)	Heat capacity top solid (W_s)	Exit gas temperature
	Nm^3/ kg.C	Nm^3/ kg.C	kcal/ kg.C	(°C)	(°C)	(kg/THM)	kcal/ THM.°C	kcal/ THM.°C	(°C)
21	4.44	5.38	3978	1200	2195	400	725	500	300
25	3.73	4.67	3694	1200	2349	400	629	500	208
30	3.11	4.04	3445	1200	2528	400	545	500	102
35	2.67	3.60	3268	1200	2693	400	485	500	4
35*	2.67	3.60	3268	1200	2693	400	485	400($W_{s,lm}$)	183

* with improved burden at solid heat capacity of 350 kcal/THM°C at the upper part of the furnace

The lower part heat balance can be shown pictorially below (Fig. 15.1). Solid line, and dotted lines depict the solid and gas heat capacities, respectively.

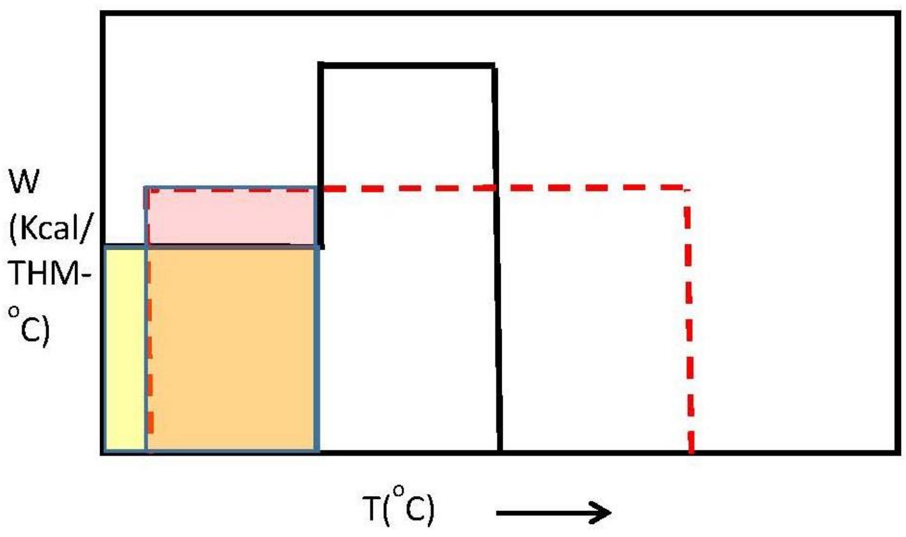

Figure 15.1 Pictoral representation of heat balance in the upper part of the furnace.

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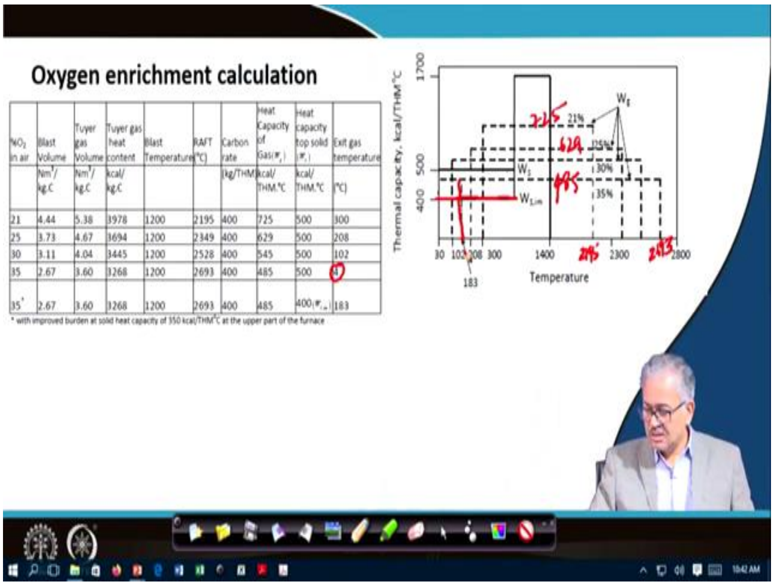

Following figure (Figure 15.2) shows variation of exit gas temperature with variation of oxygen enrichment. This figure has been drawn using the data calculated in Table 15.1.

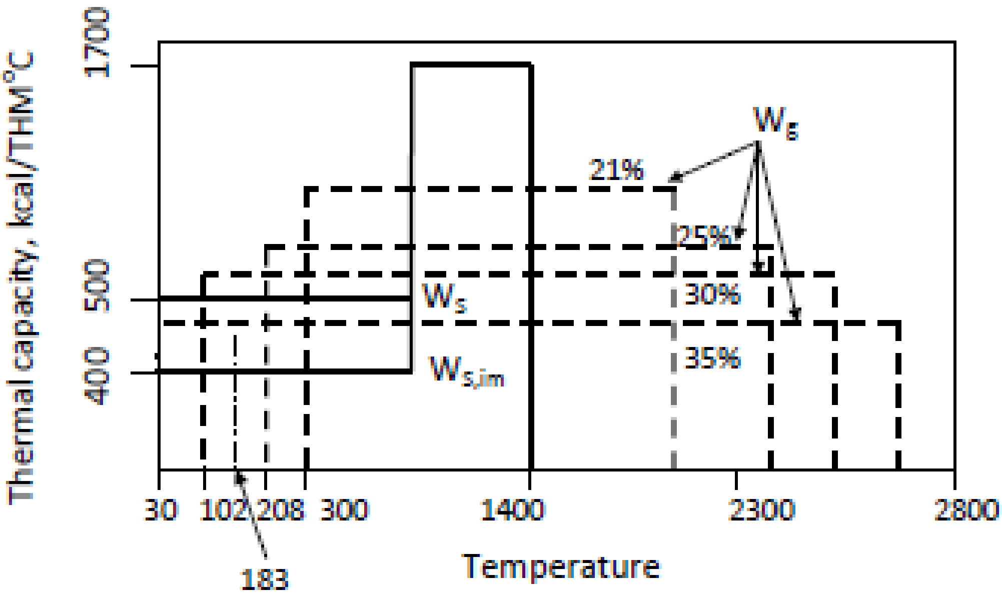

Figure 15.2: Pictoral variation of exit gas temperature with oxygen enrichment

It is seen that with increase in oxygen enrichment, the heat capacity of the gas decreases and also the exit gas temperature decreases. It is further observed that with 35% oxygen in air, thermal imbalance takes place in upper part of the furnace with respect to solid burden with heat capacity 500 kcal/THM-ºC. Under that condition heat content of the gas falls short of the heat requirement by the solid and solid xcan not be preheated to 900ºC before they descent to the lower part of the furnace causing irregularity in the furnace. However, if the improved burden with much lower heat capacity (say, 400 kcal/THM-ºC) is charged then such thermal imbalance could be averted even at higher oxygen enrichment (35% oxygen in air) because as we can see the heat capacity of the gas becomes higher than that of improved solid. Such improvement of solid could be made by reducing physical moisture, reducing impurities that unnecessarily carry out endothermic decomposition reactions and adding lime with burden that avoids limestone decomposition.

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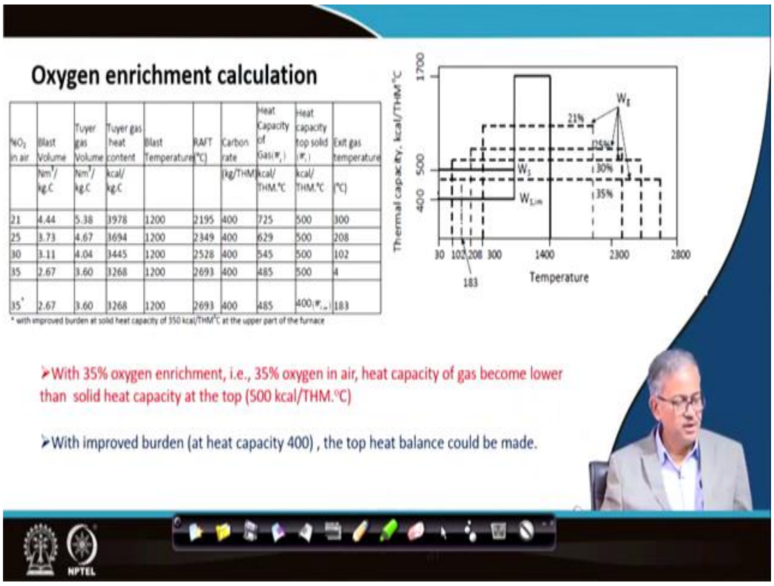

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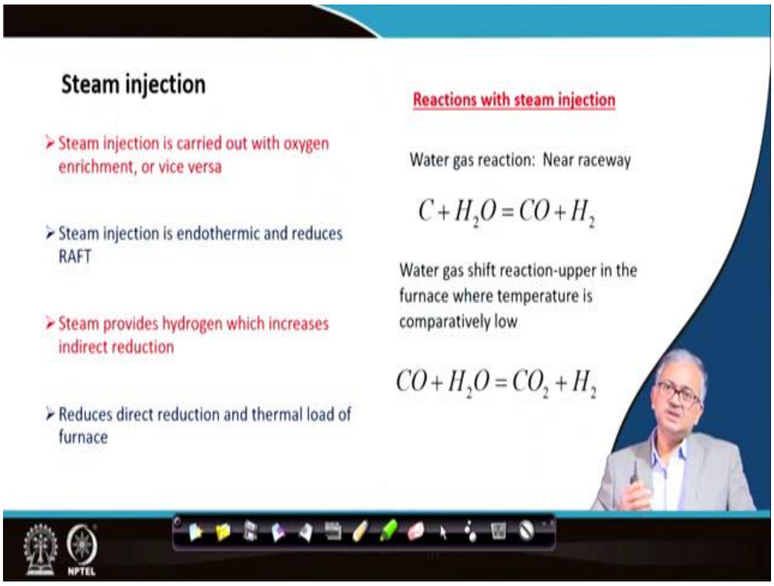


Now, we will discuss about stream injection and its association with oxygen enrichment. Two important reactions with stream that take place in blast furnace are given by equations 15.2 and 15.3.

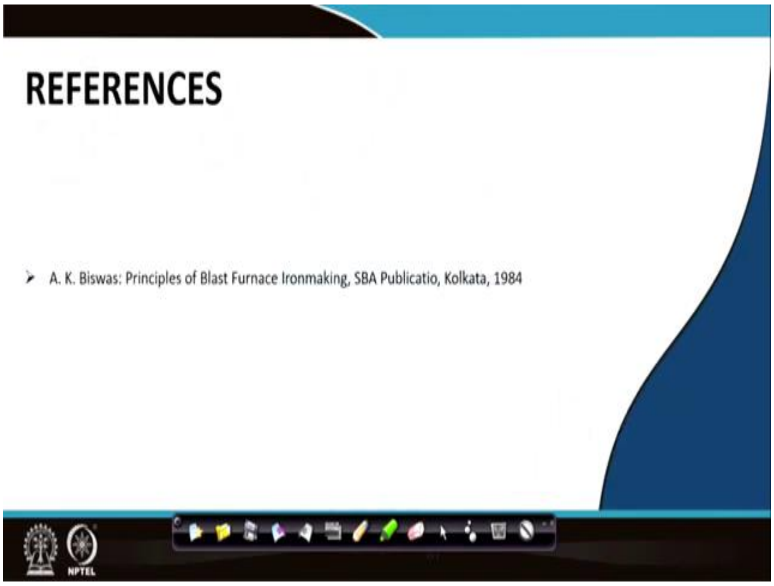
The reaction given by equation (15.2) is called the water gas reaction, which is highly endothermic and favouredat the lower part of the furnace at high temperature. The reaction given by equation (15.3) is called the water gas shift reaction, which is moderately exothermic and takes place in the upper part of the furnace and we can see hydrogen is produced at the expense of CO and that is why it is called water gas shift reaction. .

$$C + H_2O = CO + H_2 \tag{15.2}$$

$$CO + H_2O = CO_2 + H_2 \tag{15.3}$$

Steam injection is done because steam is a good source of hydrogen and hydrogen promotes indirect reduction. Hydrogen is a very good reductant it increases the reducibility of the ore by 4 to 5 times and, reduces direct reduction and thermal load of the furnace. As I have mentioned earlier that direct reduction eventually takes place in the lower part of the blast furnace through in-situ CO generation. But indirect reduction is limited by gas solid contact and type of reductant. Hydrogen helps in increasing the percentage of indirect reduction. We have seen that 46 % direct reduction in blast furnace reduces the fuel rate to minimum; but it is difficult to achieve 46% indirect reduction in blast furnace. From that point of view steam injection is very effective.

However, water gas reaction is a highly endothermic reaction and too much of steam injection reduces the RAFT. If oxygen enrichment accompanies steam injection, the RAFT can be maintained at appropriate level. (Refer Slide Time: 29:18)



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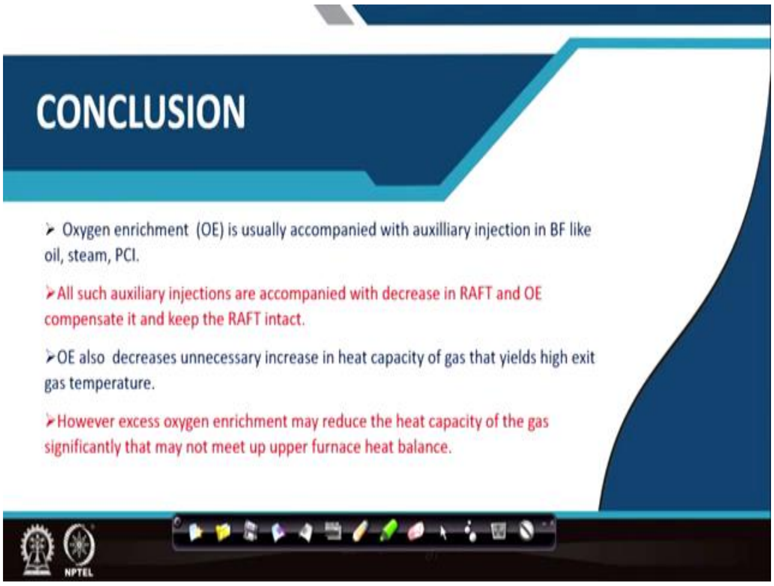

In conclusion we can say that oxygen enrichment of air increases RAFT and decreases heat capacity of the gas that may lead to thermal imbalance in the upper part of the furnace at higher level of oxygen in air. A sample calculation based on assumed typical heat capacity of solid at 500 kcal/THM-^{o}C, and with a very high carbon rate at 400 kg/THM, it was observed that oxygen enrichment upto 30% oxygen in air could be done without thermal imbalance in the furnace.

Steam injection is a good source of hydrogen but it should be accompanied with oxygen enrichment to maintain and appropriate RAFT.