Materials and Energy Balance in Metallurgical Processes
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Module No. # 01
Lecture No. # 33
Concepts in Converting

In an earlier lecture I have presented rist diagram which is just shown over here and there I have told that we will be considering diagramic representation of material and heat balance.

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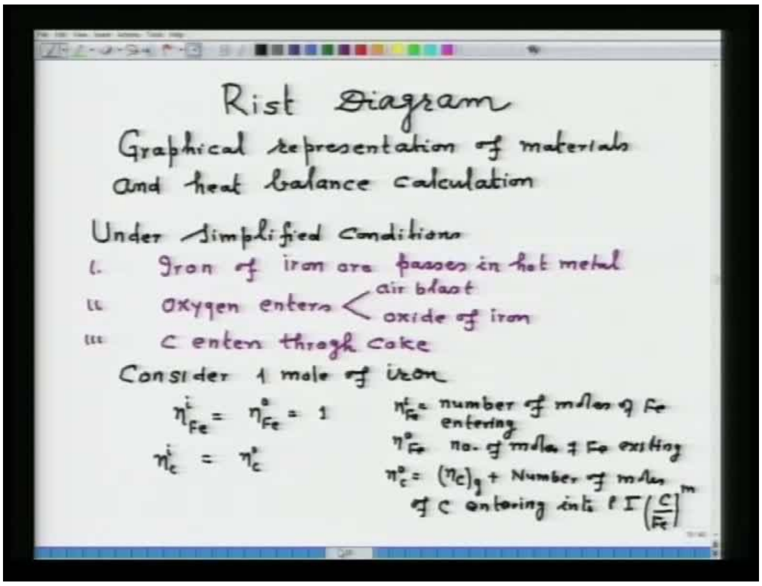

Rist Diagram

Graphical representation of materials and heat balance calculation

Under simplified conditions

i. Iron of iron ore passes in hot metal

ii. oxygen enters < air blast / oxide of iron

iii. C enters throgh coke

Consider 1 mole of iron

$n^i_{Fe} = n^o_{Fe} = 1$

$n^i_c = n^o_c$

n^i_{Fe} = number of moles of Fe entering

n^o_{Fe} no. of moles of Fe existing

$n^o_c = (n_c)_g$ + Number of moles of C entering into P I $\left(\frac{C}{Fe}\right)^m$

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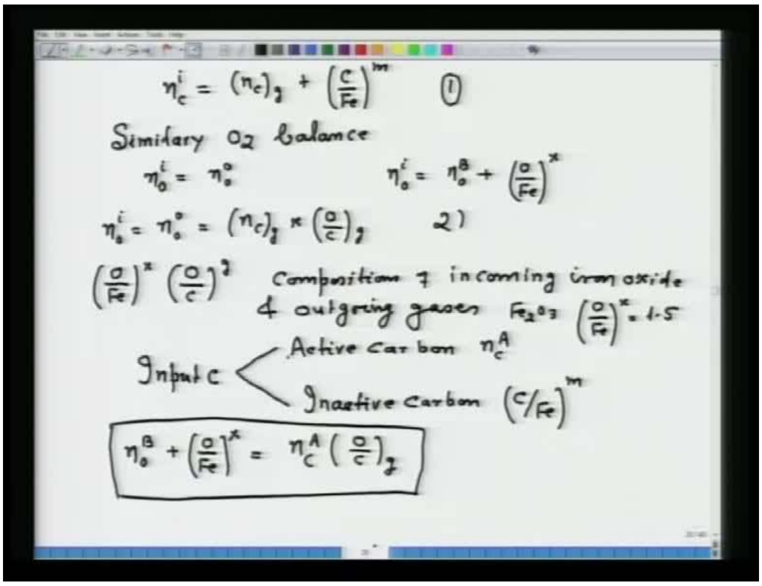

$$\eta_c^i = (n_c)_g + \left(\frac{C}{Fe}\right)^m \quad ①$$

Similary O_2 balance

$$\eta_o^i = \eta_o^o \qquad \eta_o^i = \eta_o^B + \left(\frac{O}{Fe}\right)^x$$

$$\eta_o^i = \eta_o^o = (n_c)_g \times \left(\frac{O}{C}\right)_g \quad 2)$$

$\left(\frac{O}{Fe}\right)^x \left(\frac{O}{C}\right)^g$ Composition of incoming iron oxide & outgoing gases Fe_2O_3 $\left(\frac{O}{Fe}\right)^x = 1.5$

Input C
- Active Carbon η_c^A
- Inactive Carbon $(C/Fe)^m$

$$\boxed{\eta_o^B + \left(\frac{O}{Fe}\right)^x = \eta_C^A \left(\frac{O}{C}\right)_g}$$

In that lecture, we have considered material balance and as a result of material balance we could arrive at the equation n o B plus O by Fe x where x is the type of oxide. For example, if it is Fe 2 O 3 then FO by Fe is 1.5. If it is Fe 3 O 4 then it is 4 by 3 and so on; so, that is the way O by Fe x. This equation we could obtain as a result of material balance only and in the subsequent development of this lecture I have shown that the same equation can be represented in the form of the diagram and we have seen that and we have solved some problems.

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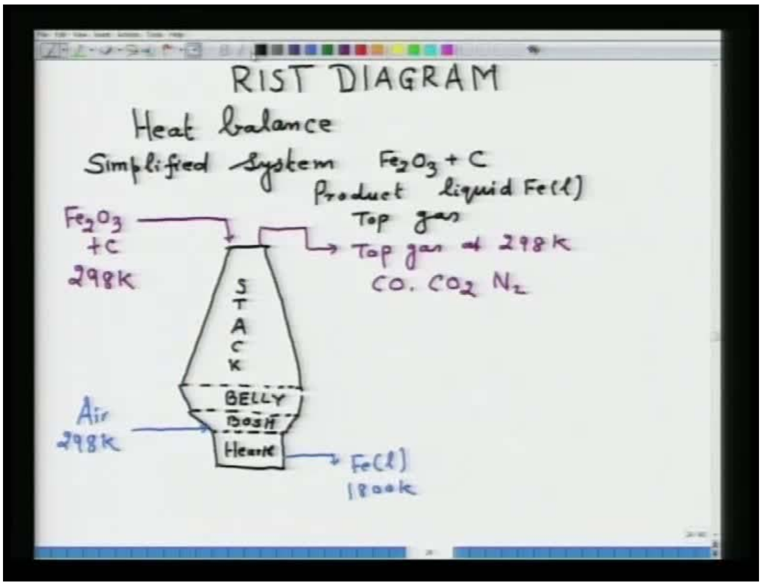

RIST DIAGRAM

Heat balance

Simplified System $Fe_2O_3 + C$

Product liquid $Fe(l)$

Top gas

Now, in a continuation of that lecture, what we would like to do today we would like to develop heat balance of the blast furnace iron making then we will combine material and heat balance and try to represent the material and heat balance in the form of a diagram.

So as such, first of all, we have to see the basics of heat balance and for that purpose I am again considering a very simplified system; so, considering a simplified system. Now, with simplified system I mean that we are not considering say the iron ore in itself or coke or pig iron. what we are considering a simplified system; that is we are considering - we are charging Fe 2 O 3 plus carbon this is our burden and the product which we are considering in order to understand the basics of rist diagram when we incorporate heat balance into it so product we are considering to develop this equation liquid iron pure liquid iron and we are considering also top gas

So in a sense, our consideration leads to the following heat balance diagram that is a blast furnace; this is the hearth, this is the bosh this is the belly; my objective is not to tell you the design of the blast furnace and this is what the stack region of the blast furnace this is the stack (Refer Slide Time: 03 12).

For our heat balance what we are considering that on the top we are charging Fe 2 O 3 plus carbon of which we already did material balance and arrived at an equation; the temperature we are considering 298 kelvin because for heat balance the temperature of heat input and heat output they are important.

So, the top gas is also discharging at 298 kelvin and comprises of CO, CO 2 and N 2. Mind you that you are considering as a simplified model. In actual practice top gas may go at 300 degree celsius or something of that sort. In reality, you do not charge pure iron oxide you charge iron ore. So after developing the simplified model we can add the complexity so that we arrive at actual blast furnace iron making. We are injecting air and mind you we are injecting air at 298 kelvin and we are discharging here iron liquid and the temperature we are considering 1800 kelvin, mind you we are not considering slag at the moment.

That means we are attempting to understand how the heat balance can be transformed in the form of an equation and we will develop equation such that all these input for example the gangue in the iron ore it can be simply added to it slag of the output can be simply added to it and so on and so forth.

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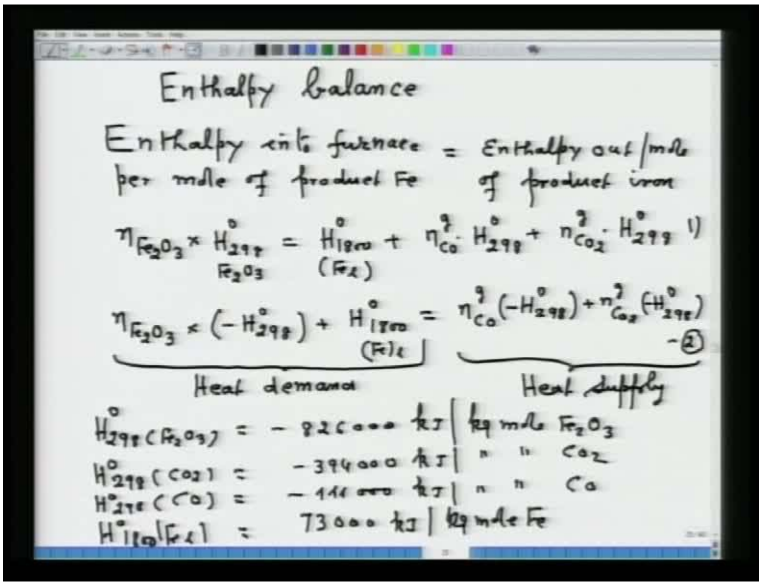

Enthalpy balance

Enthalpy into furnace per mole of product Fe = Enthalpy out/mole of product iron

$$n_{Fe_2O_3} \times \underset{Fe_2O_3}{H^\circ_{298}} = \underset{(Fe_l)}{H^\circ_{1800}} + n^g_{CO}\cdot H^\circ_{298} + n^g_{CO_2}\cdot H^\circ_{298} \quad 1)$$

$$\underbrace{n_{Fe_2O_3} \times (-H^\circ_{298}) + \underset{(Fe)_l}{H^\circ_{1800}}}_{\text{Heat demand}} = \underbrace{n^g_{CO}(-H^\circ_{298}) + n^g_{CO_2}(-H^\circ_{298})}_{\text{Heat supply}} \quad -②$$

$H^\circ_{298}(Fe_2O_3)$ = − 822000 kJ/kg mole Fe_2O_3

$H^\circ_{298}(CO_2)$ = − 394000 kJ/ " " CO_2

$H^\circ_{298}(CO)$ = − 111000 kJ/ " " CO

$H^\circ_{1800}(Fe_l)$ = 73000 kJ/kg mole Fe

This is the case when the heat balance or we can say enthalpy balance that can be written in words; say enthalpy into furnace per mole of product iron remember I am using per mole of product iron - it is not pig iron, it is product iron. Later on, when we add any element to iron then we have to see that we have developed for 1000 kg product iron that will be equal to enthalpy out again per mole of product iron.

Now say enthalpy into the furnace for example, if you consider n moles of Fe 2 O 3 into its heat of formation that is H naught 298 this is for Fe 2 O 3 that should be equal to H naught 1800 of iron liquid plus the gas consist of n moles of carbon monoxide into its enthalpy value not 298 plus n g CO 2 into H naught 298, where n Fe 2 O 3 n g CO and n g CO 2 they are per mole of product iron.

So, now what we can do? We can now bring all our terms which requires heat. So, in that process what will I do, say n Fe 2 O 3 into minus H naught 298 plus H naught 1800, mind you I am considering now the heat demand sight all where the heat is demanded; for that that will be equal to n g CO minus H naught 298 plus n g CO 2 H naught 298.

Let me consider this equation as number 1 and this equation as number 2 (Refer Slide Time: 8.30). Now this side I am considering heat demand and this side I am considering as heat supply. As I said, correction here it should be minus H naught 298.

So now I have out their values the heat of decomposition all these value so I am giving the certain value say H naught 298 Fe 2 O 3 that is equal to heat of formation of Fe 2 O 3 and that is minus 826000 kilo joule per kg mole Fe 2 O 3.

Similarly, H naught 298 and similarly H naught 298 this is for CO 2 this is for CO. So for CO 2 that is equal to minus 394000 for CO it is minus 11000 kilo joule per kg mole CO 2 and here it is kilo joule per kg mole CO. Similarly, we have to calculate H naught 1800 iron liquid so that will be equal to… in the thermo chemistry lecture I had already told you how to calculate this thing; so you can calculate. That value will be 73000 kilo joule per kg mole iron mind you it is plus.

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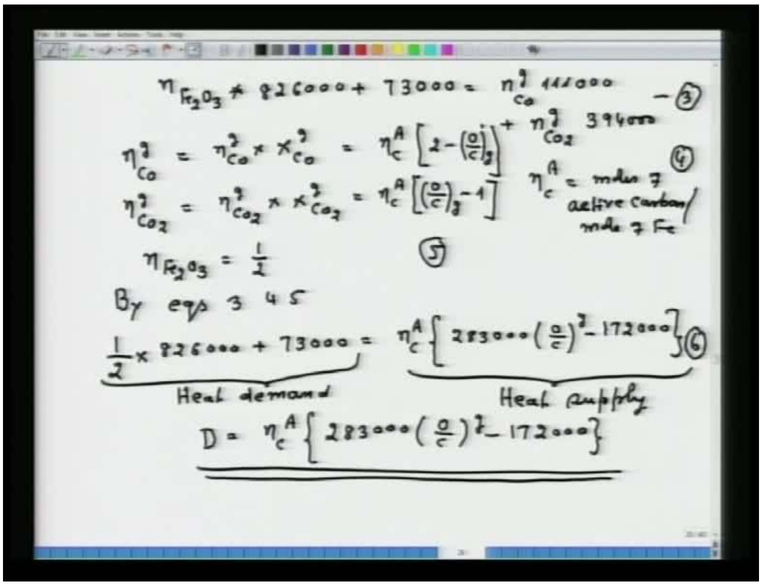

$n_{Fe_2O_3} \times 826000 + 73000 = n^g_{CO}\,111000 + n^g_{CO_2}\,394000$ — ③

$n^g_{CO} = n^g_{CO} \times x^g_{CO} = n^A_c\left[2-\left(\frac{O}{C}\right)_g\right]$ ④

$n^g_{CO_2} = n^g_{CO_2} \times x^g_{CO_2} = n^A_c\left[\left(\frac{O}{C}\right)_g-1\right]$

n^A_c = moles of active carbon/mole of Fe

$n_{Fe_2O_3} = \frac{1}{2}$ ⑤

By eqs 3 4 5

$$\underbrace{\frac{1}{2} \times 826000 + 73000}_{\text{Heat demand}} = \underbrace{n^A_c\left\{283000\left(\frac{O}{C}\right)_g - 172000\right\}}_{\text{Heat supply}}$$ ⑥

$$D = n^A_c\left\{283000\left(\frac{O}{C}\right)_g - 172000\right\}$$

So, if you substitute this value we will get an equation n Fe 2 O 3 into 826000 plus 73000 that is equal to n g CO 111000 plus n g CO 2 394000 and let us make this equation number 3. Now, as you recall I have said that n g CO and n g CO 2 that can be related to mole fraction ad that is equal to n g CO into x g CO and this will be n g CO 2 into x g CO 2 that can be related with the active carbon n A c is there active carbon 2 minus O by C g where n c A is the moles of active carbon per mole of iron or per kg mole of iron

Similarly, this will be n c A O by C g minus 1; O by C is the ratio of atomic oxygen to the moles of carbon. Now, we know that n Fe 2 O 3 that is equal to half, to produce 1 mole of iron you need half mole of n Fe 2 O 3. So, if you substitute all these things by equation 3 4 and 5 and noting that means by equations 3 4 and 5 and noting that if you want to produce 1 mole of iron you need half mole of Fe 2 O 3. If we substitute, then we will be getting equation half into 826000 plus 73000; that is equal to n c A 283000 O by C g minus 172000 and this is our equation. Now let me put it this is equation number 4 this is equation number 5 and let see this is equation number 6 (Refer Slide Time: 13:28).

Now we have seen that this equation 6 in fact it is the heat balance now it is a very simplified approach. That means we have not considered the gangue part of it we have not considered slag part of it. Now, if we see this particular equation, we note that this particular is the heat demand; this particular side is heat demand and this particular side is the heat supplied (Refer Slide Time: 14:00).

Now the heat demand is a variable; suppose you are charging iron ore and gangue, slag is also coming out then, there is a heat demand is a variable where heat supply is; if it is coming only from carbon, it is more or less in the absence of any other heat supply - this is a sort of a constant value; so we can put D which is the heat demand which is a variable that is equal to n c A 283000 O by C g minus 172000.

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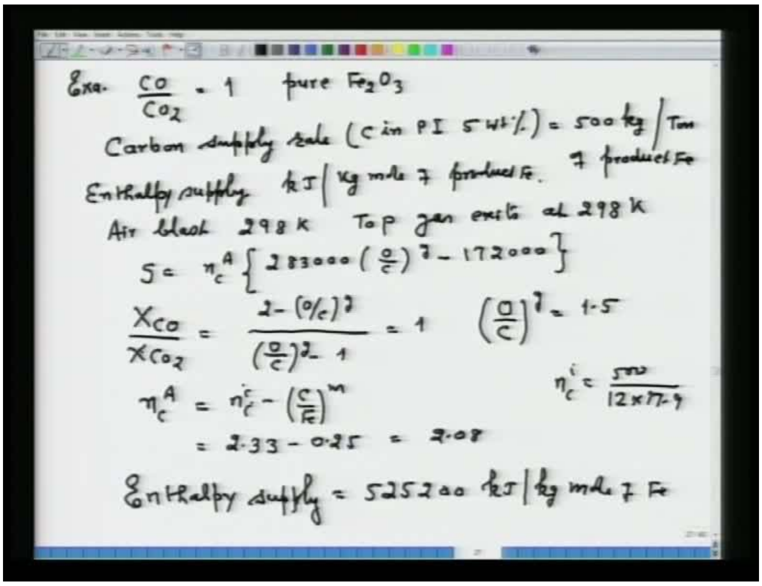

Exa. $\frac{CO}{CO_2} = 1$ pure Fe_2O_3

Carbon supply rate (C in PI 5 wt%) = 500 kg / Ton of product Fe

Enthalpy supply kJ / kg mole of product Fe.

Air blast 298 K Top gas exits at 298 K

$$S = n_c^A \left\{ 283000 \left(\frac{O}{C}\right)^g - 172000 \right\}$$

$$\frac{X_{CO}}{X_{CO_2}} = \frac{2 - (O/C)^g}{\left(\frac{O}{C}\right)^g - 1} = 1 \qquad \left(\frac{O}{C}\right)^g = 1.5$$

$$n_c^i = \frac{500}{12 \times 17.9}$$

$$n_c^A = n_c^i - \left(\frac{C}{Fe}\right)^m$$

$$= 2.33 - 0.25 = 2.08$$

Enthalpy supply = 525200 kJ / kg mole of Fe

So that is what our starting equation in order to now combine material and heat balance. Before I go I will try to illustrate by taking an example. Let me take an example CO by CO 2 ratio in a top gas of a blast furnace which is charged with pure Fe 2 O 3 that is equal to 1 when we are using pure Fe 2 O 3 - is a burden for blast furnace iron making.

Carbon supply rate, in this example carbon supply rate which includes carbon in pig iron equal to 5 weight percent; that is carbon for combustion and carbon for pig iron is also coming from this and carbon supply rate is 500 kg per ton of product iron. This is what the problem is. Now, we will have to know, what is the enthalpy supply in kilo joule per kg mole of product iron assuming assumption number 1, that air blast it enters at 298 kelvin and top gas it exits also at 298 kelvin this is our assumption.

As per the previous equation I have said that the enthalpy supply S that is equal to n c A 283000 O by C g minus 172000 that was the equation. Now from the CO, CO 2 ratio we have to find out the value of O by C. Now we know that X CO upon X CO 2 that is equal to, already I have given this expression 2 minus O by C g upon O by C g minus 1 and that is equal to 1. So we can solve from here it will come O by C g that will come out to be equal to 1.5. Now, we would like to know only n c A. So, for n c A that is equal to n c i minus c by Fe, you recall from my earlier lecture that means n c i is the total carbon supply per mole of iron and c by Fe is the moles of carbon which is dissolved in iron. So you can calculate. So, n c i that will be equal to 2.33 because n c i is simply 500 upon 1200 into 17.9; we take 1000 kg iron so 17.9 with the kg moles of iron and c by Fe that will become minus 0.25 because carbon is 5 percent and for 5 percent carbon you have 53 kgs carbon because 1000 kg is the pure iron so 53 kg becomes the carbon in iron so 53 by 12 by 17.9 gives you 0.25.

So n c A that is equal to 2.08, if it is substitutes the value of O by C g and n c A into the supply equation then enthalpy supply, I can easily calculate enthalpy supply that will equal to 525200 kilo joule per kg mole. It is not pig iron per kg mole of product iron; that is an important thing.

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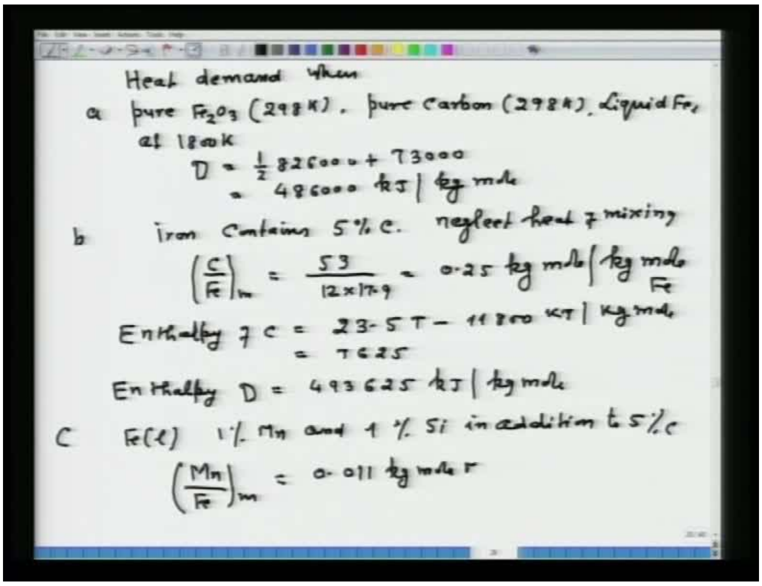

Heat demand when

a pure Fe_2O_3 (298 K). pure carbon (298 K). Liquid Fe, at 1800 K

$D = \frac{1}{2} 826000 + 73000$

$= 486000$ kJ / kg mole

b iron contains 5% C. neglect heat of mixing

$\left(\frac{C}{Fe}\right)_m = \frac{53}{12 \times 17.9} = 0.25$ kg mole / kg mole Fe

Enthalpy of C = 23.5 T − 11800 kJ / kg mole

= 7625

Enthalpy D = 493625 kJ / kg mole

C Fe(l) 1% Mn and 1% Si in addition to 5% C

$\left(\frac{Mn}{Fe}\right)_m = 0.011$ kg mole r

Now here I said that we can do certain modification. What we have done? We have taken here pure iron - is a product. Now let us calculate heat demand again in kilo joule per kg mole of iron when condition a we have pure Fe 2 O 3 as earlier supplied at 298 kelvin pure carbon again at 298 kelvin and liquid iron at 1800 kelvin.

We can calculate heat demand from the earlier equation and the heat demand that will be equal to half 826 half is coming because 1 mole of iron require half mole of Fe 2 O 3 plus 73000. So, this value is equal to 486000 kilo joule per kg mole product iron. Now let us take case b. In the case b what we are doing? Iron contains 5 percent carbon; neglect heat of mixing. I am showing how the simplified model can be tuned to the actual condition.

Condition number 2: iron contains now 5 percent carbon that is called pig iron. So, first of we will calculate C by Fe that is moles of carbon moles of iron in metal that will be equal to again 53 divided by 12 into 17.9. That is equal to 0.25 kg mole per kg mole of product iron per kg mole of iron now what we have to add it over here in the demand site we have calculated for pure iron.

Now, since carbon is there we have to add into enthalpy of carbon so that way it becomes the enthalpy supply for iron 5 percent carbon rist conditions are same liquid iron 1800 kelvin Fe 2 O 3 carbon. They are all at 298 kelvin all that we have to weight enthalpy of carbon.

Enthalpy of carbon that is equal to 23.5 T minus 11800, again kilo joule per kg mole. I substitute T is equal to 1800 kelvin and I calculate this value will become 7625 kilo joule per kg mole carbon. So, enthalpy D that will be equal to 493625 because all that we have to weight 7625 into 486000, so this is what I mean by modification.

Now, still another modification, let us come closer to what the blast furnace is producing. Blast furnace is producing silicon and manganese also; let us consider c part say iron liquid it contains 1 percent manganese and 1 percent silicon in addition to 5 percent carbon. That is what we have case c; we are simply modifying the case b where we are telling the liquid contains 1 percent manganese and 1 percent silicon that is, we are now approaching to the actual case.

Now, what we have to do here first of all, we have to calculate Mn upon Fe. Again, 1000 kg of product iron so Mn by so manganese and silicon that will become 10.75 kg; so kg per mole you can calculate that will be 0.011 kg mole Mn per mole of iron.

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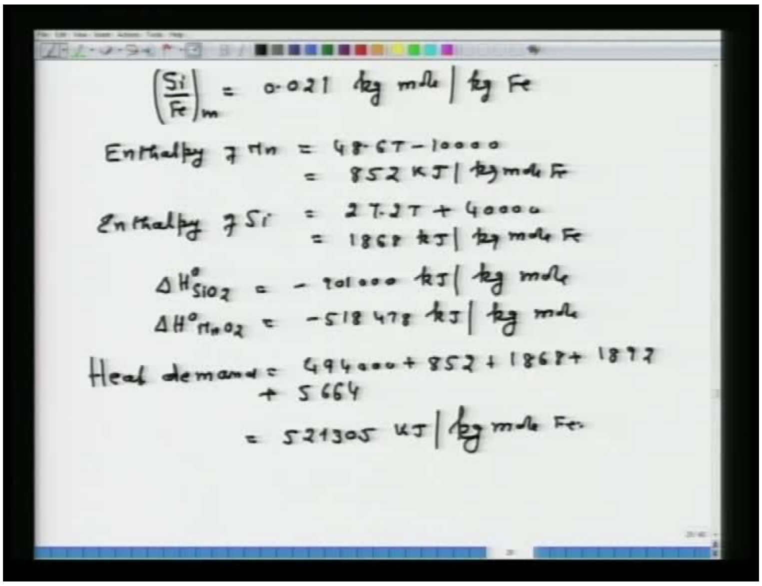

$\left(\frac{Si}{Fe}\right)_m$ = 0.021 kg mole | kg Fe

Enthalpy of Mn = 48.6T − 10000
= 852 kJ | kg mole Fe

Enthalpy of Si = 27.2T + 40000
= 1868 kJ | kg mole Fe

$\Delta H^0_{SiO_2}$ = − 901000 kJ | kg mole

$\Delta H^0_{MnO_2}$ = −518478 kJ | kg mole

Heat demand = 494000 + 852 + 1868 + 1892
+ 5664
= 521305 kJ | kg mole Fe.

Similarly, we have to calculate for silicon. Silicon upon Fe that will be equal to 0.021 kg mole per kg product iron; so what we have to do now on the heat demand side in the case b we have added enthalpy for carbon.

In the case c, we have to add enthalpy required for silicon because it will raise from 298 to 1800 kelvin and enthalpy requires to raise the temperature of manganese from 298 to

1800 kelvin. so enthalpy of manganese we need and we need enthalpy of silicon on the liquid iron side that is given by 48.6 T minus 10000 kilo joule per kg mole and silicon 27.2 T plus 40000. So for our case the enthalpy of manganese that is 852 kilo joule per kg mole of iron and in this critical case it is 1868 kilo joule per kg mole iron now this is not the total solution now you have to think how silicon in manganese are coming for that iron ore must have SiO 2 and MnO 2

So for SiO 2 and MnO 2 what you have to do? You have to weigh their heat of the composition of SiO 2 and MnO 2. So that is what I mean by the modification from the demand side in addition to enthalpy of manganese and enthalpy of silicon heat of the composition of SiO 2 and MnO 2 has to be added. Otherwise, silicon in manganese - from where are they coming? They are coming from the gain part of the iron ore.

So delta H naught SiO 2 and delta H naught MnO 2 that is equal to minus 901000 kilo joule per kg mole and MnO 2 is minus 518478 kilo joule per kg mole. Say, 0.021 kg mole of silicon will require 0.021 kg mole of SiO 2 similarly manganese also.

If you calculate all that you have to multiply by the kg mole of silicon equal to kg mole of SiO 2 to this SiO 2 quantity MnO quantity, then we get heat demand that is equal to 494000. That we have calculated for case b plus 852 for enthalpy of manganese plus 1868 for enthalpy of silicon plus 1892 required heat of decomposition for SiO 2 reduction and plus 5064 for MnO 2 reduction to manganese. So, this will be total 521305 kilo joule per kg mole of iron. So, that is what I mean the addition of the terms and to come closer to the actual case. Remember, we started with the pure liquid iron pure Fe 2 O 3; now with this addition we have come closer to what is happening in actual blast furnace iron making. We brought SiO 2 of the gangue into picture; we bought MnO 2 of the gangue part of the ore into the picture.

We now made liquid to iron and we added silicon manganese and carbon. That is what I mean to say that heat demand can always be updated according to the actual situation.

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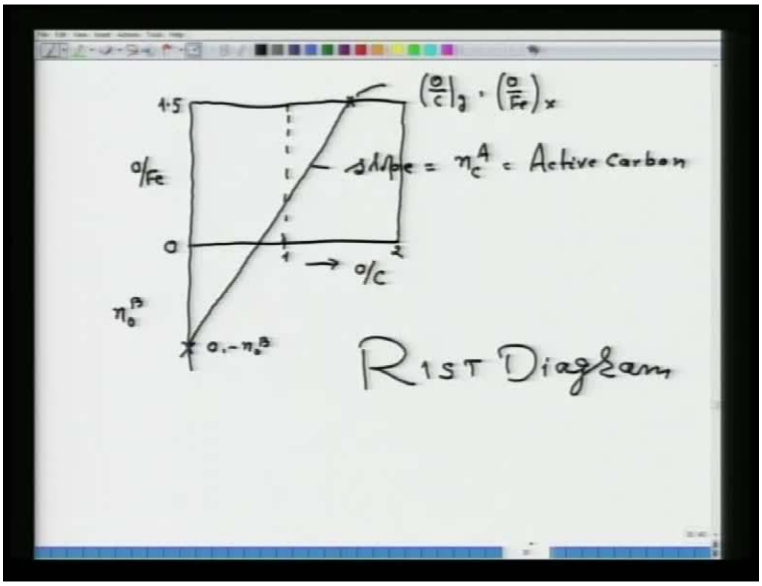

Now after understanding this, what can we do now? We can modify modify the material balance equation to incorporate heat balance equation also.

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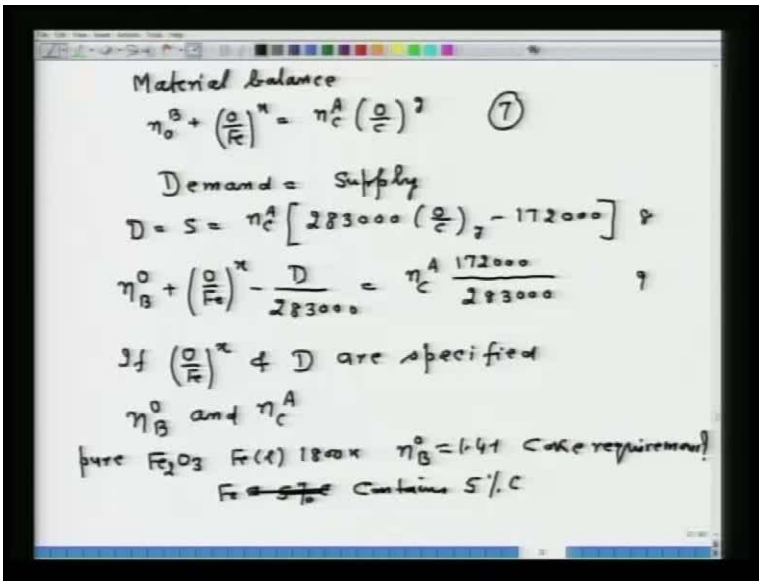

Material balance

$n_o^B + \left(\frac{O}{Fe}\right)^x = n_c^A \left(\frac{O}{C}\right)^g$ ⑦

Demand = Supply

$D = S = n_c^A \left[283000 \left(\frac{O}{C}\right)_g - 172000\right]$ 8

$n_B^o + \left(\frac{O}{Fe}\right)^x - \frac{D}{283000} = n_c^A \frac{172000}{283000}$ 9

If $\left(\frac{O}{Fe}\right)^x$ & D are specified

n_B^o and n_c^A

pure Fe_2O_3 Fe(l) 1800K $n_B^o = 1.41$ Coke requirement

Fe ~~= 5%~~ Contains 5% C

You know the material balance equation. Recall that equation was n o B plus O by Fe x that is equal to n A c O by C g that was let us say equation number 7. Now, you know demand should be equal to supply; there should be no doubt on this. We know that demand D that is equal to S that is equal to n c A 283000 O by C g minus 172000 let us make this equation 8.

Now by 7 and 8 we can write down the equation n o B plus I am rearranging and writing in this particular form plus O by Fe x minus D upon 283000 that is equal to n c A 172000 upon 283000.

Let us take equation number 9 now say if O by Fe x and D are specified that means if now for a given situation O by Fe x and demand are specified then equation 9 which is our model equation with represent combine material and heat balance it requires the specification of n o B and n c A it require the specification of n o B and n c A either one if you do it then we can calculate the variable which we will require to calculate.

Say if n o B is specified n c A can be calculated or n c A can be specified n o B can be calculated; if both are not specified then we can proceed to the graphical solution and let us see that before that let me illustrate by taking a simple example. Let us take pure Fe 2 O 3 we take a case which we are taking pure Fe 2 O 3 iron liquid at 1800 kelvin n o B I am taking 1.41 then we can find out the coke requirement. We have to find out coke requirement and the case in question producing iron which is equal to 5 percent carbon iron it contains, rather let me put iron; it contains 5 percent carbon it is not a pure iron, it contains 5 percent carbon.

So let us calculate the amount of coke that will be required. Amount of coke required means you have to calculate the active carbon plus the carbon which is entering into pig iron; both where the carbon source of carbon for both is the coke. so if we do that what We have to first of all calculate C by Fe. We have already calculated in earlier cases for the same; it is coming 0.25 the n c i that is equal to C by Fe m plus n c A.

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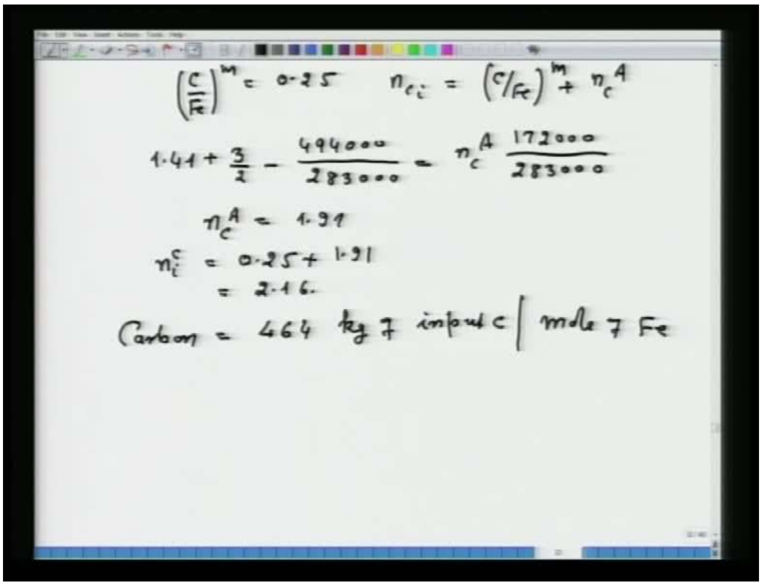

$$\left(\frac{C}{Fe}\right)^{m} = 0.25 \qquad n_{c_i} = (C/Fe)^{m} + n_c^{A}$$

$$1.41 + \frac{3}{2} - \frac{494000}{283000} = n_c^{A}\,\frac{172000}{283000}$$

$$n_c^{A} = 1.91$$

$$n_i^{c} = 0.25 + 1.91$$

$$= 2.16.$$

Carbon = 464 kg of input C | mole of Fe

So let us take it now and substitute the value that is 1.41 plus 3 by 2 minus the demand for iron 5 percent carbon. We already calculated that is minus 494000 upon 283000; that is equal to n c A 172000 upon 283000. From here, we can calculate easily n c A that will be equal to 1.91 and we know the equation that is n i c that is the total carbon per mole of iron, that will be equal to 0.25 plus 1.91; that will be equal to 2.16. Therefore, carbon supply required will be 464 kg of input carbon per mole of product iron, that is what I wanted to illustrate; how to use this equation and you have seen that how easily this equation can be updated according to the prevailing condition in blast furnace iron making.

Now, since we have the equation in our hand we can make use of the equation we have transformed material in heat balance into the form of an equation. We can plot it now and for a particular blast furnace operation we can plot the curve and see that our operation follows that particular line or whatever we get after the plot.

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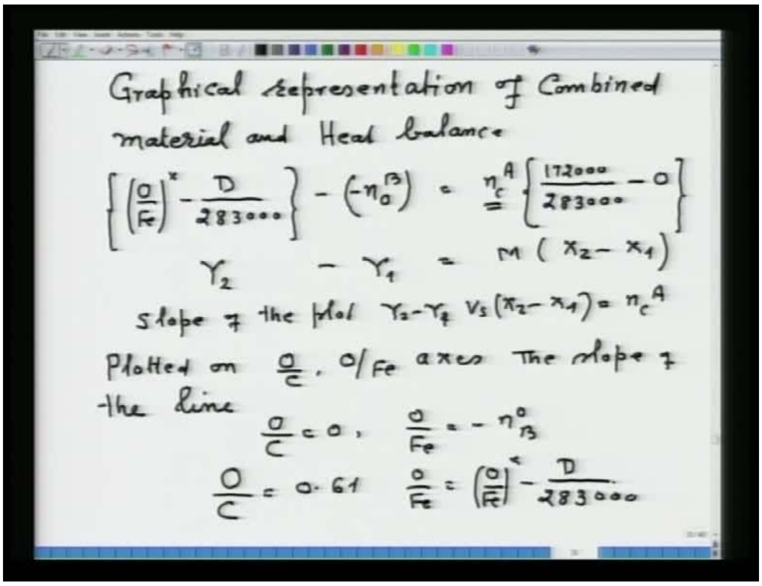

Graphical representation of Combined material and Heat balance

$$\left[\left(\frac{O}{Fe}\right)^x - \frac{D}{283000}\right] - \left(-n_o^B\right) = \underline{\underline{n_c^A}}\left[\frac{172000}{283000} - 0\right]$$

$$Y_2 - Y_1 = M(X_2 - X_1)$$

slope of the plot $Y_2 - Y_1$ vs $(X_2 - X_1) = n_c^A$

Plotted on $\frac{O}{C}$, O/Fe axes The slope of the line

$$\frac{O}{C} = 0, \quad \frac{O}{Fe} = -n_B^o$$

$$\frac{O}{C} = 0.61 \quad \frac{O}{Fe} = \left(\frac{O}{Fe}\right)^x - \frac{D}{283000}$$

So, that is the advantage of this rist diagram. Let us see say graphical representation of combined material and heat balance. I will be writing down the equation in the form in which it can be plotted. Now the way of plotting is same as it was done for material balance. Only so we can write down now the equation in the following way say O upon Fe x minus D upon 283000 minus n o B it is minus that is equal to n c A 172000 upon 283000 minus 0.

So, this equation is now same as Y 2 minus Y 1; that is equal to M X 2 minus X 1. That means, if I plot Y 2 minus Y 1 against X 2 minus X 1 the slope of the line will give me the value of n c A. So, slope of the plot Y 2 minus Y 1 versus X 2 minus X 1 that will be equal to n c A and from n c A I can determine the value of active carbon and all other variable.

Now let us see if it plots, say if those things are plotted on O by C and O by Fe axes the slope of the line. Naturally, it is a straight line the slope of the line will pass through the point O by C equal to 0 and O by Fe that is equal to minus n o B and O by C that is equal to 0.61 which is the value of 172000 upon 283000 when O by Fe that is equal to O by Fe x minus D upon 283000.

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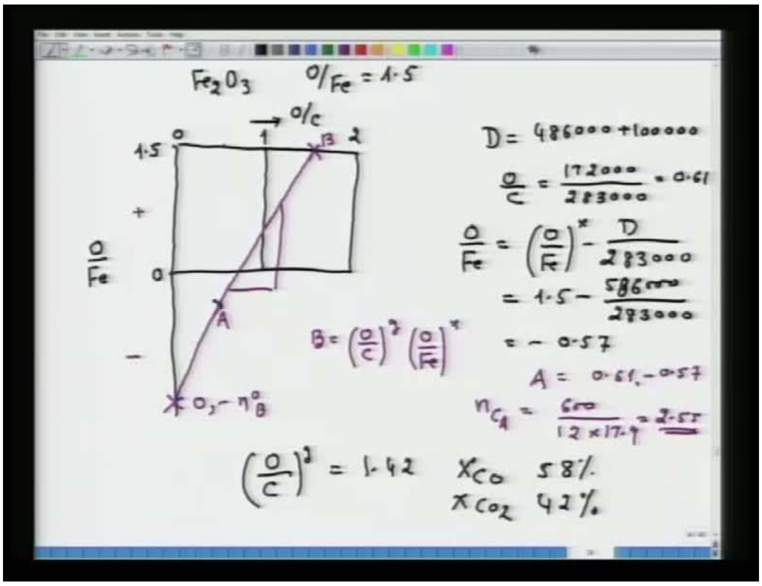

Now let us plot it. Say, we know that for Fe 2 O 3, when Fe 2 O 3 is a part of the iron ore that is iron oxide then O by Fe is 1.5; so now if you plot it say this is the plot side is 0 (Refer Slide Time: 38:45). I am plotting here O by Fe and here I am putting O by C. Naturally, O by C equal to 1 that is CO and CO 2 is 2 O by C 2 and that is here say 0 this is O by Fe for Fe 2 O 3 it is 1.5.

Now, there is certain important thing to note. Say, demand is fixed for a particular raw material. If you fix for example our D for pure Fe 2 O 3 we have calculated 486000 and we are charging pure Fe 2 O 3 and pure liquid iron was the product. Into this let us add say some though we have to calculate that value, but for the sake of illustration we can calculate some 100000 kilo joule. That is, the heat because of the gangue the presence of gangue has to be fluxed though we have to calculate the amount of slag that is produced and accordingly the heat has to be supply.

For the present case, I am just taking that 100000 kilo joule per kg mole of iron is the amount of heat that is required to form a slag. So my demand will be this equal to this one; so O by C now that is equal to 172000 upon 283000; so this value is equal to 0.6. So O by C was 0.61 now I have to find out O by Fe now O by Fe that is equal to O by Fe x minus D upon 283000. O by Fe x is 1.5 minus 586000 upon 283000 so this will be minus 0.57.

So let us take it now this point somewhere here is let us say 0.61 and this side is plus and this side is minus; here somewhere let us take it 0 point minus 57. This becomes a fixed point for this particular blast furnace which we have said it is charge a pure Fe 2 O 3 (Refer Slide Time: 41:15). Liquid iron is produced which has some heat value so for this operation of blast furnace iron making this particular point which I will say A and the point A it has the coordinate 0.61 and minus 0.57.

Now, what is to be done we know about the value of n c A. we have to know Let us take the carbon content was 600 kg per ton of iron so n c A we can calculate; n c A that is equal to 600 upon 12 into 17.9; this is equal to 2.55. That means, now the slope of the line which is passing through the point A it should have slope equal to 2.55 because n c A is the slope of the line.

So if I do that then this is a slope of the line which is equal to 2.5 and this particular point if I say B then B value of B that is equal to O by C g which is the top gas analysis corresponding to O by Fe x. This particular point is 0 and minus n o B and this slope of the line which we have fixed by calculating n c A, since we are knowing n c A, so this is equal to 2.55 that is how you will be representing a graphical representation.

Now, in this particular problem the value of B that accidently it comes O by C g if you plot properly. It will equal to 1.42 and from this one can calculate X CO and X CO 2; so that will be around 58 percent and here it will be 42 percent.

So, that is how what I mean to say a graphical representation of the combined material and heat balance. All that it can be modified for the actual case though I tried to illustrate but well depending on the heat demand one can illustrate and what is this particular diagram says is that for a particular operation this line is now available to you now we can suggest we can make certain improvement. This point again I will show by the point A.

Now, here I will give you few some one or two exercises that you can solve yourself; I will give you the problem number 1.

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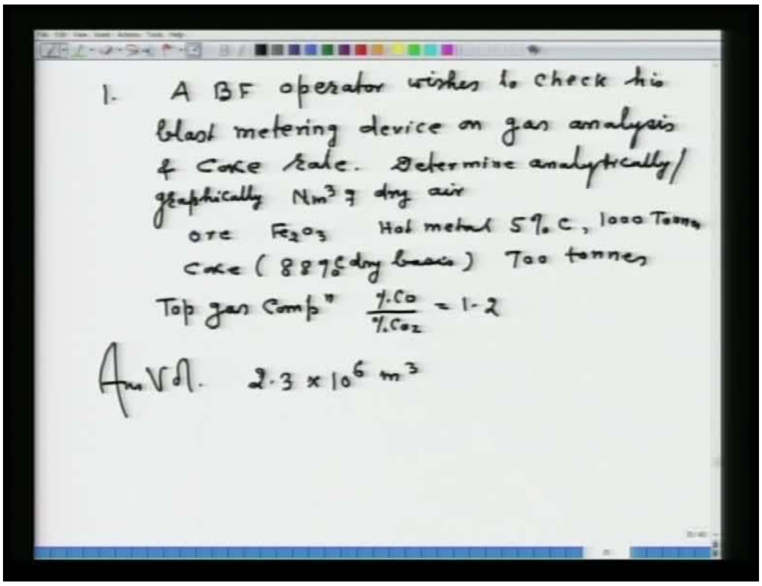

1. A BF operator wishes to check his blast metering device on gas analysis & coke rate. Determine analytically/graphically Nm^3 of dry air

ore Fe_2O_3 Hot metal 5% C, 1000 Tonnes

coke (88% C dry basis) 700 tonnes

Top gas Compn $\frac{\%CO}{\%CO_2} = 1.2$

Ans Vol. $2.3 \times 10^6\ m^3$

A blast furnace operator wishes to check is blast metering device. He is supplying air blast and he is measuring the air blast by certain device and he is thought that is there is some doubt. Blast measuring device on the basis of gas analysis - this value is known to him and coke rate. He knows both the values now what he want determine analytically probably graphically that means draw a line and determine the n o B value the N m cube of dry air.

For the condition when the ore is contains pure Fe 2 O 3 hot metal they have 5 percent carbon amount is 1000 tons coke 88 percent dry 88 percent carbon on dry basis and 700 tons the total requirements of though it is a very poor operation but does not matter.

Top gas composition is a percent CO volume percent upon percent CO 2 is given to you 1.2 so this is one particular problem you can try to calculate and the volume that will be equal to 2.3 into 10 to the power 6 meter cube will be the answer. I will give you one more problem so that you can practice it.

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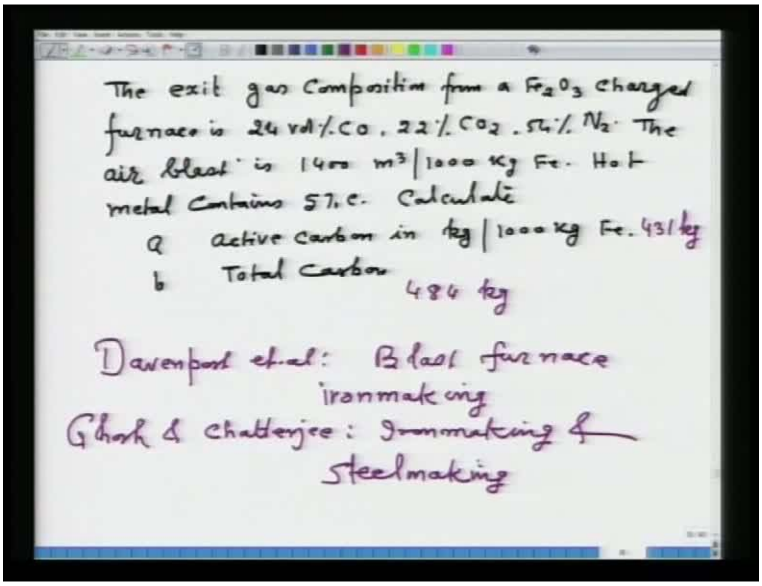

The exit gas Composition from a Fe_2O_3 charged furnace is 24 vol% CO, 22% CO_2, 54% N_2. The air blast is 1400 m^3 | 1000 kg Fe. Hot metal Contains 5% C. Calculate

a active Carbon in kg | 1000 kg Fe. 431 kg

b Total Carbon 484 kg

Davenport et al: Blast furnace ironmaking

Ghosh & Chatterjee: Ironmaking & steelmaking

Another problem that I will give you is, the exit gas composition from a Fe 2 O 3 charge furnace is 24 volume percent CO 22 percent volume percent of code CO 2 and 54 percent nitrogen all are on volume percent. The air blast is 1400 meter cube per 1000 kg iron hot metal contains 5 percent carbon; so calculate a active carbon in kg per 1000 kg of product iron b calculate total carbon. You know how to calculate, the procedure already I have said. So, the answer would be the total carbon is 484 kg and active carbon is 431 kg.

With these two problems and the rist diagram I have finished or I have covered sufficient and I have given sufficient information on blast furnace iron making and its representation on a diagram. For the details if you want to go, you can consult the book of say Davenport et al, on blast furnace iron making. We can also consult the book Ghosh and Chatterjee iron making and steel making. So, with this I finish the lectures on reduction smelting as a unit process. In the next lecture we will see the next unit process that is converting.