Materials and Energy Balance in Metallurgical Processes

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Module No.# 01

Lecture No. # 32

RIST Diagram-I1

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 diagrammatic representation of material and heat balance. 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.

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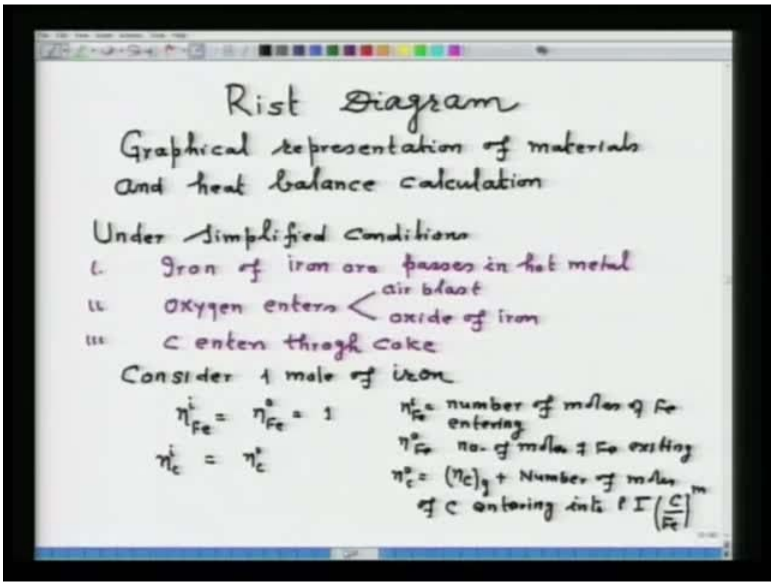

Rist Diagram

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 enten 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 exiting

$n^o_C = (n_C)_g$ + Number of moles of C entering into e I $\left(\frac{C}{Fe}\right)^m$

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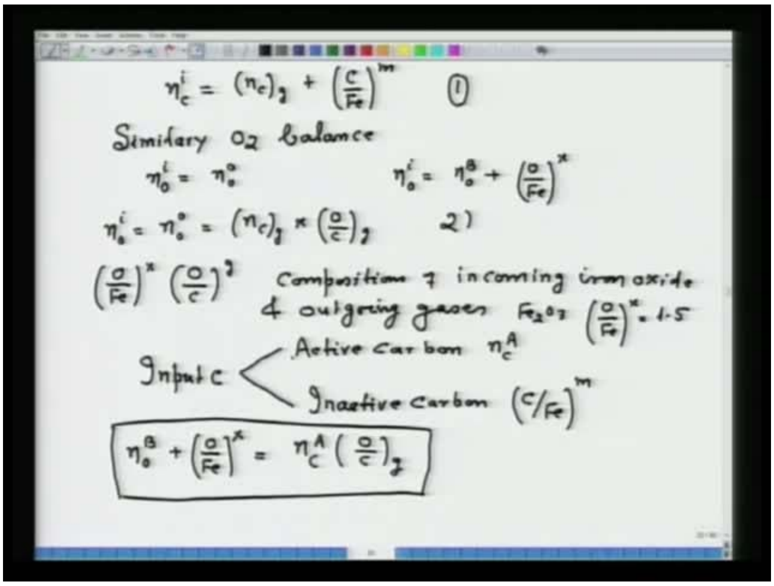

$n_C^i = (n_C)_g + \left(\frac{C}{Fe}\right)^m$ ①

Similary O_2 balance

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

$n_O^i = n_O^o = (n_C)_g \times \left(\frac{O}{C}\right)_g$ $\quad$ 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 n_C^A ; Inactive carbon $(C/Fe)^m$

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

So that is O by Fe X. So, this equation we could obtain as a result of material balance only. In the subsequent development of this lecture, I have shown that this same equation can be represented in the form of the diagram, we have seen that and we have solved some problem. Now, as a continuation of that lecture, what you would like today? We would like to develop heat balance of the blast furnace ironmaking then, we will combine material and heat balance and try to represent the material and heat balance in the form of a diagram.

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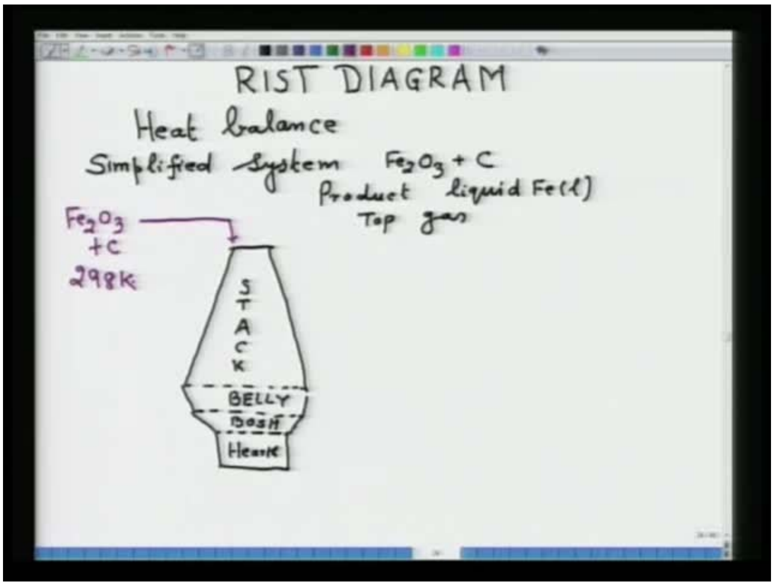

RIST DIAGRAM

Heat balance

Simplified System $Fe_2O_3 + C$

Product liquid Fe(l)

Top gas

First of all, we have to see basics of heat balance and for that purpose, I am again considering a very 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 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.

We are considering to develop this equation - liquid iron - pure liquid iron - and we are considering also top gas. So in any 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; though 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.

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

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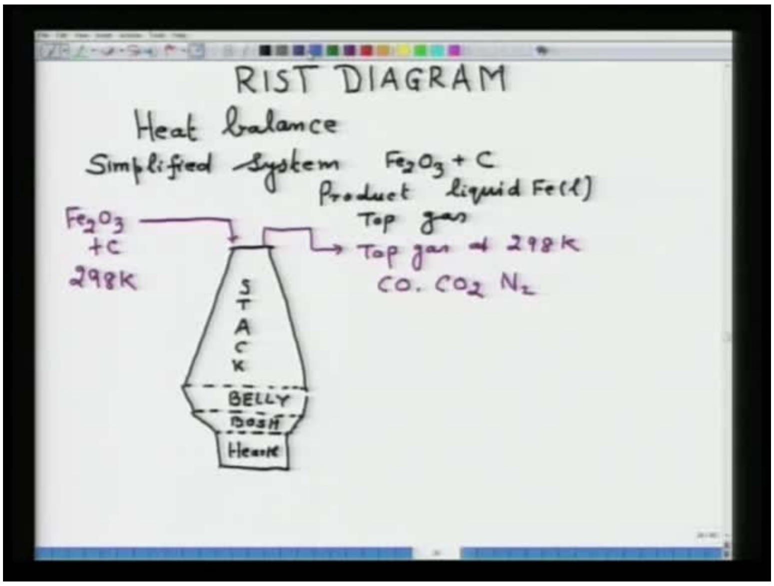

RIST DIAGRAM

Heat balance

Simplified System $Fe_2O_3 + C$

Product liquid Fe(l)

Top gas

So, the top gas is also discharging at 298 kelvin and comprises of CO, CO 2 and N 2 mind you, what we 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 which is iron ore. After developing the simplified model we can add the complexity so that we arrive at a actual blast furnace ironmaking.

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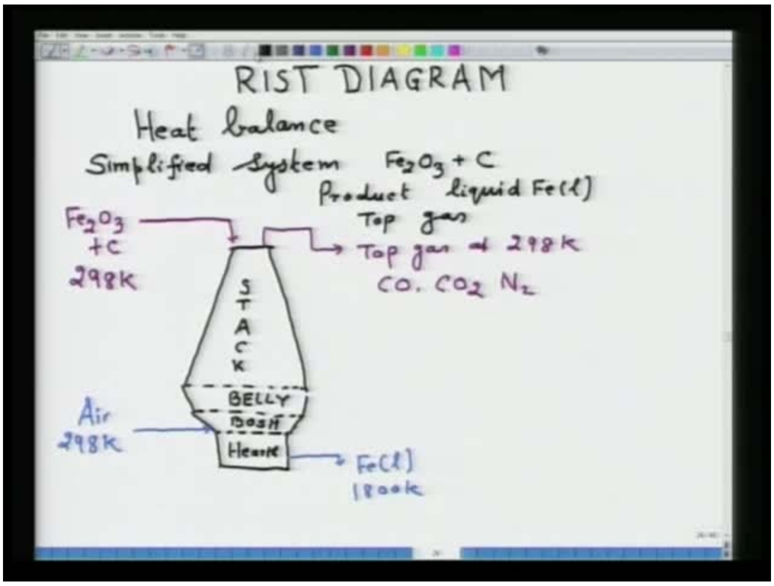

RIST DIAGRAM

Heat balance

Simplified system $Fe_2O_3 + C$

Product liquid Fe(l)

Top gas

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.

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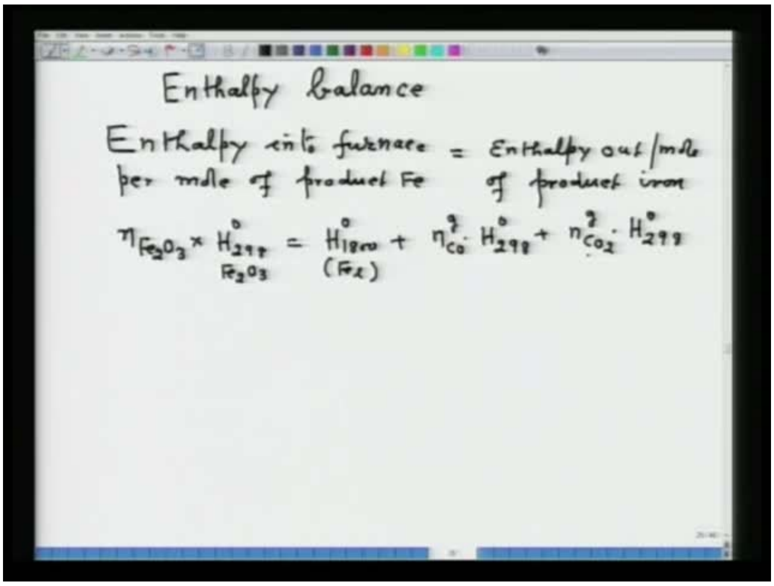

Enthalpy balance

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

$$n_{Fe_2O_3} \times \underset{Fe_2O_3}{H^{0}_{298}} = \underset{(Fe_l)}{H^{0}_{1800}} + n^{g}_{CO} \cdot H^{0}_{298} + n^{g}_{CO_2} \cdot H^{0}_{298}$$

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

Then, the heat balance or we can say enthalpy balance, it 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 we consider n moles of Fe 2O 3 into its heat of formation that is H naught 298; this is for Fe 2O 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 naught 298 plus n g CO 2 into H naught 298, where n Fe 2O 3 n g CO and n g CO 2 they are per mole of product iron.

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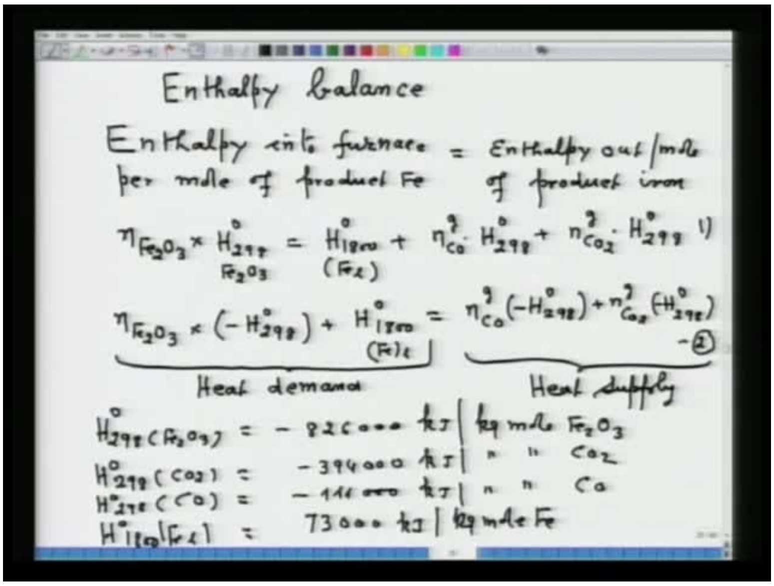

Enthalpy balance

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

Now, what we can do? We can now bring all terms which requires heat, in that process what will I do? Say, n Fe 2O 3 into minus H naught 298 plus H naught 800 -mind you, I am considering the heat demand site, 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. Now, this side I am considering heat demand and this side I am considering as heat supply. Now such site - correction here, it should be minus H naught 298. Now, I have to find their values - the heat of decomposition - all these values.

I am giving the certain value say, H naught 298 Fe 2O 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.

For CO 2, it is equal to minus 394000; for CO it is minus 111000 kilo joule per kg moles CO 2 and here, it is kilo joule per kg mole CO. Similarly, we have to calculate H naught 1800 iron liquid.

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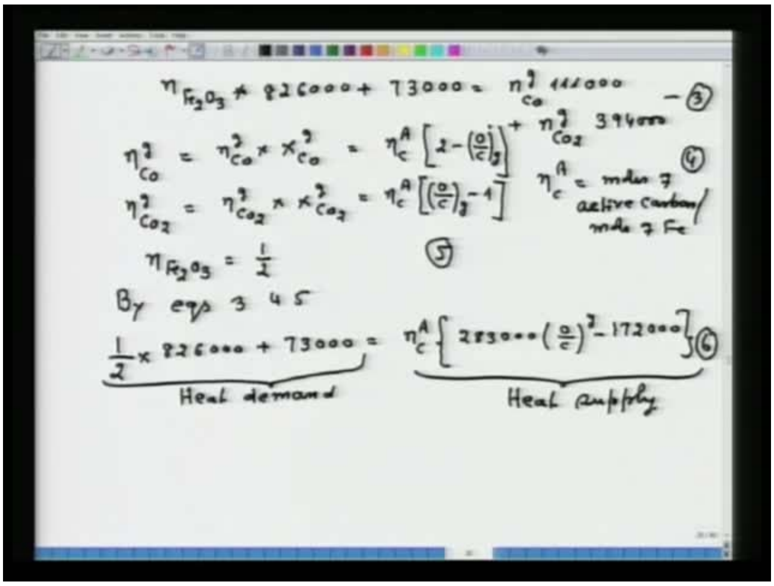

$$n_{Fe_2O_3} \times 826000 + 73000 = n^g_{CO}\,111000 + n^g_{CO_2}\,394000 \quad - ③$$

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

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

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

⑤

$$n_{Fe_2O_3} = \frac{1}{2}$$

By eqs 3 4 5

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

So that will be equal to - in the Thermo chemistry lecture, I have already told you how to calculate these things. That value will be 73000 kilo joule per kg mole iron mind you, it is plus. So, if you substitute this value 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 2394000 and let us make this equation number 3.

Now as you recall, I have said that n g CO and n g CO 2, they can be related to mole fraction and 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 the 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 carbon. Now, we know that n Fe 2O 3 is equal to half to produce 1 mole of iron; you need half mole n Fe 2O 3. So, if you substitute all these things say by equation 3, 4, 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 an 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. Let me put it this is equation number 4; this is equation number 5 and let us see this is equation number 6.

Now, what we are seen that this equation 6 in fact, it is the heat balance. Now, it is a very simplified approach; simplified approach means, we have not considered the gangue part of it; we are not consider slag part of it. Now, if you see this particular equation, we note that this particular equation is the heat demand this particular side is heat demand and this particular side is the heat supplied.

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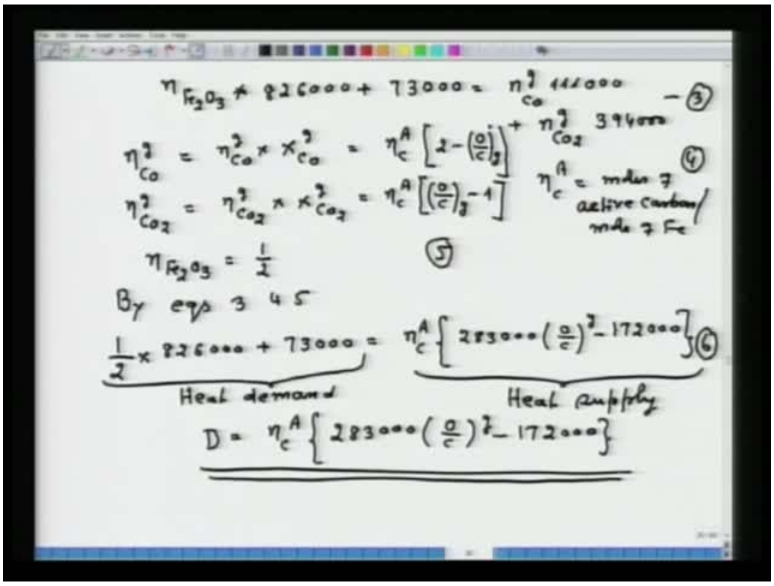

$n_{Fe_2O_3} \times 826000 + 73000 = n^g_{CO}\, 111000 + n^g_{CO_2}\, 394000$ — ③

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

$n^g_{CO_2} = n^g_{CO_2} \times x^g_{CO_2} = n^A_C \left[\left(\frac{O}{C}\right)_g - 1\right]$ ⑤

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

$n_{Fe_2O_3} = \frac{1}{2}$

By eqs 3 4 5

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

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

Now, the heat demand is variable suppose, you are charging iron ore and gangue; slag is coming also out then, this heat demand is a variable where heat supply if it is coming only from carbon. So, 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 it D 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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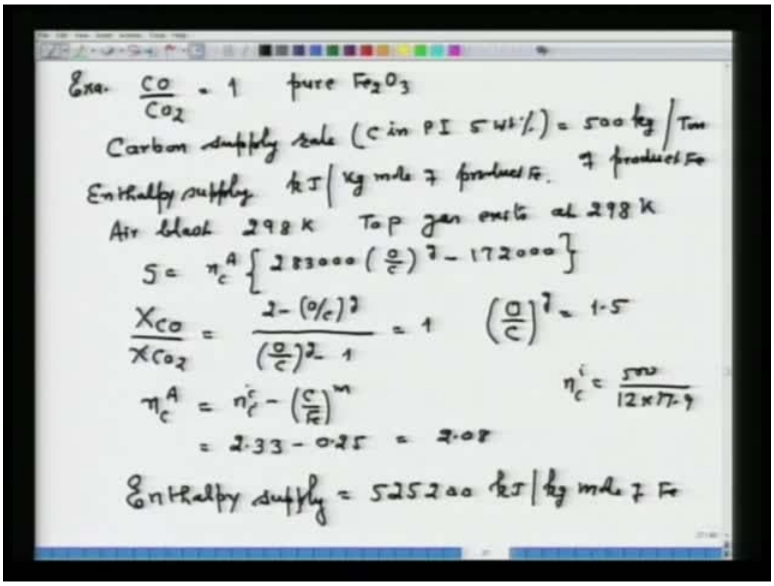

Exa. $\frac{CO}{CO_2} = 1$ pure Fe_2O_3

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

$S = n_C^A \{283000 (\frac{O}{C})_g - 172000\}$

$\frac{X_{CO}}{X_{CO_2}} = \frac{2-(O/C)_g}{(\frac{O}{C})_g - 1} = 1$ $(\frac{O}{C})_g = 1.5$

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

$n_C^A = n_C^i - (\frac{C}{Fe})^m$

$= 2.33 - 0.25 = 2.08$

Enthalpy supply = 525200 kJ / kg mole of Fe

So that is what our starting equation in order to combine material and heat balance. Now before I go, I will try to illustrate by taking an example. For example, the CO by CO 2 ratio in a top gas of a blast furnace which is charged with pure Fe 2O 3 that is equal to 1 when? We are using pure Fe 2O 3 is a burden for blast furnace ironmaking.

Say, in this example carbon supply rate which includes carbon in pig iron equal to 58 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.

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.

So 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 CO and CO 2 ratio, we have to find out the value of O by C.

Now, we know that X CO upon X C O 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 up equal to 1.5.

Now, we would like to know only n C A, for n C A that is equal to n C i minus C by Fe - you recall from earlier lecture. That means, active carbon is the total carbon - 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, we can calculate 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 kg S 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.

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

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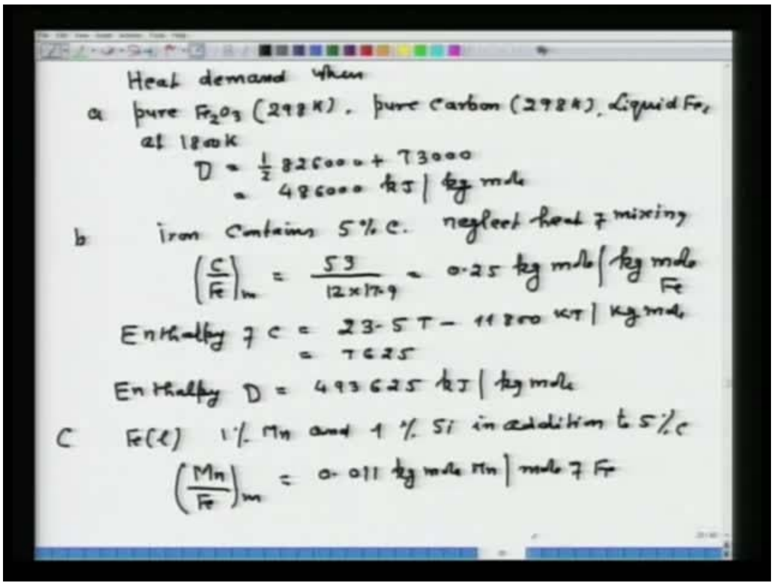

Heat demand when

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

$$D = \frac{1}{2}\,826000 + 73000$$
$$= 486000 \text{ kJ / kg mole}$$

b iron contains 5% C. neglect heat of mixing

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

$$\text{Enthalpy of C} = 23.5\,T - 11800 \text{ kJ / kg mole}$$
$$= 7625$$

$$\text{Enthalpy D} = 493625 \text{ kJ / kg mole}$$

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

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

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

So, we can calculate heat demand from the earlier equation. 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? Let us now take iron contains 5 percent carbon iron, neglect heat of mixing.

Now, I am showing that how the simplified model can be tuned to the actual condition. Condition number 2 iron contain of 5 percent carbon that is called pig iron. So, first of all will calculate C by Fe that is moles of iron in metal that will be equal to 53 divide by 12 into 17.9 and that is equal to 0.25 kg mole per kg mole of product iron. Now, what we have to add it over in the heat demand side, we have calculated for pure iron.

Now since carbon is there, we have to add into enthalpy of carbon that way it becomes the enthalpy supply for iron 5 percent carbon, rest conditions are same; liquid iron 1800 kelvin, Fe 2O 3 carbon they are all at 298 kelvin all that we have it. So, enthalpy of carbon that is equal to 23.5 T minus 11800 again kilo joule per kg mole.

So, I substitute T is equal to 1800 kelvin and I calculate now, so 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 add 7625 into 486000 this is what I mean by modification. Now still another modification, let us come closer what blast furnace is producing? Blast furnace is producing silicon and manganese also.

Now, let us consider c part; iron liquid it contains 1 percent manganese and 1 percent silicon in addition to 5 percent carbon that is what the case c we are doing. We are simply modifying the case b, where we are telling the liquid iron 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 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. Similarly, we have to calculate for silicon, so silicon upon Fe that will be equal to 0.021 kg mole per kg product iron.

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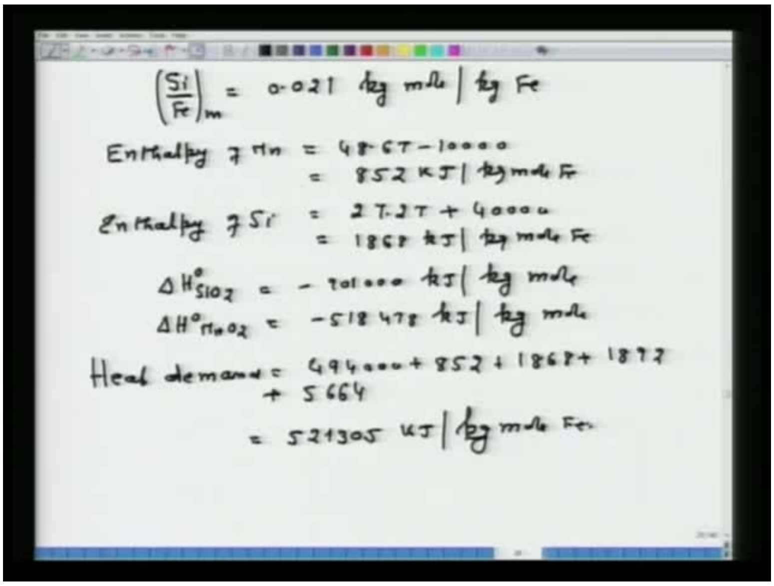

$\left(\frac{Si}{Fe}\right)_m = 0.021$ kg mole | kg Fe

Enthalpy of Mn $= 48.6T - 10000$

$= 852$ kJ | kg mole Fe

Enthalpy of Si $= 27.2T + 40000$

$= 1868$ kJ | kg mole Fe

$\Delta H^\circ_{SiO_2} = -901000$ kJ | kg mole

$\Delta H^\circ_{MnO_2} = -518478$ kJ | kg mole

Heat demand $= 494000 + 852 + 1868 + 1892$

$+ 5664$

$= 521305$ kJ | kg mole Fe

So, what we have to do now? On the heat demand side in the case b, we added enthalpy for carbon. Now in the case c, we have to add enthalpy required for silicon because, it will raise from 298 to 1800 kelvin and enthalpy required 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 so 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 manganese is 852 kilo joule per kg mole of iron and in this particular case it is 1868 kilo joule per kg mole iron. This is not the total solution, you have to think how silicon in manganese are coming. For that iron ore must have Si O 2 and Mn O 2, so for Si O 2 and Mn O 2 what you have to do? You have to add their heat decomposition of Si O 2 and Mn O 2, so that is what I mean by the modification.

So, on the demand side in addition to enthalpy of manganese and enthalpy of silicon heat of decomposition of Si O 2 and Mn O 2 has to be added because otherwise silicon and manganese from where they are coming? They are coming from the gangue part of the iron ore. So, delta S naught Si O 2 and delta S naught Mn O 2 that is equal to minus 901000 kilo joule per kg mole and Mn O 2 is minus 518 478 kilo joule per kg mole say, 0.021 kg mole of silicon will require 0.021 kg mole of Si O 2 similarly, manganese also.

So if you calculate all, all that you have to multiply by the kg mole of silicon equal to kg mole of Si O 2 to this Mn O 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 Si O 2 reduction and plus 5664 for Mn O 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 closure to the actual case. Remember, we started with the pure liquid iron Fe 2O 3.

Now, with these addition we had come closure to what is happening in actual blast furnace ironmaking. We brought Si O 2 of the gangue into picture, we brought Mn O 2 of the of the gangue part of the ore into the picture. We made liquid iron and we added silicon, manganese and carbon. So, that is what I mean to say that heat demand can always be updated according to the actual situation.

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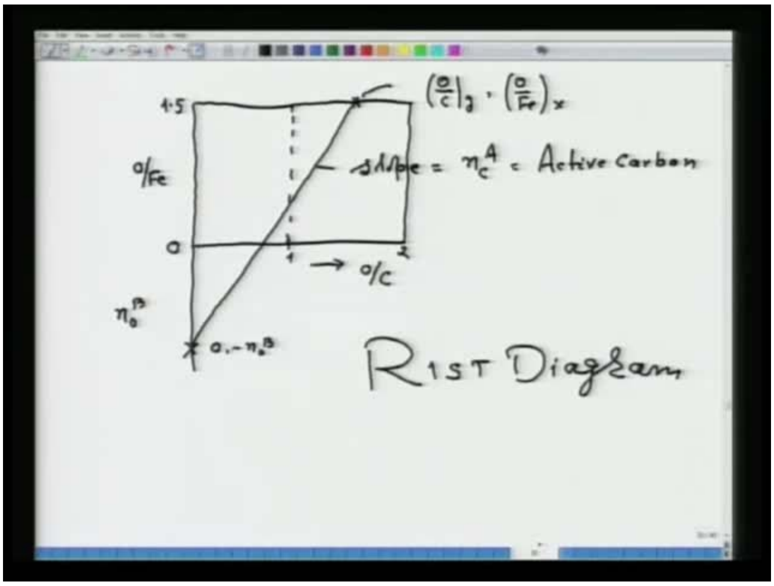

Now, after understanding this, what we can do now? We can now modify the material balance equation to incorporate heat balance equation also.

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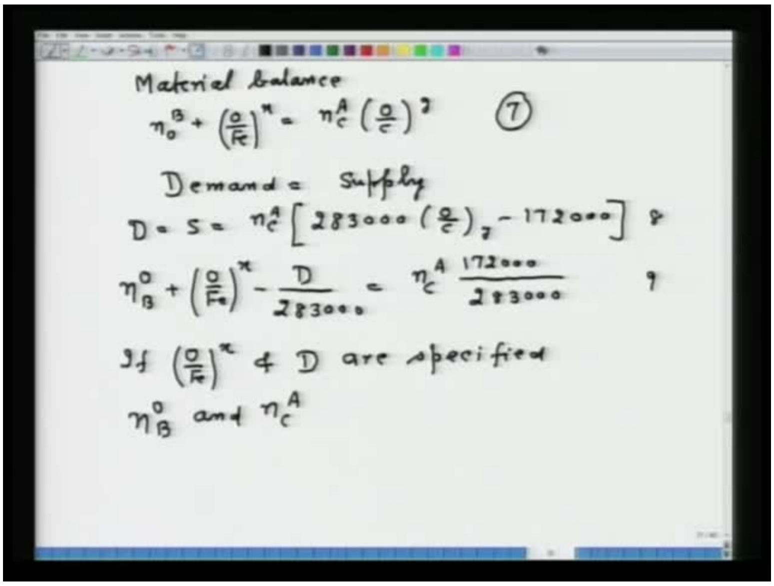

Material balance

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

Demand = Supply

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

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

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

n_B^O and n_C^A

The material balance equation - you 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. So, 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 as equation number 9.

Now, if O by Fe x and D are specified that means, if for a given situation O by Fe x and demand are specified then, equation 9 which is our model equation with represent combined material and heat balance, it has requires the specification of n O B and n C A it required the specification of n O B and n C A either one if you do it then, we can calculate the variable which we required to calculate say, 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 specify then, we can proceed to the graphical solution, let us see that.

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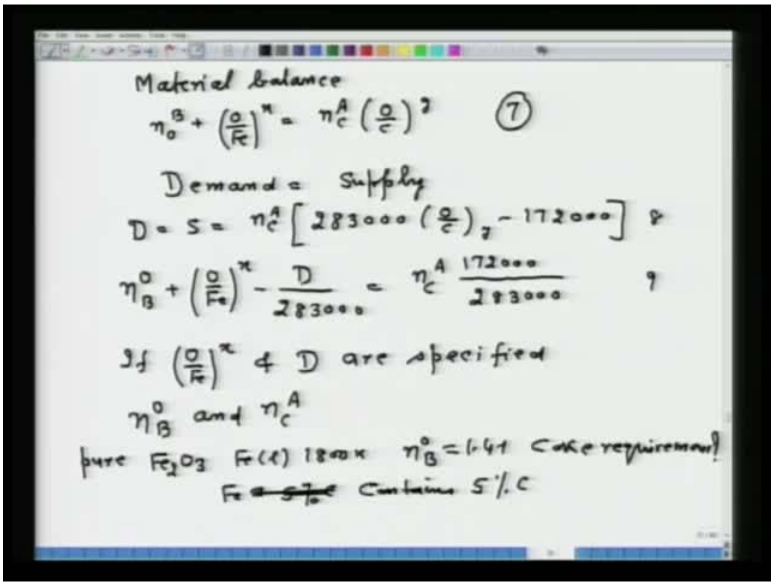

Material balance

$n_O^B + \left(\frac{O}{Fe}\right)^x = n_C^A \left(\frac{O}{C}\right)^y$ ⑦

Demand = Supply

$D = S = n_C^A \left[283000 \left(\frac{O}{C}\right)_y - 172000\right]$ 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) 1800 K $n_B^O = 1.41$ Coke requirement?

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

Before that let me illustrate by taking a simple example, let us take for pure Fe 2O 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 and the case in question are producing iron which is equal to 5 percent carbon rather, let me put it as iron contains 5 percent carbon; it is not the pure iron.

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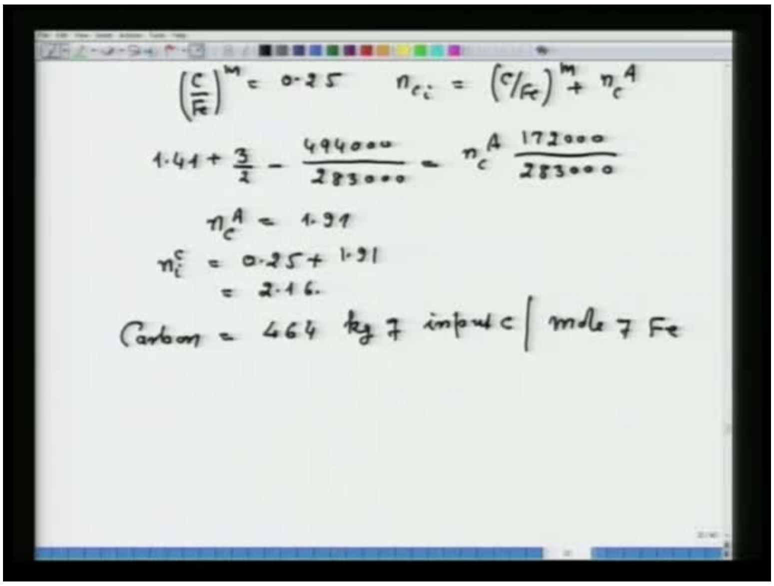

$\left(\frac{C}{Fe}\right)^m = 0.25$ $n_{C_i} = (C/Fe)^m + n_C^A$

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

$n_C^A = 1.91$

$n_i^C = 0.25 + 1.91$

$= 2.16$

Carbon = 464 kg of input C | mole of Fe

Let us calculated the amount of coke that will be required; amount of coke required means, we have to calculate the active carbon plus the carbon which is entering into pig iron both, because the carbon source of carbon for both is the coke. So, if we do that what we have to do? First of all, we calculate C by Fe - already we have calculated in earlier cases - for the same it is coming 0.25 then, n C i that is equal to C by Fe m plus n C A.

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. So from here, we can calculate easily the n C A will be equal to 1.91 and we know the equation that is n i C that is the total carbon per 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. You are seen that how easily this equation can be updated according to the prevailing condition in blast furnace ironmaking.

Since, we have the equation it in our hand; we can make use of the equation. We have transformed material and heat balance into the form of an equation. We can plot it and for a particular blast furnace operation, we can plot the current. See that our operation follows that particular line or whatever we get after the plot that is the advantage of this RIST diagram.

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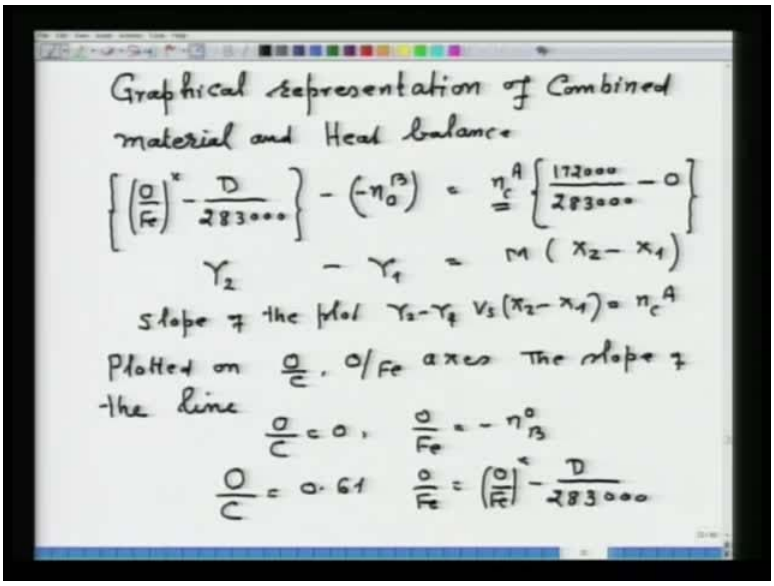

Graphical representation of Combined material and Heat balance

$$\left[\left\{\left(\frac{O}{Fe}\right)^{*} - \frac{D}{283000}\right\} - \left(-n_{O}^{B}\right)\right] = \underline{\underline{n_{C}^{A}}}\left[\left\{\frac{172000}{283000} - 0\right\}\right]$$

$$Y_2 \quad - \quad Y_1 \quad = \quad m\,(x_2 - x_1)$$

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

$$\frac{O}{C} = 0, \quad \frac{O}{Fe} = -n_{B}^{O}$$

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

So, let us see now the graphical representation of combined material and heat balance. Now, 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 the equation in the following way. O upon Fe X minus D upon 283000 minus n O B; this minus that is equal to n C A 172000 upon 283000 minus 0.

This equation is same as Y 2 minus y 1 that is equal to M X 2 minus X 1 that means, if I plot Y2 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.

Let us see, if those things are plotted on O by C and O by Fe axis. The slope of the line - naturally it is a straight line - will pass through the point O by C equal to 0 and O by Fe that is equal to minus and 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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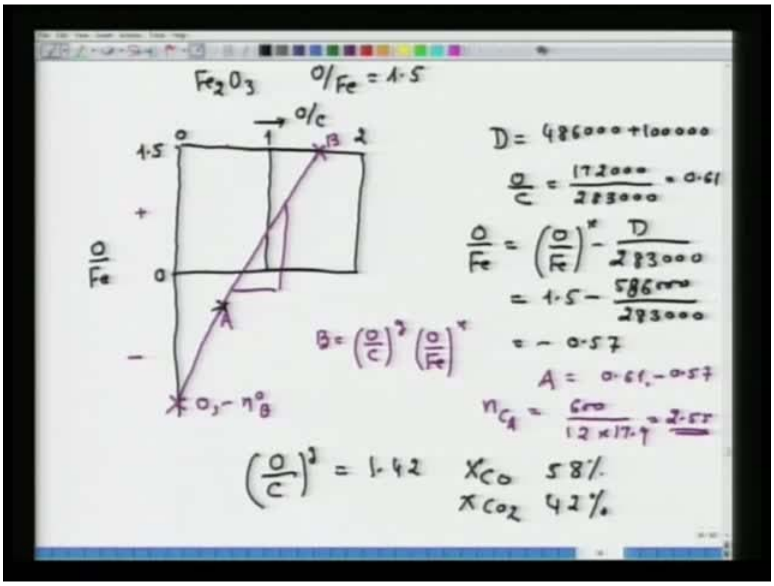

$D = 486000 + 100000$

$\frac{O}{C} = \frac{172000}{283000} = 0.61$

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

$= 1.5 - \frac{586000}{283000}$

$= -0.57$

$A = 0.61, -0.57$

$n_{C_A} = \frac{600}{12 \times 17.9} = 2.55$

$\left(\frac{O}{C}\right)^y = 1.42$

x_{CO} 58%

x_{CO_2} 42%

Let us plot it now. You know that when Fe 2 O 3 is the part of the iron ore that is the iron oxide then, O by Fe is 1.5. Now if you plot it, this plot side is 0, 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 Fe 2 and that is here say 0, this is O by Fe for Fe 2 O 3 it is 1.5.

There is certain important thing to note, say a demand is fixed for a particular raw material. Now, if you fix for example, D for pure Fe 2O 3 we have calculated 486000 and we are charging pure Fe 2O 3 and pure liquid iron was the product. 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 - presence of gangue - has to be fluxed.

We have to calculate the amount of slag that is produced and accordingly, heat has to be supplied. For 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 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 that is equal to O by Fe x minus D upon 283000. So, O by Fe X is 1.5 minus 586000 upon 283000, so this will be minus 0.57.

Let us now take this point somewhere is - let us say - 0.61 and this side is plus and this is of course is minus, so somewhere let us take it minus 0.57. This becomes a fixed point for this particular blast furnace which we have said, it is charged with pure Fe 2O 3; liquid iron is produced with some heat value. So, for these operation of blast furnace ironmaking this particular point which I will say A and the point A has the coordinates 0.61 and minus 0.57. Now, what has to be done? We know about the value of n C A, so n C A we can calculate.

The n C A is equal to 600 upon 12 into 17.9, this is equal to 2.55. That means, the slope of the line which is passing through the point A should have slope equal 2.55 because n C A is the slope of the line. So if I do that, then this is the slope of the line which is equal to 2.5 and this particular point if I say B then, value of B that is equal to O by C g which is the top gas analysis corresponds 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 know n C A, this is equal to 2.55 that is how you will be representing the graphical representation.

Now, in this particular problem the value of B that accidently comes as O by C g. If you plot properly, it will come 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.

This is how what I mean to say, a graphical representation of the combined material and heat balance. All that it can be modify it for the actual case though, I try to illustrate but well, depending on the heat demand you illustrate. What is this particular diagram says is that for a particular operation this line is available to you. Now, what we can suggest? We can make certain improvements, so this point again I will show by the point a.

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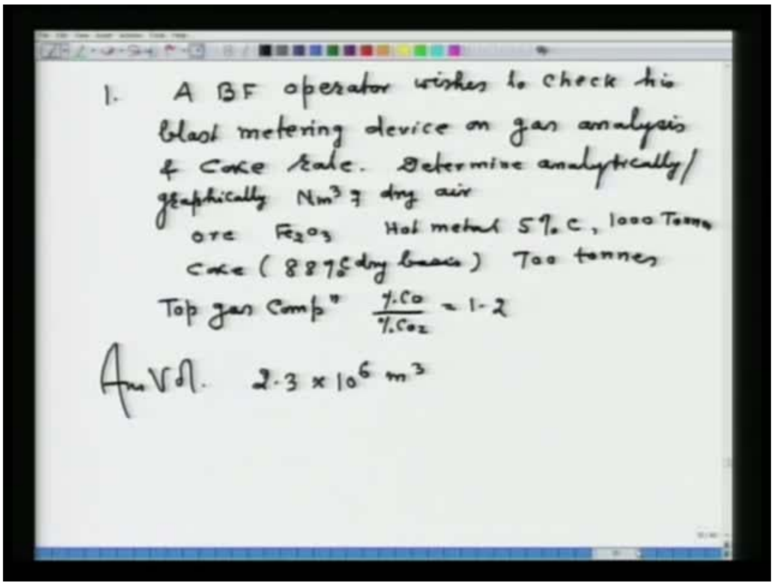

1. A BF operator wishes to check his blast metering device on gas analysis & coke rate. Determine analytically/graphically Nm^3 of dry air

ore Fe_2O_3 Hot metal 5% C, 1000 Tonnes

coke (88% C dry basis) 700 tonnes

Top gas Comp^n $\frac{\%CO}{\%CO_2} = 1.2$

Ans Vol. 2.3×10^6 m^3

Here, I will give you some one or two exercises that you can solve yourself, so I will give you the problem number 1. The blast furnace operator wishes to check his blast metering device, he is supplying air blast and he is measuring the air blast by certain device and he thought that there is some doubt.

Blast measuring device on the basis of gas analysis, because this value is known to him and coke rate; he knows both the values. Now, what he wants? Determine analytically or graphically that means, draw a line and determine the n O B value, the Nm cube of dry air for the condition when the ore contains pure Fe 2 O 3, hot metal you have 5 percent carbon and amount is 1000 tons, coke 88 percent carbon on dry basis and 700 tons. Total requirement although is a very pure operation but does not matter.

Top gas composition is a volume percent C O upon percent CO 2 is given to you 1.2. So, this is one particular problem you can try to calculate and the answer - volume - that will be equal to 2.3 into 10 to the power 6 meter cube will be the answer.

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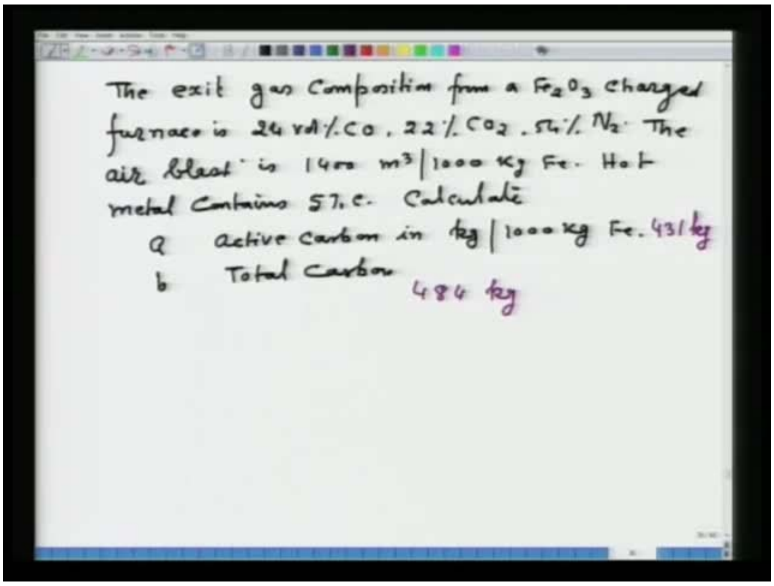

The exit gas Composition from a Fe_2O_3 charged furnace is 24 vol% CO, 22% CO_2, 54% N_2. The air blast is 1400 m^3 | 1000 kg Fe. Hot metal Contains 5% C. Calculate

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

b Total carbon 484 kg

I will give you one more problem so that you can practice it. Another problem that I will give you is the exit gas composition from a Fe 2O 3, charge furnace is 24 volume percent CO, 22 volume percent of course CO 2 and 54 percent nitrogen - all are on volume percent.

So, the air blast is 1400 meter cube per 1000 kg iron, hot metal contains 5 percent carbon. Calculate; a, active carbon in kg per 1000 kg of product iron; b, calculate total carbon, so you know how to calculate. The procedure already I have said that the answer would be the total carbon is 484 kg and active carbon is 431 kg.

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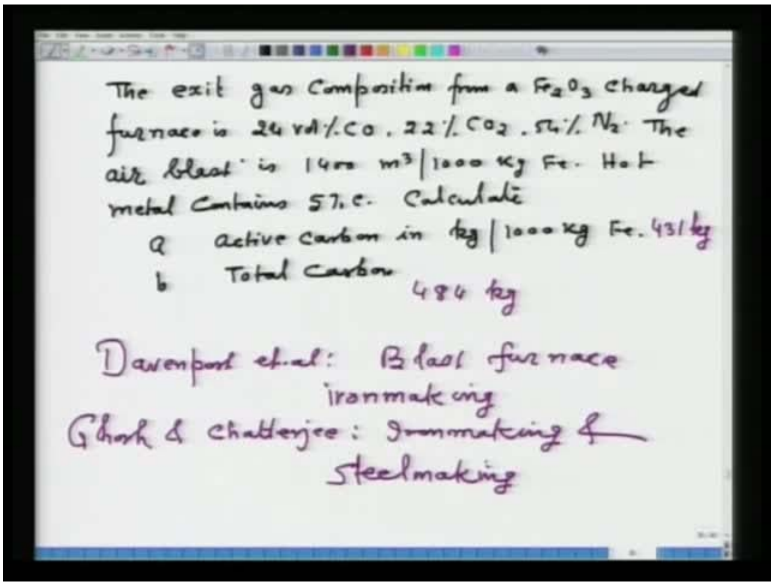

The exit gas Composition from a Fe_2O_3 charged furnace is 24 vol% CO, 22% CO_2, 54% N_2. The air blast is 1400 m^3/1000 kg Fe. Hot metal Contains 5% C. Calculate

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

So, with these two problems and the RIST diagram, I have finished or I have given sufficient information on blast furnace ironmaking and its representation on a diagram. For more details you want to know, you can consult the book of Davenport Etal on blast furnace ironmaking. You can also consult the book Ghosh and Chatterji, ironmaking and steel making.

So with this, I finished the lectures on reduction smelting as a unit process. In the next lecture, we will see the next unit process that is, converting.