

Materials and Energy Balance in Metallurgical Processes

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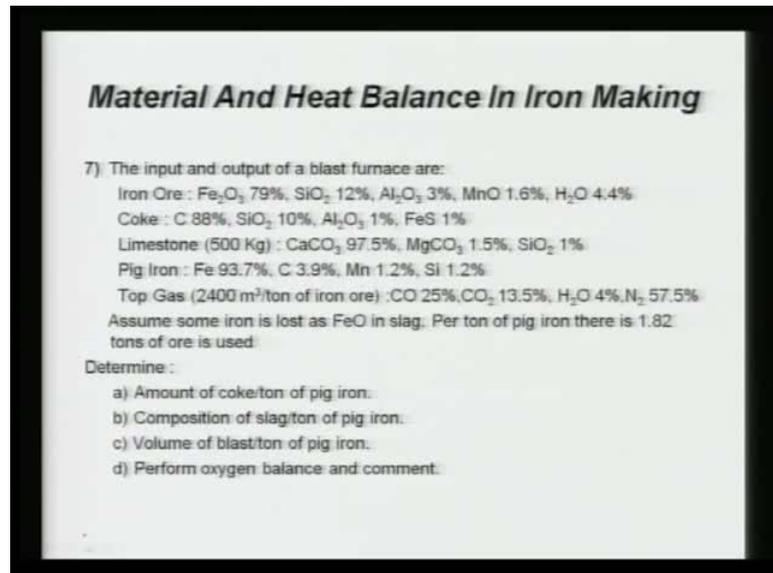
Indian Institute of Technology, Kanpur

Lecture – 31

RIST diagram-1.

Here is one more problem on Material and Heat Balance in Iron Making; that is in continuation with the earlier problems on Material and Heat Balance in Iron Making.

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Material And Heat Balance In Iron Making

7) The input and output of a blast furnace are:

- Iron Ore : Fe_2O_3 79%, SiO_2 12%, Al_2O_3 3%, MnO 1.6%, H_2O 4.4%
- Coke : C 88%, SiO_2 10%, Al_2O_3 1%, FeS 1%
- Limestone (500 Kg) : CaCO_3 97.5%, MgCO_3 1.5%, SiO_2 1%
- Pig Iron : Fe 93.7%, C 3.9%, Mn 1.2%, Si 1.2%
- Top Gas (2400 m³/ton of iron ore) : CO 25%, CO_2 13.5%, H_2O 4%, N_2 57.5%

Assume some iron is lost as FeO in slag. Per ton of pig iron there is 1.82 tons of ore is used.

Determine :

- Amount of coke/ton of pig iron.
- Composition of slag/ton of pig iron.
- Volume of blast/ton of pig iron.
- Perform oxygen balance and comment.

The problem is - The input and output of a blast furnace are: that is Iron Ore, Coke, Limestone, Pig Iron and Top Gas.

Now, remember, here the amount of Top Gas is given per ton of Iron Ore; it is not per ton of Pig Iron. If it is per ton of Iron Ore and if you take the basis per ton of Pig Iron then, you have to calculate that amount of Top Gas because it is per ton of Iron Ore. So, the composition of Iron Ore, you can read from the slide; it is shown over here and the Coke which is also an input is shown over here.

Limestone input is also shown. Mind you, the Limestone contains Calcium Carbonate as well as Magnesium Carbonate. The outputs - Pig Iron and Top Gas; the composition of Pig Iron in Top Gas are given.

Now, here, one of the conditions under which you have to solve the problem is given. That is assume some iron is lost as FeO in the slag; so, the amount is not known; so, that point is to be known. Now, per ton of the Pig Iron, 1.82 tons of ore is used. Now, you have to determine: amount of Coke, composition of slag, volume of blast, and perform Oxygen balance.

Somewhat similar problem I had solved earlier also. Here, let us go to the solution of this particular problem.

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Solution to problem 7

Basis 1000 kg pig iron

$$C \text{ from coke} + C \text{ from } CaCO_3 + C \text{ from } MgCO_3 = C \text{ in pig iron} + C \text{ in gases}$$

Amount of gas 4368 m³/ton pig iron

I = amount of coke

I = 1000.37 kg Ans

Amount of slag

$$SiO_2 \text{ in slag} = SiO_2 \text{ from iron ore} + SiO_2 \text{ from coke} + SiO_2 \text{ from limestone} - Si \text{ equivalent to } SiO_2 \text{ in pig iron}$$

So, again we can take basis of 1 ton of Pig Iron - 1000 kg Pig Iron. On that basis, you will make the balance. So, in order to calculate amount of Coke, we have to do the balance: a Carbon from Coke plus Carbon from Calcium Carbonate plus Carbon from Magnesium Carbonate; do not forget because here though the Carbon from Magnesium Carbonate is small, but if you forget, that is a mistake. So, that is equal to Carbon in Pig Iron plus Carbon in gases. Now, note the amount of Top Gas is 2400 meter cube per ton of Iron Ore charge.

So, the amount of Top Gas because you will be needing to calculate Carbon in gases. So, amount of Top Gas - that would be 4368 meter cube per ton Pig Iron. So, the balance is very simple and if x is the amount of Coke, then I can do the balance and the value of x , either side simple, and I have done at various occasions; so, I will not be doing in detail here. I will straightaway write down x will be equal to 1000.37 kg and that is the amount of Coke and that is the answer for the part A.

Now, the second part says that you have to calculate the composition of slag and no conditions are given; now, all that you have to know first of all here, from the basics of blast furnace iron making, what elements will be in Pig Iron and what elements will be in the slag. Accordingly, you have to make the balance because the amount of Pig Iron is known to you; amount of Iron Ore is known to you and amount of Limestone is known to you. So, all other parameters are unknown. Only what is known is that how much amount of an element is going into the slag.

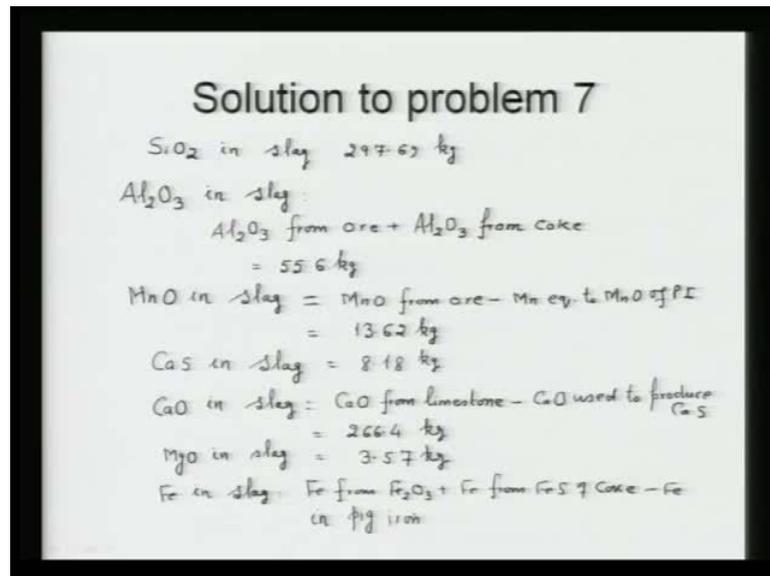
So, if you know the amount of an element which is going into slag, you calculate that amount and convert into oxide. So, you will get now the amount of that oxide in the slag. So, similarly, you calculate for all elements which are possibly entering into the slag and at the end of the calculation, you sum total it and you will get the amount of slag.

So, as I have said, I will be brief in my solution because I will like you to do it; say for example, say amount of slag we have to calculate now.

So, first of all, let us take SiO_2 in slag. SiO_2 in slag, that will be equal to SiO_2 from Iron Ore plus SiO_2 from Coke plus SiO_2 from Limestone. Now, since we are making SiO_2 balance, you have to convert Silicon of Pig Iron into its equivalent to SiO_2 ; that you have to subtract because that Silicon is entering into the Pig Iron and its equivalent amount of SiO_2 will not be entering into the slag.

So, that will be here minus say Si equivalent to SiO_2 in Pig Iron because Pig Iron does not contain SiO_2 , it contains Silicon, but since we made an SiO_2 balance, you can write Si equivalent SiO_2 in Pig Iron; Or other way around, you can do Silicon balance. So whichever way you want to do, the solution will be the same. So, I am omitting the values.

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You can write down those values. So, SiO_2 in slag will be coming; substitute all these values; that will become 297.69 kg.

Now, next, let us do Al_2O_3 in slag. Now, on several occasions I have said that Al_2O_3 cannot be reduced under the condition of the blast furnace. So, Al_2O_3 from whatever sources enters into blast furnace, whether from Coke, whether from Iron Ore, whether from Limestone, whatever the sources, all of it enters into the slag. So, straightaway, in this particular example, you can calculate Al_2O_3 in slag. The source is say Al_2O_3 from ore plus Al_2O_3 from Coke. We have just calculated Iron Ore amount. So, all that you have to sum total and the answer would be Al_2O_3 in slag; that will be equal to 55.6 kg.

Now, in such type of problem where you do not know anything about the composition of the slag, you must know what elements are entering into slag. Now, in earlier problems, if you recall, their composition of slag was given in one of the problem. It was said that the slag contains certain percentage of Calcium Oxide. So, there, one quantity was known; here nothing is said. So, here it is important to know the chemistry of blast furnace iron making, which elements goes where, and then, you will be able to calculate the correct value of slag; that is an important thing. So, here, the basic of blast furnace iron making is important to know.

Similarly, MnO in slag; again, you have to make the balance or that is equal to MnO from Iron Ore minus Mn equivalent to MnO of Pig Iron.

So, you can substitute the value and that will become 13.62 kg. Similarly, in this particular problem, the Coke contains FeS. If you notice the composition, Coke contains FeS. So, FeS of Coke will react with Calcium Oxide and it will form Calcium Sulphide. So, the slag will also have Calcium Sulphide; say Calcium Sulphide in slag. That can be calculated from reaction CaO plus FeS; that is equal to CaS plus FeO because you know Coke contains FeS; the source of Calcium Sulphide is FeS in the Coke. So, from the amount of FeS and kg mole, you can calculate Calcium Sulphide in slag. So, Calcium Sulphide in slag will be equal to 8.18 kg. This we can calculate very easily.

Then, you have Calcium Oxide in slag. Now, the Calcium Oxide in the slag requires a balance to be done which is equal to say CaO from Limestone; that is only source for Calcium Oxide minus CaO used to produce CaS.

So, you can substitute the amount and Calcium Oxide in slag; that is equal to 266.4 kg. Similarly, one can calculate MgO in slag; remember, source of MgO is only MgCO 3. So, that will be 3.57 kg.

Then, iron in slag. Now, here say iron from Fe 2 O 3; that is the total iron from Fe 2 O 3 plus iron from FeS of Coke; this is total input of iron minus iron in Pig Iron.

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Solution to problem 7

<p>FeO = 97.48 kg</p> <p>Amount of slag = 742.78 kg</p> <p>Amount of air Top gas = 4368 m³/tm PE</p> <p>Amount of air = $\frac{4368 \times 0.575}{0.73}$ = 3470 m³</p> <p>O₂ in top gas:</p> <ul style="list-style-type: none"> O₂ from reduction of Fe₂O₃ O₂ from reduction of SiO₂ O₂ from reduction of MnO O₂ from decomposition of CaCO₃ O₂ from decomposition of MgCO₃ <p>O₂ from air = 32.653 kg m³</p>	<table style="width: 100%; border-collapse: collapse;"> <tr><td style="width: 50%;">%</td><td style="width: 50%;">SiO₂</td><td style="width: 50%;">40</td></tr> <tr><td></td><td>Al₂O₃</td><td>7.5</td></tr> <tr><td></td><td>MnO</td><td>1.8</td></tr> <tr><td></td><td>CaS</td><td>1.1</td></tr> <tr><td></td><td>CaO</td><td>36</td></tr> <tr><td></td><td>MgO</td><td>0.5</td></tr> <tr><td></td><td>FeO</td><td>13.12</td></tr> </table> <p style="text-align: right; margin-right: 20px;">Ans</p> <p>18057 kg O₂ available from oxide reduction</p> <p>O₂ in top gas = 50.77 kg m³</p> <p>Volume of blast = 3483 m³</p>	%	SiO ₂	40		Al ₂ O ₃	7.5		MnO	1.8		CaS	1.1		CaO	36		MgO	0.5		FeO	13.12
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Now, as a result of balance, you have calculated the iron and it has to convert into Fe O. So, then the amount of Fe O will be equal to 97.48 kg. So, with this, the amount of slag that is a sum total of all the oxide that we calculated, that will be equal to 742.78 kg; as regards to percentage, you have to calculate percentage. We have percentage SiO₂ 2 percent Al₂O₃ MnO.

We have Calcium Sulphide; we have Calcium Oxide; we have MgO and we have FeO. They all will be calculating in percent. So, SiO₂ is 40. This is 7.5, 1.8, 1.1. Calcium Oxide 36; MgO is 0.5, and Fe O is 13.12 percent. So, that is what the answer for amount and composition of slag. That is how it can be done.

Now, the next part says we have to calculate the amount of air and then make an Oxygen balance and comment on the result. So, in order to calculate the amount of air, you know the amount of Top Gas. So, amount of Top Gas is given that is 4368 meter cube per ton of Pig Iron. So, from here, we can calculate amount of air because Nitrogen is given. Nitrogen of air will straightaway go to into the Top Gas because it is inert; it does not react. So, from the Nitrogen balance, one can calculate the amount of air; of course, by properly converting into kg moles and so on. So, that will be 4368 into 0.575 upon 0.79. That will be equal to 3470 meter cube. That you have calculated from directly from the Top Gas.

Now, you have to compare it by Oxygen balance because one can do the Oxygen balance and compare from the two independent sources. Now, one independent source was Top Gas and another independent is Oxygen balance.

So, now, you know that Oxygen in Top Gas, O₂ in Top Gas is also from O₂ from reduction of Fe₂O₃ because iron is forming. So, iron will be formed by the reduction of Fe₂O₃. So, that amount of Fe₂O₃ is reduced to iron and that is entering into the Pig Iron. So, that Oxygen will also be leaving in the Top Gas and accordingly that amount of Oxygen has to be subtracted in order to know how much amount of Oxygen has come from air.

Similarly, if you see Pig Iron, it also contains Silicon. The Silicon is also formed from the reduction of SiO₂, and accordingly, the corresponding amount of Oxygen equivalent

to Silicon in Pig Iron has been released into the Top Gas. So, similarly, we can have Oxygen from reduction of SiO₂.

Third, Pig Iron contains Manganese. That will also come from the reduction of MnO. So, Oxygen from reduction of MnO; you have to calculate this Oxygen. Then, your Calcium Carbonate and Magnesium Carbonate are present. Now, the Calcium Carbonate decomposed to CaO and CO₂ is available. MgCO₃, MgO, and CO₂ is available.

So, O₂ from decomposition of CaCO₃ as well as O₂ from decomposition MgCO₃; so, these are the sources from where Oxygen is entering into the system. So, if you subtract the total Oxygen from this Oxygen which you have calculated due to the reduction of Ferrous Oxide, then that much Oxygen remaining comes from air is what the philosophy of calculation from the Oxygen balance.

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Solution to problem 7

$FeO = 97.48 \text{ kg}$
 Amount of slag = 742.78 kg
 Amount of air = $4368 \text{ m}^3/\text{ton PE}$
 Top gas = 4368×0.575
 Amount of air = $\frac{4368 \times 0.575}{0.73}$
 $= 3470 \text{ m}^3$

$FeO = 97.48 \text{ kg}$ $Amount \text{ of slag} = 742.78 \text{ kg}$ $Amount \text{ of air} = 4368 \text{ m}^3/\text{ton PE}$ $Top \text{ gas} = 4368 \times 0.575$ $Amount \text{ of air} = \frac{4368 \times 0.575}{0.73}$ $= 3470 \text{ m}^3$	<table border="0" style="width: 100%;"> <tr><td style="width: 50%;">%</td><td style="width: 50%;">SiO₂</td><td>40</td></tr> <tr><td>%</td><td>H₂O</td><td>7.5</td></tr> <tr><td>%</td><td>MnO</td><td>1.8</td></tr> <tr><td>%</td><td>CaS</td><td>1.1</td></tr> <tr><td>%</td><td>CaO</td><td>36</td></tr> <tr><td>%</td><td>MgO</td><td>0.5</td></tr> <tr><td>%</td><td>FeO</td><td>13.12</td></tr> </table>	%	SiO ₂	40	%	H ₂ O	7.5	%	MnO	1.8	%	CaS	1.1	%	CaO	36	%	MgO	0.5	%	FeO	13.12
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Ans

O₂ in top gas:

O_2 from reduction of Fe ₂ O ₃ O_2 from reduction of SiO ₂ O_2 from reduction of MnO O_2 from decomposition of CaCO ₃ O_2 from decomposition of MgCO ₃	$18.057 \text{ kg moles of } O_2 \text{ available from oxide reduction}$ $O_2 \text{ in top gas} = 50.71 \text{ kg moles}$
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O_2 from air = 32.653 kg moles Volume of blast = 3483 m^3

So, if you sum total all, I am writing all these and you can calculate. So, accordingly you will have 18.057 kg moles of Oxygen available from oxide reduction. Now, total amount of Oxygen: What will be the total amount of Oxygen that is in the Top Gas? You know the amount of Top Gas and you can calculate the amount of Oxygen in the Top Gas. That will be equal to 50.71 kg moles.

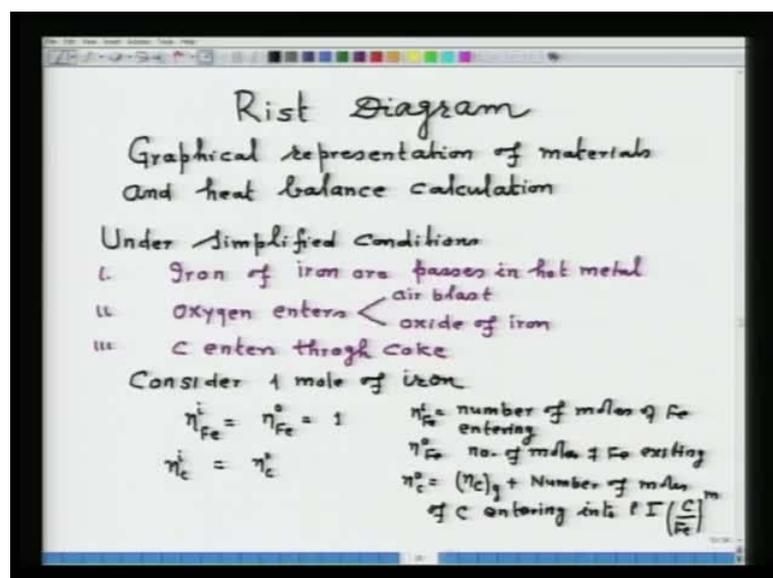
So, how will you do this calculation? You know the amount of Top Gas that is 4368 meter cube per ton of Pig Iron; you convert into kg mole; 25 percent is CO. You

calculate that amount and half will be that of Oxygen. Similarly, 13.5 percent is amount of CO₂ multiplied by the amount of Top Gas. So, you get the amount of CO₂ and one mole Oxygen; sum total it; that value will be 50.71. So, Oxygen from air will be 50.71 minus 8.057; that will be 32.653 kg moles. You see how simple it is, once you understand the basics of iron making. Then, the things are simple.

So, the Oxygen from air: Now, we have to calculate the volume of blast air contains 21 percent Oxygen divided by 0.21 multiplied by 22.4. So, volume of blast from this is coming 3483 meter cube.

Now, in the comment you can only say that there is a small difference of say 13 meter cube; well it may be due to the rounding off in calculation of the Oxygen input from reduction of iron oxide, or there could be some error in the composition of Top Gas, but however, the error is not that significant. So, that is the comment you can make and that is where the problems on iron making. Material and heat iron balance in iron making, I have sufficiently illustrated plus some of the problems I have given to you for solving. Even on the problem which I have solved, I appeal they do not see the solution. Solve yourself and see whether you understood the matter or not.

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Now, this now I will proceed next to the RIST diagram. So, this RIST diagram, in fact is a graphical representation of materials and heat balance calculation. You know so far

what we have done; we have done material and heat balance 1000 kg Pig Iron. Whatever we have done, we write the balance, calculate the amount and so on so forth.

Now, if you are looking for a graphical representation of the entire stoichiometry of blast furnace iron making, then a different approach is to be adopted because now what we are looking? By doing this graphical representation for a particular blast furnace, we can represent the data on a plot with whose help we can predict the performance of blast furnace iron making in the future.

So, the graphical representation is also very important part of the stoichiometry though it is also a material and heat balance, but I thought that this RIST diagram which is a graphical representation of material and heat balance in iron making could be very very useful. Slightly different approach is adopted here. So, I will tell you little bit about the RIST diagram.

Now, just a little bit; two or three lines of introduction in blast furnace iron making: iron oxide, Coke, Limestone are introduced from top and Oxygen from bottom through the 2s. Carbon and Oxygen leave the furnace. Now we are not talking in terms of CO or CO₂; we are telling that Carbon and Oxygen leave the furnace, I mean through the Top Gas except Carbon dissolved in Pig Iron. Pig Iron and slag leave through the bottom; that is what we know from the operation of the blast furnace.

Now, let us make a very simplified approach to see how this material balance can be represented. Now, what we say is that let us taken the very simplified condition. under simplified condition, we can obtain an equation to represent the material balance in the form of a diagram. Now, what are those simplified conditions?

Now, the first condition is that iron of Iron Ore passes in hot metal; that means we are not considering the oxidation of iron to FeO; that we will leave at the later state. First all we have to understand how these diagrams can be constructed.

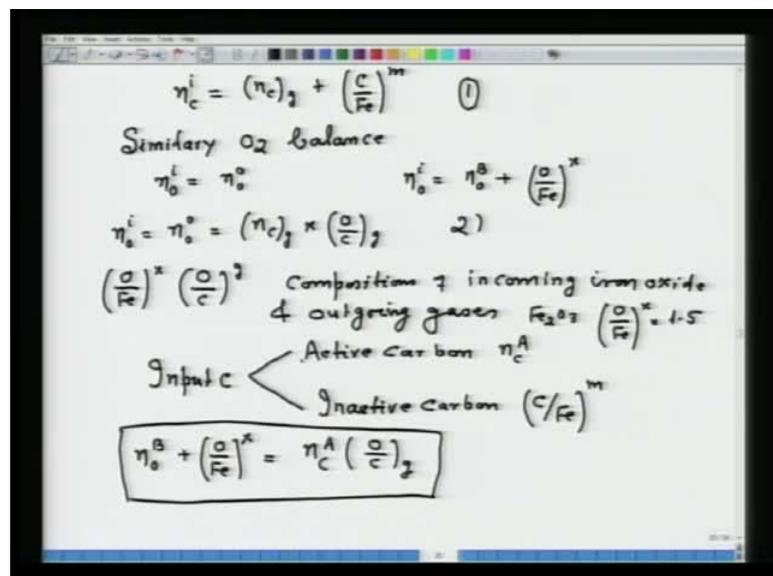
Second, Oxygen in the blast furnace enters through air blast and through oxide of iron. So, at the moment what we are considering is there is a pure iron oxide burden; no iron is lost in the slag; all iron is entering into the Pig Iron. That is very very simplified approach just to understand how to make this diagram and then later on you can add the terms over here.

Third, Carbon enters through Coke. The other sources like Carbon entering from Calcium Carbonate, $MgCO_3$, we will keep in our mind for later step.

So, under this simplified assumption, what we can say now? Consider 1 mole of iron. Then $n_i Fe$ that is equal to $n_o Fe$ that is equal to 1 where, $n_i Fe$ is number of moles of iron entering into the system. We can also say $n_i c$; that is number of moles of Carbon entering into the system. That should also be equal to numbers of moles of Carbon leaving the system.

So, $n_o c$ that is equal to number of Carbon moles in the Top Gas leaving the system. So, that will be equal to number of moles of Carbon in the gas plus number of moles of Carbon entering into Pig Iron. What I am telling here is that input of Carbon is equal to output of Carbon. The two sources of in which Carbon being out: one, in the Top Gas and another, the Carbon dissolved in Pig Iron; that is, we will be representing that is equal to C upon Fe that is in the metal.

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Then we can write down $n_i c$ that is equal to $n_c g$ plus C upon Fe to the power m . Let us say this is our equation number 1.

Similarly, we can do Oxygen balance. Now, O_2 balance: $n_o i$ Oxygen entering; that is equal to $n_o o$ Oxygen leaving; so, $n_o o$ is the number of Oxygen leaving the system and

n_{O_i} is moles of Oxygen that is entering into the system. So, n_{O_i} is equal to n_{O_B} plus $n_{O_{Fe_x}}$.

Now, here I have to say what we are doing here. We are in fact making the atomic Oxygen balance because we are writing O by Fe. So, similarly, while calculating number of Oxygen in the blast, we have to calculate number of Oxygen atom entering to the blast so that it becomes similar to O by Fe. Because suppose, if you take Fe_2O_3 is the oxide then O by Fe that is equal to 1.5. So, that was the important thing that you should know it over here. So, that n_{O_B} is number of Oxygen atoms entering through the blast and O by Fe is through the iron oxide.

Now, all Oxygen which enters into the system leaves either a CO or CO₂. Therefore, we can write it now - n_{O_i} is equal to n_{O_o} that is equal to n_{C_g} into O by C g where I can just put the notation O by Fe x and O by C g; they are compositions of incoming iron oxide and outgoing gases. For example, if I have Fe_2O_3 , then $n_{O_{Fe}}$ is equal to 1.5.

Now, little bit about what is meant by input Carbon in this model. Now, the input Carbon; the two parts of the input Carbon: one is the active Carbon that we will call n_{C_A} ; the active Carbon is that amount of Carbon which reacts with Oxygen; second is the inactive Carbon. Inactive Carbon is that Carbon which dissolves in Pig Iron that is $n_{C_{Fe_m}}$; the Carbon which is dissolved in iron; we call it to be an inactive Carbon.

So, if I write this is equation 2, and then equation 2 can be slightly modified in terms of active Carbon because the Carbon in the Top Gas will be that Carbon which is reacted with the Oxygen of the blast or say Oxygen of the iron oxide; whatever Oxygen dissolved in Pig Iron will not be available to a top.

So, I can write down this the equation; say n_{O_B} plus O by Fe x; that is equal to n_{C_A} O by C g. So, this equation can be obtained. You replace say n_{O_i} by n_{O_B} plus O by Fe x and n_{O_o} by n_{C_g} into O by C g. Now, n_{C_g} is replaced by the active Carbon. So, we get this and this is the material balance represented in the form of equation.

Now, we have an equation and we can plot it. Before I plot it, I will illustrate the use of this equation by a problem.

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Consider calculation of top gas composition
 Fe_2O_3 and coke coke 475 kg / ton of iron
 90% C - Blast introduces $\text{O}_2 = 350 \text{ kg} / 1000 \text{ kg}$
 of product iron
 Iron contains 4.5% C

Basis: 1000 kg product iron 17.9 kg moles Fe
 $\text{Fe}_2\text{O}_3 \quad \left(\frac{\text{O}}{\text{Fe}}\right)^x = 1.5 \quad \text{Pig iron 4.5\% C} = 47 \text{ kg}$
 $\left(\frac{\text{C}}{\text{Fe}}\right)^m = \left(\frac{47}{12 \times 17.9}\right) = 0.219$

Coke 428 kg $n_{\text{C}_i} = 35.6 \text{ kg mole / ton of iron}$ Inactive Carbon

$$(n_{\text{C}})_a = \left\{ n_{\text{C}_i} - \left(\frac{\text{C}}{\text{Fe}}\right)^m \right\} \text{ ton of iron}$$

$$= \frac{35.6}{17.9} - 0.219$$

$$= 1.77$$

So, let us take now consider calculation of Top Gas composition. We are considering for an ideal blast furnace which is operating with a mixture of Fe_2O_3 and Coke, pure iron oxide and Coke; nothing else. Coke amount is 475 kg per ton of iron; remember per ton of iron and contains 90 percent Carbon. Coke contains 90 percent Carbon blast introduces O_2 which is equal to 350 kg per thousand kg of product iron and iron contains 4.5 percent of Carbon; that is Pig Iron contains 4.5 percent Carbon. Now, let us use this equation. Earlier we did material balance. Now, let us use this equation to find out the solution.

Now, the basis I am taking 1000 kg product iron; that makes 17.9 kg moles iron. Now, in Fe_2O_3 , I have O by Fe that is equal to 3.3 by 2 or 1.5. Now, in the Pig Iron, it contains 4.5 percent Carbon; that will be equal to 47 kg; remember, 1000 kg product iron I have taken. So, it will not be 45, it will be 47 kg. So, from here, C upon Fe m which is the inactive Carbon I have to represent or I have to calculate in terms of moles of Carbon per moles of iron. So, I have 47 kg; 47 by 12 kg mole of Carbon; 47 by 12 into 17.9; that will be the C by Fe ratio.

So, that will be if I calculate here 47 upon 12 into 17.9, that value will be equal to 0.219. This is the inactive Carbon that you have calculated. Now, Coke I have; supply 428 kg active part of it. So, n_{C_i} will be equal to 35.6 kg mole per ton of iron.

Now, I have to calculate n_C^A , active Carbon; that will be equal to n_{Ci} minus C upon Fe m. So, n_{Ci} will be equal to 35.6 upon 17.9 per mole of iron minus 0.219. So, active Carbon is 1.77.

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Oxygen from blast

$$n_o^B = \frac{350}{16} = \frac{21.9}{17.9} = 1.22$$

$$n_o^B \times \left(\frac{O}{Fe}\right)^x = n_{c_A} \left(\frac{O}{C}\right)_g$$

$$1.22 \times 1.5 = 1.77 \left(\frac{O}{C}\right)_g$$

$$\left(\frac{O}{C}\right)_g = 1.54 \rightarrow \text{equivalent to CO + CO}_2 \text{ in top gas}$$

$$X_{CO_2} + X_{CO} = 1$$

$$X_{CO_2}^1 = \left(\frac{O}{C}\right)_g - 1 = 0.54$$

$$X_{CO}^1 = 2 - \left(\frac{O}{C}\right)_g = 0.46$$

$$n_{CO_2}^2 = n_C^A \times (X_g)_{CO_2} = 0.96 \text{ moles/mole of product Fe}$$

$$n_{CO}^2 = n_C^A \times (X_g)_{CO} = 0.81 \text{ moles/mole of product Fe}$$

$$N_2 = \frac{0.77}{0.22} \times \frac{1}{2} \times 1.22 = 2.29 \text{ moles of } N_2$$

Now, Oxygen from blast: Oxygen from blast say n_o^B you have 350 kg; mind you O by Fe atoms. So, I will divide by 16; that will be equal to 21.9 o per ton of iron. So, n_o^B that will be, if you divide by 17.9 that will be equal to 1.22 n_o^B per mole of iron.

Now, I have the equation n_o^B into O by Fe x; that is equal to n_C^A into O by C g; means gaseous form. So, if I solve this equation, now I have to put n_o^B that is equal to 1.22 into 1.5 1.77 n_C^A . So, I can find out O by C ratio in the Top Gas. So, O by C in the Top Gas comes out to be equal to 1.4 and this ratio is equivalent to CO and CO₂ in Top Gas. Now, if I want to calculate the volume percent and so on, now I know that $X_{CO_2} + X_{CO}$ that is equal to 1.

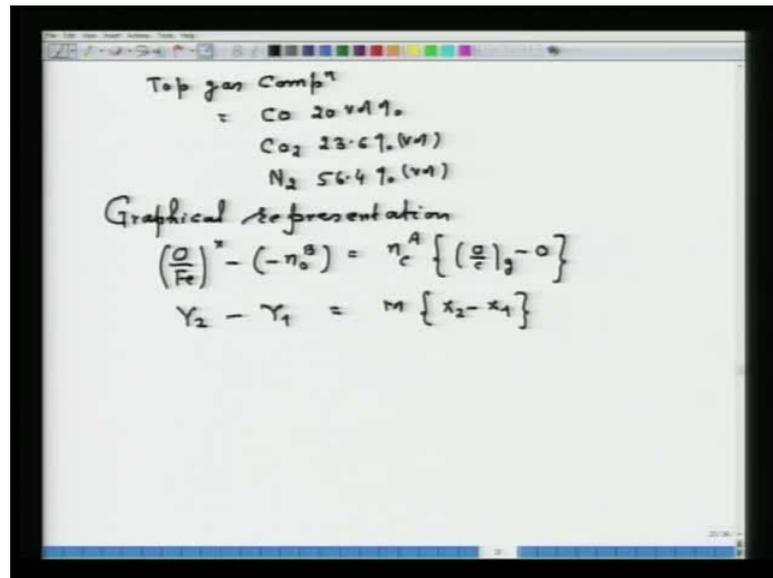
So, I can calculate now, say X g CO₂ that is equal to O by C g minus 1 and X g CO that is equal 2 minus O by C g. So, from here, I can now calculate. This is what is known to me; I know the O by C g value.

So, I know now n g CO₂; that will be equal to n_C^A into X g CO₂ and n g CO; that is equal to n_C^A into X g CO. So, from here, n g CO₂, it comes out to be equal to say from this X g CO₂ and X g CO, I can calculate X g CO₂ will be equal to 0.54 and X g

CO will be 0.46. So, I have to multiply this value. So, n g CO₂ will be 0.96 moles per mole of product iron and n g CO will be 0.81 moles per mole of product iron.

Now, I can calculate Nitrogen. That will be equal to 0.79 upon 0.22 into one half into 1.22; that will be equal to 2.29 moles of Nitrogen per mole of product iron.

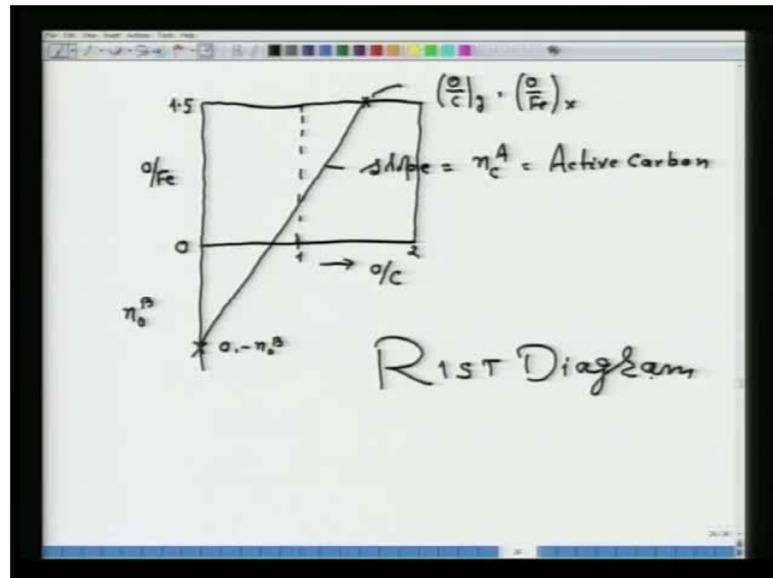
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So, Top Gas composition: I can find now Top Gas composition. Simply I have to add it when I have find out the percent CO - 20 volume percent, CO₂ - 23.6 on volume percent, and Nitrogen that is equal to 56.4 percent, of course, on volume basis. So, that is how you can solve this particular problem. Now, the advantage of this way of solving the material balance problem is that.

We have an equation before us that represents the material balance. Once you have the equation, here in this particular case, in idealized blast furnace operation, the operation can be represented by a graph. Let us see how to do it. So, graphical representation can be made. We have the equation O by Fe x minus n o B; that is equal to n C A O by C g minus 0. Now, this equation is very similar to Y₂ minus Y₁ that is equal to M X₂ minus X₁. so, this straight line, we will have slope M; it will pass through the point X₁ Y₁ and Y₁ Y₁. So, I will represent this line.

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For example, if I plot this, this is 0; it is equal to 1 and that is equal to 2. O by C, here we are representing O by C ratio; O by C equal to 1 and O by C equal to 2; that is the CO₂ and that is CO (Refer Slide Time: 47:11 to 47:36). Here, it is 0. So, this side is O by Fe and this side is η_0^B . Now, somewhere you have this value of η_0^B . So, O by Fe this point we have Fe₂O₃. So, this value is 1.5; this particular point is 0 and minus η_0^B .

Top Gas composition I have. Somewhere here, if I know the Top Gas composition that I have calculated, for example, that is the point; then this is here, this point is O by C g O by Fe x; now, this particular thing. So, this is called a RIST diagram. So, this particular line is the slope of the plot $Y_2 - Y_1$; that is equal to $m \times (x_2 - x_1)$ and the slope tells you η_C^A . What is η_C^A ? η_C^A is the active Carbon that is the Carbon which has reacted with the Oxygen of the blast. So, that is called the RIST diagram.

Now, in this particular diagram, we have made so many simplifications. We have said Fe₂O₃ Oxygen is entering only Fe₂O; suppose it contains SiO₂, MnO, accordingly, this O by Fe, the Oxygen entering will be O by Fe plus O by Si and whatever the case may be. So, now, the later cases we will only be the addition of certain terms so that this diagram can represent the actual operating conditions.

So, in the next lecture, we will be discussing further aspects of RIST diagram.