Materials and Energy Balance in Metallurgical Processes

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Module No. # 01

Lecture No. # 30

Material and Heat Balance in Iron Making-II

Today, I will be further solving the problems on material and heat balance in iron making. Here is the problem number 3; hematite ore of 80 percent, Fe 2 O3 is reduced in blast furnace using coke of 85 percent carbon, the reduction equation is given.

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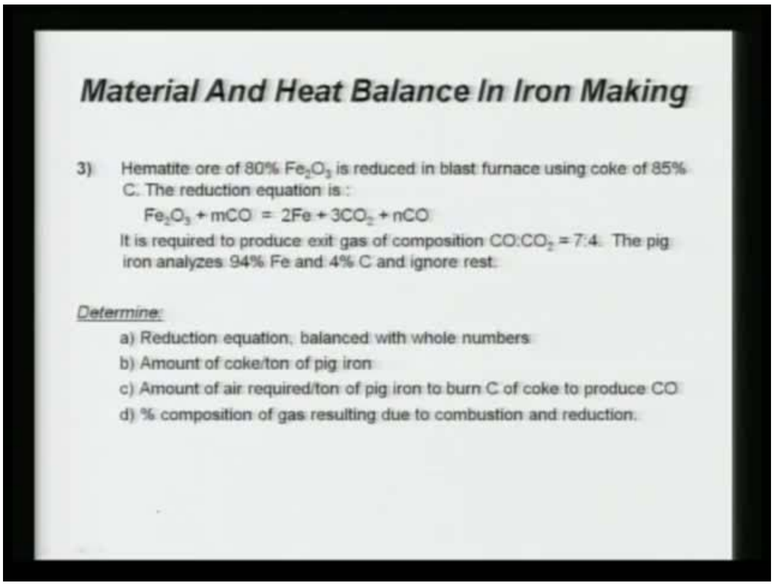

Now, the condition under which you have to calculate, it is required to produce exit gas of composition 7:4, pig iron analyzes is also given. You have to determine reduction equation balanced with whole numbers, amount of coke per ton of pig iron, amount of air required per ton of pig iron to burn carbon of coke to product carbon monoxide and percent composition of gas resulting due to combustion and reduction.

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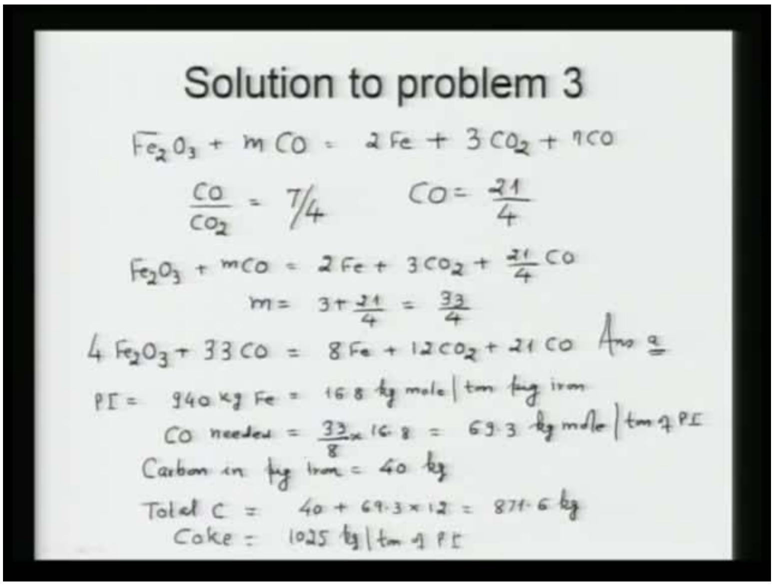

Now, let us see the solution of this particular problem. Here, I will just write down the reduction equation, which is required to put in whole number, Fe 2 O 3 plus m CO that is equal to 2 Fe plus 3 CO 2 plus n carbon monoxide that is what is given. We are also given CO upon CO 2 ratio is given to us 7 by 4; that ratio is given to us. So, with this we can have CO that will be equal to 21 by 4 according to this stoichiometric equation.

Then, we can write down Fe 2 O 3 plus m CO that is equal to 2 Fe plus 3 CO 2 plus 21 upon 4 carbon monoxide, so with this we can get m that is equal to 3 plus 21 by 4 that will be equal to 33 upon 4. Here, we have the reduction equation with whole number, 4 Fe 2 O 3 plus 33 carbon monoxide that is equal to 8 iron plus 12 CO 2 plus 21 CO, so here is the answer for part a.

Next, we have to calculate the carbon use, so we have given pig iron that is equal to - contain 940 kg iron, which is equal to 16.8 kg mole, this is per ton pig iron; that is what is given to us. So, carbon monoxide which we need according to our stoichiometric equation that is equal to 33 upon 8 into 16.8, because 2 moles of iron is appearing in the picture, so that is equal to 69.3kg mole per ton of pig iron; PI that stands for pig iron.

Now, it is also said carbon in pig iron is given to us. Carbon in pig iron that is 40 kg, because this carbon will also be coming from - somewhere it has to come, so this carbon is also coming from the coke. So, total carbon used, total carbon that will be equal to 40 kg plus 69.3, they are the kg mole multiply by 12 kg, so that is equal to 871.6 kg. From here, we can find out the amount of coke, we are given coke has 85 percent of carbon, so that will be 1025 kg per ton of pig iron.

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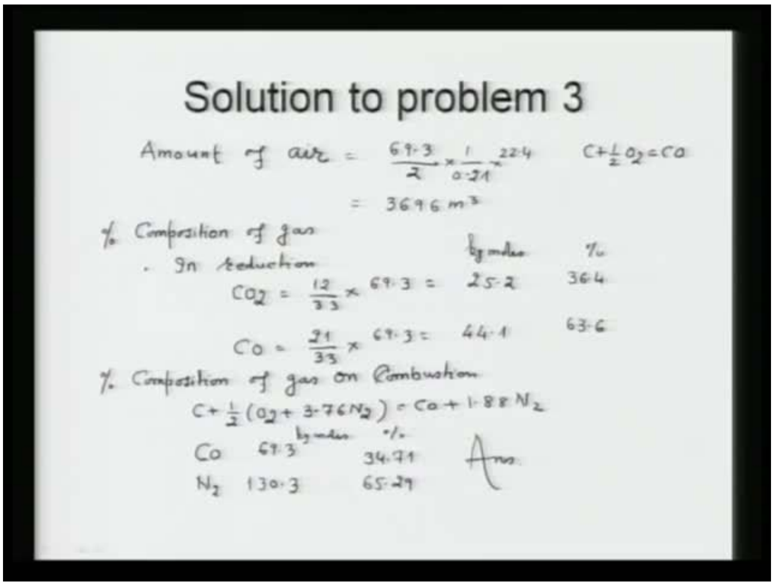

Remember, this problem is just for illustration, nowhere in the world the coke is 1 ton per ton of iron is used, it is just an illustration. Then further, we can calculate amount of air that will be equal to 69.3 by 2, because C plus half O 2 that is equal to CO into1 upon 0.21 into 22.4, so that gives us 3696 meter cube that is the amount of air.

Further, we have to find out percentage composition of gas - percentage compositions of gas in reduction, because reduction and combustion both are there, so in reduction it is being asked. So, in reduction the CO 2 that will be equal to 12 upon 33 into 69.3 CO that will be equal to 21 upon 33 into 69.3, so here that will be 25.2. Here, it will be 44.1, they are in kg moles. So, percent here it is 36.4 and here this is 63.6 that are how (Refer Slide Time: 07:00).

Now, percentage composition of gas on combustion; we have to write down the combustion equation with the nitrogen. So, I am straightaway writing the answer or well I will write down the equation for you. The equation is - fundamental equation is this C plus half O 2 plus 3.76 N 2; that is equal to CO plus 1.88 N 2. So, you can substitute the moles of carbon and accordingly you can write down. So, total CO and nitrogen that will be present in the gas, so CO will be 69.3 and nitrogen will be 130.3, they are in kg moles.

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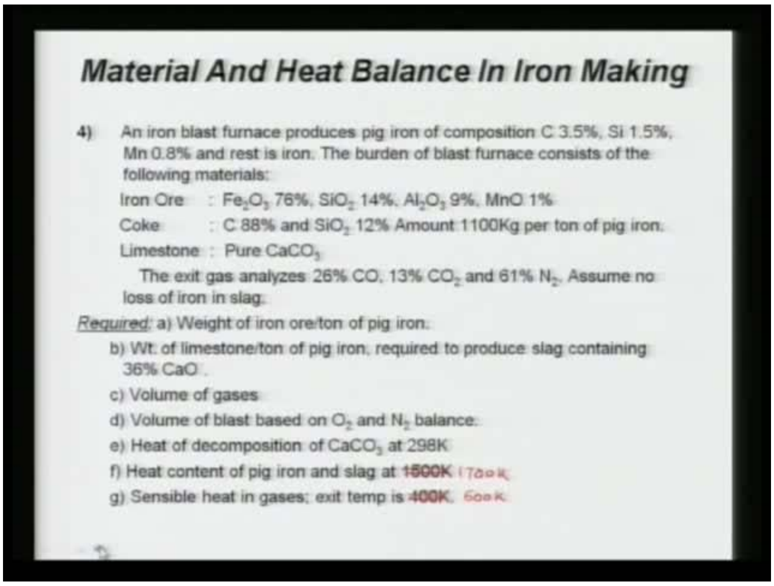

So, percent would be 34.71 and here it is 65.29. So, this is the answer for that particular problem. That is how I have illustrated now the problem number three.

Let us go to the problem number 4. Now, in problem number 4, it reads an iron blast furnace produces pig iron of composition this, this and this. Composition of pig iron is given, rest is iron. The burden of blast furnace consists of the following materials; iron ore, its composition is given and it contains Fe 2 O 3, Si O2, Al 2 O 3 and Mn O. Coke composition is given, 88 percent carbon and 12 percent SiO2. However, amount is also given, which is 1100 kg per ton, limestone is calcium carbonate.

The analysis of exit gas is given; assume no loss of iron in slag. Required is weight of iron, per ton of pig iron, weight of limestone, volume of gases and volume of blast. EFG, they concern with the heat balance that is what I have done. Prior to prepare you for the heat balance what I will be doing in this particular problem, I will try to illustrate the various heat inputs, various outputs and how to calculate them.

I will not be stressing much on actually forming the heat balance, but I will be giving all steps that concern to this problem, which rather calculates heat input as well as heat output. How to calculate those things? This is what I am going to tell you in this particular problem, but prior to that we have to calculate - as all of you know, before we calculate heat balance first of all material balance has to be calculated.

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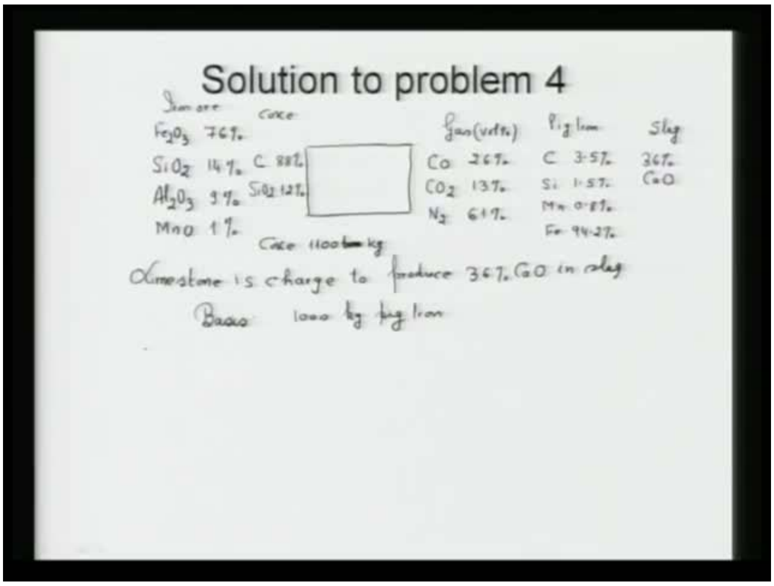

Accordingly let us proceed for the calculation of material balance. So, as such what I will represent here is the solutions to the problem 4. Make a block diagram, where I will write all the inputs and outputs.

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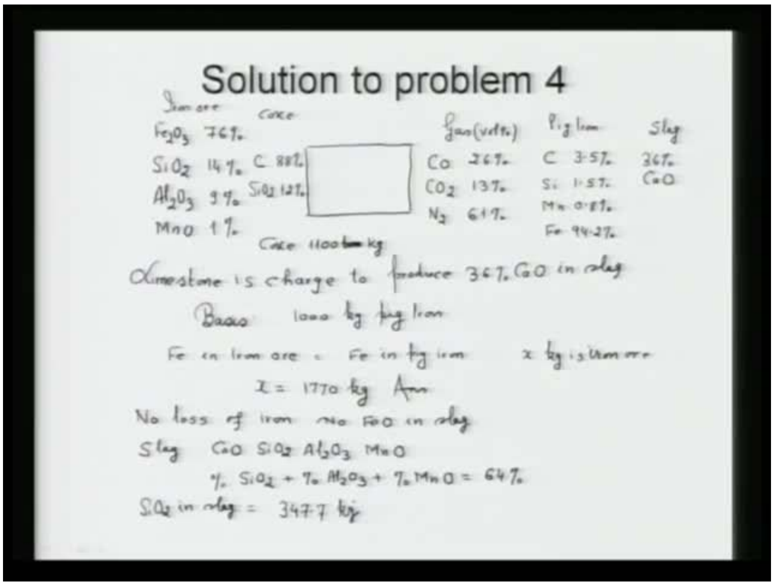

So, input we have iron ore that is Fe 2 O 3 is given, SiO2, Al 2 O 3, Mn O. Fe 2 O 3 percentages is 76 percent - weight percent, SiO2 14 percent, Al 2 O 3 9 percent and manganese oxide 1 percent.

Then, it is also said on the input side say this is the iron ore. Here, it is coke; coke is carbon 88 percent again on weight basis and SiO_2 is 12 percent. So, coke is 1100 tons, sorry coke is used 1100 kg per ton of pig iron.

On the output side, we have gas and its composition is given in volume percent. Dry basis, we have carbon monoxide, we have carbon dioxide and we have nitrogen. So, CO it is 26 percent, it is 13percent and this is 61 percent. Then the pig iron, its composition is given, it contains carbon which is 3.5 weight percent, it contains silicon which is 1.5 percent, then it contains manganese which is 0.8 percent and rest iron which comes out to be equal to 94.2 percent.

Then, it is said that slag it forms which contains 36 percent calcium oxide and no iron is lost in the slag. So, we also have sufficient limestone charged - the problem says sufficient limestone is charged to produce 36 percent CaO in slag; that is what I have also written.

So, let us proceed to solve this problem now, all the data is before us, so first we take basis. Our basis of solution is 1000 kg pig iron. Now, first of all, we have to find out the amount of iron ore, so what we do? We do iron balance, because since no iron is lost in the slag in this particular problem, so all iron which is charge it enters into the pig iron.

It is very straight forward. So, iron in iron ore that is equal to straightaway iron in pig iron. So, if we assume say x kg is the amount of iron ore - x kg is iron ore, then we can make this balance. Immediately the balance gives us 1770 kg is the amount of iron ore that is used in this particular problem.

Now, then we have to find out amount of slag, because amount of slag is also not known to us. So, first of all we have to see the problem. The problem says, no loss of iron; no loss of iron that means no Fe O in slag. So that means, what that mean? Slag it consists of Ca O, Si O2, Al 2 O 3 and Mn O. Since, calcium oxide is 36 percent, therefore percent Si O2 plus percent Al 2 O 3 plus percent Mn O that will be 64 percent, what this means? That means 64 percent consist of SiO_2 Al_2O_3 and MnO.

Since, their inputs and output are known to us, so we can calculate the amount of SiO_2 Al_2O_3 and MnO, from that amount 64 of that we can find out the amount of slag.

Now, let us find out SiO2 in slag, so straightaway SiO2 in iron ore plus SiO2 in coke minus Si of pig iron converted to SiO2 that will be equal to slag. So, if I do that then SiO2 in slag that will become 347.7kg that is what it will come.

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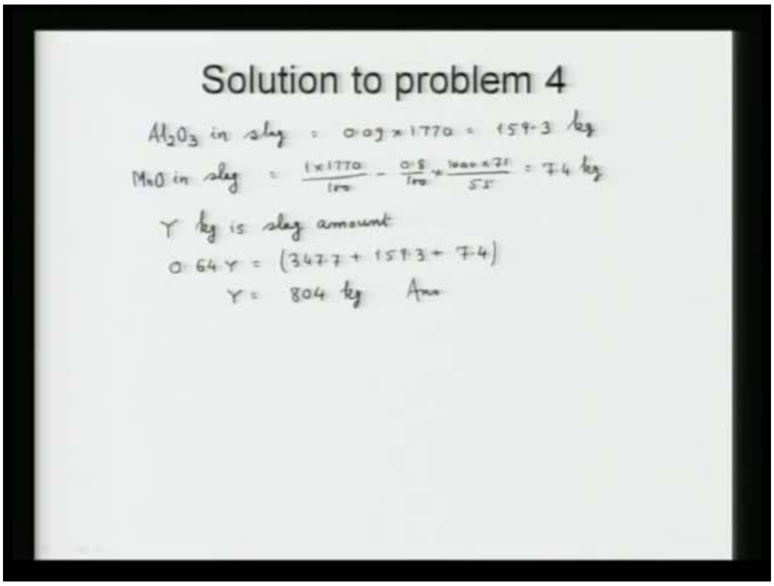

Now, let us do next, it is Al 2 O 3 in slag. Now, the source of Al 2 O 3 is only iron ore, so straightaway that is equal to 0.09 into 1770 that is equal to 159.3 kg.

Similarly, MnO in slag that would be say 1 into 1770 upon 100 minus 0.8 upon 100 that is in the pig iron into 1000 into 71 upon 55, I am converting M into MnO, so that is straightaway it is 7.4 kg. Now, if we say Y kg is the slag amount, then we can write down 0.64 Y that will be equal to summation of say 347.7 plus159.3 plus 7.4, of course you can solve, Y will come out to be equal to 804 kg; that is what the amount of slag and that is the answer.

Now, then we can also find out calcium oxide in limestone. Though it is not asked, but well when we do the heat balance, when we are charging limestone, then we have to calculate the amount of heat that is required to decompose limestone.

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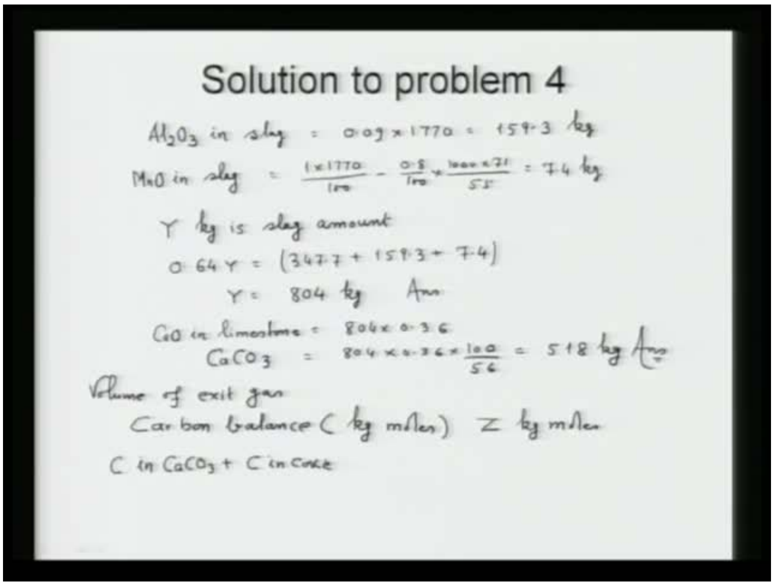

So, we can calculate, CaO in limestone that is equal to CaO in slag, so straightaway we can calculate CaO in limestone that is already given that is equal to 804 into 0.36. So, from here the amount of calcium carbonate that is limestone that will be equal to 804 into 0.36 into 100 upon 56, so that will be 518 kg that is the calcium carbonate.

Now, we have to also calculate volume of exit gas. We have to calculate volume of exit gas, now the problem says that the CO, CO2and N2 that is a given to us, so what we have to do? We have to do carbon balance. We will be doing carbon balance and I will be doing in kg moles, so let us consider Z is the amount of gas in kg moles.

Now, if I do the carbon balance that means I know carbon - do not forget carbon is also entering to calcium carbonate, so carbon in calcium carbonate that is input plus another input is carbon in coke. Normally, many times, some students they forget to take into account carbon of CaCO3 and they calculate. But, then it is not correct, because CaCO3 on decomposition gives you CaO plus CO 2. CO 2 has carbon as well as oxygen.

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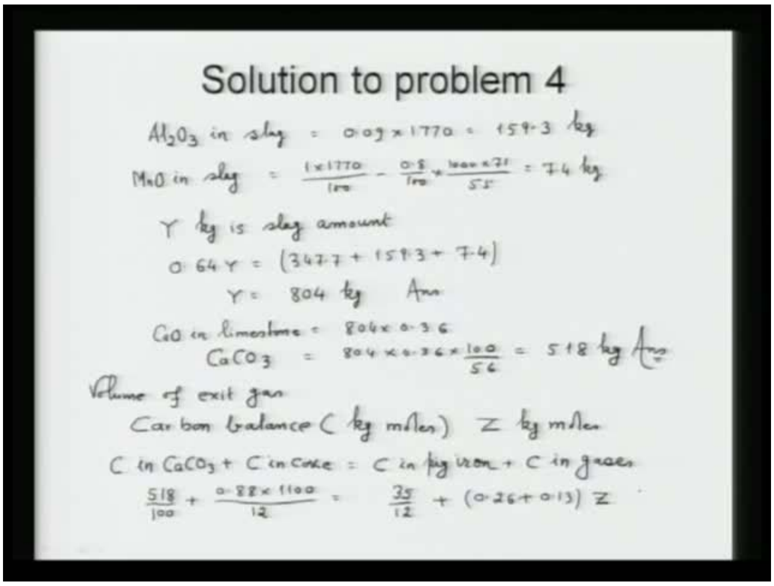

So, while doing carbon balance, you have to consider the carbon content of calcium carbonate, because that is also entering that should be equal to carbon in pig iron plus carbon in gases. This is to be written, so carbon in CaCO3 that will be 518 upon 100 plus 0.88 into 1100 upon 12 that is carbon in coke.

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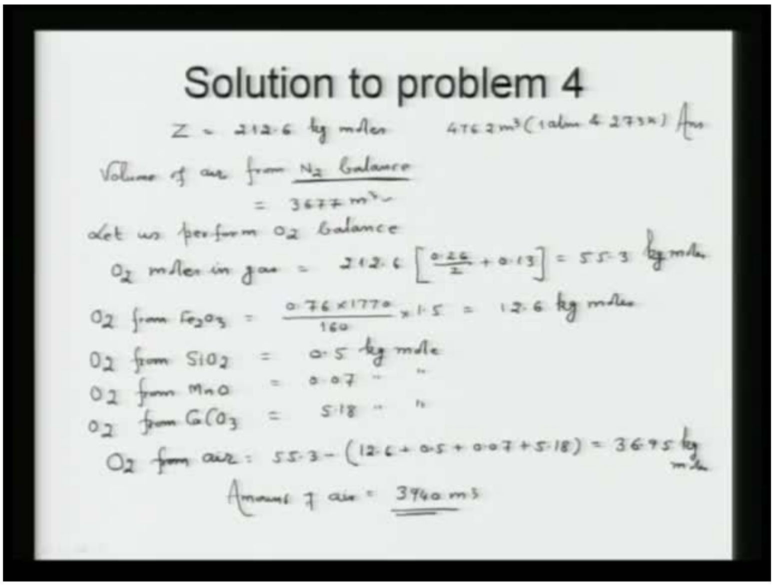

Carbon in pig iron in kg mole 35 upon 12 plus carbon in gases 0.26 plus 0.13and Z is the kg mole, so Z is the only unknown. We can calculate the amount of Z, so Z will be equal to 212.6 kg moles. Its amount - it's a volume if you watch that will be 4762 meter cube expressed at 1 atmosphere and 273 Kelvin that is the answer.

Now, it is said that calculate volume of air from nitrogen balance as well as oxygen balance. So, volume of air from nitrogen balance is very easy, we know the amount of gases. Nitrogen is 61 percent and air contains 79 percent of nitrogen, so straightaway if we do the nitrogen balance that is nitrogen from air that is equal to nitrogen in gases, it is very easy.

So, volume of air will be equal to 3677 meter cube, this is from nitrogen balance. Now, problem says you have to do oxygen balance, also let us perform oxygen balance, and let us perform O 2 balance.

Now here, we have to know that oxygen is entering through the charge also, because you are charging Fe 2 O 3, Fe 2 O 3 will be reduced and oxygen will be in the system. Similarly, SiO2 oxygen will be in the system depending upon how much silicon as entered into pig iron, similarly manganese oxide, similarly from calcium carbonate.

So, oxygen from air will be equal to considering the amount of oxygen, which is available from the charge. So, first of all we have to calculate how much amount of oxygen is available in the charge.

Let us do First of all say oxygen moles in gas that we can calculate - oxygen moles in gas that will be equal to 212.6 0.26 upon 2 plus 0.13 that is equal to 55.3 kg mole, these are the total oxygen available in the gas, but mind you this oxygen consist of oxygen from air as well as oxygen from the charge. So, we have to subtract that oxygen from the charge.

So, O 2 from Fe 2 O 3, no iron is lost in the slag, all the oxygen will be available. I am just giving one example of calculation 0.76 into 1770 upon 160 kg moles of Fe 2 O 3 oxygen is 1.5, so available will be 12.6 kg mole; this is also kg moles. Similarly, oxygen from SiO2 reduction, I hope you will be able to calculate, so I am straight away writing it down 0.5 kg mole.

Similarly, oxygen from MnO reduction, we have to calculate amount of MnO that is entering Mn equivalent to MnO in pig iron that oxygen will be entering into the gases.

So, oxygen from MnO reduction that is equal to 0.07 kg mole, then O 2 from CaCO3 that is straightaway it is 5.18 kg mole. Now, O 2 from air that will be 55.3 minus all this which are available that is 12.6 plus 0.5 plus 0.07 plus 5.18, so oxygen from the air that is 36.95 kg mole. Therefore, amount of air that is equal to 3940 meter cube.

This is difference than the nitrogen balance, but still you should consider that the amount of air calculated from oxygen balance may have error from several sources. First of all, oxygen is reactive, this mismatch could be due to rounding off or it can also be due to the some of the leakage of the oxygen. So that is what about the material balance.

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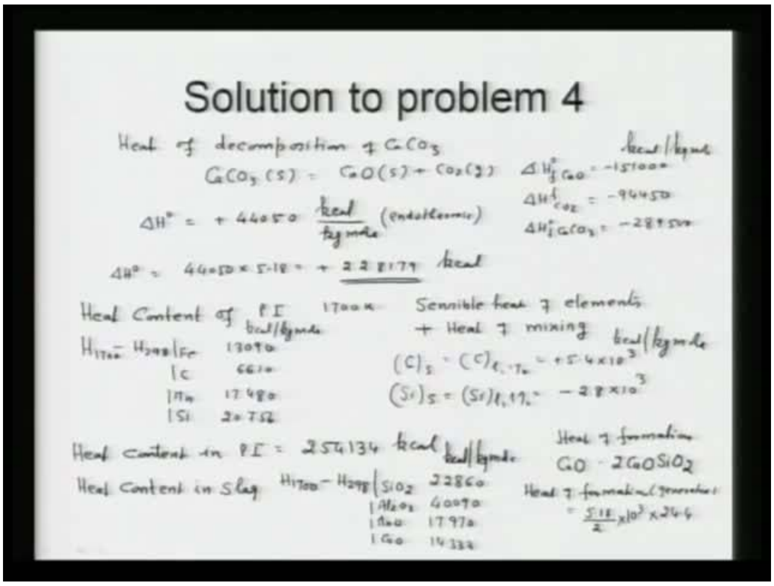

Now, let us do some heat balance exercises. So, first of all let us calculate say heat of decomposition of calcium carbonate. Here, I will be presenting all say inputs and outputs so that while doing heat balance you know how to do it. So, heat of decomposition of calcium carbonate - you know the calcium carbonate it decomposes to calcium oxide solid plus CO 2 gas, so delta H naught f CaO; H naught means 298; that is, minus 151000, it is kilocalorie per kg mole.

Then, we have delta H naught f CaO sorry CO 2 that is minus 94450 and delta H naught f calcium carbonate that is equal to minus 289500. If we calculate say delta H naught for this decomposition, then it will be coming plus 44050 kilo calorie per kg mole. Mind you, this is plus, so the reaction is highly endothermic that means, a large amount of heat produced from whatever this sources is utilized to decompose calcium carbonate. In our problem delta H naught will be equal to 44050 into 5.18 kg moles that will be plus 228179 kilo calorie; that is, a very large amount of heat is required here.

Now, we have to calculate heat content in pig iron. The temperature is given 1700 kelvin, so heat content in pig iron will be consisting of sensible heat of elements that probably all of you know; do not forget to consider heat of mixing - we should consider heat of mixing.

First, I will consider sensible heat of element. The temperature given H1700 minus H 298, I am giving you these values for iron, carbon, manganese, and silicon. For iron 13090, 661017480 and 20756; mind you, they are all in kilocalorie per kg mole. Now, I can calculate heat content of pig iron, I know the kg moles. So, heat of mixing means, because we have say carbon, solid that goes carbon, liquid say 1 weight percent and heat of mixing is 5.4 into 10 to the power 3 plus that is kilocalorie per kg mole.

Similarly, silicon solid equal to silicon liquid; 1 weight percent equal to; mind you, it is minus 28 into 10 to the power 3 kilocalorie per kg mole. If we calculate all then the heat content in pig iron that will be equal to 254134 kilo calorie that is how you will. Similarly, we have to calculate heat content in slag; we know the component of slag, so H 1700 minus H 298 we know, for SiO2 we should know, for Al 2 O 3 we should know, for MnO we should know and for calcium oxide we should know. Here, for SiO2 it is 22860, Al 2 O 340090, MnO 17970 and calcium oxide is 14333; mind you, they are again in kilocalorie per kg mole.

Normally, in this calculation of the heat content of slag one is to take into account heat of formation of slag on the basis - says if you assume in this particular problem that all CaO that is 5.18 kg moles of CaO, it is present in the form of 2 CaOSiO2. If we do that then, heat of formation of this one will be equal to 5.18 upon 2, because 2 CaOSiO2 into 10 to the power 3 into 24.4, because 24.4 into 10 to the power 3 is a heat of formation of slag when 2 CaOSiO2 is formed. So, this is the heat of formation. Now, mind you this is the heat generated, which is generated it is exothermic, remember.

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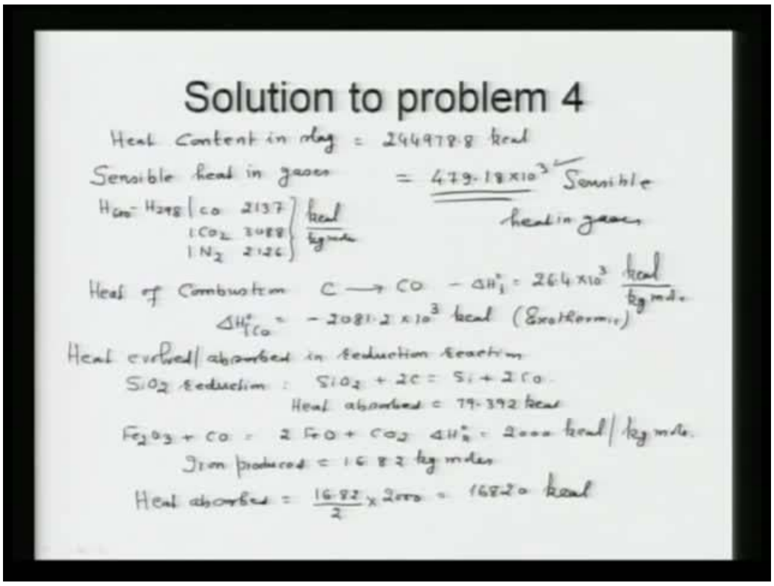

So, while calculating the heat content in the slag, if we sum total, then heat content in slag that value will come 244978.8 kilo calorie. Do not forget to subtract the heat of formation of slag, because that will be generated, it is important. Then, we have to calculate sensible heat in gases; again the gases are discharged at 600kelvin, so we have to know H 600 minus H 298 for carbon monoxide, for carbon dioxide and for nitrogen. So, for carbon dioxide it is 2137 kg moles, it is 3088 and this is 2126; these values are given in kilocalorie per kg mol, all that now we have to subtract. Sensible heat in gases - sensible heat in gases will be equal to 479.18 into 10 to the power 3. All that you have to multiply 2137 by the moles of CaO and so on, and then you will get this is the heat which is taken away by the gases.

Now, heat supply term for example, heat of combustion - say carbon is forming carbon monoxide and minus delta H naught f that is equal to 26.4 into 10 to the power 3 kilocalorie per kg mole. It is straight forward, we can calculate now delta H naught f CO that will be minus 2081.2 into 10 to the power 3 kilocalorie and mind you this is the exothermic reaction.

Now, straightforward we have to multiply by the kg mole of carbon; the thing very great here. Also, you have to see, while doing the heat balance, heat evolved or heat absorbed by the reduction reaction, so Fe 2 O 3 is reduced to FeO, FeO to Fe, SiO2 to silicon and so on.

For example, for SiO_2 reduction, we writes say SiO_2 plus 2 C that is equal to Si plus 2CO and heat absorbed that will be equal to 79.392 kilo calorie. You have to calculate heat of reaction with this reaction, so the values of SiO_2 - heat of formation of SiO_2 and from the heat of formation of carbon monoxide, you can calculate this particular value. Similarly, say Fe 2 O 3 to FeO reduction, Fe 2 O 3 plus CO that is equal to 2 FeO plus C O 2, delta H naught R is given here, 2000 kilocalorie per kg mole.

Total iron which is produced we have to calculate now; iron produced that is 16.82 kg moles, hence 16.82 kg moles of FeO will also be produced. Therefore, heat absorbed that will be 16.82 divide by 2, because 2 moles of FeO into 2000, because it is said that for 2000 kg of iron that is equal to 16820 kilocalorie.

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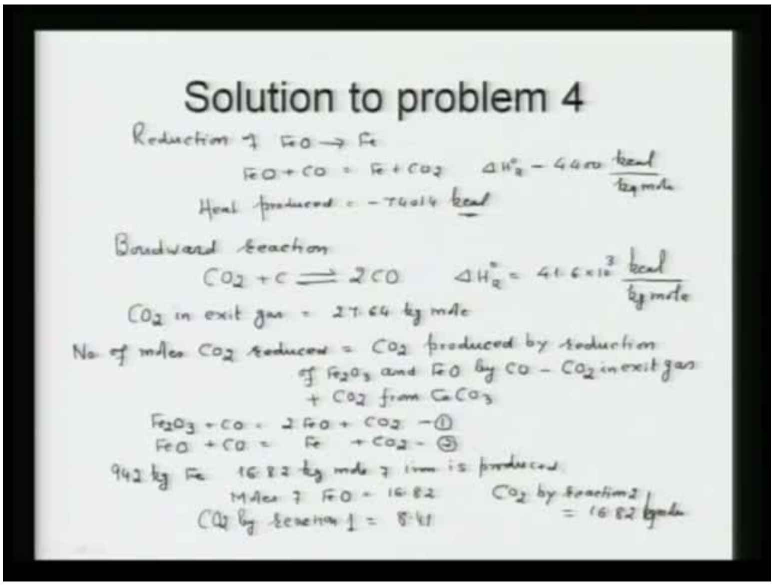

Similarly, say reduction of FeO to iron, the reaction is FeO plus CO that is equal to Fe plus CO 2 and delta H naught R for this reaction is 4400 kilocalorie per kg. Mind you, it is exothermic reaction, it will generate the heat, so I am a straightaway calculating heat produced and it is simple calculation. I think you can do it that will be equal to minus 74014 kilo calorie; it is how this calculation is being done.

Another very important thing is, in the blast furnace iron making the Boudward reaction. This Boudward reaction is the most important part of the blast furnace iron making and the Boudward reaction is highly endothermic reaction. Boudward reaction consist of CO

2 plus C that is equal to 2CO that means, the Boudward reaction corresponds to reduction of carbon dioxide by carbon and produces carbon monoxide.

Here, the delta H naught reaction, I mean the heat of reaction for this that is delta H naught R that is equal to 41.6 into 10 to the power 3 kilocalorie per kg mole; that is how this 1 is there. Now, we have to find out from the exit gas how much amount of CO 2 is being reduced by carbon? In order to find out that first of all we have to find out CO 2 in exit gas that is straightforward. We know the percentage CO 2, we know the total amount of CO 2, percentage CO 2 in exit gas is 27.64kg mole; see amount of gas multiply by its percent.

Now, number of moles of CO 2 reduced by reaction CO 2 plus C is equal to 2 CO that is equal to CO 2 produced by reduction of Fe 2 O 3 and FeO by CO minus CO 2 in exit gas; that is what is happening. Also, plus that mind we always forget, plus CO 2 from calcium carbonate, do not forget this calcium carbonate and its contribution to this, because this also giving CO 2 every chance that CO 2 may be reduced by the carbon according to the Boudward reaction, this is our balance.

Now, we have to calculate the reactions Fe 2 O 3 plus CO plus 2 FeO plus CO 2; say this reaction 1, FeO plus CO that is equal to Fe plus CO 2; this is our reaction number 2. Now, say if 942 kg of iron is produced or 16.82 kg mole of iron is produced, then we have to reduce moles of FeO have to be 16.82. Then, CO 2 by reaction 2 that will be equal to 16.82 kg moles. Now, CO 2 by reaction 1 that will be equal to 8.41.

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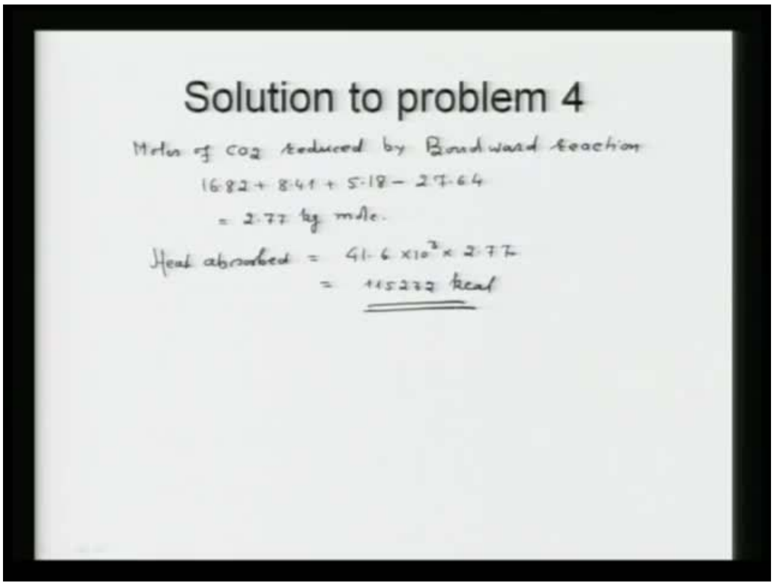

We are in the position to find out see moles of CO 2 reduced by Boudward reaction. Straightaway we need to substitute the values that will be 16.82 plus 8.41 plus 5.818. Do not forget to 802 results from decomposition of calcium carbonate minus 27.64; so that will be equal to 2.77 kg mole. Then, heat absorbed that will be equal to 41.6 into 10 to the power 3 into 2.77 that is equal to 115232kilocalorie.

See a substantial amount of heat here is absorbed by the Boudward reactions. So, what I have illustrated it here is the various items which are responsible for heat input and heat output in the blast furnace iron making.

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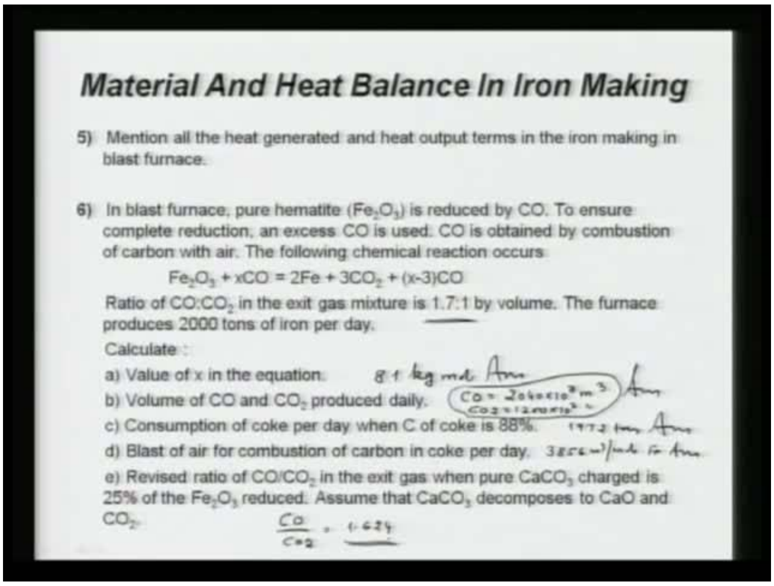

So, with this no problem 5 th says mention all the heat generated in heat output in terms the iron making in blast furnace. Most of the things I have illustrated, heat generated term we have to see from there, say combustion of carbon, FeO2 Fe reaction, heat of mixing and all those things. Heat output terms say heat taken by pig iron, heat taken by gases, heat taken by slag; all these things are important, so that you can narrate in problem number 5 after calculating problem number 4.

Now, problem number 6th, Fe 2 O 3 is used by CaO and the equation is given. A similar problem I have solved just before, the problem number 3; that is, the equation is given, CO CO2 ratio is given, so you should be able to answer the value of x in the equation and so on.

I just give you the answer - the value of x that is in the equation that is equal to say 8.1 kg mole that is the answer. Then, volume of CaO and CO 2 produced, volume of CO- say CO that is equal to 2040 into 10 to the power 3 meter cube and that of CO 2 is equal to 1200 into 10 to the power 3 meter cube. Now, combustion of coke required that is equal to 1972 tons; these are the answers - this is the answer. Now, blast of air that will be equal to 3856 meter cubed per mole of iron, this is the answer (Refer Slide Time: 48:45).

Now, revised ratio of CO CO2 in the exit gas when CaCO3 is charged, so the revised ratio will come CO upon CO 2 that will be equal to 1.624, I think the ratio in the original is 1.7 is to 1, now it is 1.6 is to 4, because you are charging calcium carbonate and this is giving carbon dioxide. So, 6th problem you do yourself, I have already given the answers.