Fuels, Refractory & Furnaces
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Lecture No. # 05
Materials balance in Coke-making

So, today we will talk on material and heat balance in coke oven. We have learned how coke is produced, coke oven is used and we know the various products that are being produced. Now material and heat balance they are important from energy conservation point of view. If you want to identify the places where energy is being lost that means without being used in the process. Then material and energy balance, they are that effective tools to identify the flow of energy in a particular process.

So, today we will deal something with the material and heat balance in the coke oven. Now in order to perform energy balance, material balance must be done. So, the title of lecture could be both energy balance in coke oven or material and heat balance in coke oven.

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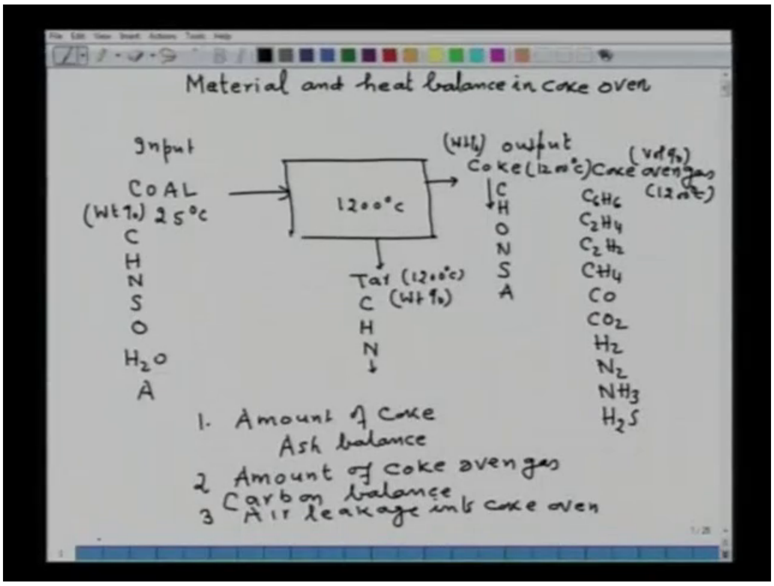

So, I will just make a balance type of a diagram for example, this is the coke oven, this side I will write as input and this side as output. That is how, we should proceed to solve material and energy balance problem. So, in the input side, we have coal say coal is charged for example, as 25 degree Celsius into the coke oven.

Then the output is coke of certain compositions say it may have carbon, it may have hydrogen, it may have oxygen, it may have nitrogen, it may have sulfur and it may have ash. The temperature of the coke, if the oven temperature for example is 1200 degree Celsius, then the coke temperature would also be at least 1200 degree Celsius. Then another output is coke oven gas and coke oven gas for example, it could be C 6 H 6, could be C 2 H 4, could be C 2 H 2, CH 4, CO, CO 2, H 2, N 2, NH 3 or H 2 S. That is a complete composition of coke oven gas is to be known and coke oven gas probability is also discharged at for example, a temperature of 1200 degree Celsius.

Now another output is a tar, tar is also produced and tar may contain carbon, hydrogen nitrogen and other component also. Tar will also be discharge for example, as 1200 degree Celsius. Similarly, the composition of coal is also has to be given composition of coal for example, contained carbon, hydrogen, nitrogen, sulfur, oxygen, H 2 O and ash. So, this is how a material balance program, a material balance problem has to be dealt with.

So, just for your mention, the percentage of coal is given on wet basis say they are given as wet percent. The coke is also given on wet percent and coke oven gas normally it is given on volume percent, it may be given on dry basis or it may be given on wet basis. Similarly, tar percentage is given on wet basis; that is say wet percent. Now what is required to determine is first of all the amount of coke amount of coke. In all such problems one is to paid basis, you may take a basis one kg of coal, hundred kg of coal or thousand kg of coal and with reference to that, you perform your calculations.

Now if you want to find out the amount of coke, then as you know from the basic of the coke oven that ash is conserved. That is ash of coal; it transfers to ash in coke. So accordingly to find out the amount of coke as balance is to be performed. To be performed the ash balance you are able to calculate the weight of coke. Then second number calculation that is required, what is the amount of coke oven gas? What is the amount of coke oven gas? Now in finding out the amount of coke oven gas, you may find either in kg mole or in meter cube.

When you want to find out in meter cube, then you avoid specifying what is the temperature and pressure at which you are determining meter cube of coke oven gas? Now in order to find out amount of coke oven gas, the best way is to start with the carbon balance. That is carbon in coal, it is distributed in this particular diagram which I given in tar in coke and in coke oven gas. So, by knowing the amount of coke, amount of tar, amount of coal, one can calculate from carbon balance; the amount of coke oven gas that is formed.

Third calculation could be of the … or could be, because the coke oven they are operating under atmospheric environment. So, it is quite possible air mail have lead into the coke oven. And you are required to find out the air leakage into the coke oven air leakage into the coke oven. Now for the air leakage into the coke oven, you should perform nitrogen balance, because nitrogen is non-reactive. If you do on oxygen balance, then oxygen reacts and you may not get a right answer.

So, always perform a nitrogen balance in order to find out air leakage into the coke oven say nitrogen from coal plus nitrogen from air. That is again distributed into the product by knowing the quantity of each product, you can find out the nitrogen which is leaked into the coke oven, if at all it is leaked.

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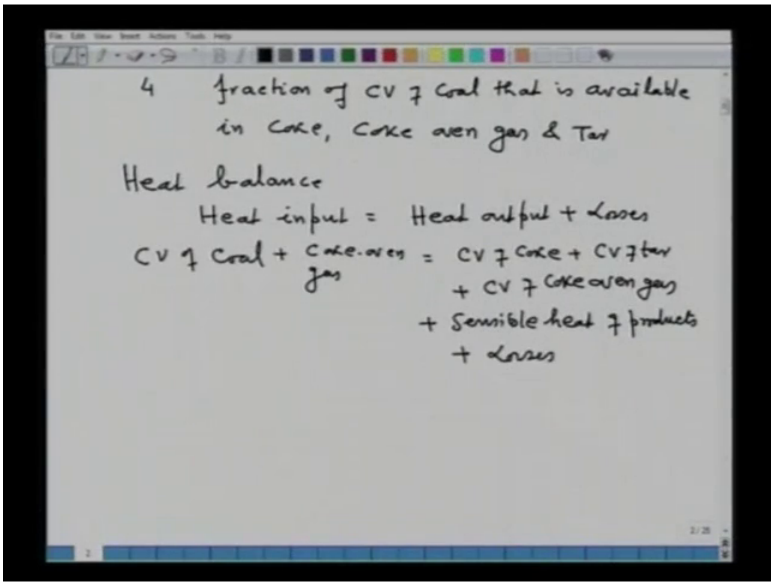

Then another thing that is sometimes asked is, because when you put coal you are putting calorific value of also in to the coke oven. So, the calorific value of coal is also distributed into the calorific value of coke oven gas, calorific value of tar and calorific value of coke. Because coke is also receiving its calorific value from coal, coke oven gas also from coal and tar is also from coal. So, it is also required to find out, what is a fraction of calorific value fraction of calorific value of coal that is available in coke, coke oven gas and tar.

Well, for that you have to determine the calorific value of coal; you might use the dulong formula, the calorific value of coke, you also determine can determine through dulong formula that of tar also from dulong formula, and that of coke oven gas you have to determine from heat of formation visa versa heat of combustion values. Then by knowing that you know the calorific value of carbon, you can find out the fraction that is available in coke, coke oven gas and tar. And towards the end, you are required to do a heat balance. So, in the heat balance, what is to be done? In the heat balance, the heat input that is equal to heat output heat output plus loses; loses somewhere, loses through the valves of the coke oven chamber.

So, heat input a for example, heat input could is only calorific value of coal plus if coke oven gas is introduced. That is heat of introduced through coke oven gas and heat output that is in the calorific value of coke plus calorific value of tar plus calorific value of coke oven gas plus sensible heat of products and plus loses.

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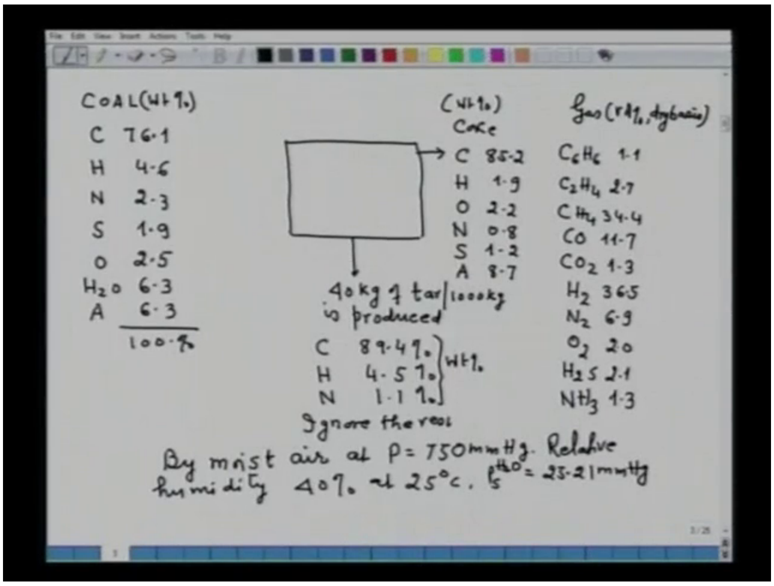

Now let me illustrate this whole material balance and heat balance by taking an example. Now let us take an example so, in a coke oven I am just trying a material balance sketch so, in a coke oven a charge coal and the analysis is given on weight percent. So, carbon 76.1, hydrogen 4.6, nitrogen 2.3, sulfur 1.9, oxygen 2.5, S 2 O 6.3 and ash is 6.3; the total becomes

100 percent. Now output say coke again it is given in weight percent; it has carbon, hydrogen, oxygen, nitrogen, sulfur and ash. Now carbon here is given 85.2 percent, hydrogen 1.9 percent, oxygen 2.2 percent, nitrogen 0.8 percent, sulfur 1.2 percent and ash is again 8.7 percent; this also becomes hundred. Now it is also given the gas which is forming that is given in volume percent, no dry basis and the composition of gas is given as follows: it has C 6 H 6, and then it has C 2 H 4, CH 4, carbon monoxide, CO 2, H 2, N 2, O 2, H 2 S and ammonia.

Now from this material balance, you should also get a feel; the various percentage which are involved during conversion of coal to coke. Also, you should get a feel the coke oven gas and its composition which is produced. So, C 6 S 6 is 1.1 percent, C 2 H 4- 2.7 percent, CH 4- 34.4 percent, CO- 11.7 percent, CO- 2 1.3 percent, hydrogen- 36.5 percent, nitrogen- 6.9 percent and oxygen is 2 percent, H 2 S - 2.1 percent and ammonia is 1.3 percent.

Also it is given in the output 40 kg of tar is produced; 40 kg of tar per 1000 kg coal is produced, not the amount of tar is known per 1000 kg. In this particular problem, 40 kg is produced the composition of tar, carbon 89.4 percent, hydrogen 4.5 percent, nitrogen 1.1 percent and ignore the rest ignore the rest and these percentage again are given on weight percent.

Now it is also said that the coke oven is surrounded by moist air; it is also said that the coke oven is surrounded by moist air at pressure P that is equal to 750 millimeter mercury. The relative humidity in air is given to be 40 percent at 25 degree Celsius and off course, 750 millimeter mercury. At this pressure and temperature, the saturation vapor pressure that is P S H 2 O is given to be equal to 25.21 millimeter mercury. So this is what a particular operation of the coke oven has been described over here.

Coal of certain composition is given; coke gas, tars are produced and it is said that the coke oven is surrounded by moist air at seven hundred and fifty millimeter pressure of mercury. Relative humidity is 40 percent at 25 degree Celsius and at this temperature and pressure, the saturation vapor pressure is given to you twenty five point one millimeter mercury.

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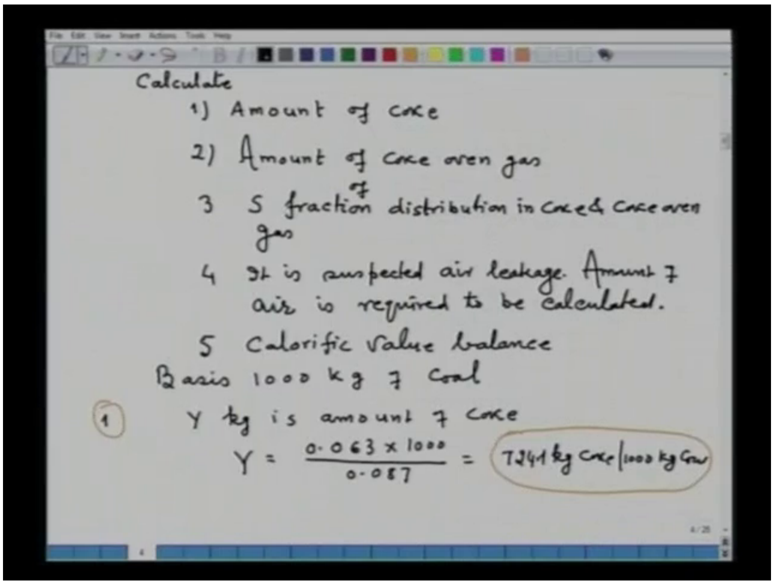

Now, what is to be found out? Determine or calculate the one, to calculate amount of coke calculate amount of coke, then also calculate amount of coke oven gas amount of coke oven gas, also calculate the sulfur fraction sulfur fraction distribution in coke and coke oven gas. That is sulfur fraction of coal or say sulfur fraction distribution in coal and coke oven gas; that sufficient. Fourth, it is suspected it is suspected air leakage; amount of air is required to be calculated. Then you have to perform, calorific value balance calorific value balance and all this calculation from one to five, you perform by taking basis as 1000 kg of coal.

So that is why that is how or that is what we have to calculate. Now first we have to calculate amount of coke per thousand kg of coal. As I have said, so to calculate one: you have to calculate amount of coke. To let us see that let us consider Y kg is the amount of coke. Now if you perform ash balance and then we write down the equation that is Y that will be equal to 0.063 into 1000 upon 0.087. So, that is straight away gives us 724.1 kg of coke per 1000 kg coal and that is the answer for one. I have simply performed an ash balance, ash in coke that is equal to ash in coal. And from that, I get the amount of coke per 1000 kg of coal.

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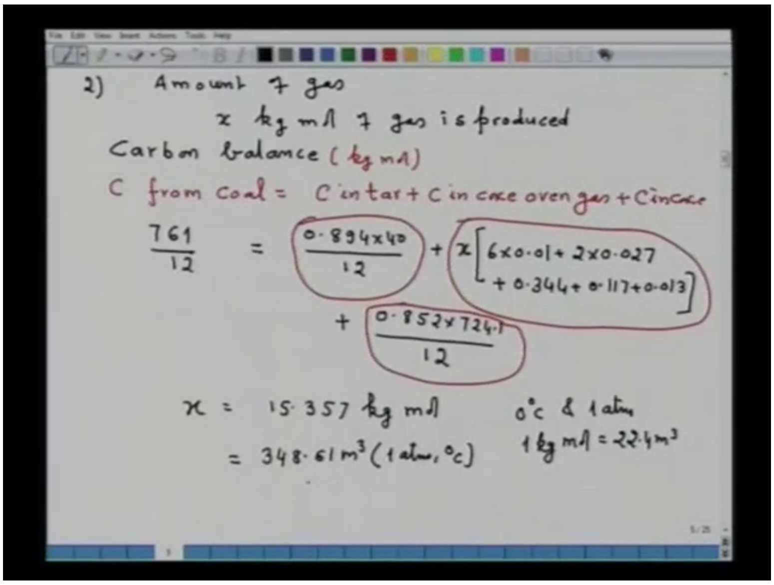

Now next I have to find out amount of gas which is a second part, find out amount of gas. Now here the calculation procedures could be different for different person who may assume. Let Y meter cube of the gas which is being produced or you may assume let Y kg mole of gas being is being produced. This is simply a choice and a matter of convenience; you have to develop your own style of calculation. Whatever my style is that cannot be your style or that may be your style. Ultimately you have to find out, how you want to determine?

For example, I will be determining I consider let X kg mole gas be produced X kg mole of gas is produced. So, I have to do carbon balance carbon balance. Let me perform carbon balance. So carbon balance, carbon from coal that is equal to carbon in tar plus carbon in coke oven gas plus carbon in coke and that is why, that is how, the carbon balance appear. Now, what I have to do? I have to now insert the appropriate values, say carbon from coke or carbon from coal say I have it, because I am doing kg mole balance. So, I have to convert all kg into kg mole so, carbon balance is done in kg mole. So, if I do in kg mole, then I get carbon from coal 761 by 12, say carbon in tar 0.894 into 40 upon 12; this is the carbon in tar. Carbon in coke oven gas, the X is the kg mole of coke oven gas, then 6 into 0.01 plus 2 into 0.027 plus 0.344 plus 0.117 plus 0.013; that is what the carbon in kg mole in coke oven gas.

Now I find that is advantage if I take X kg mole, because volume percent and mole percent for gas is same; that is where I can directly write down carbon in moles. For example, 6 into 0.01 that is coming from the C 6 x 6 is 1.1 percent; that is how you can determine straight away the moles of carbon in the coke oven gas? Then plus… so, this is the carbon in kg mole in the coke oven gas. Now I have to find out carbon in coke that is equal to 0.852 into 724.1 divide by 12 so, that is the carbon content, carbon in kg mole in coke.

Now simply I have to solve this equation and I will get… so, if I solve this equation, I will be getting X; that will be equal to 15.357 kg mole. Now if I want to report in meter cube, what I have to do? I have to find out temperature and pressure at which I want to convert kg mole into meter cube. Now for example, if I want to report at 0 degree Celsius and 1 atmospheric pressure then I will know 1 kg mole that is equal to 22.4 meter cube and accordingly I can find out this X that is equal to 348.61 meter cube.

Now it is necessary to specify, it is at one atmospheric pressure and 0 degree Celsius. Now this value of meter cube will be different; if I take pressure and temperature to be different, then what I have taken over here? All that you have to find out, what is the value of 1 kg mole at the respective temperature and pressure? That is how you can find out or you can convert kg mole into the meter cube.

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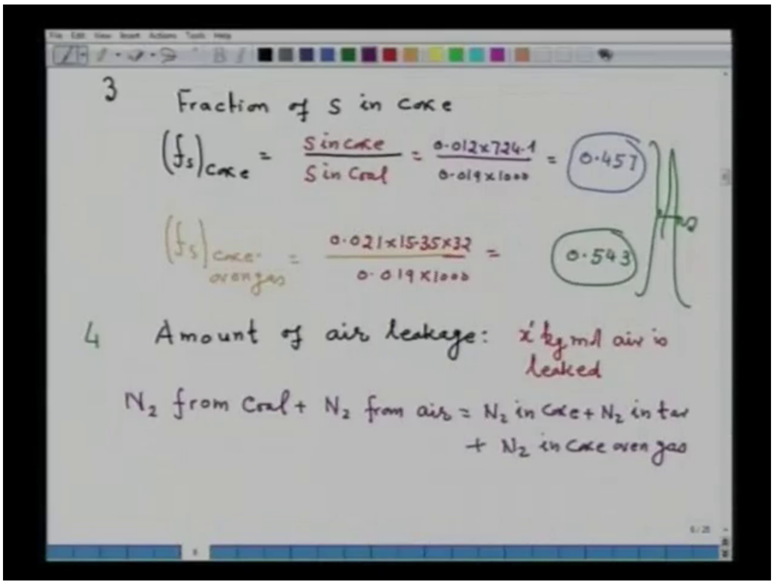

Now as regard the third one, fraction of sulfur of coke, I mean fraction of sulfur that is distributed. Now what we have to find out? Say fraction of sulfur, say fraction of sulfur in coke, and say if I put f s coke that is equal to sulfur in coke upon sulfur in coal. Now I had to put the values that will be 0.012 into 724.1 upon 0.019 into 1000. So, that will be equal to 0.457; that is the fraction of sulfur in coke.

Now say fraction of sulfur in coke oven gas, in coke oven gas again that will be equal to straight away I am writing 0.021 into 15.35, because sulfur in coke oven gas is present as H 2 S, multiply by the total kg mole into 32 that has become kg and if you divide by again 0.019 into 1000. So, that will give you the 0.543 and this is the answer for question number three. Now it is required to find out the amount of air leakage. Air leakage was suspected and you are required to find out the amount of air which has been leaked into the coke oven. So fourth one, amount of air leakage amount of air leakage now again let X kg mole or let X kg mole air is leaked let X kg mole air is leaked now what I have to do as I have said, I have to perform nitrogen balance.

So, nitrogen from coal nitrogen from coal plus nitrogen from air; that is equal to nitrogen in coke plus, nitrogen in tar plus, nitrogen in coke oven gas plus nitrogen in coke oven gas now just to differentiate, because X I think I had taken earlier, I put here just here X base, just to differentiate. So, I had to perform this nitrogen balance.

Now here one thing that we should note that the air is not dry, air is moist; in a dry air the composition is seventy five percent nitrogen and twenty one percent oxygen; 760 millimeter of the atmospheric pressure. Now, here atmospheric pressure is 750 millimeter, the air is moist. So, we have to recalculate the percentage composition of air; now that is being done as follows.

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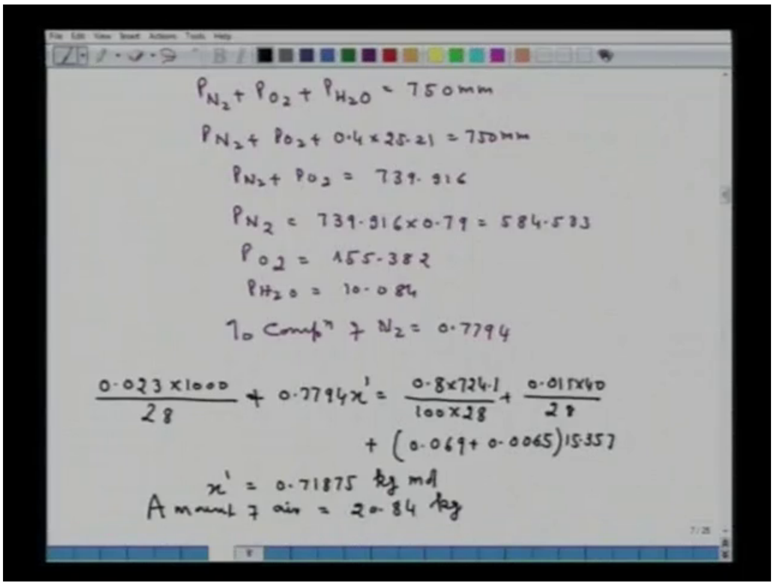

Now again considering air consist of nitrogen, oxygen air so, we know that P N 2 plus P O 2 plus P H 2 O; that is given to us 750 millimeter mercury. Now relative humidity is given, this maximum saturation vapor pressure is also given. So, we can find out P N 2 plus P O 2 plus 0.4 into 25.21; that is equal to 750 millimeter. And from here, we can find out P N 2 plus P O 2 that is equal to 739.916 millimeter of mercury. The one kg mole air, you have 3.76 kg mole of nitrogen; that is always there. So, P N 2 that will be equal to 739.916; now this P N 2 plus P O 2 that is equal to 739, it has become equal to the dry air composition so, I can again use 79 and 21 percent. So, P N 2 will be equal to 0.79 so, that will be equal to 584.533 and P O 2 that is equal to 155.382, and P S 2 O that is equal to 10.084. So, the percentage percentage composition of nitrogen that will be equal to 584.533 divide by 750 and that will be equal to 0.7794.

So, now I have got that the percentage nitrogen in moist air is 0.7794. Now I perform the nitrogen balance so, nitrogen balance I am straight away writing say that is 0.023 into 1000 upon 28; that is plus 0.7794 X dash; that is from the air. That is equal to 0.8 into 724.1 upon 100 into 28 I am converting all kg into kg mole.

Dividing by the molecular weight of nitrogen plus 0.011 into 40 divide by 28 plus 0.069 plus 0.0065 into 15.357 so, that has become how my nitrogen balance by considering all. So if I solve these thing, then I will be getting X dash value, you can simply solve it. That will come out to be equal to 0.71875 kg mole of air; that is leaked into the furnace. Now if I multiply by the molecular weight of air, then I will be getting the amount of air. So, the amount of air that is equal to 20.84 kg; that is the amount of air that is leaked into the furnace.

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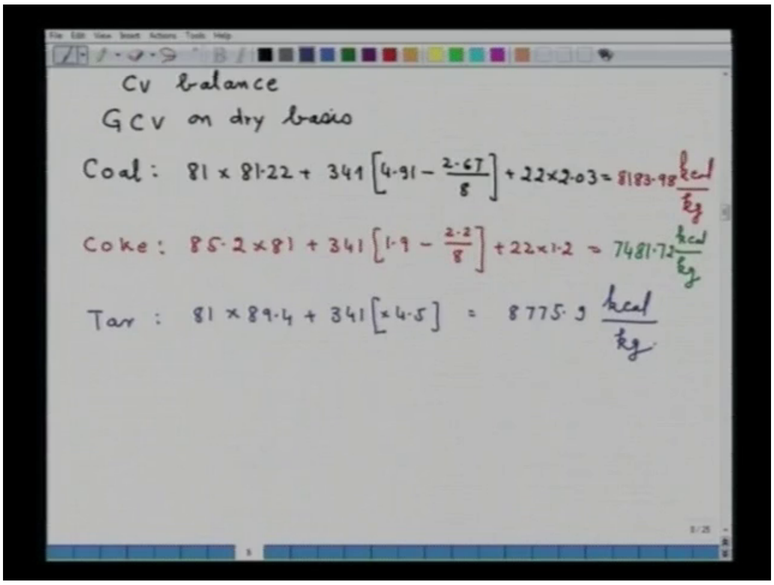

Now next we have to do the calorific value balance; next we have to perform calorific value balance. So, first let us determine the calorific value of coal, I am determining now gross calorific value of coal on dry basis. So, it can be determined by the dulong formula and as you know, the dulong for coal that will be equal to 81 into 81.22, because first then I have to convert the coal analysis from wet basis to dry basis. So, you know that conversion; only after that conversion, you can determine the GCV on dry basis plus 341 4.91 minus 2.67 upon 8 plus 22 into 2.03. That will be equal to 8183.98; the units are kilo calorie per kg. So, that is the calorific value of coal. Now we have to find out calorific value of coke. Same way we find out, say 85.2 into 81 plus 341, 1.9 minus 2.2 upon 8 plus 22 into 1.2 and that is equal to 7481.72 kilo calorie per kg. Now next try to find out the calorific value of tar. So, calorific value of tar, it is determined as tar 81 into 89.4 plus 341 into 4.5, because it does not have any oxygen. So, that is equal to 8775.9 kilo calorie per kg.

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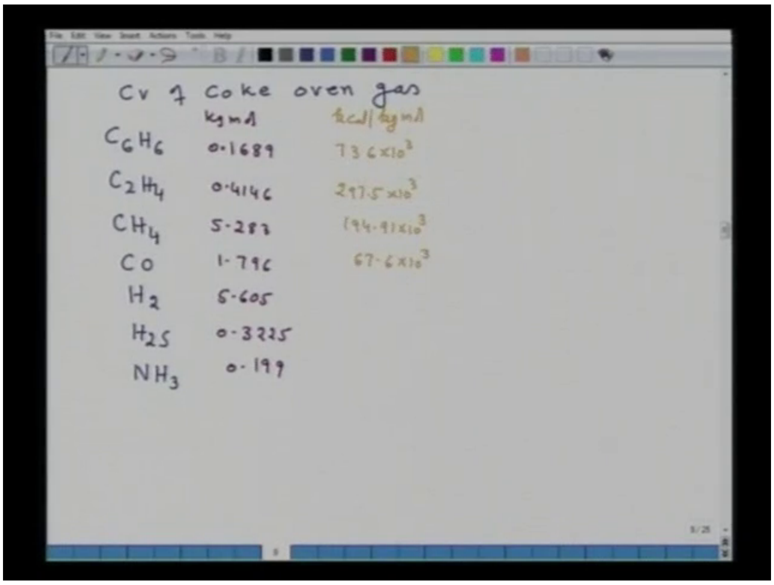

Now next we have to determine the calorific value of coke oven gas calorific value of coke oven gas. Now the combustible, the combustible component of coke oven that are C 6 H 6, C 2 H 4, CH 4, CO, hydrogen, H 2 S and ammonia. They all will contribute to the calorific value of coke oven gas. Now, first we will determine the kg mole of respect to gaseous C 6 H 6 - 0.1689, C 2 H 4 - 0.4146, CH 4 - 5.283, 1.796, 5.605, 0.3225 and 0.199. Now then I will write down, the kilo calorie per kg mole value, which I have given in my earlier lecture; C 6 H 6 - 736 into 10 to the power 3, 297.5 into 10 to the power 3, 194.91 into 10 to the power 3, 67.6 into 10 to the power 3.