Fuels, Refractory and Furnaces

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Lecture No. # 08

Materials and Heat Balance in Gasification

Today, we will talk on Material Balance in Gasification.

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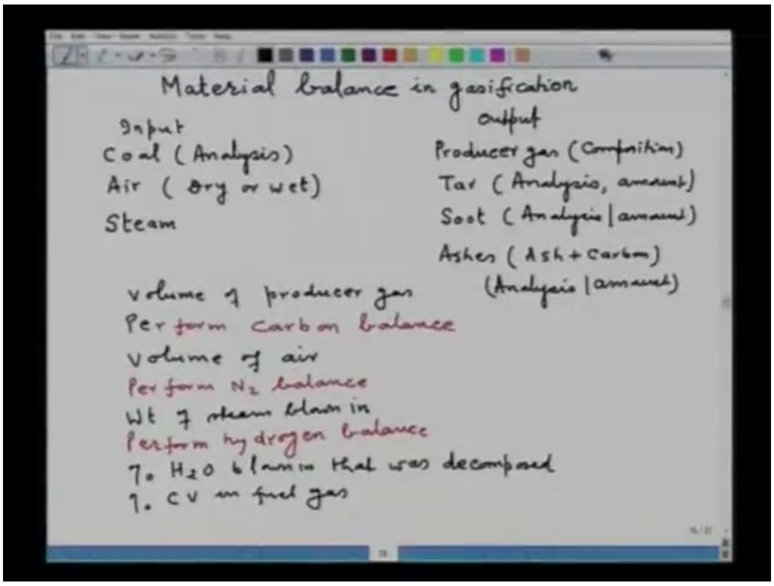

Now, material balance is also an important exercise in order to know the information that is required during gasification. Normally in material balance say inputs are say coal, then analysis is to be known, the analysis can be given on wet basis or on dry basis. Then air air is used for gasification, then this air can be dry or you can have wet air. So, here one has to be careful, if it is dry air, then the composition of air is 79 percent nitrogen and 21 percent oxygen. If it is wet air that means it is a moist air, then one has to determine the composition of air, because now the air contains in addition to nitrogen and oxygen water vapor also.

So, another important input is the steam. Normally it is given that so much amount of steam is blown per kg of coal or it may not be given depends upon the type of problem and type of gasifier under consideration. So, under these output, what is required to find out say in the output output is say producer gas normally its composition is given. Now, this composition can be given on dry basis or on wet basis that depends on the type of problem. Then also amount of tar, tar also analysis is given and its amount may or may not given depends again on the problem.

Then output another is soot again analysis oblique amount should be known. Then ashes, the ashes are in fact ash plus carbon, again its analysis and amount should be known. Now here, the analysis of producer gas is given on volume percent. In most of the cases, the analysis of gaseous fuel is always given on volume percent unless and until specified, where volume of solid product is always given on the wet basis.

So, for these given input and output, you are required (( )) you are required to find out for example, say what is the volume of producer gas is. Now, in order to find the volume of producer gas, one has to perform say perform carbon balance. To perform the carbon balance, a carbon from all inputs should be equal to carbon in output and from that balance one can determine the volume of producer gas.

Then, also it is also sometimes require to find out volume of air, volume of air now the if air supply is dry then volume of dry air, if supply is moist, then volume of moist air. So, in order to find out volume of air, one has to perform nitrogen balance. Now, in performing nitrogen balance one has to be careful that all sources of input and all sources of output must be considered, number 1. Number 2, if the air is dry then and if the air is moist then or the moist air, one has to recalculate the composition of air depending upon the saturated vapor pressure and relative humidity which will be given in the problem.

Then in certain cases, it is also required to find out what is the weight of steam that is blown in weight of steam that is blown in and in order to find out weight of steam that is blown in, this amount maybe given, but if it is not given, then it is weight can be find out perform hydrogen balance perform hydrogen balance. Say here, you have to take into account, input of hydrogen from all sources, then output of hydrogen from all sources and automatically the hydrogen in steam becomes a known variable, and the amount of a steam can be determine from the hydrogen balance.

Now, it is also asked say what is the percentage H 2 O blown in or steam blown in that was decomposed that was decomposed. Now here, one has to perform sort of H 2 O balance in the case, because all the H 2 O that is contained in coal it enters into the producer gas; whereas, the steam or the hydrogen of a steam it enters into the producer gas and the H 2 O of moist air it also takes part in the decomposition of a steam.

So, by performing water balance one can determine what is the percentage of H 2 O is blown in that was decomposed. And last, you are also required to find out say what is the percentage calorific value in fuel gas. So, these are the ways or these are sometimes these are the questions that are being asked and for that purpose, one has to perform so called elemental balance. Now, let me illustrate by taking a particular problem.

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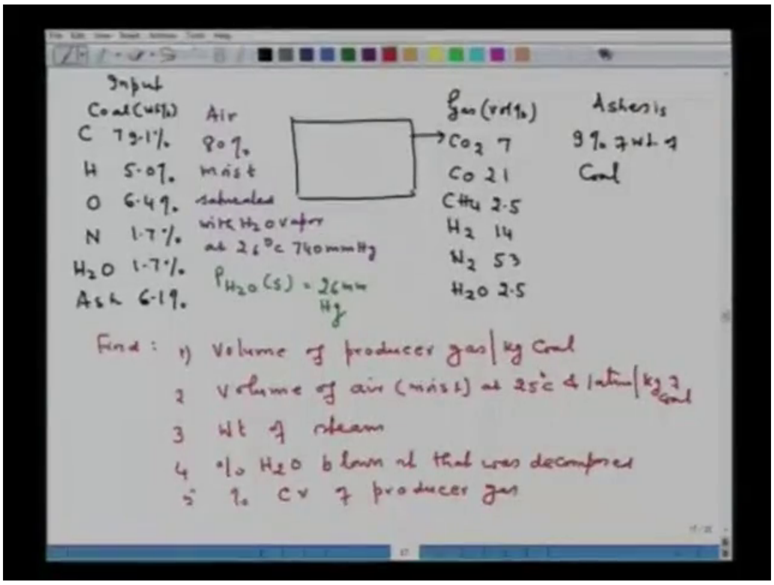

Now, in a in a gasifier coal of the following composition is used which is I am just representing a box just to say separate input and output. So, on the input side, coal of the following analysis it is used for gasification say, the carbon 79.1 percent, hydrogen 5.0 percent, oxygen 6.4 percent, nitrogen 1.7 percent, H 2 O 1.7 percent and ash 6.1 percent and that makes 100.

Now here, air select (( )) this is the coal and this analysis is on wet percent. Now, another input let us take it air, so air is given air is 80 percent moist and it is saturated with water vapor at 26 degree Celsius and 740 millimeter of mercury that is the air is moist and it is saturated with water, the temperature of air is 26 degree Celsius and its pressure is 740 millimeter of mercury. And it is also given that, P H 2 O at saturation at this temperature 26 and 740 millimeter mercury is given to you is 26 millimeter of mercury.

Now, in the output producer gas, whose value is given on volume percent is formed and its composition is C O 2, C O, C H 4, H 2, N 2 and H 2 O. So, C O 2 is 7, C O is 21, C H 4 is 2.5, H 2 is 14, nitrogen is 53, and H 2 O is 2.5. Also it is given the ashes, ashes is simply mixture of ash and carbon. So, ashes are 9 percent of weight of coal that is charged into the gasifier.

Now, you are required to find find volume of producer gas on the find for example, per kg coal number 1. Number 2, you have to find out volume of air volume of air say moist at 25 degree Celsius and 1 atmospheric pressure also per kg of coal. 3, you are required to find out what is the weight of a steam that is blown in. Then you are also required find out percentage H 2 O blown in that was decomposed, because mind you the H 2 content in the producer gas is due to the decomposition of steam.

And all steam decomposes it enters with hydrogen plus also the steam of moist air it also enters or it also takes parts in the decomposition, whereas the moisture of the (( )) is directly enters to the producer gas, because it just evaporates at around 100 degree Celsius and it is it enters to the producer gas. Then, 5 th you have to find out the percentage calorific value of producer gas, so this is what we have to find out.

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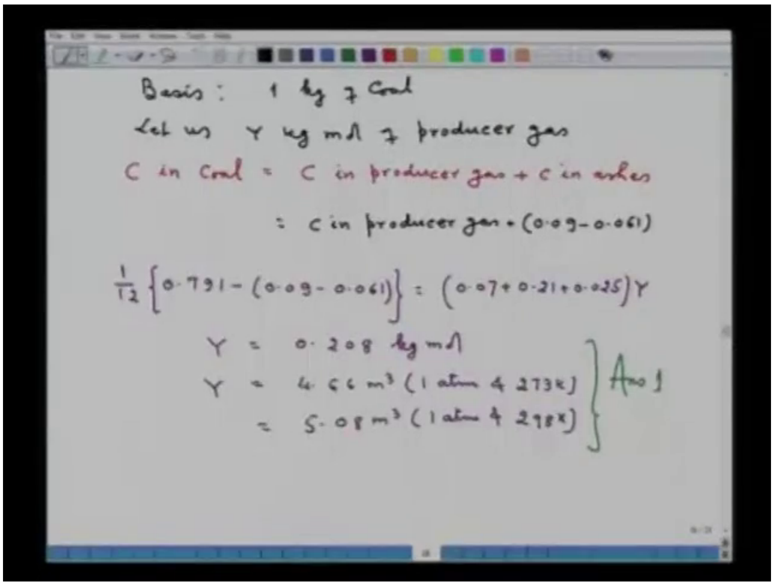

So now, we take first of all basis this is very important here, it is already given you have to find out per kg of coal. So, basis is already clear, so basis is say 1 kg of coal that is you are finding these values per kg of coal. Now, let us consider y kg mol of producer gas. Now here, there is no hard and fast rule that you should consider only kg mole, you can also consider volume the choice is yours say in meter cube.

So now, if you do the balance then carbon in coal that is equal to carbon in producer gas as you see from the input and output diagram and plus carbon in ashes and no where carbon is present. So, we have made the balance that is carbon in coal, carbon in the producer gas, and carbon in ashes. Now, this will be equal to carbon in producer gas.

Now, remember the ash is conserved that is ash of the coal it enters as the ashes. So, directly this will be carbon will be equal to 0.09 minus 0.061 that is what the problem says. So now, if you do the kg balance of coal, then we will be getting say 1 by 12 0.791 minus 0.09 minus 0.061 because this is in k g, so converted to kg mol you have to divide by 12 that will be equal to carbon in producer gas.

Now, since producer gas content C O 2, C O and C H 4, so volume percent is equal to mole percent, so I took kg mol. So, directly I can write down the carbon in producer gas that will be equal to 0.07 plus 0.21 plus 0.025 into y. Now, in this equation the only unknown is y and it can be solved and by solution of this equation you will get the y, if you solve it, it will come to be 0.208 kg mol.

Now, one can transfer it to meter cube say y that will be equal to 4.66 meter cube at 1 atmospheric pressure and 273 Kelvin, whereas this value is 5.08 meter cube at 1 atmosphere and 298 Kelvin. So, that is how you can find out the amount of producer gas by making the carbon balance. So, this is the answer for one which is being asked.

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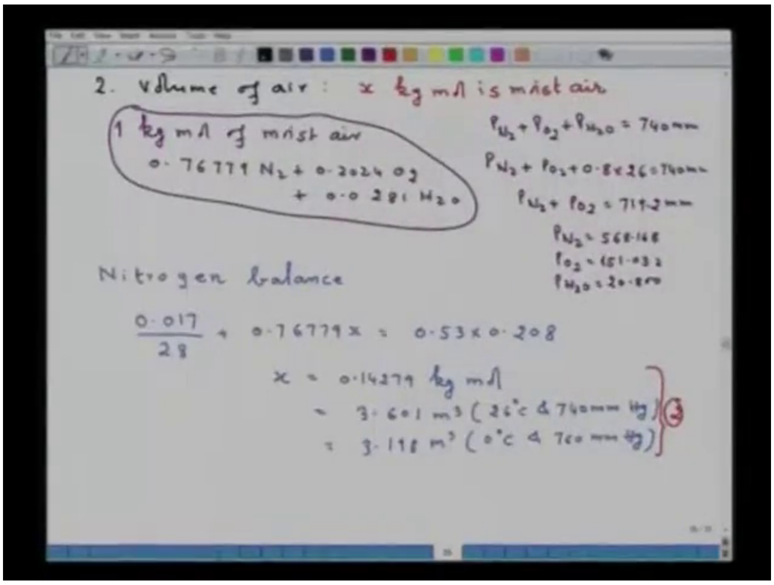

Now, second asked is the volume of air it is the moist air, so second is volume of moist air or I will put just volume of air. Now, let us consider again x kg mol is moist air x kg mol is moist air. Naturally we have to make nitrogen balance, but before nitrogen balance as I have said, you have to first of all find out the composition of moist air, because 79 percent nitrogen and 21 percent oxygen is the composition of dry air.

So, for moist air we have to find out in the following way say for example say, we have now p N 2 plus p O 2 plus p H 2 O that is given to us 700 and 40 millimeter mercury. Now, say p N 2 plus p O 2 plus 0.8 which is the humidity into 26 that is equal to 740 millimeter.

So that, if you solve the equation, then this p N 2 plus p O 2 that is equal to 719.2 millimeter of mercury. Now, again the distribution will be again (( )), so the partial pressure of nitrogen in moist air in this present problem 568.168, p O 2 151.032 and p H 2 O that will be equal to 20.800 and that makes again 740 millimeter.

So from here, we can find out say 1 kg mol of moist air has the composition it will have say, 0.76779 nitrogen I am writing in terms of fraction a percent will be 76.779 plus 0.201 fraction oxygen plus 0.0281 H 2 O. So, this is what the composition of dry of moist air in this particular problem.

Now, once I determine this then nitrogen balance is very easy. Now, the making nitrogen balance always remember to find out the volume of air, always attempt nitrogen balance never attempt oxygen balance, because oxygen is reactive and nitrogen is inert. So, making now nitrogen balance very simple nitrogen from coal plus nitrogen from air that is equal to nitrogen in producer gas, since tar and those things are not given, so it is very simple, so I am straight a way writing nitrogen balance in kg mol. So, that will be equal to 0.017 upon 28 plus 0.76779 that is the, into x which is from air and that is equal to 0.53 into 0.208 that is in the producer gas.

So now, all that you to solve this equation it has only one variable. So, the value of x that is equal to 0.14279 kg mol that is the answer. And this value will be equal to 3.601 meter cube at 26 degree Celsius and 740 millimeter of mercury. Because you have to find out the volume of 1 kg mol at 26 degree Celsius and 740 millimeter and that 1 kg mol it comes out to be equal to 25.22 meter cube you can calculate yourself and convince.

Now, this will also be equal to 3.198 meter cube at 0 degree Celsius and 760 millimeter mercury which is the so called NTP. So, that is how you can calculate the volume of moist air and in fact this is the answer for the question, which is asked number 2.

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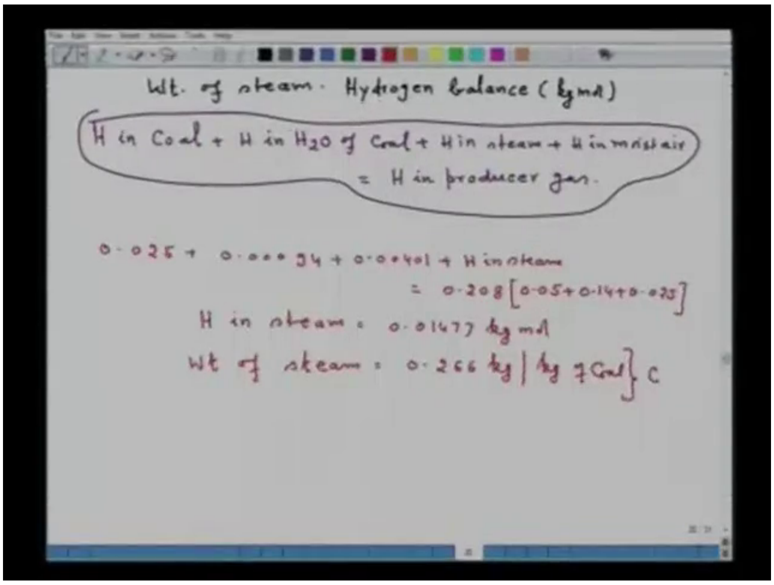

Now, let us go to the weight of steam. Now, third is which is asked the weight of steam, because it is not given. So, as I have said for weight of a steam, you have to do hydrogen balance So, that is what you have to do, you have to make hydrogen balance. Now, again on kg mol basis I am doing on kg mol. So, by performing hydrogen balance in fact H in coal plus H in H 2 O of coal you have to consider from all sources from (( )) H is entering plus H in the steam plus H in moist air, they are all input and the output is only single that is H in producer gas H in producer gas.

So, that is what the balance of hydrogen (( )) make it, now this balance I will be writing in kg mol. So, the balance look that is 0.025 plus 0.00094 I am straight away writing the values plus 0.00401 plus H in steam that is unknown, this will be equal to 0.208 into 0.05 plus 0.14 plus 0.025, because the hydrogen in in producer gas is in the form of C H 4, hydrogen and H 2 O. So, this is how the hydrogen balance looks.

Now here, the only unknown is H in steam. So, I can solve this equation and I can find out now H in steam H in steam that comes out to be equal to 0.01477 kg mol. Now, I have to convert it in terms of k g, so weight of a steam would be multiply by 18, so that answer will be 0.266 kg per kg of coal. So, this is the answer for third one where it is asked what is the weight of a steam.

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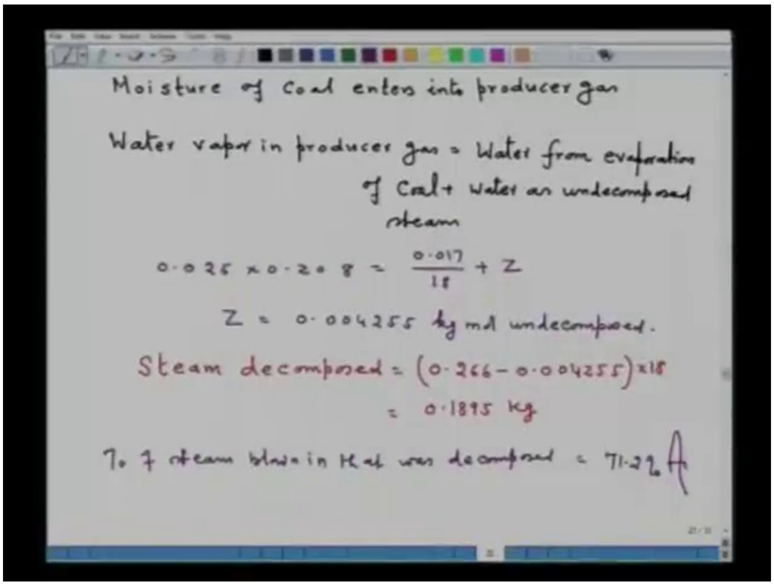

Now, fourth which is asked the percentage H 2 O blown in that was decomposed. Now, here say moisture of coal moisture of coal it enters into producer gas. Say, I will do now say water vapor in gas producer a water vapor in producer gas that is equal to water from evaporation of coal plus water as undecomposed steam, because the steam which does not decomposed it directly enters into the producer gas. So, by doing the water vapor balance, one can determine the undecomposed steam, and from the total steam we subtract it we get the steam which is decomposed.

So, if I do this balance and write it say for example, 0.025 into 0.208 that is equal to 0.017 upon 18 plus, if I consider z mols of water which are undecomposed, then I can find out the value of z that is equal to 0.004255 kg mol undecomposed. So, steam decompose will be, steam decomposed that will be equal to 0.266 minus 0.004255.

So now, here itself if we want to know in kg multiplies by 18, so the answer will be 0.1895 kg steam which is decomposed. So, percentage of steam blown in that was decomposed, it was decomposed simply decomposed upon total into 100. So, that answer is 71.2 percent. So, that is the answer for fourth one.

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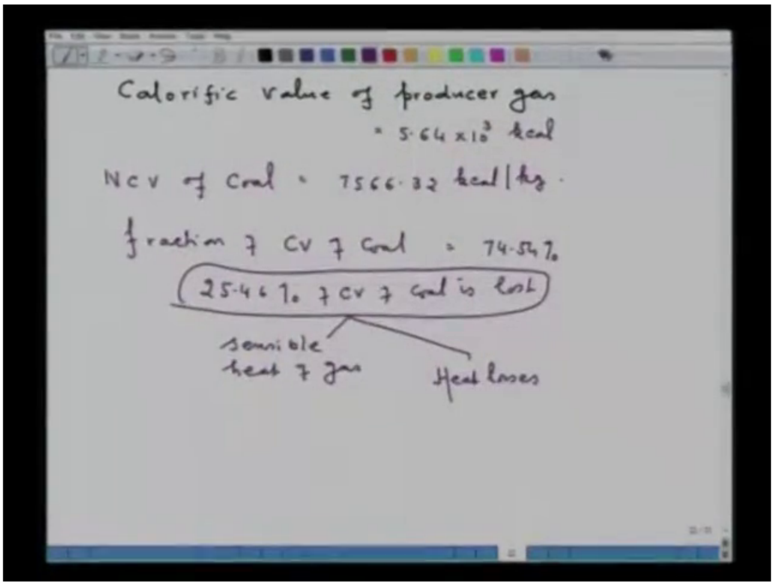

Now, we have to find out calorific value to determine calorific value of producer gas. Now, the determination of calorific value we have done on several occasions in the earlier lectures also. So, all that you to find out the combustible component of the producer gas, find out there kg mols multiply by their respective heat of combustion; add them together and you will be getting the calorific value of the producer gas. I do not enter into those detail calculation that you can do yourself. So, the calorific value of producer gas that you will be getting is 5.64 into 10 to the power 3 kilo calorie.

Now, if you are if you are interested in finding out what is the fraction of calorific value of coal that is present in producer gas, then you have to find out say N C V of coal, Net Calorific Value of coal; again by Dulong formula and this comes out to be equal to 7566.32 kilo calorie per k g. Now here, section to find out the fraction, so the fraction of C V of coal fraction of C V of coal that is available in producer gas, that is comes out to be equal to 74.54 percent.

Now here, it is also important to know what happens that means you are unable to find 25.46 percentage of calorific value of coal is lost that is, this analysis is very important. Now, these losses they can be of several nature one loss could be, so sensible heat of gas, because producer gas is discharged at some temperature, so it will also carry sensible heat and second loss could be heat losses.

So, this thing will help you to locate and take effective measure in order to conserve the heat. So, that is how you will be performing the, so called material balance. Now, for your practice I am giving you one more problem that you can solve yourself and the problem is as follows.

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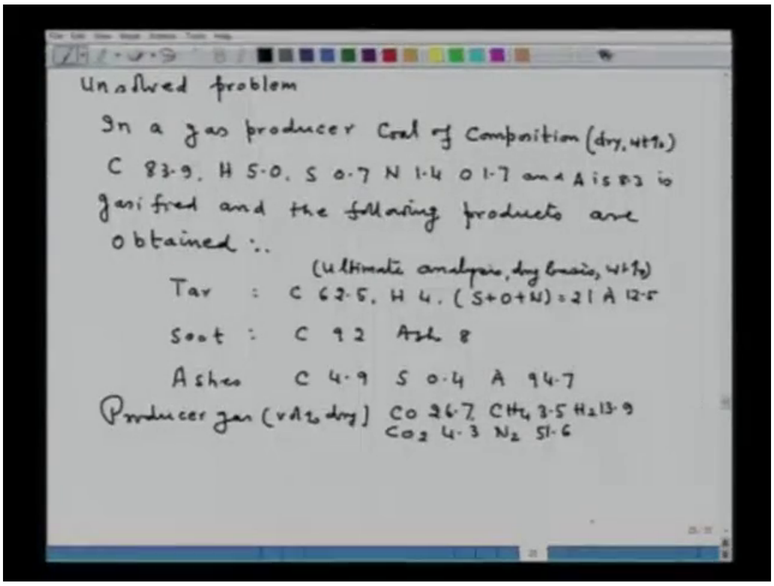

So, I am giving you an unsolved problem and this unsolved problem I have taken from the book of human metallurgical engineering principles. So, the problem is as follows. In a gas producer in a gas producer coal of composition composition is on dry basis and given in wet percent. Say, carbon 83.9, hydrogen 5.0, sulfur 0.7, nitrogen 1.4, O 1.7 and the ash is 8.3 all in percent, A is for ash. Now, this coal is gasified and the following products are obtained and the following products are obtained.

So, tar, soot and ashes, the analysis is given ultimate analysis, ultimate analysis dry basis and given in (( )) percent of all the three products. Tar analysis, carbon 62.5, hydrogen 4, now mind here given percent sulfur plus oxygen plus nitrogen that is equal to 21 and ash is 12.5; soot, carbon 92, ash 8; ashes, carbon 4.9, sulfur 0.4 and ash 94.7 percent. Producer gas composition on volume percent and on dry basis, it is given C O 26.7, C H 4 3.5, hydrogen 13.9, C O 2 4.3 and nitrogen 51.6. The problem continues on the next page.

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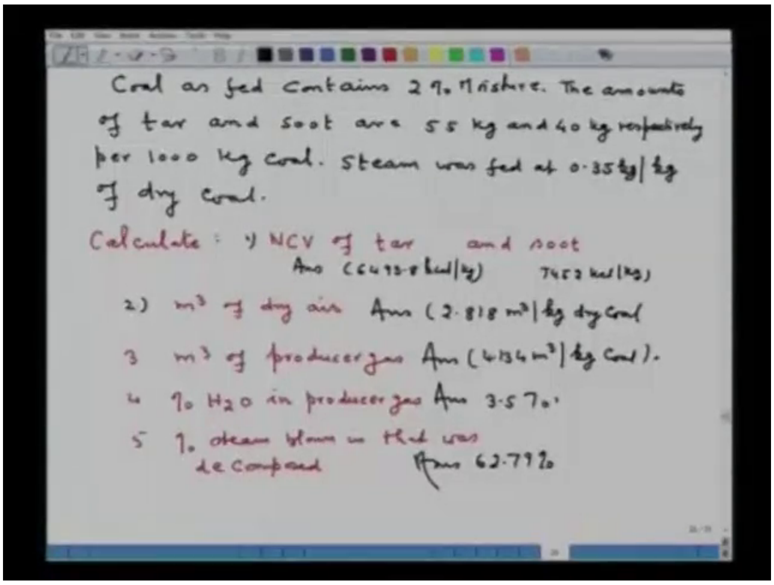

Say, coal as fed contains 2 percent moisture air is dry. The amounts of tar the amounts of tar and soot are 55 kg and 40 kg respectively per 1000 kg coal. Steam was fed at 0.35 kg per kg of dry coal. Now, in the problem we are referring only the dry coal, because the analysis is given on the dry basis.

So, what you are required, you are required to calculate say, calculates net calorific value of tar and soot. Now, mind you in calculating the Net caloric value of the tar, in the tar decomposition N plus O plus S is total is given. So, we have to find out first of all, the O content of the tar according to do proper balances. So, I am giving straight away the answer to you, so that you can solve. So, the N C V of tar is 6493.8 kilo calorie per kg and that of soot is 7452 kilo calorie per kg this is the answer.

Now, second you have to find out meter cube of dry air, and the answer for this is 2.818 meter cube per kg dry coal. Third, find out meter cube of producer gas and the answer for the meter cube of producer gas, answer is 4.134 meter cube per kg coal. Then, you find out percentage H 2 O in producer gas, answer 3.5 percent. Then you have to find out percentage steam blown in that was decomposed, that was decomposed and the answer for this is 62.79 percent.

Now, mind you here, you have to do the proper balance in order to find out the various things which have been asked over here, example I already given. So, you have perform it, you have to find out the weight of ashes then again do carbon balance, hydrogen balance, nitrogen balance, oxygen balance and so on. I think you should be able to do it.

Now next, which I want to illustrate a little bit about the heat balance as I have said, that is heat consumed for decomposition of a steam that should be equal to heat produced by the gasification reaction. So, if you do a simple problem. So, the problems on say heat balance.

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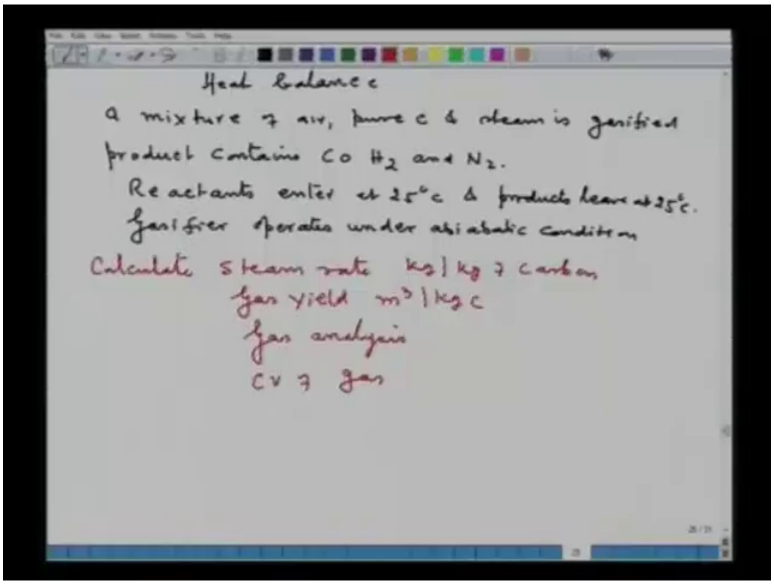

Say, in a producer, a mixture of air a mixture of air pure carbon and steam is gasified and steam is gasified. So, that the gasification reactions go to completion and the product contains C O, H 2 and nitrogen. Reactants enter at 25 degree Celsius and products leave at 25 degree Celsius, the gasifier it operates under adiabatic condition under adiabatic condition.

Now for this, ideal adiabatic gasifier you calculate a steam rate that is kg per kg of carbon, you calculate gas yield in meter cube per kg of carbon, then gas analysis and then calorific value of producer gas or of gas which is being made, calorific value of gas that is what you have to calculate. This gasifier uses air for gasification. So, very simple the gasification reaction we have to write down, so the gasification reactions are.

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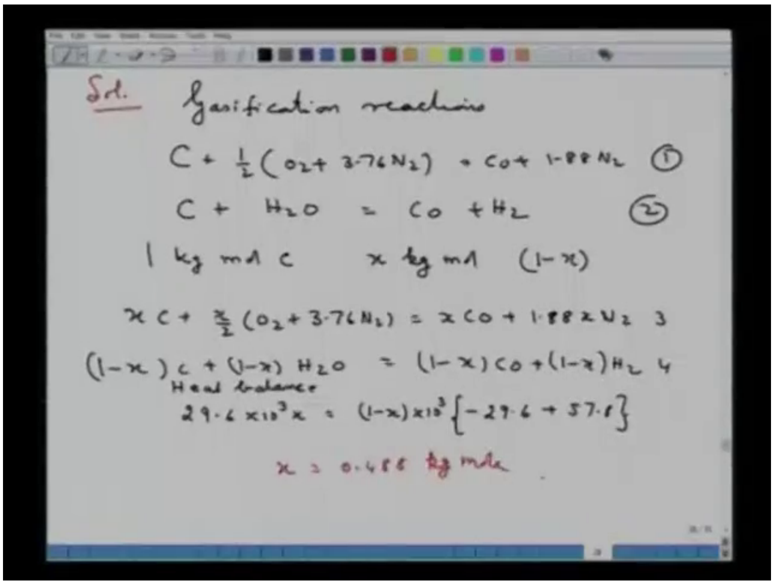

The solution gasification reactions are C plus half O 2 plus 3.76 N 2 that is equal to C O plus 1.88 N 2 it is number 1. Number 2, C plus H 2 O that is equal to C O plus H 2. So, reaction 1 is exothermic, reaction 2 is endothermic. So, now say considered 1 kg mol of carbon, 1 kg mol carbon that is available to us.

And let say, x kg mol carbon is used in reaction 1. Then 1 minus x kg mol of carbon will be left for reaction number 2. So, if you write down those reaction again, say x C plus x by 2 O 2 plus 3.76 N 2 that will be equal to x C O plus 1.88 x N 2, this is reaction number 3. Now, then 1 minus x C plus 1 minus x H 2 O that will be equal to 1 minus x C O plus 1 minus x H 2 that is what the reaction is there.

Now, by doing the heat balance say, heat produced by equation 1 that will be equal to heat produced by equation 2 or more precisely in terms of mols that you have used, x kg of mols, then heat will be produced by 3 and heat will be consumed by 4. So, if you write down the heat of combustion values I had already given on several occasions.

So, I am straight away writing from here, the heat balance the heat balance will come to be equal to 29.6 into 10 to the power 3 x that is I write here heat balance, that will be the heat produced by consumption of x kg mol in reaction 3; and that will be equal to 1 minus x into 10 to the power 3 minus 29.6 plus 57.8 that is the heat consumed by reaction 4. So, I solve this equation I will be getting the value of x that equal to 0.488 kg mol.

So, what I do now, I rewrite the equations 3 and 4, and straight away I can calculate the questions which have been asked I am straight away calculating.

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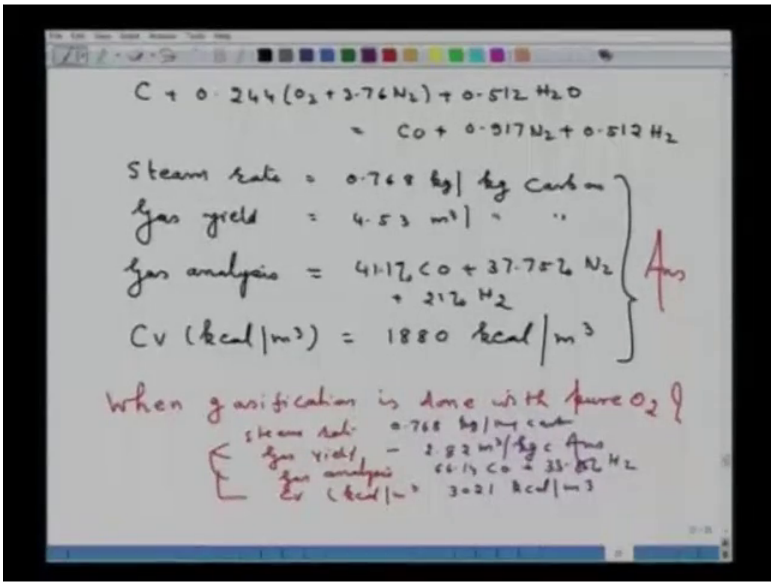

I will write equation for you, so the equation now C plus 0.244 O 2 plus 3.76 N 2 plus 0.512 H 2 O that will be equal to C O plus 0.917 nitrogen plus 0.512 H 2. Now, it is straight away, so steam rate steam rate will be simply 0.512 into 18 divided by 12. So, this answer will be 0.768 kg per kg carbon.

Gas yield, 1 plus 0.917 plus 0.512 multiply by 22.4. So, the gas yield will be equal to 4.53 meter cube per kg carbon. Now, gas analysis simply 41.1 percent, C O 37.75 percent, nitrogen and 21 percent is the hydrogen. Now, you can find out calorific value, it has been done on several occasions in per meter cube that will come to be equal to 1880 kilo calorie per meter cube. So, that is the answers along with the solution for that particular problem.

Now, I will request you to do this problem and repeat the calculation on a steam rate, gas yield, gas analysis, when gasification is done with pure oxygen. So, I repeat once again for the same adiabatic operation of the gasifier the only difference now is that the gasifier is operated now using pure oxygen. Earlier, it was operated with air. Now, I am operating with pure oxygen, rest all are same.

So, you have to calculate again steam rate, so calculate gas yield, calculate gas analysis and calculate calorific value again kilo calorie per meter cube. So, if I thought I will not give you the answer, but well answer I should give, because steam rate will be the same as it was earlier, the gas yield now the answer would be equal to 2.82 meter cube per kg carbon, this is the answer.

A steam rate is same as 0.768 kg per kg carbon. Gas analysis would be 66.14 percent C O, and 33.86 percent hydrogen, and its calorific value per meter cube is 3021 kilo calorie per meter cube. So, you are seeing now, if you operate the gasifier with pure oxygen, then the calorific value of the producer gas it increases by a factor of say, earlier it was 1880, now it is 3021 is of the order of I will say of the order of 1.6 times and that is what the advantage of gasification with oxygen.