Materials and Energy Balance in Metallurgical Processes

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Module No. # 01

Lecture No. # 37

Additional Topics-III Material Balance in Gasification

In the previous lecture, I have discussed the concept of gasification. Now, I thought, let us go for material and heat balance in gasification. So, what I have designed for this lecture is as follows: first, I will give you how to calculate the various parameters in material and heat balance of gasification. Then, I will take an example, to illustrate what I have told you and how to do this thing. So, first of all, let us consider a simple gasification process.

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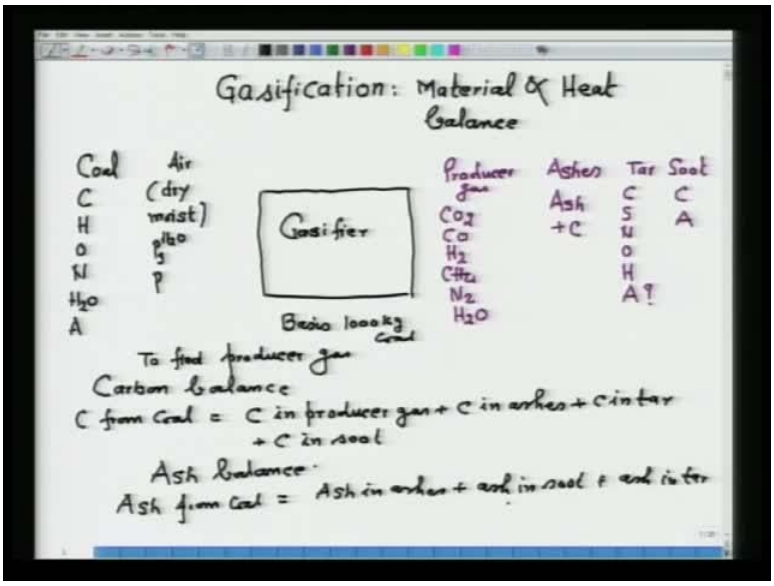

So, if you consider, this is a gasifier and here we are supplying coal. A composition is given: carbon, hydrogen, oxygen, nitrogen and it may have H_2O, Ash - this is what is given; then air may be given; it is dry or it may be moist. When moist air is given, then, saturation pressure of water vapor in air should also be given. Then, pressure - that is atmospheric pressure at which air is supplied, are also to be given. Now, in the output, you have producer gas. I am taking a simple example where producer gas could have CO_2; it could have carbon monoxide; it could have hydrogen; it could have CH_4, nitrogen and it could have H_2O; main constituents in producer gas then output of gasifier is also ashes.

Now, ashes means - it is a mixture of ash plus carbon because in the previous lecture you have seen, when the coal come burns, then ash is left over and it is discharged. Along with that, some very fine particles of carbon are also discharged. So, that is called ashes; not ash. So, ashes is a mixture of ash plus carbon; then, you have output also as a tar; tar may contain carbon, sulfur, nitrogen, oxygen and hydrogen. Then another output could be soot and the soot composition may contain carbon or it may contain ash. Tar may also contain ash; it depends on the problem.

So, given this - the balance, or given these inputs and outputs, we are required to find out, for example: volume of producer gas, then amount of air that is required, calorific value and so on and so forth. So, in order to find out for example, to find out let us say producer gas, what will we do to find out producer gas? produced

I mean there are various terms. You may call producer gas; you may call fuel gas; also all that means simple that it is a mixture of CO plus hydrogen. So, if you want to find out the amount of producer gas, then simple; one has to do carbon balance. One has to do carbon balance and carbon balance say you have to take into account, all sources from where entering and out. So, in this particular example, a carbon from coal - that is equal to carbon in producer gas plus carbon in ashes plus carbon in tar plus carbon in soot. So, out of which, the amount of soot must be given, amount of tar is also given, then amount of coal you may declare - the basis of your calculation could be 1000 kg coal. You can take 1 kg coal, 1000 kg coal; whatever you like, the basis is always clear.

So, in some cases, the amount of ashes is also not given. Then you have to do ash balance. Ash balance in this particular case, say ash from coal - that goes, ash in ashes plus ash in soot plus ash in tar, if it is given. Then, from the amount of soot is known, amount of coal is known, amount of tar is known, and percentage of ash is ashes, is known.

So, by that balance, you can find out the amount of ashes, and from the amount of ashes, you can complete the carbon balance; the unknown is only amount of producer gas. So, you can find out the amount of producer gas. Now, next thing that you have to find out is, for example, how much amount of steam is decomposed?

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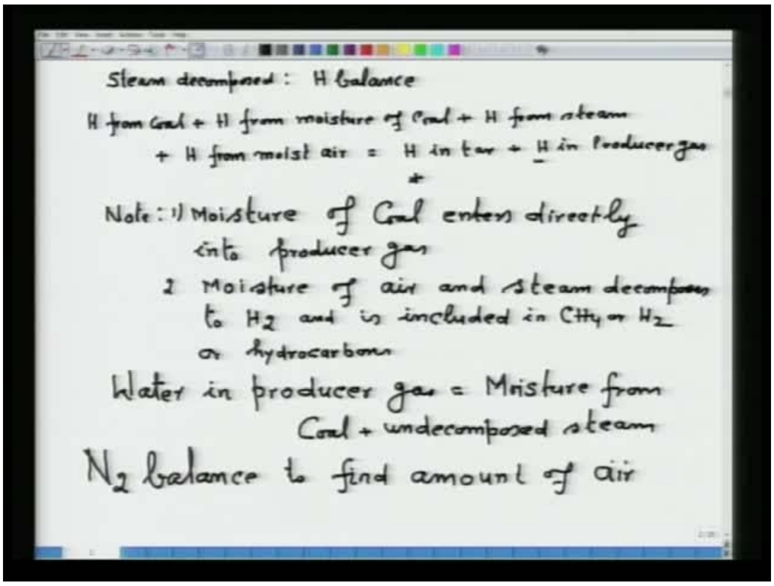

So, to find out steam decomposed, what you have to do? You have to perform hydrogen balance. You have to perform hydrogen balance. I am writing H balance because the coal, tar or soot - they always contain elemental hydrogen; whereas, gas - it contains H_2; it does not contain H. So, write down hydrogen balance. Then, hydrogen balance - H from coal plus H from moisture of coal plus H from steam because you are supplying steam whose amount is given. Plus, do not forget to add H from moist air because when you have the moist air, H will also enter into the system.

So, that will be equal to H in tar plus H in producer gas plus H in producer gas. Here, what I have done by taking H in producer gas? I have taken into the account, H_2 of producer gas as well as H_2O of producer gas. So, both I am putting under the term H; as you wish, you can write down. H_2 in producer gas plus H in water of producer gas - that is one and the same thing. So, choice is yours.

So, while performing H balance and calculating the steam decompose, you have to take note of the following. So, note the following important aspect of gasification, say, moisture of coal enters directly into producer gas - that is one important thing. Second important thing that you should note is - moisture of air and steam decomposes to H_2 and is included and the hydrogen so produced is included in CH_4 or hydrogen or other hydrocarbons, if they are present.

That means if you want to calculate water in producer gas, it follows: That is water in producer gas is equal to moisture from coal plus undecomposed steam. So, that point is important to remember. I will illustrate once again when I solve the problem for you.

Now, nitrogen balance is to be done to find the amount of air.

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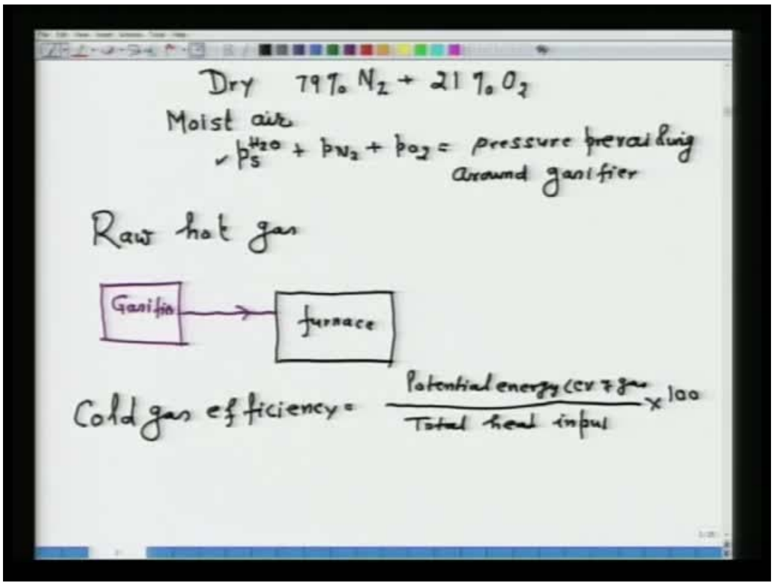

Here, one should note that, if the air is dry, then it is clear that 79 percent nitrogen and 21 percent is oxygen - that is clear. Now, if the air is moist, for the moist air, this composition is no longer valid. So, there you have to find, say for example, Ps H_2O plus pN_2 plus po_2 - that is equal to pressure prevailing around the gasifier. It could be 740 millimeter, 745 millimeters; it will be given the problem.

Now, in order to find out Ps H_2O, you have to take into account, the relative humidity and the saturation vapor pressure. If you multiply, you will get this particular amount. So, if you subtract this Ps H_2O from pressure prevailing the around the gasifier, you get pN_2 plus po_2.

Now, this becomes dry air. So, 79 percent of that and 21 percent of that will give you the proportion of nitrogen and oxygen and H_2O in there. So, that part is to be taken into care. This is all about the material balance.

One should also note that the raw hot gas because in the material balance, you have seen on the right hand side. The right hand side contains producer gas, tar, soot and everything; I will call it to be a raw hot gas. This raw hot gas can be delivered directly into the furnace. That means, if I take, for example, this is a furnace and I put one gasifier here - this is a gasifier (Refer Slide Time: 12:38), what can I do? I can connect this output of the gasifier with an insulated pipe to the furnace and I am using the gas which is produced from the gasifier.

The advantage of such is that, besides using the calorific value of the producer gas, tar, soot, you will also be able to use the so called sensible heat of producer gas, sensible heat of tar and sensible heat of soot and so on. So, that is the advantage of using directly, the producer gas from the gasifier to the furnace, but at the same time the producer gas is not clean. So, it may clog the nozzles through which you are supplying the producer gas into the furnace. So, the normal practice is to cool the gas to clean it. In that process, we are losing the sensible heat. I will show you how much percent we are losing and how much we can use the cold gas; that means, its potential energy only.

So, in that case, we define certain efficiency. For example, you may define cold gas efficiency. Cold gas efficiency would be say potential energy; the potential energy is called calorific value of producer gas divided by total heat input. Of course, you have to multiply it by 100 in order to get the percent.

Now, the total heat input comprises of what? calorific value of fuel plus sensible heat of coal - if it is heated plus sensible heat of air plus sensible heat in steam. So, all will correspond to total heat input. So, that is called the cold gas efficiency. Now, you see here, in that cold efficiency, you are taking only the potential energy of the fuel. You are not taking the sensible heat of the various constituents that are present in the output of a gasifier because you have cooled down everything.

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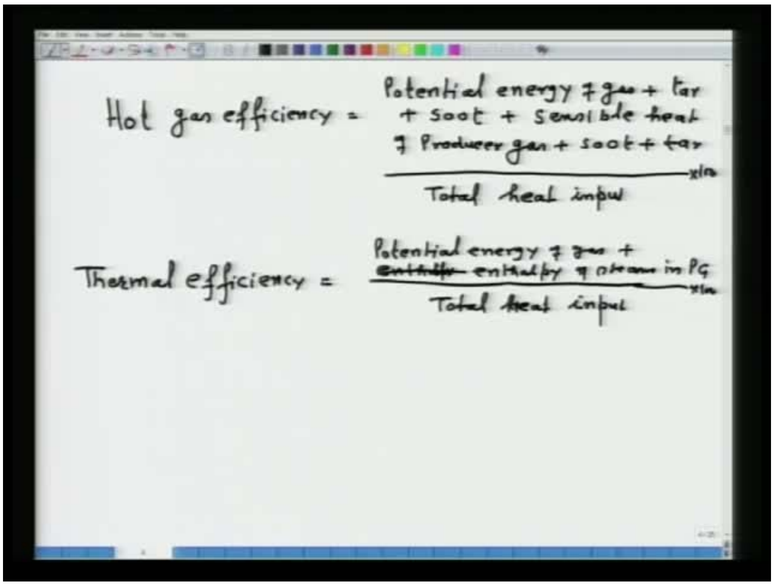

So, next we will define the hot gas efficiency. and also define hot gas efficiency

Now, the hot gas efficiency will contain potential energy of gas. Mind you, potential energy is also called calorific value of gas plus tar plus soot plus sensible heat of producer gas plus soot plus tar. If other outputs are also there, you divide by the total heat input.

The total heat input, of course, you have to multiply by 100 in order to get the percent. Naturally, the hot gas efficiency will be much much higher than the cold gas efficiency because you have incorporated in your calculation, the sensible heat, which was not there in case of cold gas efficiency.

Then, we can also define the third term, that is, the Thermal efficiency.

The thermal efficiency - that is equal to potential energy of gas; gas, I mean the producer gas; potential energy of gas plus enthalpy of steam in producer gas because you know the producer gas contains water, but it is high in temperature; so, it is in the form of the steam. So, again you divide by the total heat input. Total heat input, of course, you have to multiply by 100 to get the percentage. Normally, the cold gas efficiency lie within the range 60 to 80 percent. Hot gas efficiency is in the order of around 90 percent because you are adding all sensible heat into your calculation.

Then, the losses - there will be losses also by conduction and radiation from the gasifier. It may verify from 8 to 12 percent; It depends upon insulation that you provided on the gasifier.

Now, given all this way to solve the problem, let me take a problem to illustrate the various concepts.

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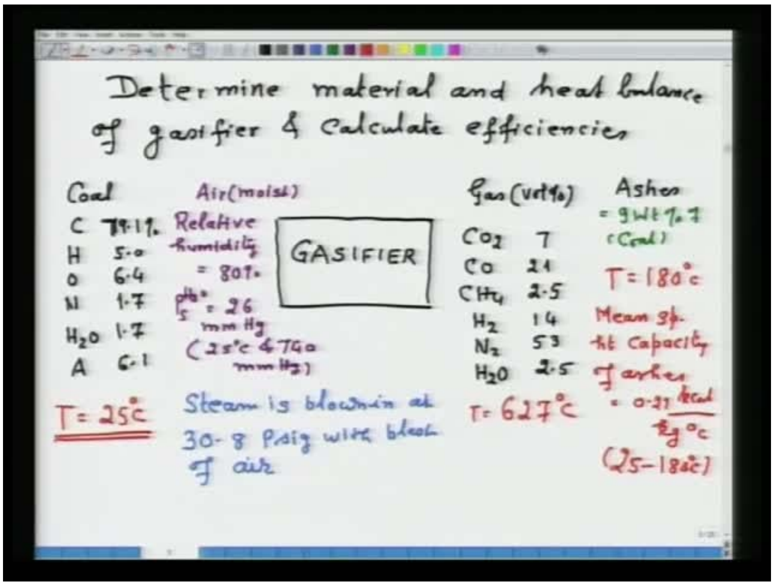

Let us find out, say determine, material and heat balance material and heat balance of gasifier and calculate various efficiencies.

Now, various data that I am giving over here, in the form of a material balance. So, let us take, this is a sort of gasifier to which the coal is supplied. The composition of coal: carbon, hydrogen, oxygen, nitrogen, H_2O and ash; carbon 79.1 of course, it is on weight percent, hydrogen 5.0 percent, oxygen 6.4 percent, it is 79.1 percent nitrogen 1.7 percent, H_2O 1.7 percent and ash is 6.1 percent.

Since I wrote that heat balance is needed, I am giving you are supplying at temperature T that is equal to 25 degree Celsius. I am writing in red so that you remember and you can see easily. Now, air is moist; you put that air is moist and it has relative humidity that is equal to 80 percent and the vapor pressure at saturation that is given - that is equal to 26 millimeter mercury at 25 degree Celsius and 740 millimeter pressure. That means the pressure around the gasifier is not 760, but it is 740 millimeter.

Now, here also, it is given that steam; you have to blow at certain pressure. So, steam is blown at 30.8 Psig; you must know this unit - pounds per square inch gas pressure. That means it is gas pressure; it is not absolute pressure; you have to add 14 .7 to get the absolute pressure. Pressure steam is blown in at this pressure with blast of air. That is given. Now, in the output, it is given - gas which is forming and it's analysis remember is on volume percent. It has CO_2, it has CO, it has CH_4, it has hydrogen, it has nitrogen and it has H_2O.

Now, CO_2 is 7 percent - that is 21 percent, 2.5 percent, hydrogen is 14 percent, nitrogen is 53 percent and H_2O is 2.5 percent. (Refer Slide Time: 21:47) The temperature at which it is discharged is 627 degree Celsius - that is the temperature of its discharge. Now, ashes - they are forming also. Ashes - its amount is 9 weight percent of coal; that is given. 9 weight percent of coal, that is ashes, is given, and it is discharged at temperature T that is equal to 180 degree Celsius.

Now, it is also given the mean specific heat capacity of ashes; mean specific heat capacity of ashes is given to you; that is, 0 point 21 kilocalorie per kg degree Celsius between 25 to 180 degree Celsius.

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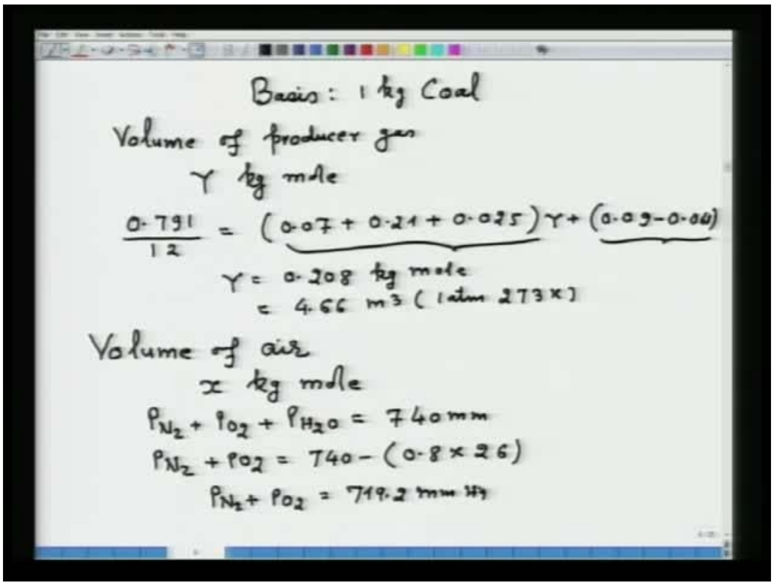

So, these values are all given. Now, let us proceed first of all for the material balance. So, first you have to take the basis as I have said. So, the basis of our calculation is 1 kg coal. Now, to find out the volume of producer gas, we have to find out volume of producer gas because in order to do heat balance, you must know the amount of all.

The problem does not say what amount you have to find; the problem says, do the material balance and heat balance; so, it is up to your thinking that, what is required to perform the heat balance. You must know the amount; without that you cannot do. So, first amount is - missing volume of producer gas. So, volume of producer gas we have to find.

As I illustrated in the beginning, if we take Y kg mole as the volume of producer gas and if we do the carbon balance, then I am simply straight away writing the carbon balance 0.791 upon 12 - that will be equal to 0.07 plus 0.21 plus 0.025 into Y Plus 0.09 minus 0.061. That is the carbon in ashes and this is carbon into producer gas (Refer Slide Time: 24:51). So, if I solve, I will be getting Y, that is equal to 0.208 kg mole; mind you, it is per kg of coal, or that is also equal to 4.66 meter cube per kg coal at 1 atmosphere and 273 Kelvin. So, I have got the volume of producer gas. Now, I have to find out volume of air.

To find out the volume of the air - remember, here it is a moist air. So, let us see.

Let us say, x kg mole is the amount of air. Since air is moist, we have to calculate the composition of air; it is not 7921. So, PN_2 plus PO_2 plus PH_2O - that is equal to 740 millimeter; that is given to us. Now, we can find out PN_2 plus PO_2 - that is equal to 740 minus 0.8 into 26; that will give you PH_2O. So, with this, I am getting PN_2 plus PO_2 and that is equal to 719.2 of course, millimeter of mercury.

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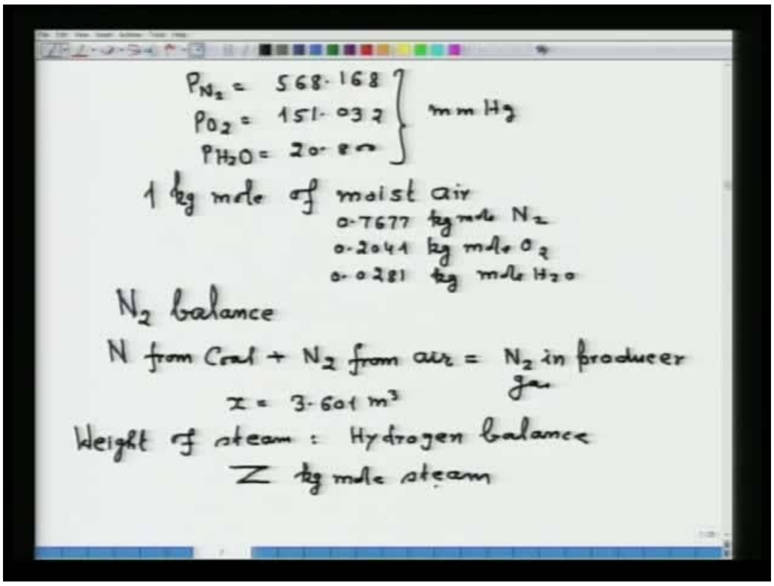

Now, this 719 will be divided 7921. So, I can get PN_2 568.168 millimeter mercury, PO_2 151.032 and PH_2O is 20.800; they are all in millimeter mercury. Now, I can say, 1 kg mole of moist air will contain 0.7677 kg mole nitrogen, 0.2041 kg mole oxygen and 0.0281 kg mole H_2O. Of course, this should become 1, if you round off. I am seeing that, it is not becoming equal to 1; somewhere round off and it will become equal to 1; that does not matter.

Now, we can do nitrogen balance. Nitrogen balance is simple. N from coal plus N_2 from air - that is equal to nitrogen in producer gas. So, you can do this balance and the value of x that we assume is equal to 3.601 meter cube at the temperature of 25 degree Celsius and 740 millimeter mercury.

Now, we have to find out weight of steam because that is not given in the problem. Sometimes it is given; sometimes it is not given. So, you have to find out weight of steam, and for that, you have to do hydrogen balance.

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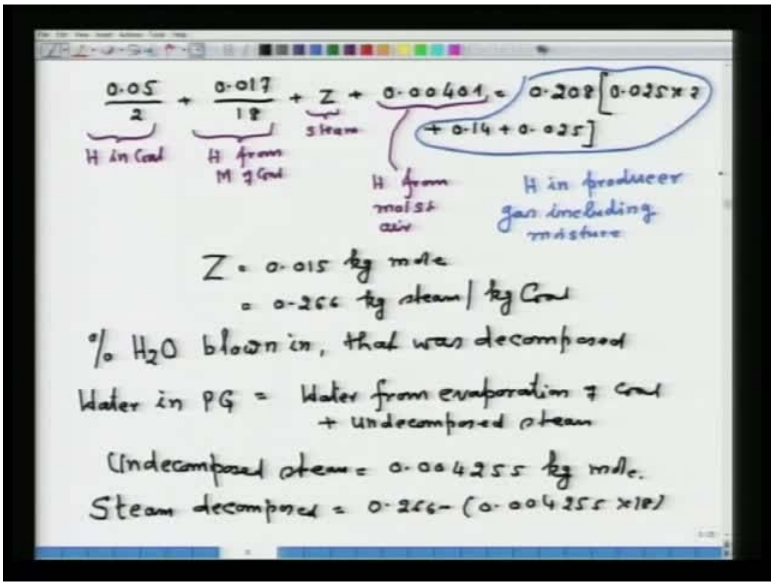

Let us consider Z kg mole. Z kg mole is the amount of steam. So, if I do that hydrogen balance, it is 0.05 upon 2 plus 0.017 upon 18 plus Z plus 0.00401 that is equal to 0.208 0.025 into 2 plus 0.14 plus 0.025. So, for your orientation, what I am doing this amount is H in coal (Refer Slide Time: 30:16). This amount is H from moisture of coal; M stands for moisture; Z we assume as steam and this is, this amount is H from moist air (Refer Slide Time: 30:39). This amount is H in producer gas, including moisture or steam or H_2O (Refer Slide Time: 30:52), whatever you like to call. If you are doing at the cold then it is H_2O; if it is hot it is a steam.

So, that is the hydrogen balance; I have written this thing so that you can orient yourself what I have done. Now, I have to simplify this. You can do it. So, the value of Z is equal to 0.015 kg mole. So, that is equal to 0.266 kg steam, of course, per kg coal.

Now, we have to find out percentage H_2O blown in, that was decomposed. Now, that simply mean, whatever steam that decomposes is available to you in the form of hydrogen or CH_4 and so on. So, we can do that balance, say, water in producer gas or steam or moisture in producer gas - that is equal to water from evaporation of coal plus undecomposed steam because that will also enter as water in the producer gas.

So, if you do this balance, you can find out the amount of undecomposed steam. The undecomposed steam; here it comes; you can simply substitute the value. Undecomposed steam - that comes to be equal to 0.004255 kg mole. Therefore, steam decomposed will be equal to 0.266 kg minus 0.004255 into 18. So, the amount of steam decomposed will be equal to 0.1895. This is the kg; this is the steam decomposed.

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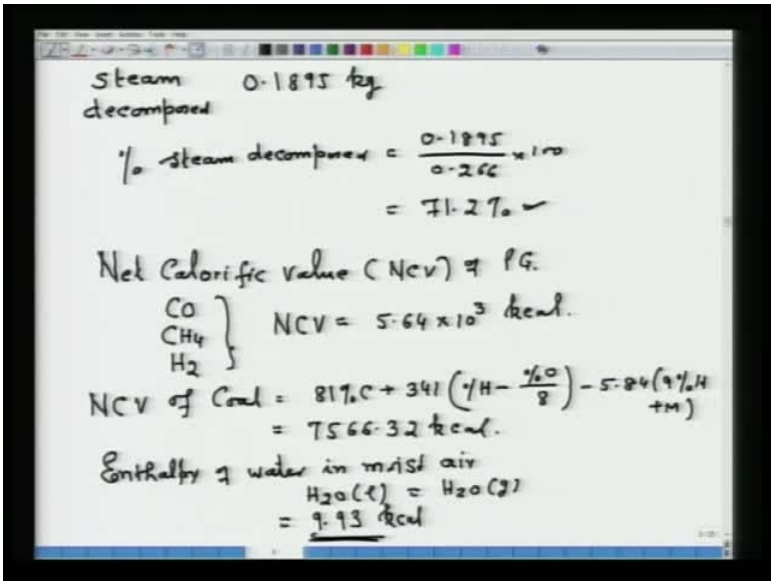

Mind you, this steam which is decomposed will be available to you in H_2, CH_4 and other hydrocarbons of the producer gas. So, percentage steam that is blown in, percent steam decomposed will be equal to 0.1895 divided by 0.266 into 100. So, the decomposed steam is 71.2 percent. So, this is the answer of this problem. Now, having done material balance, we are in a position to do heat balance. For that, we have to calculate the various values. First of all, we have to calculate Net calorific value. Net calorific value, in short, I am writing NCV of producer gas.

Now, the procedure of calculation, I had already given in my previous lecture. The various heat of formation values are also available. So, straight away, the NCV of producer gas, I can calculate. The combustible components of the producer gas are: carbon monoxide, CH_4 and hydrogen. We know their heating values; we know how much kg mole they are forming. So, as such, NCV will come out to be equal to 5.64 into 10 to the power 3 kilo calorie.

Similarly, we can calculate NCV of coal. I given the formula, but once again, I can write down NCV of coal; that will be equal to 81 percent carbon plus 341 percentage H minus percent O upon 8 minus 5.84 into 9 percent H plus M this will be in kilo calorie per kg. So, it substitutes the percent value. So, NCV of coal will be equal to 7566.32 kilo calorie.

Then, you have to find out enthalpy of water in moist air. You have to find out enthalpy of water in moist air.

So, that means, we have to find out H_2O liquid to H_2O gas, and seeing the amount of this, the enthalpy would be 9.93 kilo calorie. This enthalpy is simply the latent heat of condensation.

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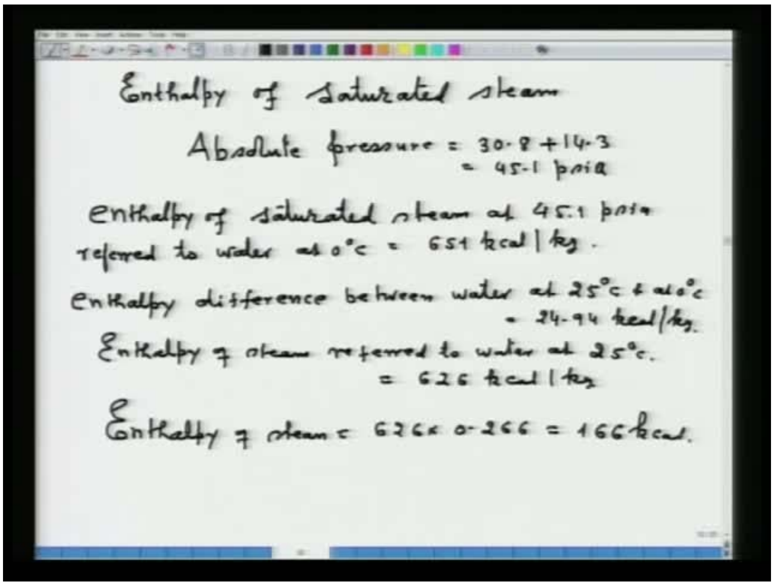

So, from that, you can calculate. Now, we are supplying steam also; so, another input you require, that is enthalpy of saturated steam. For that, you have to see the steam table and the relevant values I am giving here. Our gas pressure is 30.8 psi - that is given. Pressure surrounding the gasifier is 740 millimeter and if you convert, it comes out to be 14.3 psi. So, the absolute pressure is equal to 30.8 plus 14.3; that is equal to 45.1 psi. Now, it is an absolute pressure psi a.

Now, here, some data say, enthalpy of saturated steam.

Enthalpy of saturated steam at 45.1 psi a referred to water at 0 degree Celsius - that you can find out from steam table; that is equal to 651 kilo calorie per kg.

Now, say, enthalpy difference: because you are supplying at 25 degree Celsius, enthalpy difference between water at 25 degree Celsius and at 0 degree Celsius is equal to 24.94 kilo calorie per kg. Therefore, enthalpy of steam referred to water at 25 degree Celsius is equal to 626 kilo calorie; approximately, 24.95 to 25. So, it is kilo calorie per kg.

Enthalpy of steam: Now we can find out enthalpy of steam which is going into the process 626 into 0.266. So, enthalpy of steam - that is equal to 166 kilo calorie.

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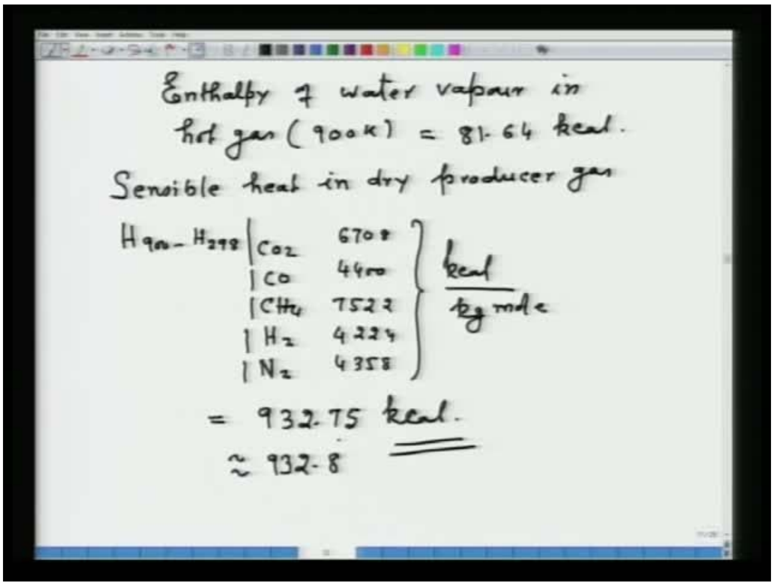

We have to calculate now enthalpy of water vapor in hot gas.

Enthalpy of water vapor in hot gas that is at 627 degree Celsius and the temperature is 900 and Kelvin. So, you know the procedure. So, that enthalpy will come out to be 81.64 kilo calorie.

Now, one has to calculate also sensible heat in dry producer gas; dry I am writing because water I already found out. So, now, I do not need to find out the enthalpy content of H_2O of producer gas. So, the sensible heat the values are: H 900 minus H 298 for CO_2, for CO, for CH_4, for hydrogen and for nitrogen.

So, this value is 6708, 4400, 7522, 4224, 4358 - these values are all in kilo calorie per kg mole. So, now, all that you have to multiply by the kg mole of the respective component of the producer gas. If you do that, then the sensible heat in dry producer gas - that comes out to be equal to 932.75 kilo calorie. So, now, we are in a position to make the heat balance. Now, this I am putting, say, approximately 932.8.

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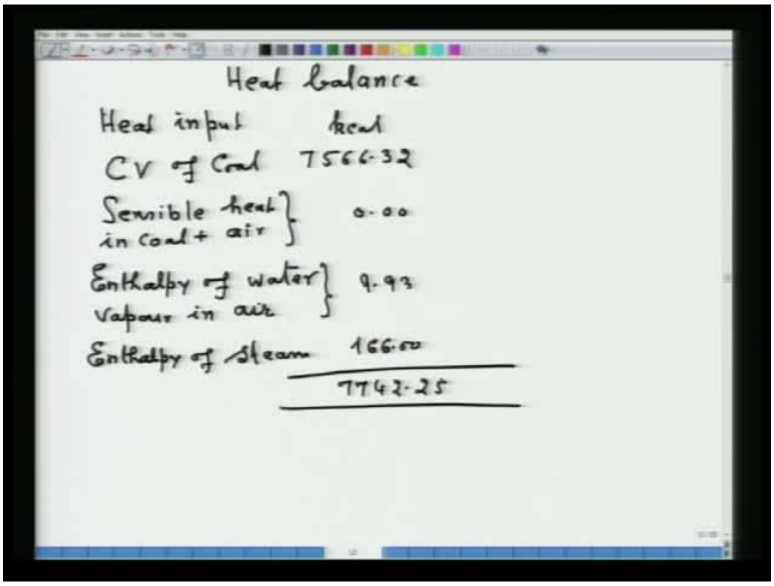

So, let us perform the heat balance and try to calculate the various efficiencies. First of all, heat input. So, heat input I have calorific value; CV stands for calorific value of coal and that is equal to 7566.32; that is, in kilo calorie. Then sensible heat in coal plus air; in this problem, it is not there; so, it is 0.00.

Then, enthalpy of water vapor in air - In air, we have calculated that to be 9.93 kilo calorie. Enthalpy of steam - we have calculated that to be 166.00 kilo calorie. So, that makes a total; 7742.25 kilo calorie is our heat input. Now, let us take a balance of heat output.

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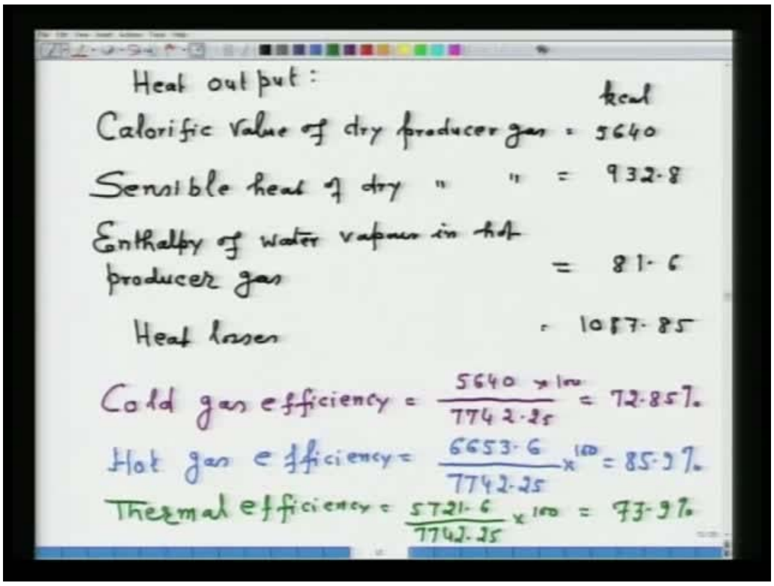

So, heat output - that comprises of first of all calorific value of dry producer gas. Calorific value of dry producer gas - mind you, we can also call it to be potential energy because now this energy will be available to you by combustion. So, we are writing dry producer gas because when you cool down the gas and clean it, then only calorific value will be available. So, that is 5640 kilo calorie in our calculation.

Then sensible heat of dry producer gas - that we have calculated 932.8 kilo calorie. Now, enthalpy of water vapor: Now, when we say water vapor, we are talking in hot producer gas. In hot producer gas, that will be equal to 81.6 kilo calorie - we have calculated.

So, if we sum total it and subtract from the heat input, then the rest we term as heat losses. Here, I am ignoring the sensible heat in ashes because of very small amount. So, the heat losses - by subtraction, that comes out to be equal to 1087.85 kilo calorie.

Now, I can determine the efficiency. For example, let me determine first of all cold gas efficiency. Cold gas efficiency - that is equal to 5640 upon total heat input that is 7742. If you multiply by 100, well of course, you can put 0.25; that is not significant. So, that will be equal to 72.85 percent. That is how the efficiency of the producer can be calculated.

Now, next efficiency that we have to calculate is hot gas efficiency.

Hot gas efficiency - that will be equal to 6653.6. You have to add sensible heat calorific value of dry producer gas. Sensible heat Everything you have to add and divide by again heat input 7742.25. Of course, you have to multiply by 100; so, that becomes equal to 85.9 percent.

Now, it is also interesting to calculate the so called thermal efficiency. Also, it is interesting to calculate thermal efficiency of the producer gas and this thermal efficiency is equal to 5721.6 divided by 7742.25 into 100. So, the thermal efficiency becomes 73.9 percent.

Now, you will also be interested in the losses - the heat losses is 1087, and if you divide 1087 by 7742, then you will be getting approximately around 10 to 15 percent as the heat losses. Now, you can say that, these heat losses will principle occur by conduction, radiation and there could be other losses in such a high temperature operation; 9 to 10, or 12 percent heat losses is quite normal.

So, this particular problem illustrates the material and heat balance in gasification, and with this, the additional topic which I have begun, the gasification - that rather ends over here.

Now, the title of the next lecture will be additional topic III and there I will be discussing industrial furnaces.