Waste to energy conversion
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Lecture – 09
Tutorial on Incineration

Good morning. Now we will start discussion on a new module Tutorial on Incineration. In the previous module we have discussed different aspects of incineration and waste to energy conversion. In this module we will solve some numerical problems on incineration. The first problem is it dry MSW has the following composition on mass basis, carbon 40 percent, hydrogen 5 percent, oxygen 30 percent and Ash 25 percent.

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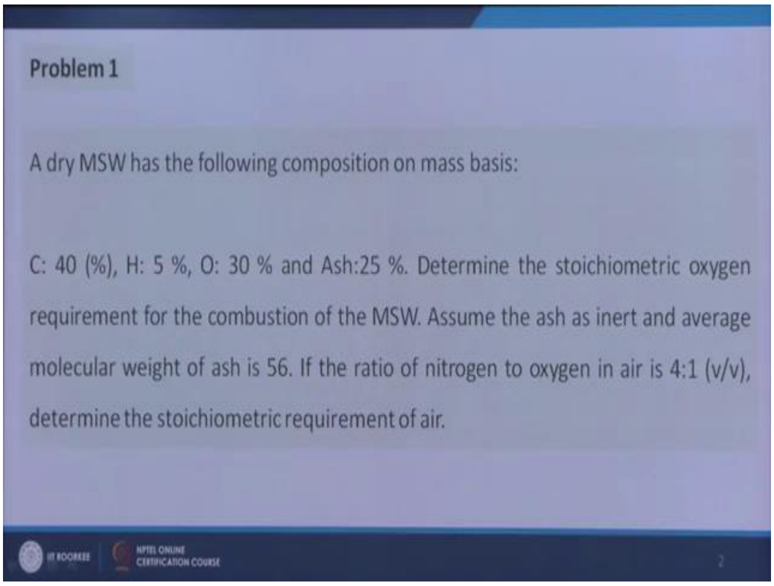

Determine the stoichiometric oxygen requirement for the combustion of the MSW; assume the Ash at inert and average molecular weight of Ash is 56. If the ratio of nitrogen to oxygen in air is 4 is to 1 volume by volume ratio determine the stoichiometric requirement of air. So, this is the problem statement we have to determine the stoichiometric requirement of air and we have to also determine the stoichiometric oxygen requirement. So, to solve this problem we have to take some basis. So, or basis here say 100 gram of dry MSW.

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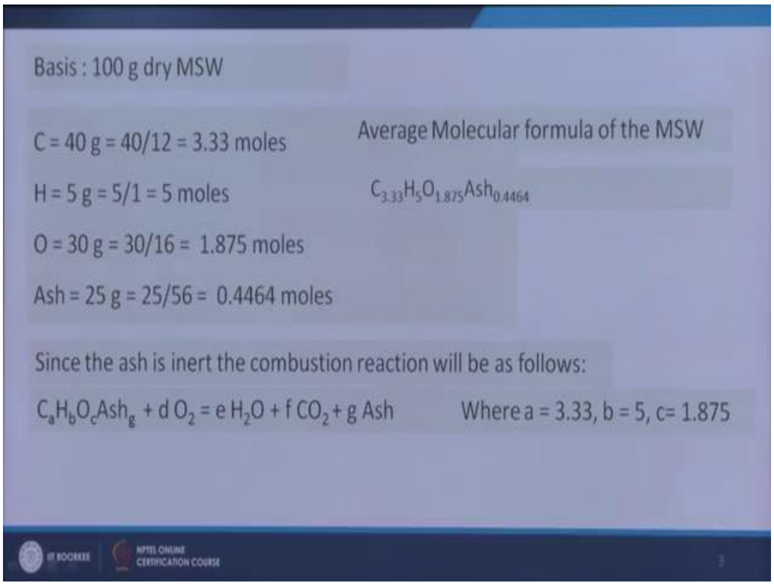

So, we will try to understand out of this 100 gram how many grams of carbon hydrogen oxygen and Ash are present then we will convert it into moles to get the molecular formula of the waste. So, carbon is say 40 gram 40 percent, it is here 40 percent.

Show out of 100 it will be 40 gram hydrogen out of 100 will be 5 gram and oxygen out of 100 grams will be 30 gram. So, remaining 25 gram is Ash as for the statement. Now if you want to convert this gram into moles we will divide by the molecular rate of carbon that is 12. So, 40 by 12 that is equal to 3.33 moles for carbon, for hydrogen this is 5 divided by 1 that is equal to 5 moles and for oxygen 30 divided by 16. So, 1.875 moles, for Ash it is 25 divided by 56. So, that is equal to 0.4464 moles, so in the basis of these moles which is present in 100 gram of dry MSW.

So, we can represent this biomass in terms of the C 3.33 hydrogen, 5 oxygen; 1.875, it is coming from this 1.875 and Ash is equal to 0.4464. So, this is the molecular formula of the MSW, we can represent in this way then what we need to do we have to calculate the oxygen requirement and air requirement. So, this is the representation of the MSW the C a H b O c and S g. So, this is reacting with say d mole of oxygen and it is giving us e mole of H2O, f mole of CO2 plus g mole of Ash, here we do not have any sulphur nitrogen all chloride therefore, and those elements will not be present in the product.

So, here basically the MSW is composed of carbon hydrogen and oxygen and ash. So, the products will also contain CO2 and H2O basically and rest will be the Ash. So, this is the representation of the reactions the combustion reactions. Now we have to get the value of d. So, this is one mole is reacting with d moles of oxygen. So, molecular stoichiometric requirement of oxygen is d with 1 mole of this material or we can say also for 100 gram of the MSW. So, if we can find out the value of d then we can get how much oxygen is required for the stoichiometric combustion of this MSW which is represented by C 3.33, H 5, O 1.875 and Ash 0.4464 and this is a reactions. Now you see if we do the balance, by this reactions and which is given here. So, a C 3.33 mole of carbon is present.

So, this CA, in these reactions, if we consider this is our biomass, this is our waste, MSW it has 3.33 of carbon. So, a is equal to 3.33 then b is equal to we are having 5. So, b is equal to 5 and c is equal to 1.875 we are getting. So, Ash g of Ash is here this will be inert. So, this is not reacting. So, the amount of Ash here in g mole of Ash will be available here at g mole of Ash. Now WE will be going for component balance and we will find out the value of d.

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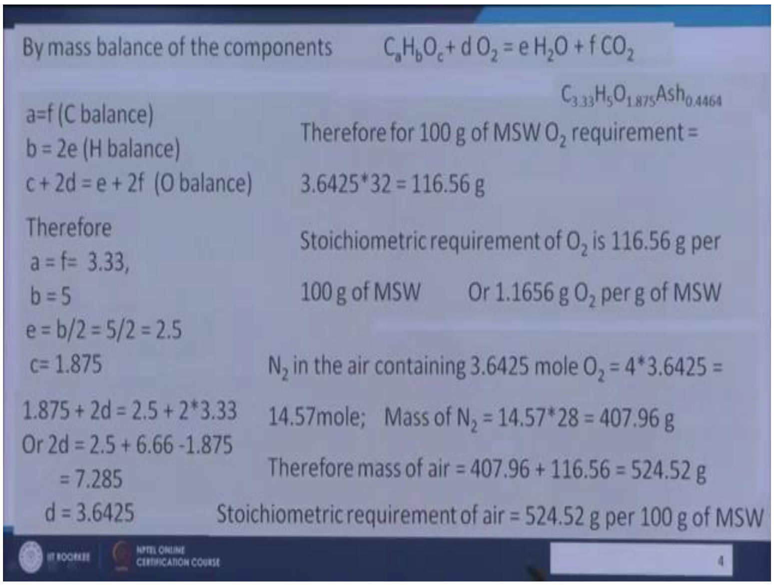

So, how this can be done? So, this is our reactions, we are ignoring the Ash, this is inert and this is your molecular formula molecular representation of this MSW. So, for carbon balance C a that is a is equal to f, a is equal to f. So, left hand side of this reaction or equation where getting a moles of carbon right hand side we are getting a mole of carbon.

So, a is equal to f and b for hydrogen balance b is equal where getting 2 into e. So, b is equal to 2 into e and for oxygen balance c moles and plus 2 into d c plus 2 into d in the left hand side and in the right hand side we are getting e plus 2 f. So, e plus 2 f, oxygen balance there is a balance of the components. So, a is equal to f equal to 3.33 we have got 3.33 a equal b equal to 5. So, here v equal to 5 and b equal to 2 e. So, e is equal to b by 2. So, e is equal to b by 2, 5 by 2 is equal to 2.5 and c is equal to already we have got 1.875 and from this expression c plus 2 d is equal to e plus 2 f, if we replace the values of this c, e and f we can get the value of d.

So, that has been done here. So, c is 1.875 plus 2 d that is equal to e 2.5, just we have calculated d is equal to 2.5. So, if with the value of 2.5 here and plus 2 into f. So, 2 into f, value of f equal to a equal to 3.33; you have got. So, we will multiply this 2 into 3.33. So, this is expression through which we will get the value of d or by rearranging we are getting 2 d equal to 2.5 plus 2 into 3.33 that is 6.66 minus 1.875. So, that is equal to 7.285. So, that is equal to 2 d. So, d will be 7.285 divided by 2 that is equal to 3.6425.

So, this is our d moles; moles of oxygen which is reacting with this MSW. So, this is the d, we are getting then what is the stoichiometric requirement of oxygen now? So, therefore, 100 gram of MSW oxygen requirement will be these moles of 3.6425 into O2. So, O2 is equal to 32.

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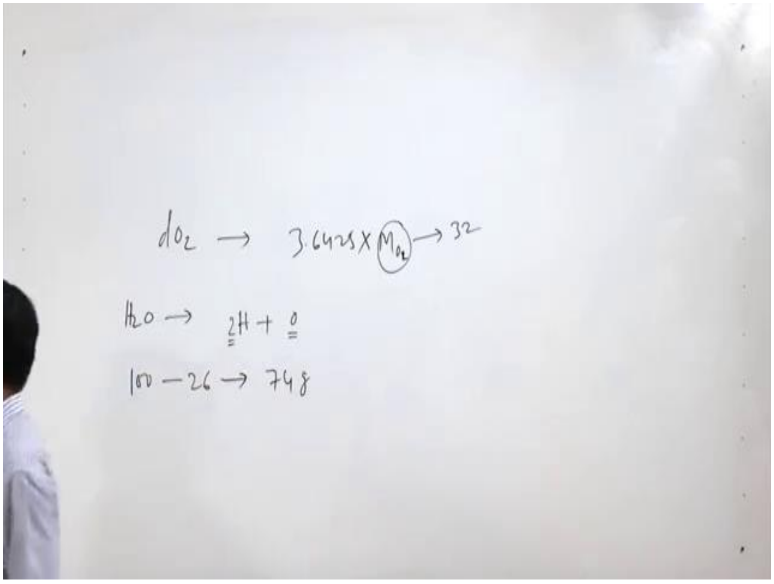

That is we need here d moles of O2 and d value; we are getting 3.6425; 3.6425 and then molecular weight of oxygen; molecular weight of oxygen. So, here we have to put; this is equal to 32 not 16, if only O then it will be 16, but it is here O2 as per the expression d O2. So, that is why how much oxygen is required 3.6425 moles multiplied by 32.

So, 116.56 gram, so, 116.56 gram of oxygen is required. So, this is the stoichiometric requirement of oxygen 116.56 gram per 100 gram of MSW or 1.1656 gram oxygen per gram of MSW. So, this is the first part of the problem the determine the stoichiometric oxygen requirement for the combustion of the MSW now second we have to calculate the requirement of air it is also given that nitrogen to oxygen in the air is 4 is to one volume by volume ratio. So, we will consider this information here. So, nitrogen in the air will be how much? 4 of this 4 of 3.26425, 4 into 3.6425 that is equal to 14.57 mole.

So, this is nitrogen present in it as where the statement. So, mass of nitrogen will be how much molecular weight of nitrogen. So, 14.57 into 25, so then we are getting 407.96 gram. So, this gram of nitrogen and this gram of oxygen is required. So, what is the total mass of this? So, total mass of air that is equal to 407.96 plus 116.56 that is equal to 524.52 gram. So now, stoichiometric requirement of air is equal to 524.52 gram air per 100 gram of MSW. So, this is the second part of the problem.

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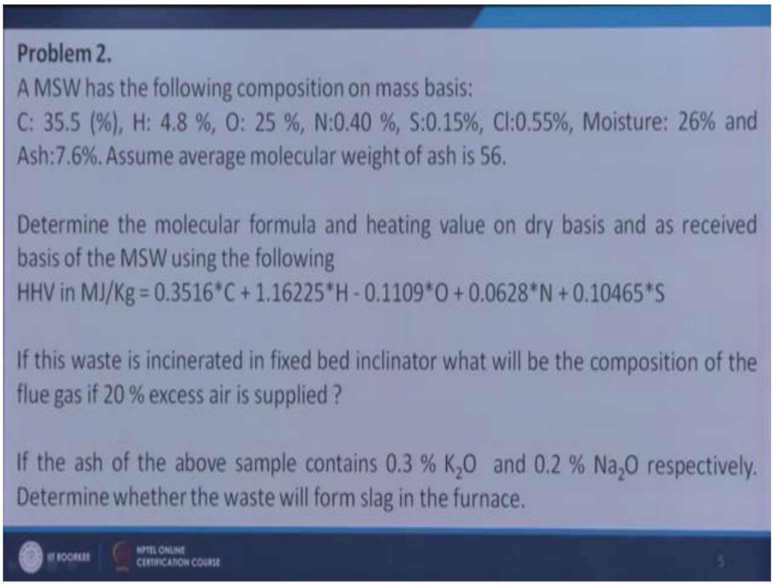

Now, we will come to our second problem. So, the statement of the second problem is MSW has the following composition on mass basis carbon 35.5 percent, hydrogen 4.8

percent, oxygen N25 percent, nitrogen 0.40 percent, sulphur 0.15 percent, chloride 0.55 percent, moisture 26 percent and Ash 7.6 percent.

Assume average molecular weight of Ash is 56; determine the molecular formula and heating value on dry basis and as received basis of the MSW using the following. So, this formula is given, hiding value in kilo joule mega joule per kg that is equal to 0.3516 into carbon plus 1.16225 into hydrogen minus 0.1109 into oxygen plus 0.0628 into hydrogen plus 0.10465 into sulphur. So, here carbon hydrogen oxygen nitrogen and sulphur are the percentage of these components in the biomass. So, if this waste is incinerated in fixed bed incinerator what will be the composition of the flue gas if 20 percent excess air is supplied? So, this is the first question.

We have to determine the compositions of the flue gas if 20 percent excess air is supplied you also have to determine the dry basis and as received basis heating value of this material and the next part if the Ash of the above sample contents 0.3 percent K2O and 0.2 percent NA2O respectively determine whether the waste will forms slag in the furnace. So, we can divide it into 3 part that is first is heating value determination, second part it determination of the composition of the gas streams and third part whether there will be slagging in the reactor or not.

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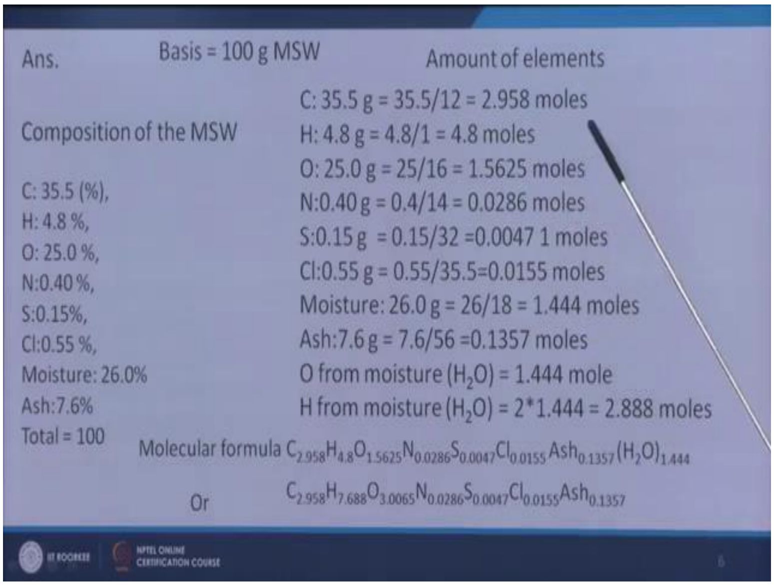

So, here also we will take some basis 100 gram of MSW. So, here it is given that carbon 35.5 percent, hydrogen 4.8 percent, oxygeN25 percent, nitrogen 0.40 percent, sulphur 0.15 percent, C l0.55 percent, moisture 26 and Ash 7.6 percent.

So, total is equal to 100 percent. So, out of 100 gram, we will get carbon 35.5 carbons, hydrogen 4.8 gram, oxygeN25, nitrogen 0.4 sulphur 0.15 gram, C l0.55 gram, moisture 26 gram and Ash 7.6 gram. So, these are the mass out of 100 grams, we will convert it into moles just like the previous problem just divided by molecular weight of carbon. So, 35.5 by 12; 2.958 moles this is 4.8 divided by hydrogen. So, by 14.8 moles and 25 by 16 there is a oxygen. So, we are getting 1.5625 moles and then for nitrogen 0.4 by 14. So, 0.0286 moles for sulphur 0.15 divided by 32. So, these will be 0.00471 moles and then for write there is 0.55 divided by 35.5.

So, it is 0.0155 moles and moisture 26 divided by 18. So, 1.444 moles, this is for Ash 7.6 divided by 56 that is 0.1356 moles. Now after this if you get then we can represent the molecular formula the presentation of the MSW is C 2.958, hydrogen 4.8, oxygen O 0.5625 like this, nitrogen will be 0.0286, sulphur will be 0.0047 and chloride will be 0.0155, Ash will be 0.1357 and H_2O moisture that is given 0.44. So, H_2O will be 1.444. So, this is the molecular formula of the MSW now the moisture that is 0.44 moles which is present in it we can represent in the same way similar way or this can also be presented like this when H and O present in the moisture is considered here.

So, that way also we can represent, so, H_2O this h plus O_2 h plus O; so, how many moles of H_2O will be available here the same number of moles of oxygen and 2 of that number of moles for hydrogen. So, hydrogen from moisture is equal to 2 into 0.44 that is 2.888 moles and oxygen from moisture is equal to 0.44 moles. So, these 2 this part can be replaced H_2O 1.444 can be replaced in spite of that the 2.888 can be added with 4.8 that is equal to 87.688 and this oxygen 1.444 can be added with 0.5625. So, it is coming 3.0065. So, this is the way we can represent the MSW.

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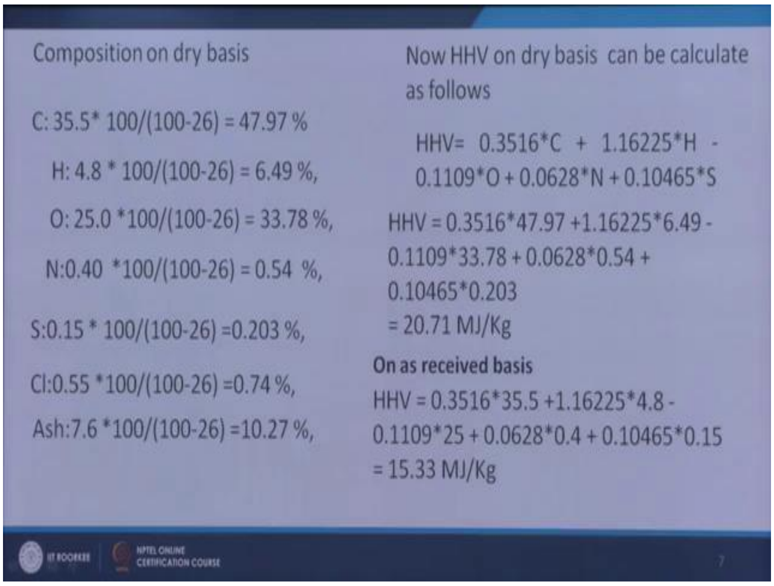

So, if you want to solve the first part this will be require to solve the second part there if you want to solve the first part we need only the percentage of carbon percentage of hydrogen percentage of oxygen percentage of nitrogen and percentage of sulphur because this formula is given this is the percentage of carbon hydrogen oxygen nitrogen and sulphur are required. So, we have two basis one is Ash received basis and another is dry basis. So, on the basis of Ash received basis we have 35.5 carbon, 4.8 hydrogen, 25 oxygen, 0.4 nitrogen, 0.15 sulphur and 0.55 chlorine in 7.6 Ash.

So, directly on Ash received basis we will put the value of carbon has 35.5 value of hydrogen is 4.8 oxygen is 25 and for nitrogen 0.4 and for sulphur 0.15. So, this is one is 35.5 4.8 for hydrogen, this is for 25 for oxygen and 0.44 nitrogen and this is 0.15 for sulphur. So, I getting 15.33 mega joules per kg, but if you want to find out this HHV on dry basis, we have to convert these values on dry basis first. So, drive basis means we have to remove the moisture first and then the 35.5 percent will be convert it to 47.97 percent because this is 35 35.5 into 100 divided by 100 minus 26.

Now, out of this 100 our basis, we are getting 26 moistures that will be removed. So, remaining will be 74 gram will be our material dry material. So, that out of that 35.5 gram is carbon. So, 35.5 into 100 divided by 100 minus 26 that is 74 gram that is equal to 47.97 percentage similarly for hydrogen this will be 4.8 into 100 divided by 100 minus 26 that is equal to 6.49 percent. Similarly for oxygen will be getting this way that is

33.78 percentage and the similar process nitrogen is equal to this 1 into 100 divided by 100 minus 26 is equal to 0.54 percent.

Similarly, sulphur is equal to 0.203 percent chlorine is equal to 0.74 percent and Ash is equal to 10.27 percent. So, these percents will be use now to calculate the HHV value high heating value and that will be on dry basis; so 0.3516 into C. This C is equal to here 47.97, this H is equal to here 6.49 and then this oxygen is equal to here 33.78 and nitrogen is equal to 0.54 and sulphur is equal to 0.203. So, we are getting 20.71 mega joules per kg. So, the first part is over we have discussed now for the second part we have also calculated the molecular representation of the material now we will consider the reactions.

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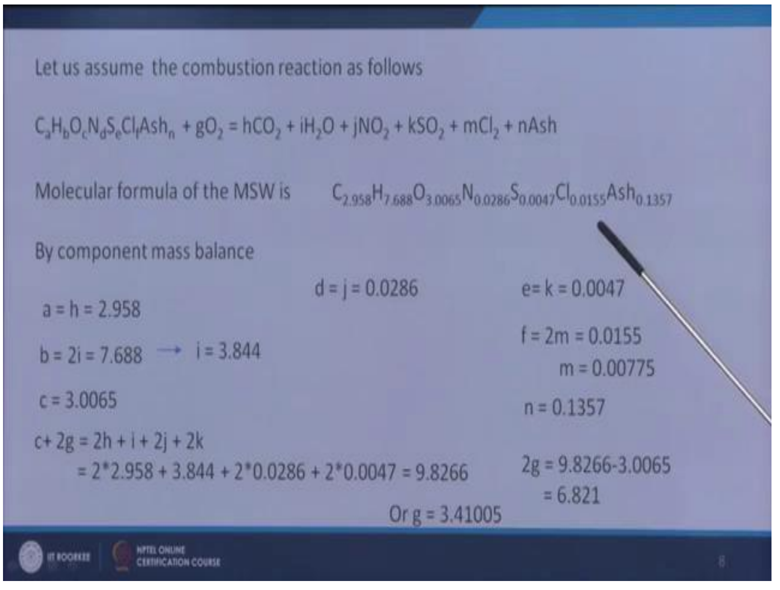

So, some combustion reactions is going on we are we are assuming that C a H b O c N d S e C l f and S n this is the presentation of the MSW that is reacting with g moles of oxygen and then it is giving us h mole of CO2 i mole of H2O j mole of n O2 k mole of SO2 m mole of CL 2 and n mole of Ash.

So, this is our molecular representation that is C a is equal to 2.958 h is equal to 7.688 just we have discussed 7.688 and then next is equal to 3.0065; 3.0065 n equal to 0.0286 sulphur is equal to 0.0047 and cell is equal to 0.0155 and Ash is equal to 0.1357 again component balance. So, left hand side and right hand side if you do the carbon balance.

So, you can get a is equal to H and that is equal to 2.958. So, that is equal to a equal to H equal to 2.958.

Hydrogen balance b left hand side right hand side hydrogen is 2 i. So, b is equal to 2 i and b is equal to how much 7.688. So, i is equal to b by 2 that is equal to 3.844 then we have n for oxygen balance. So, oxygen C plus 2 g; So c plus 2 g that is equal to 2 h, here we are getting 2 h plus I, here it is coming i and from this 2 j plus 2 j and here we are getting 2 k. So, this is the oxygen balance from right and left hand side of this reaction then we will consider nitrogen balance should d is equal to j d is equal to j and that is equal to here getting 0.0286 and here also we have got the value of c from this stoichiometric from the molecular representation of the material that is c is equal to 3.0065 and then we will see the sulphur balance.

So, e in the left hand side is equal to k and that is equal to 0.0047 then we do right balance. So, f left hand side and right hand side is equal to 2 m. So, f is equal to 2 m and that is equal to 0.155. So, m is equal to f by 2 that is equal to 0 find 0155 divided by 2 that is 0.00775. Now n is equal to Ash. So, that will be 0.1357. So now, we have got the values of different coefficients here, but we need to get the value of g. So, we need to get the value of g that will be our stoichiometric requirement of oxygen. So, g can be obtained from this formula that is c plus 2 j equal to 2 h plus i plus 2 j plus 2 k. So, 2 into h, h we have got 2.958 here. So, 2 into 2 into 2.958 plus I; i is equal to 3.844 plus 2 j 2 j is equal to 2 into 0.0286 plus 2 k.

So, 2 into 0.0047, this is we are getting is equal to c plus 2 g. So, 2 g is equal to this minus c. So, 2 g is equal to 9.8266 minus this c that is 3.0065; so 3.0065. So, it is coming 6.821. So, 2 g is equal to 6.821. So, g is equal to 6.821 divided by 2 that is equal to 3.4100 5. So, this is the value of g that is desirable we are interested to know the value of g and we are seen here that is equal to 3.4100 moles.

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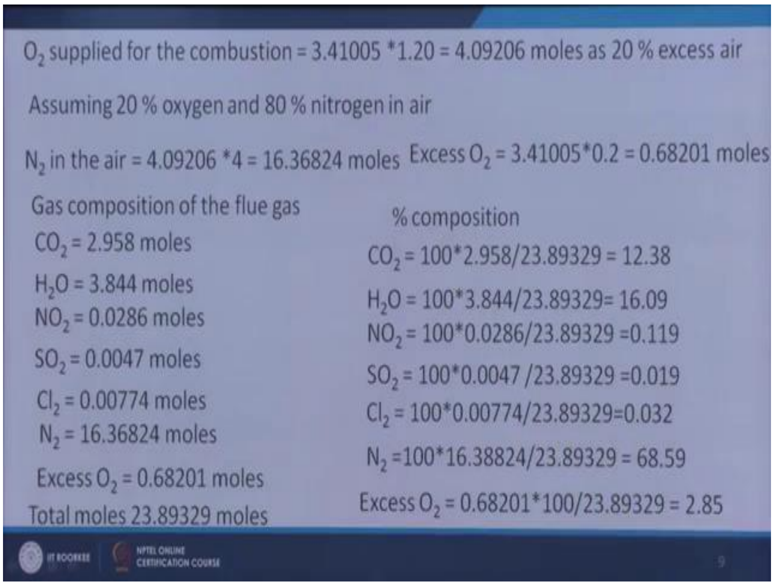

Now, as per the statement 20 percent excess oxygen is supplied. So, this is the stoichiometric requirement 3.41005 if 20 percent excess oxygen is supplied. So, oxygen supplied will be 1.2 into this much, 3.41 g 05 into 1.2 that is equal to 4.09206 moles of oxygen, again we assuming we are assuming that 20 percent oxygen and 80 percent nitrogen in air if this is the fact and if you can assume this one then; obviously, the nitrogen in the year will be 4 times of this; so 4.09206 into 4. So, that is 16.36824 moles. So, this is the nitrogen which is present in the air which is used for this combustion method.

Now, what is the excess oxygen excess oxygeN20 percent? So, that will be these moles into 0.2. So, that is equal to 0.68201 moles. So, that will be the excess oxygen that will also be present in the flue gas then what will be the gas composition carbon dioxide is produced by these h moles. So, that h value will be here 2.958 moles carbon dioxide H2O will be how much i. So, I will is equal to 3.844. So, will it will be 3.844 moles and what is NO2, NO2 value will be that is equal to j and j is equal to 0.0286. So, I getting 0.0286 moles SO2; SO2 will be how much k. So, k value is equal to 0.0047. So, we are getting at 0.0047 moles and what is chloride that is equal to m.

So, chlorine not chloride chlorine, so that will be m. So, m value is equal to 0.00775. So, that will be 0.00775 moles and N2 is equal to how much this is the N2 we are getting that how much N2 is present in the air. So, that is equal to 16.36824 moles that is equal to total nitrogen represent in it and excess oxygen this much is also present. So, it will come here excess oxygen is equal to 0.68201 moles. So, these are the total moles present in the flue gas. So, that is equal to 23.89329 moles. So, now, we can convert it in terms of percentage. So, CO2 will be 100 into 2.958 divided by 23.89329 moles is equal to 12.3 eight percent.

Similarly, H2O will be 100 into 3.844 divided by 23.89329. So, that is equal to 16.09, similarly NO2 will be this divided by 23.89329 that is equal to 1.119 and SO2 will be determined like this 100 into 0.0047 divided by 23.89329. So, it is coming 0.019, similarly for chloride; chloride chlorine for chlorine, this is 0.032 and for nitrogen this is 68.59 percent is and excess oxygen that is 0.68201 divided by 23.89329 into 100. So, that is equal to 2.85.

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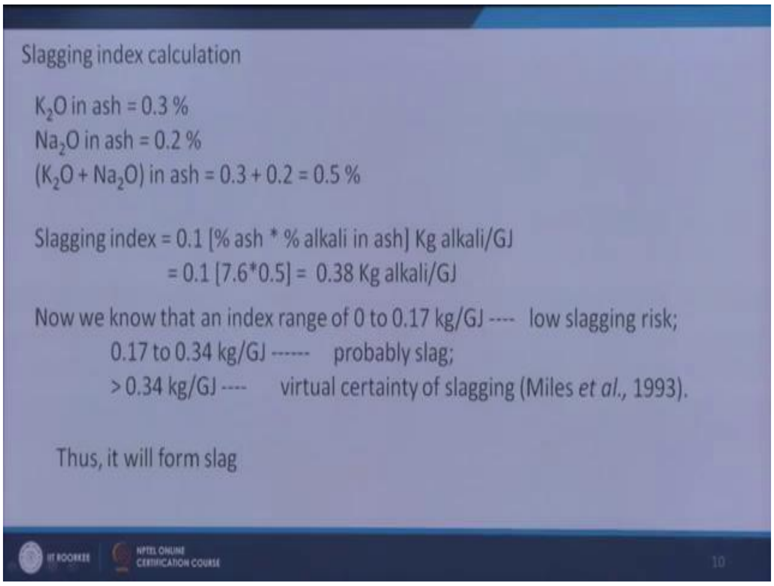

So, this is the composition of the flue gas now the third part we have to find out whether there will be any slag formation or not for this we need to determine the slag index and slag index we know the slagging index is equal to 0.1 into percentage of Ash into percentage alkali in Ash. So, this is the expression for slagging index in k g alkali for gigajoule. So, this is the unit of it. So, here if we put the value of percentage Ash that is 7.6 percent Ash as for the statement Ash is 7.6 percent. So, 7.6 into percentage alkali as per the statement K2O is 0.3 percent NA2O in Ash is equal to 0.2 percent.

So, total alkali in Ash is equal to 0.3 plus 0.2 that is equal to 0.5 percentage. So, this is 0.5 into 7.6 into 0.1 that is equal to 0.38 k g alkali per gigajoule. Now these value we have to find out where it is as we know we have already discussed in the previous module the tips slagging index to using 020.17 kg alkali per gigajoule then this is not slagging no slag will form, but 0.172; 0.34 kg per gigajoule there may be some slagging probably slag, but if it is greater than 0.34 kg per gigajoule that is virtual certainty of slagging. So, slagging will be taking place, so in this case, the value 0.38, so more than the 0.34.

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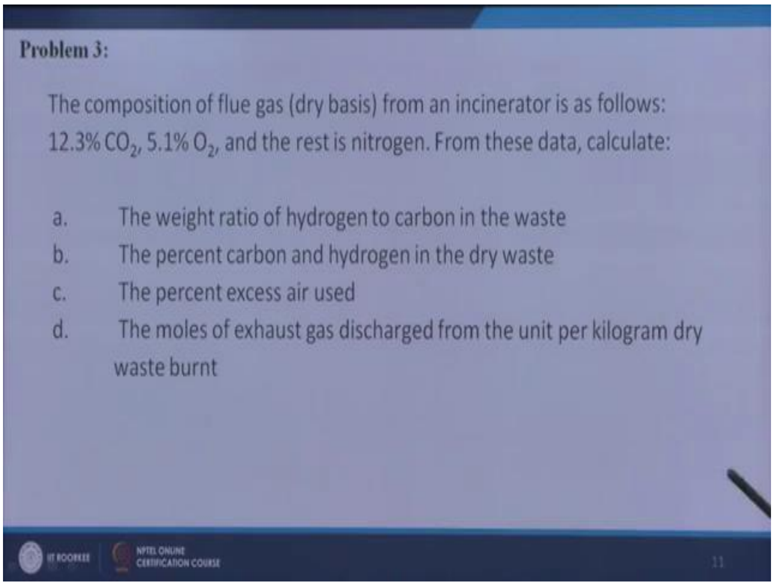

So, slagging will take place in this case now problem number 3 the composition of flue gas dry basis from an incinerator is as follows 12.3 percent CO2; 5.1 percent oxygen and the rest is nitrogen from these data calculate the weight ratio of hydrogen to carbon in the waste the percent carbon and hydrogen in the dry waste the percent excess here used the moles of exhaust gas discharged from the unit per kilogram dry waste burnt. So, these are the statements and we have to solve these 4 problems; so a, b, c, d, 4 parts. So, for this what we need to do we again need one basis.

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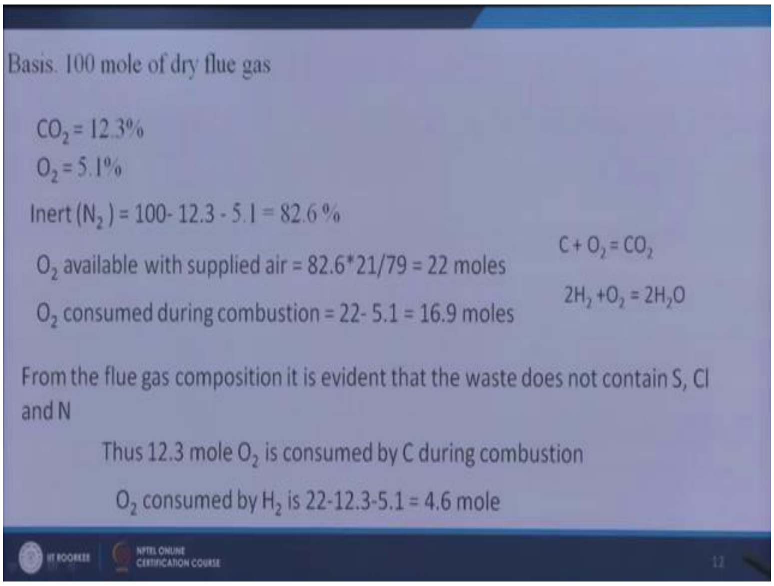

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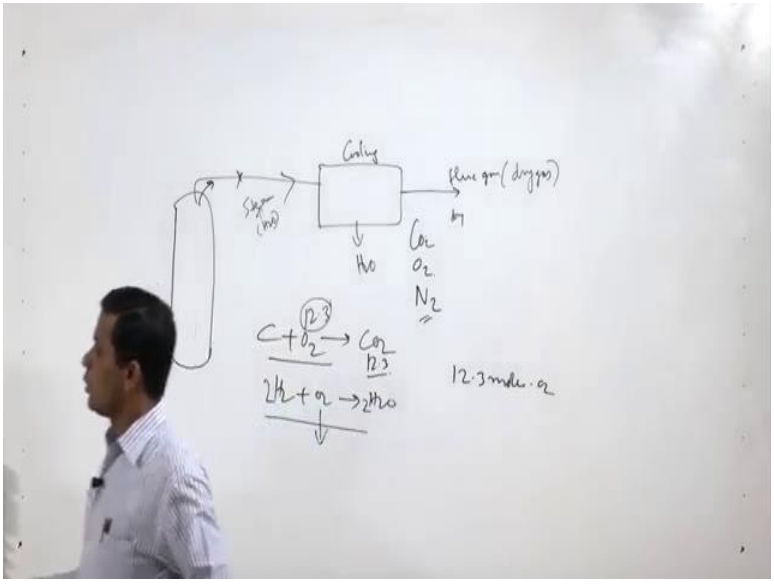

So, we are considering the basis is 100 moles of dry flue gas. So, flue gas is dry basis say we have. So, we have on incinerator. So, we have getting some gas.

So, this gas after cooling, it is cooling then we will get flue gas dry what is happening it is basis as dry basis. So, when will be making the flue gas in incinerator that will be containing steam H2O which is H2O form here due to the combustion that that will been vapor form. So, that will be reduced here. So, H2 will be separated. So, this will be dry gas. So, here the composition is given the composition which is given here that is CO2 and oxygen excess amount of oxygen and oxygen H_2 is already separate it here some arrangement is made to separate the H20. So, this is the situation.

Now, the composition of the dry gas is given here on this basis we have to find out the composition of gas here and what will be the H_2O which is coming out from the incinerator also that is the most of exhaust gas discharged from the unit per kilogram dry waste burnt other 3 the percentage excess here how much excess here is required and on the first 2 weight ratio of hydrogen to carbon in the waste and percent carbon and hydrogen in the waste very similar. So, the basis is a 100 moles dry flue gas 12.3 percent CO_2 and oxygen is 5.1 percent. So, what is the rest the rest will be here nitrogen this nitrogen is coming from air.

So, CO_2, O_2 and nitrogen is present in it. So, that will give us 100. So, 100 minus 12.3 minus 5.1 that is equal to 82.6 percent of nitrogen. So, what is the oxygen available its supplied air. So, 82.6 is nitrogen. So, into 21 divided by 79, we are assuming that 20 is 2, 21 is 2, 79 is the ratio of oxygen is to nitrogen in the air. So, this is our 22 moles of oxygen is available now oxygen consumed during combustion equal to how much. So, 5.1 percent is available has Ash excess oxygen. So, the consumed is 22 minus 5.1 that is the 16.9 moles and there what was the reaction this C plus O_2 that is CO_2 and another was H_2 plus O_2 H_2O we got.

So, that was the reaction. So, from the flue gas composition it is a within that the waste does not content sulphur chloride and nitrogen therefore, 12.3 mole oxygen, the 12.3 moles of oxygen will be used by the carbon due to this reactions 12.3 moles, this is 12.3 mole it is present. So, that was also oxygen was also 12.3 moles. So, oxygen consumed by hydrogen is 22 total oxygen that was supplied 22 total oxygen minus used for carbon that is 12.3 minus the amount of excess oxygen present, So that is 4.6 mole was used for the reaction or the combustion of hydrogen.

So, this reaction oxygen was thus much. So, that is equal to 4.6 mole therefore, hydrogen present in waste is equal to 4.6 into 2. So, here we are getting stoichiometric we are getting 2 moles 2 is 2.

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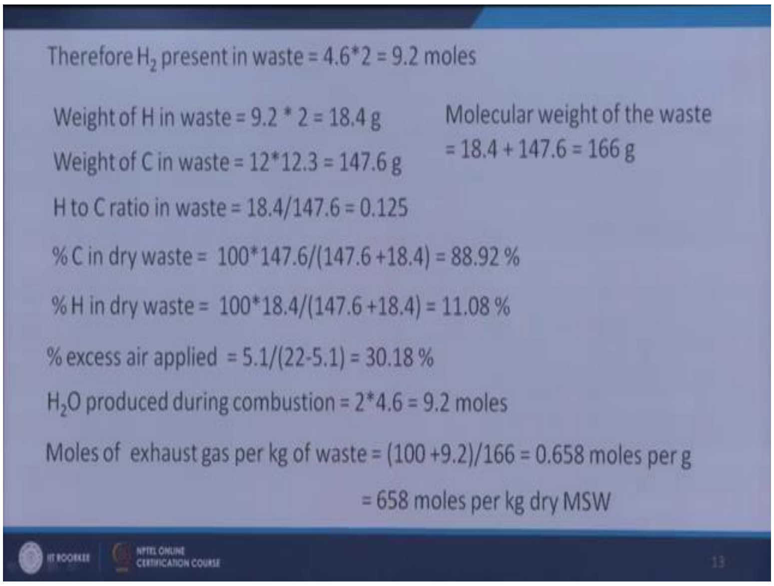

So, that will be 4.6 into 2; 9.2 moles and then weight of hydrogen in waste that is equal to 9.2 into 2 that is 18.4 gram. So, weight of carbon in waste is equal to 12 into 12.3 that is equal to 147.6 gram, H2 carbon ratio in waste then how much 18.4 divided by 147.6. So, that is equal to 0.125 we are getting.

And percent in dry waste that is 100 into this divided by this plus this. So, I getting 88.92 percent, similarly for hydrogen the percentage is this one and 11.02 percent, 08 percent that is equal to 11.08 percent. So, percent excess here applied equal to how much we have 5.1 and reacted 22 minus 5.1. So, that is equal to 5.1 divided by 16.9. So, that is equal to 30.18 percent H2O produced during combustion is equal to how much the N2 into 4.6 that is equal to 9.2 moles because this is our 2 reactions. So, that is equal to 9.2 moles.

So, moles of exhaust gas per kg of waste that is equal to 100 was our assumption for dry flue gas here we are 100 moles and now we are having here 100 plus the H2O. So, that is equal to 9.2. So, 100 plus 9.2 divided by 166 that is equal to 0.658 moles per gram up MSW that is equal to 658 moles per kg of dry MSW. So, now, we have solved both the third; 3 parts of this problem and with this with this we are the end of this module.

Thank you very much for your patience.