Material and Energy Balances
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Module No # 04
Lecture No # 20
Material Balances for Combustion Reactions

Hello everybody welcome back for today's lecture on material balance for combustion reactions in the last lecture we looked at some of the terminologies associated with combustion reactions and we understood the fundamentals associated with combustion reaction. So these reactions are important for industries because they help in producing energy. So now we will be performing material balance calculation that are done for combustion reactive process.

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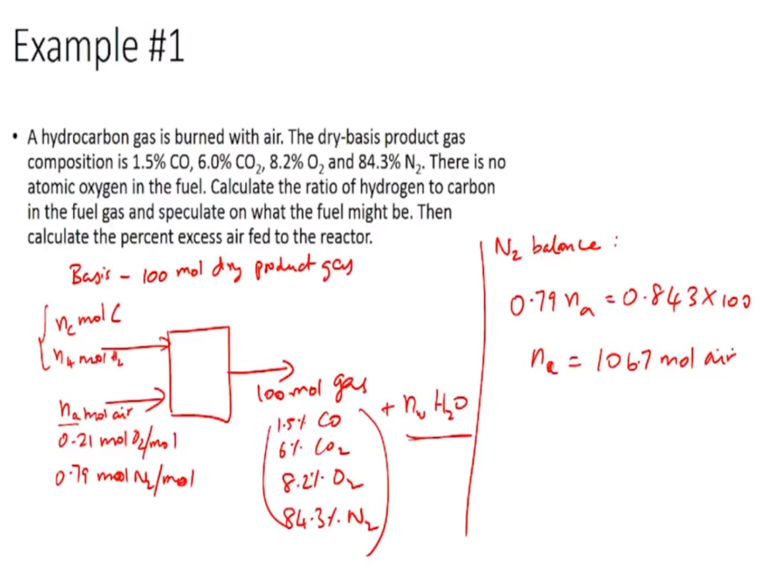

So here is the first example a hydrocarbon gas is burnt with air the dry basis products which is formed is 1.5% carbon monoxide, 6% carbon dioxide, 8.2% oxygen and 84.3% nitrogen. There is no atomic oxygen in the fuel. Calculate the ratio of hydrogen to carbon in the fuel gas and speculate what the fuel might be then calculate the percent excess of air that is being fed to the system.

So here you are asked to calculate the carbon to hydrogen ratio which would help us identifying what fuel have been used. So let us see how we can solve this problem just like any other material balance problem we will start with assuming a basis here the composition of the product as is known so this is the dry basis based on that we will use the basis or the product base on the dry basis.

So the basis would be 100 moles of dry product gas so the flow chart for this system can be written as you have product stream which contains 100 moles of gas and this gas contains 1.5% carbon monoxide 6% carbon dioxide 8.2% oxygen and 84.3% nitrogen. So in addition to this you would also have water vapor which is leaving the system. So the dry gas contains these components and in the actual product gas which contains water vapor that there is water as NW moles of water which is leaving the system.

So you would have tow inputs one being the fuel and other being air which is supplied for burning the fuel which is supplied for burning the fuel so the fuel would contain N moles of NC moles of carbon and NH moles of hydrogen so it has been mentioned that the hydro carbon gas an it does not contain any oxygen in the fuel gas which means you have only carbon and hydrogen which have been resented here.

So you have air which is supplied as NA moles of air s this would contain 0.21 moles of oxygen per mole and 0.79 moles of nitrogen per mole. So now with all this information we now need to calculate how much of water is leaving the system and what is ratio of NC to NH and what is NA so that we can identify the percent excess of air which is being supplied.

So how do we go about performing this calculation the first simple balance equation we can write would be the nitrogen balance when we write the nitrogen balance what happens is it is 0.79 times NA which is the number of moles of air will be equal to 0.843 times 100 as nitrogen is considered to inert component and as a process is at steady state you would not have generation consumption terms for nitrogen accumulation would also be 0.

So this means input = output which is what I have written now so based on this you can calculate the number of moles of air is entering into the system as 106.7 moles of air. So the next step is to calculate the ratio of carbon to hydrogen how do we go about what balances can be write.

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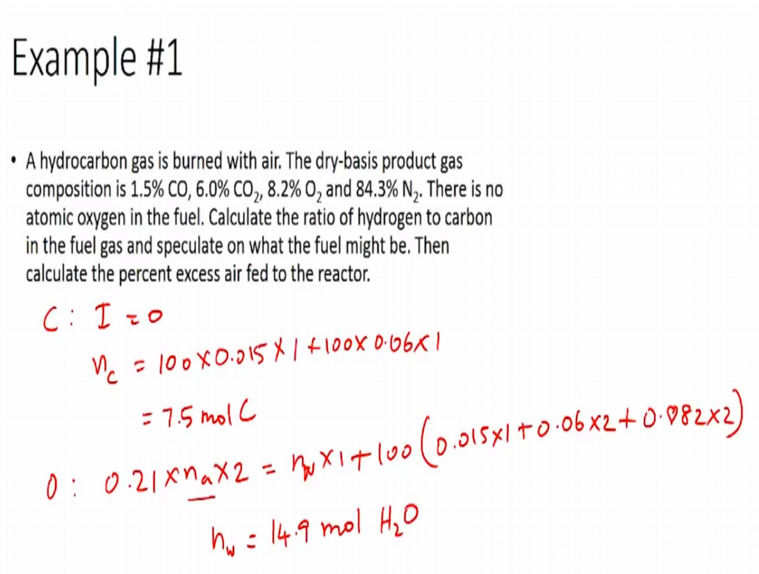

To calculate the ratio of carbon to hydrogen we will be writing atomic balances for carbon hydrogen and oxygen using this will be able to calculate number of atoms of carbon which is entering and number of atoms of hydrogen which is entering form which we can calculate the ratio of carbon to hydrogen. Let us start with the carbon balance so the carbon balance would be input = output or steady state accumulation 0 and atoms cannot be created or destroyed.

So generation consumption terms are 0 so giving us input = output input is NC we have assumed NC = number of moles of carbon atom which is entering and carbon atom are leaving the system in the form of carbon monoxide and carbon dioxide. So you have 100 moles of dry gas times 0.15 which is the mole fraction of carbon monoxide in the dry gas times 1 which is number of atoms of carbon in carbon monoxide.

This + 100 times 06 times 1 which is the amount of carbon atoms leaving in the form of carbon dioxide. So solving this we get 7.5 moles of carbon is present in the input in the fuel gas now writing a balance equation for oxygen we would have 0.21 times NA which is the number of moles of air which is entering times 2 + oxygen enters as molecular oxygen which contains two atoms of oxygen per molecule of oxygen present in air this equals NW times 1 where NW is the number of moles of water vapor leaving the system and contains on atoms of oxygen.

So similarly we have product gas which is 100 moles containing oxygen in the form of carbon monoxide carbon dioxide and oxygen. So you have 0.15 times atom for carbon monoxide + 0.06

times 2 representing carbon monoxide + 0.082 times 2 representing molecule in this particular equation we already know the value of NA so from here we calculate the value of W as 14.9 moles which is the number of moles of water which is leaving the system in the form of water vapor.

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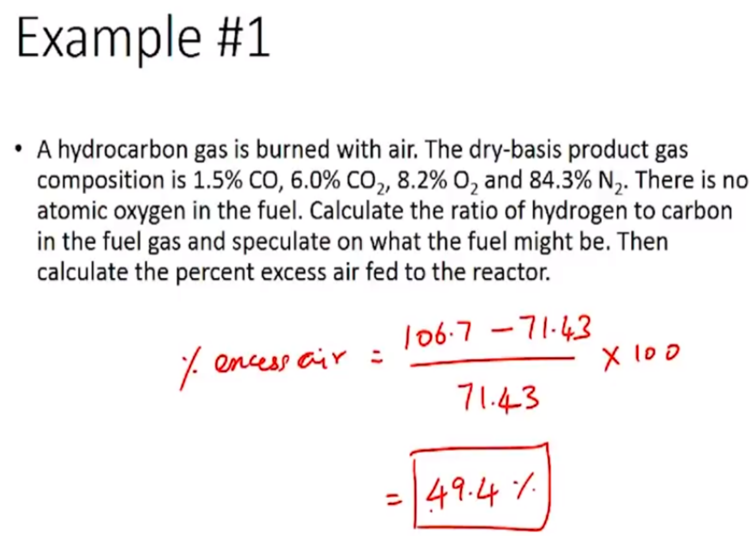

To calculate the number of atoms of hydrogen which is entering into the system you would have to write the atomic balance for hydrogen. The hydrogen should be NH which is number of moles hydrogen entering in the form of fuel gas would be equal to the number of atoms of hydrogen leaving the system which would be only through water vapor.

So that would be two times NW as we already calculated NW as 14.9 we can identify NH as 29.8 moles of hydrogen. So this implies ratio of hydrogen to carbon is NH / NC would be 29.8 / 7.5 this comes out to be 3.97 moles of hydrogen per moles of carbon with the ratio of carbon to hydrogen being 1 is to 4 roughly we can assume that the fuel gas which has been used would be CH4 which is methane.

Now that we have the information fuel gas which is being fed the next part of the gases asked us calculate the percentage excess of air. So for performing this calculation we first need to identify what would be the complete combustion reaction for the fuel gas which is used. So the fuel gas we have identified to be methane so which means methane + oxygen should form carbon dioxide + water vapor so this reaction when balanced would be 2 atoms of oxygen 2 molecules of oxygen reacting with one molecule of methane would form one molecule of carbon dioxide with 2 molecules of water.

So this would be a balanced reaction you have one atom of carbon in both sides 4 atoms of hydrogen and 4 atoms of oxygen on both sides. So this means one mole methane requires two moles of oxygen for complete combustion. From the calculations we have done we know that 7.5 moles of carbon is entering which means 7.5 moles of methane is also entering into the system.

So for 7.5 moles methane require 15 moles of oxygen so this means moles of air required would be equal 15 divided by 21 which is 71.43 and perform material balances for new system.

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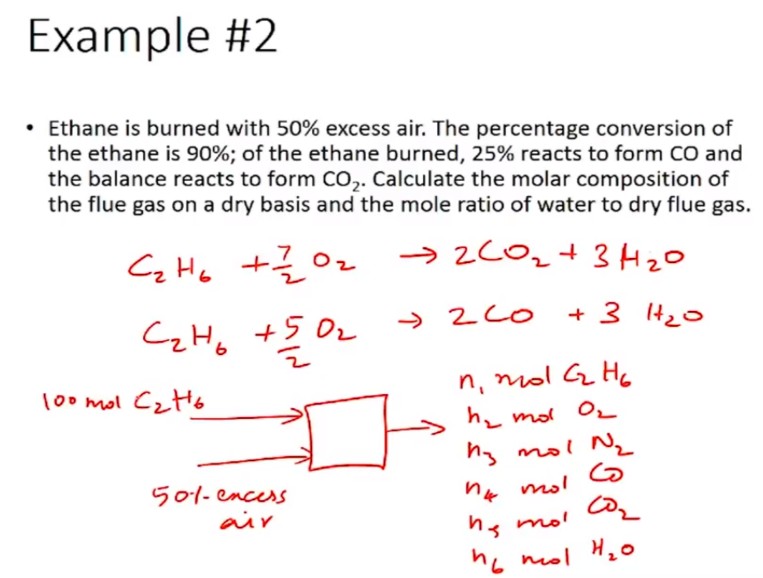

This example problem states that methane is burnt with 50% excess air the percentage conversion of ethane is 90% and among the ethane is burnt 25% reacts to form carbon monoxide and the rest reacts to form carbon dioxide calculate the molar composition of flue gas of dry basis and moles ratio of water per dry flue gas. So this problem gives us partial combustion reaction that is why you have carbon monoxide and carbon dioxide forming.

So ethane is the fuel gas so we now need to write two different equation one for complete combustion and other for partial combustion produces carbon monoxide. Let us write (())(12:40) equation ethane is C2 H6 reacting with oxygen to form carbon dioxide and water vapor would be the complete combustion reaction ethane + oxygen forming carbon monoxide and water vapor would be partial combustion reaction.

Now let us balance these two equations so we have two atoms of carbon so this becomes 2 and to balance hydrogen we had a 3 here. So finally to balance oxygen to be 7/2 and similarly 2, 3 and you have 5 /2. So these are the two balanced equations for partial and complete combustion reactions.

So the problems statement tells us that we have ethane which is entering C2H6 which is entering and you have excess air 50% excess air is being fed and product obviously contains both the partial and final combustion complete combustion product in addition you also have unreacted ethane because you only have 90% conversion of ethane.

So some of the ethane which is coming in is leaving the system without being combusted so this would mean the final composition of the product gas would be N1 moles of ethane N2 moles of oxygen N3 moles of nitrogen N4 moles of carbon monoxide N5 moles of carbon dioxide and N6 moles of water vapor with all these leaving the system. For performing calculation we will assume a basis of 100 moles of ethane which is being fed to the system.

So this would be 100 moles so the basis we have used is 100 moles of ethane let us go about performing these to calculations.

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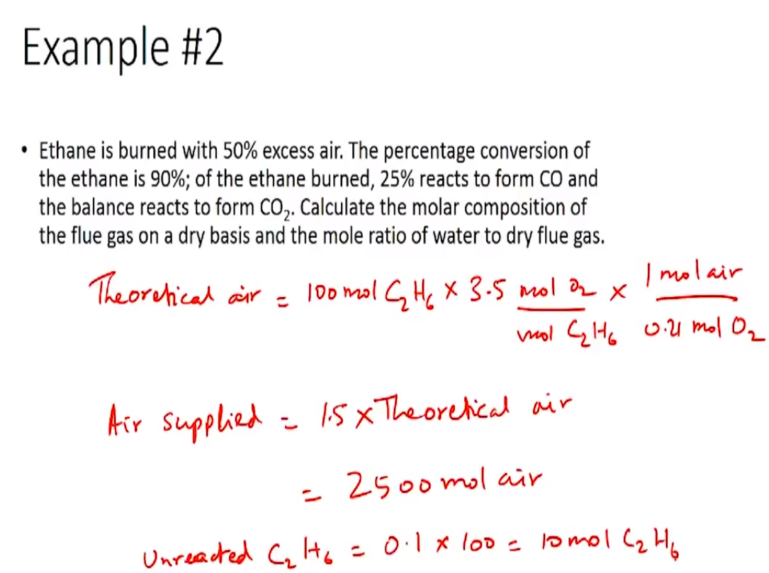

First thing we need to do is identify how much air is being fed we have been told that 50% excess air is fed. So based on that we have to calculate how much addition air has been fed. So using this stoichiometric we can calculate the theoretical amount of air which is required theoretical air required would be for 100 moles of methane sorry 100 moles of ethane you have to have to calculate theoretical air which is required we will have to assume complete combustion.

So for every mole of ethane which is fed we need to have 3 and half moles of oxygen for complete combustion to occur. So the theoretical air requirement would be based on theoretical oxygen which is 3.5 moles of oxygen for per mole of ethane. So theoretical moles of air would be equal to 100 moles of ethane times 3.5 moles of oxygen per moles of ethane times 1 mole of air per 0.21 moles of oxygen this would give us the number of moles of air which is required.

So to calculate the amount of air which is supplied you would multiply this by 1.5 times theoretical air calculations. So the amount of air which is actually supplied would be 2500 moles of air. We also have been told that 90% of ethane is consumed in the conversion so that means 10% is remaining and it will be leaving the system as unused reactants. So unreacted ethane would be 0.1 times 100 which is 10 moles of ethane.

So this is the unreacted ethane so rest 90 moles has been consumed in the process now let us start with the material balance problems.

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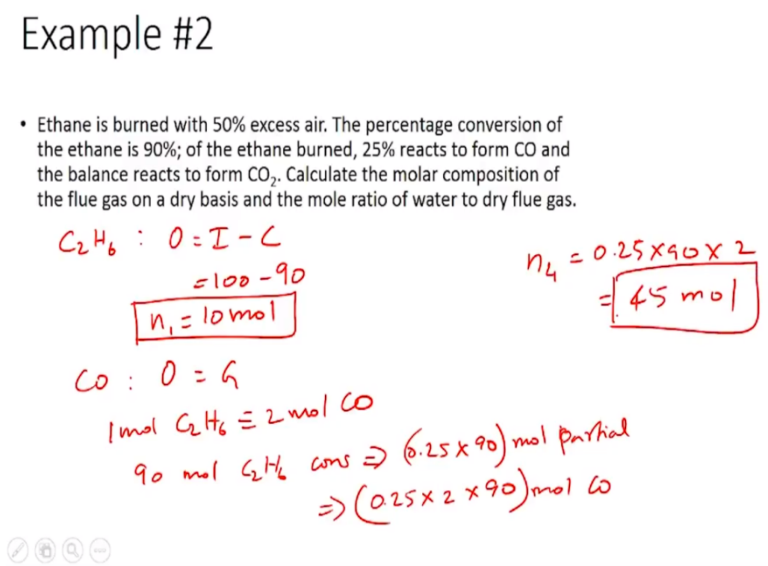

So let us start for ethane so ethane is actually taking part in the reaction however it is only being consumed have any generation of ethane. So your output would be equal to input – consumption so input here is 100 moles based on the basis we used and consumed it just said was 100 so out of ethane which calculate written down which we wrote down as N1 = N moles.

So if where to use the other information that has been given that is 25% of the ethane is consumed actually goes into carbon monoxide and the rest is going to carbon dioxide you will be able calculate how much ethane went into carbon monoxide reaction and how much went into carbon dioxide reaction. So if you were to write into balance equation for carbon monoxide it would be output = generation and the generation would be based on the stoichiometric of martial combustion.

We know that one mole of C2H6 produces two moles of carbon monoxide so this means the amount of ethane with is consumed for this reaction times 2 would be the amount of carbon monoxide generated so we know that 90 moles of ethane is consumed this implies 0.25 times 90 moles is consumed in combusted partially. So this implies you have 0.25 times 2 times 90 moles of CO generated so the number of moles of CO in the output which is N4 would be equal to 0.25 times 90 times 2 which is 45 moles.

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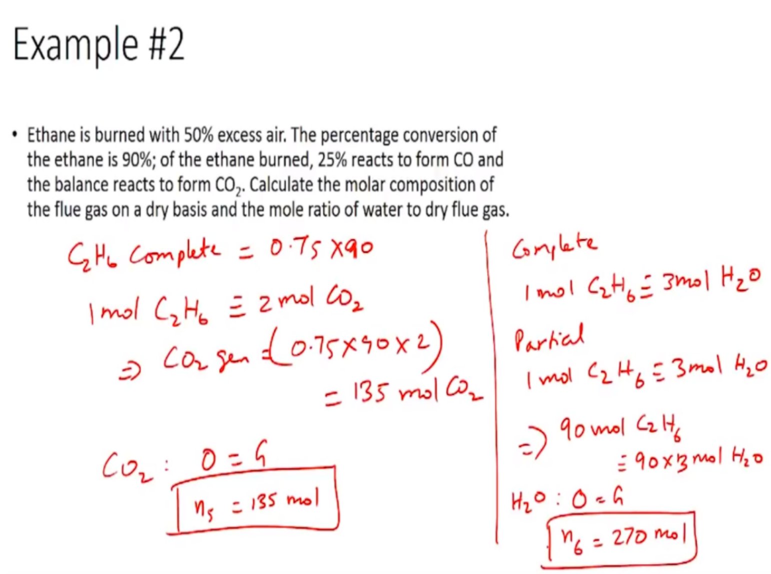

The problem statement says that 25% of the gas consumed ethane gas consumed goes into forming CO the rest actually goes into forming CO2 which means 75% of 90 mole which is consumed would go into formation of CO2. So ethane that is completely combusted complete combustion would be equal to 0.75 times 90.

So based on the stoichiometric we know that 1 mole of ethane produces 2 moles of carbon dioxide this means carbon dioxide would be equal to 0.75 times 90 times 2 which would be 135 moles of carbon dioxide. When we write balance equation for carbon dioxide will be equal to generation you do not have an input or consumption term and accumulation is 0 for steady state process.

So you output which is N5 which is equal to 135 moles of carbon dioxide so the next aspect we need to look at is calculating the number of moles of water vapor which is produced. So based on the stoichiometry for complete combustion one moles of ethane produces one moles of water vapor. So what you have is the next aspect we calculate the number of moles of water vapor produced during this combustion reaction.

Based on the stoichiometry for complete combustion you have one mole of ethane reacting to form 3 moles of water and similarly for partial combustion you still have one mole of ethane forming 3 moles of water vapor. So this means for every moles of ethane which is you would have 3 moles of water vapor produced. So we know that 90 moles of ethane is consumed which would produce 90 times 3 moles of water vapor.

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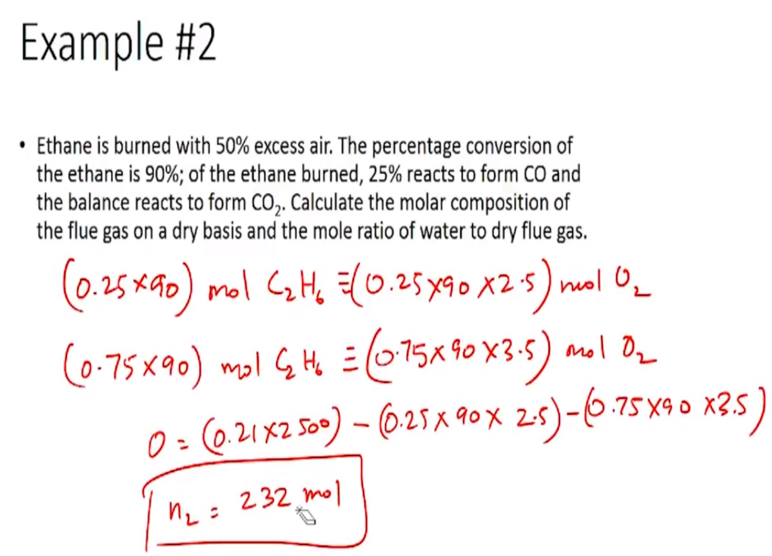

So again water balance would be output = generation giving output as N6 = 270 moles so with this we have calculated the number of moles of most of the combustion we still need to calculate the number moles of number of moles of nitrogen and oxygen. So nitrogen is non-reactive component whatever nitrogen is happening would be leaving the system so nitrogen is input = output.

So input is moles of air times 0.79 which should be the number of moles which is leaving the system N3 so N3 = 0.79 times 2500 giving you N3 as 1975 moles so the only final thing which needs to calculated is number moles of oxygen which is leaving the system. So for performing the balances for oxygen you would have oxygen which is coming in and oxygen leaving and oxygen being consumed there is no oxygen which is generated and accumulated to process.

So oxygen output would be input – consumption input for oxygen is 0.21 times 2500 moles of air consumption of oxygen would be calculated based on the stoichiometric. So if you look at the stoichiometric for complete combustion you have one mole of C2H6 reacting with 3.5 moles of oxygen for partial combustion. You have one mole of C2H6 reacting with 2.5 moles of oxygen so based on the number of atoms number of moles of ethane going into complete combustion of and partial combustion.

We can calculate the number of moles of oxygen which has been consumed so we know that 0.25 times 90 moles of ethane went into partial combustion which means 0.25 times 90 times 2.5 moles of oxygen was consumed in the partial combustion reaction in the complete combustion reaction we have 0.75 times 90 moles of C2H6 taking part implying times 90 times 3.5 moles oxygen being consumed.

So output would equal to input which is 0.21 times 2500 – the two consumption which is 0.25 times 90 times 2.5 – 0.75 times 3.5 giving a value for the output which is N2 as 232 moles of oxygen. With this we have calculated the number of moles of each of the component which is present in the product gas it is formed.

We also need to calculate the molar composition of the flue gas on the dry basis and the mole ratio of water to dry flue gas. So this can be done basically by calculating the total number of moles ignoring the moles of water which would be the dry basis let us try and do this for next part. Now that we have the number of moles for each of the component we will have to calculate the molar composition of the flue gas on the dry basis.

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Example #2

- Ethane is burned with 50% excess air. The percentage conversion of the ethane is 90%; of the ethane burned, 25% reacts to form CO and the balance reacts to form CO_2. Calculate the molar composition of the flue gas on a dry basis and the mole ratio of water to dry flue gas.

Component	Moles	Mole fraction
C_2H_6	10	0.0034
O_2	232	0.0968
N_2	1975	0.8239
CO	45	0.0188
CO_2	135	0.0563
Total	2397	

So let us do that so what we have done here is we have written down the number of moles of each component except water as we wanted to calculate the dry basis we have written the number moles of ethane which is 10 number moles of oxygen which is 232 number moles of nitrogen which is 1975 number moles of carbon dioxide which is 135 number moles of carbon dioxide which is 45.

The summation of all these components gives us a total number moles as 2397 so the moles fraction for each of these components would be 10 divided the total number which is 2397 giving you a moles fraction of 0.0034 and for oxygen it would be 232 / 2397 which is 0.0968 and for nitrogen it will be 1975 / 2397 giving a value of 0.8239 and carbon monoxide moles fraction would be 0.188 and carbon dioxide moles fraction would be 0.0563.

Now that we have calculated the composition of flue gas based on the dry basis we now need to calculate the mole ratio of water to dry flue gas we know that the total number of moles of dry gas is 2397 and we also know the number moles of water.

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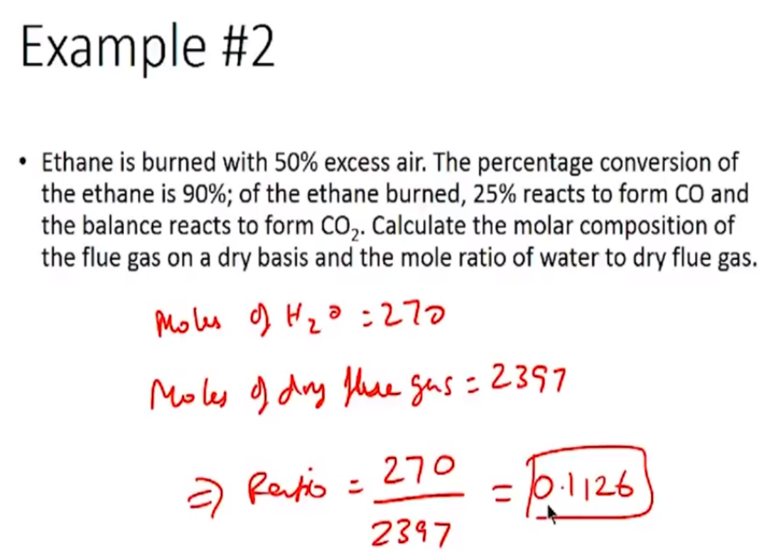

So moles of water would be moles of water would be calculated as 70 moles of dry flue gas is 2397. So the ratio is 270 / 2397 giving you a value of 0.1126 with this we have performed material balance calculation for a combustion reaction where ethane was burnt with 50% excess air now that we have performed these two example problems for material balances we have reasonable example for performing such material balance calculations in processed where combustion are taking place thank you.