Hydrogen Energy: Production, Storage, Transportation and Safety
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Lecture - 19
Tutorial - 3

Welcome; welcome again for the another module for this particular portion of the course. So, we have looked into the hydrogen energy being produced from coal and biomass and the technology behind it. We will just look into some of the tutorial problems so that to get a hang of how to convert some of the numbers, some of the figures, efficiencies and hydrogen production numbers and all. So, we will just have couple of tutorial problem and then you can practice more at your own.

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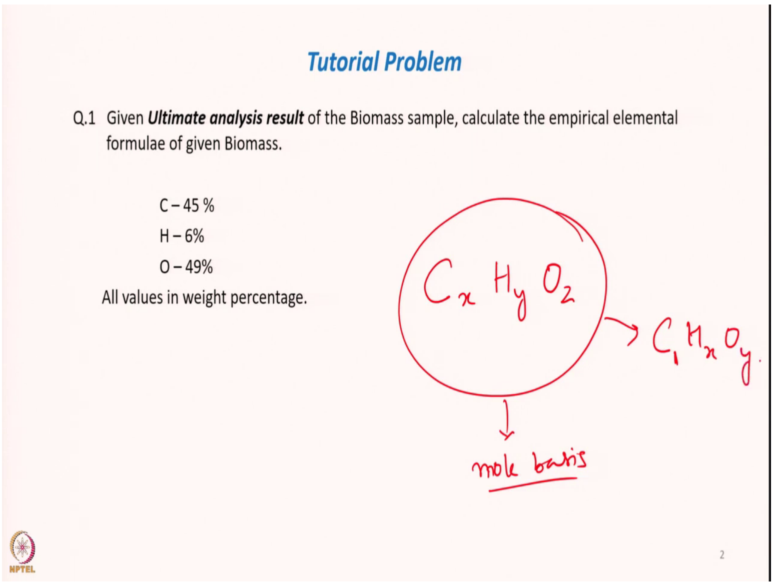

So, first problem that we will discuss now, will be the. If we are given an ultimate analysis result of the biomass sample, then we how we can calculate the empirical elemental formula. So, what exactly is the ultimate analysis result? So, ultimate analysis is done when you give any hydrocarbon or a solid or a liquid fuel to the sort of a system and it gives you how much is the mass fraction of different elements.

So, carbon, hydrogen, oxygen are the major components. So, typically for biomass you will also have nitrogen and sulphur. So, just for the keeping it a bit simple I have not included nitrogen and sulphur in this, but if we just assume that our biomass is having only carbon hydrogen and oxygen, then the machine or the instrument will give us the result in this form. So, carbon and hydrogen and typically most of the machines which do ultimate analysis gives the oxygen as balance.

So, oxygen typically is not detected, but indirectly whatever the numbers you get, mass fractions of the different element we just subtract that from one you will get the oxygen mass fraction. So, this carbon 45 percent, hydrogen 6 percent and oxygen 49 percent. Whatever the number you are seeing here is actually the mass fraction and that is what the ultimate analysis of a solid fuel, whether it is a coal or a biomass that is what we get through the ultimate analysis.

Now, our task is to calculate the empirical elemental formula. So, this is something like this, you will have something like $C_xH_yO_z$. So, similar to what you see a typical hydrocarbon or any oxy hydrocarbon or any oxygenated hydrocarbon formula, but typically all the chemicals which has a standard formula are molecules or the elements of a similar type.

But here what we are looking into is when we have a heterogeneous compound like biomass or a coal which will not have any single chemical species, but mixture of hundreds or even thousands of different chemical species. So, in that case for a simplification, for many analysis this empirical formula helps us, for simple simplification we get a sort of a uniform empirical formula for a given biomass or a coal.

That gives us how much of moles of hydrogen or oxygen present per unit of carbon in that particular sample of wood or a coal, and that we can use it for many of our study specially when we are looking into the kinetics reactions and the output and the how much of extensive reactions of water gas or (Refer Time: 04:16) or water gas shift reaction etc., they will go.

So, it helps us so, we will just see how we get this. So, we have another tutorial problem 2, we will discuss after this.

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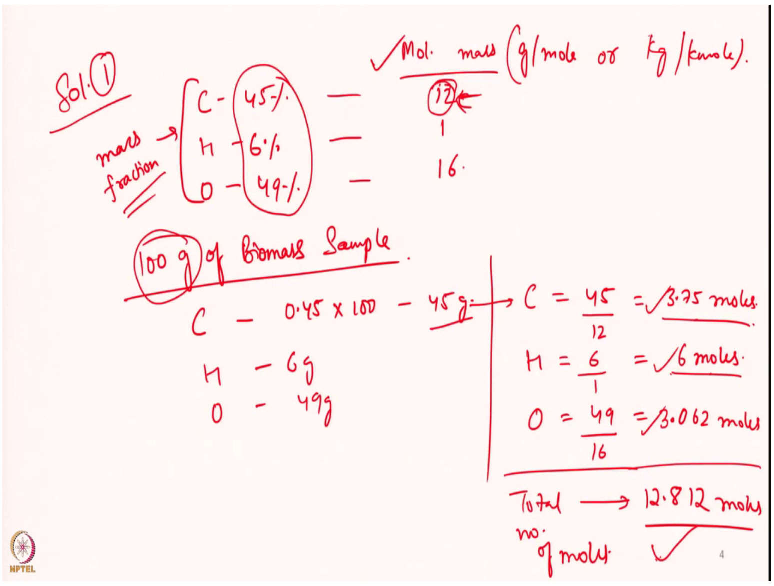

So, if we are looking for the solution here, so let us say solution of tutorial problem 1. So, what exactly we are getting is we are having carbon as 45 percent, hydrogen as 6 percent and oxygen as we have got around 49 percent. So, now, if we put the molecular mass of individual species ahead it. So, for carbon it is 12, so we know that this we can get it from the data book. Hydrogen it is 1 and then oxygen it is 16. And this is in grams per mole or kg per kilo mole.

Now to start with we have to assume that, let us say we have 100 grams of biomass sample, 100 grams of biomass sample, then in one 100 grams of biomass sample and all these are mass fraction. So, all these are mass fraction; that means, you have carbon as 0.45 into 100; that means, you have 45 grams and for hydrogen you have 6 gram, for oxygen you have 49 grams.

So, now what we can get is how many number of moles first we have to find out, because what we are getting into is. So, what we have to find out? We have to find out in this particular format and this is basically on the mass basis. So, we have to convert the mass basis to mole basis. So, how to do that? So, we have got this number of grams and we know how much is the molecular mass of each and every specie.

So, carbon will be whatever amount that we have divided by the molecular mass of this particular species. So, 45 by 12 and it comes out to be 3.75 moles. Why? Because it is 12 gram per mole. So, 12 gram per mole gives us for 45 grams it gives us 3.75 moles. So, similarly for hydrogen, it will be 6 grams divided by 1 gram per mole. So, it will be 6 moles.

So, now you can see that number of moles of hydrogen is more than the number of moles of carbon. But from the mass fraction data, it looks like hydrogen is a very small component, it looks small in this number because its molecular mass is less.

So, it gives a very wrong intuition so that is why this elemental analysis or this getting the empirical formula helps us and that is what we are now doing. So, for oxygen similarly we will get 49 divided by 16 which is its molecular mass and we will get that as 3.062 moles.

So, (Refer Time: 08:10) it will be 3.062. And how many total number of moles? Total number of moles will come as 12.812 moles. Now, it is very simple, we know how many number of moles are there in the 100 grams of the sample and we know individually how much moles of how many moles of carbon, hydrogen and oxygen.

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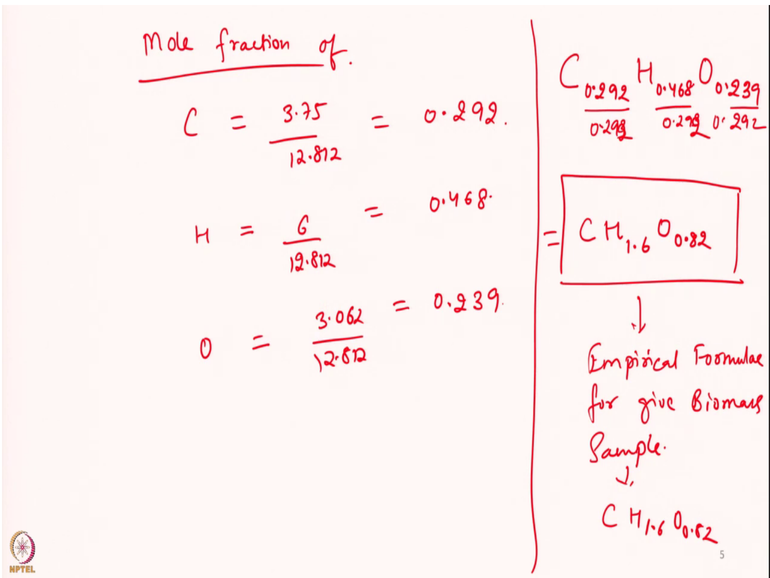

So, simply what we have to do? We just have to calculate the mole fraction. And mole fraction we know how to calculate. So, it is simply the total number of moles which we have and we know how many of the carbon moles. So, carbon moles are 3.75, total number of moles is 12.812. So, we get the mole fraction as 0.292, so 0.292 or 29 percent is the mole fraction. So, it does not have any unit it is just the fraction.

Similarly, for hydrogen it will be it will be 6 by 12.812 and it comes out to be 0.468. And similarly for oxygen it will come out to be 3.062 by 12.812 it will come out to be finally, 0.239. So, what is the empirical formula that we get? So, simply we can just write $C_{0.292}H_{0.468}O_{0.239}$, but looking at this empirical formula, it also looks a little bit means uncomfortable.

So, what we have seen here CxHyOz looks a little bit comfort uncomfortable because of this some fractions of number. So, the easier version is, we calculate for 1 mole of carbon or 1 atom of carbon, how many hydrogen and how many oxygen. So, and simply what to do? We just have to divide all this number by the fraction of carbon, 0.292. And what we get here is $CH_{1.6}O_{0.82}$. So, this is what is our empirical formula for given biomass sample.

So, this is simply, we can write that that is $CH_{1.6}O_{0.82}$. So, and it looks quite different from what we have seen in the mass fraction, because of the different molecular mass of the carbon, hydrogen and oxygen. Similar is when we get into nitrogen, sulphur, phosphorus and many other compounds, elements which are very much present in any of the biomass. So, similarly similar exercise can give us that. So, this is the solution for our first role problem. So, now moving to the second problem.

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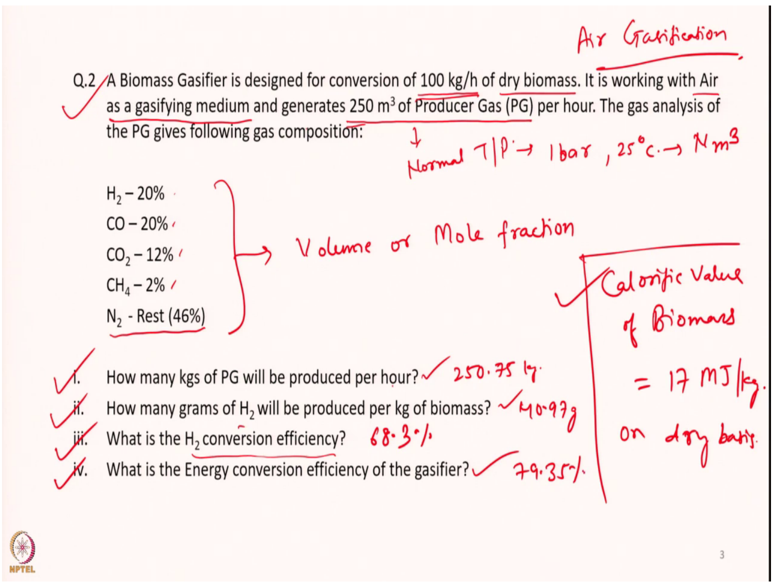

So, second problem is also little bit interesting from the perspective that when we convert any biomass through gasification process, whether it is a coal or a biomass we convert how to get the output numbers, how to convert it into efficiencies, conversion efficiency of hydrogen and energy. So, this particular exercise or this understanding we will get it from when we solve this tutorial problem. So, let us see what is the tutorial problem.

So, it says a biomass gasifier is designed for conversion of 100 kg of dry biomass, it is working with air as a gasifying medium. So, here it is air as a gasifying medium means, it is air gasification problem. So, air gasification problem and it generates 250 meter cube of producer gas, which we call as producer gas which is the product gas of the gasification process.

So, we have 100 kg per hour of dry biomass being fed and we are getting 250 meter cube of producer gas and this is at normal temperature and pressure which is 1 bar and 25 degree centigrade or typically we also denote it as normal meter cube. So, this is 250 normal meter cube producer gas. And now the gas analysis result of that producer gas.

So, gas analysers give us the data and that is the volume fraction. So, all these data of gases are the volume or mole fraction. So, volume fraction and mole fraction are interchangeable. So, the analyser gives us the volume fraction. So, hydrogen is 20 percent by volume, carbon monoxide 20 percent, CO2 = 12 percent, methane = 2 percent and rest is nitrogen because we are using air as a gasifying media.

So, there will be bulk of nitrogen also. Now, the question asks how many kg of producer gas will be produced per hour, how many grams of hydrogen will be produced per kg of biomass and what is the hydrogen conversion efficiency, means we have seen lot many efficiencies numbers and all. So, here the hydrogen conversion efficiency means, if you have hydrogen and that we see how many grams of hydrogen.

So, it was 6 percent. So, 6 percent means if you have 1 kg of biomass it will have 60 grams of hydrogen in it. So, out of 60 grams of hydrogen how much you are able to convert it into elemental hydrogen or the H_2. So, that is the H_2 conversion efficiency and then last one, what is the energy conversion efficiency and it is very simple energy conversion means if you have a solid fuel, which you fed to the gasifier and you get the gaseous fuel.

So, how much of the energy or the chemical energy you have been able to conserve, when you convert it from solid fuel to gaseous fuel through gasification process and yeah. So, one number missing that is the calorific value of biomass is 17 megajoule per kg, so on dry basis. So, now, let us go one by one. So, how many kg of producer gas will be produced per hour?

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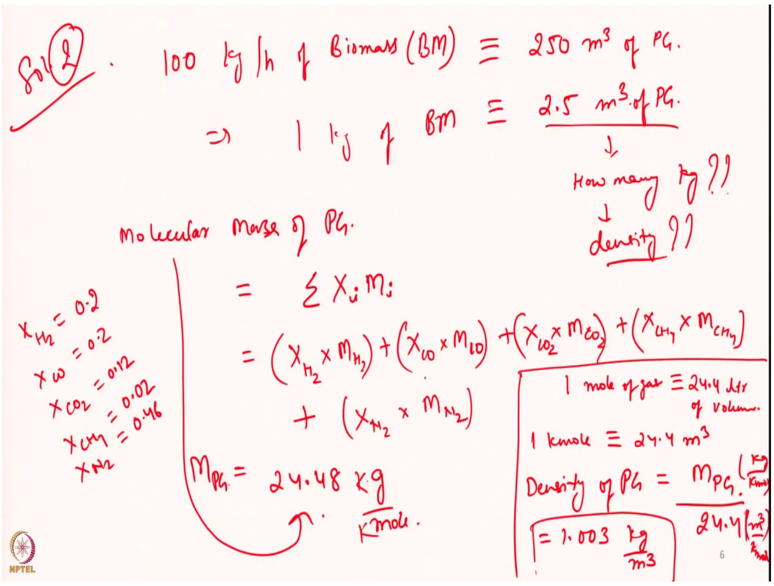

So, we have given the volume fraction. So, here solution for 2. So, here what we are given? We are given the volume fraction. So, 100 kg per hour of biomass that we can denote it as BM, is giving us 250 meter cube of producer gas or PG. That means, 1 kg of biomass is giving us 2.5 meter cube of producer gas. Now, this 2.5 meter cube of gas and our question is how many kg.

So, for this what we need to know? We need to derive the density. So, we will find out the density first and then straight away multiplying it with this volume we can get the mass of the gas. So, now, first we need to get the molecular mass of producer gas, again it is a mixture of different gas species, but the common if we get the molecular mass just like we calculate for air.

When we want to calculate for producer gas it will be nothing but the summation of all the volume fraction of all the ith species of gases, molecular mass of the ith species of the gases and this you can get. So, what we have is X of hydrogen multiplied by molecular mass of hydrogen plus volume fraction of CO multiplied by molecular mass of CO plus volume fraction of CO2 multiplied by molecular mass of CO2 plus. So, we can just put it in bracket to avoid confusion; so plus volume fraction.

So, volume fraction is denoted by X. So, of methane multiplied by molecular mass of methane and plus we also have nitrogen so that is, volume fraction of nitrogen multiplied by molecular mass of nitrogen. And we know all the numbers for this we can get it from the database if you do not have. So, volume fraction of the hydrogen, X hydrogen is given as 0.2.

So, 20 percent here we have to use the number, not the percentage. And X of CO is given as 0.2, X of CO_2 is given as 0.12 or 12 percent and volume fraction of methane is given as 2 percent so 0.02 and rest is for the nitrogen and that is 0.46. And then you put the molecular mass of all. So, finally, you will get the number as 24.48 gram per mole.

So, this is what you get as the molecular mass of the producer gas. So, once you get the producer gas molecular mass. So, density how it is given? We know that 1 mole of gas by Avogadro number for that law; it occupies 24.4 litres of volume. So, 1 kilo mole will occupy 24.4 meter cube of volume. So, when we look into density of producer gas it will come as molecular mass of PG which is this, molecular mass of producer gas divided by 24.4. So, this is again at the normal temperature and pressure, 1 bar and 25 degree centigrade.

So, this comes out to be 1.003 kg per meter cube. So, you can just cross check it, molecular mass is kilogram per kilo mole. So, here this is in kg we can convert that and this is nothing but meter cube per kilo mole. So, it comes out to be kg per meter cube, that is the density of the producer gas. So, now, our question is how many kg of producer gas will be produced per hour?

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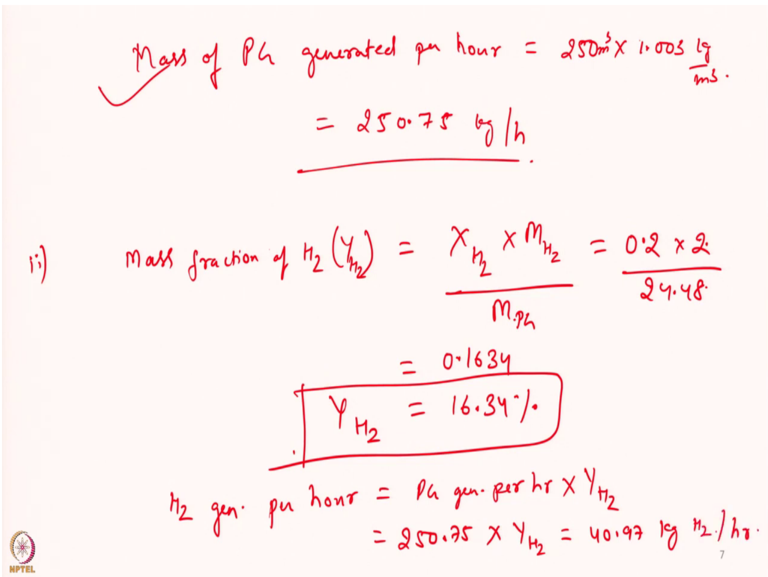

So, it is very simple it is simply or you can say the mass of producer gas generated per hour is nothing 250 meter cube multiplied by its density kg per meter cube. So, it comes out to be 250.75 kg per hour. So, what was our question? Our question was how many kg of producer gas will be produced per hour. So, this we have got it.

So, now come how many grams of hydrogen will be produced. So, now, we know how many kg will be produced per hour and we also know if 100 kg per hour of biomass then per kg biomass also we know, but we do not know how much of hydrogen. And this we can get it straight away if we know the mass fraction of the hydrogen. So, now, for the second part of the problem, we know what we need to know what is the mass fraction of hydrogen and this mass fraction of hydrogen which is denoted by symbol Yi or here if we know i is hydrogen. So, it to be Y_{H2}.

So, this is given by formula mole fraction multiplied by molecular mass of hydrogen divided by the molecular mass of producer gas and we know how much is the mole fraction is 20 percent. So, 0.2, molecular mass of hydrogen is this H_2, so this is 2 and divided by molecular mass of producer gas that is 24.48 that we just derived for the first part.

So, this comes out to be 0.01634 which is nothing but your 1.634 percentage. So, our Y of hydrogen that is the second part is this thing, but we need to know how much is the kgs of hydrogen produced. So, for that we know per kg of biomass. So, hydrogen generated per hour will be equal to this mass of producer gas generated per hour, producer gas generated per hour multiplied by Y of hydrogen, this comes out to be 250.75 into Y of hydrogen.

So, this comes out to be 4.097 kg of hydrogen per hour. And now we need to know how many per kg.

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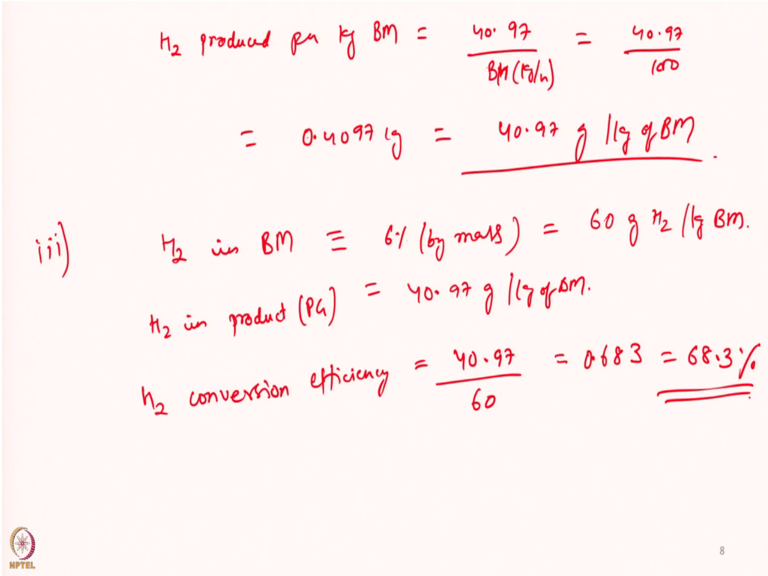

So, hydrogen produced per kg of biomass is equal to 4.097 divided by biomass consumed in kg per hour. So, this is 4.097 by 100 kg biomass is being consumed per hour. It comes out to be 0.04097 kg or it is 40.97 grams per kg of biomass.

So, this is our answer for the second part. So, per kg of biomass we are getting around 40.97 grams' hydrogen. So now, the third part is what is the hydrogen conversion efficiency. So, second part we got it; we got 40.97 grams. And how many kg will be produced here? So, first part we got 250.75 kg and now what is the conversion efficiency hydrogen conversion efficiency? So, that is again once we have got this so our third part will be simple.

So, hydrogen in biomass is 6 percent biomass, that we know by its elemental analysis that is 60 gram hydrogen per kg biomass and hydrogen in product that is your producer gas is 40.97 grams per kg of biomass. So, your hydrogen conversion efficiency comes out to be just fraction of this, that is 40.97 divided by 60 what we had in our biomass.

So, this comes out to be 0.683 or 68.3 percentage. This comes out to be 68.3 percentage of hydrogen and rest of the hydrogen goes either in methane or it comes out as H2O which get condensed when we cool the gas. So, it is lost, but 68.3 we still get as an elemental hydrogen. So now, the last part is what is the energy conversion efficiency of the gasifier, given the calorie value of the biomass is 17 megajoule.

So, now we have more or less all the numbers that we need to calculate the energy efficiency.

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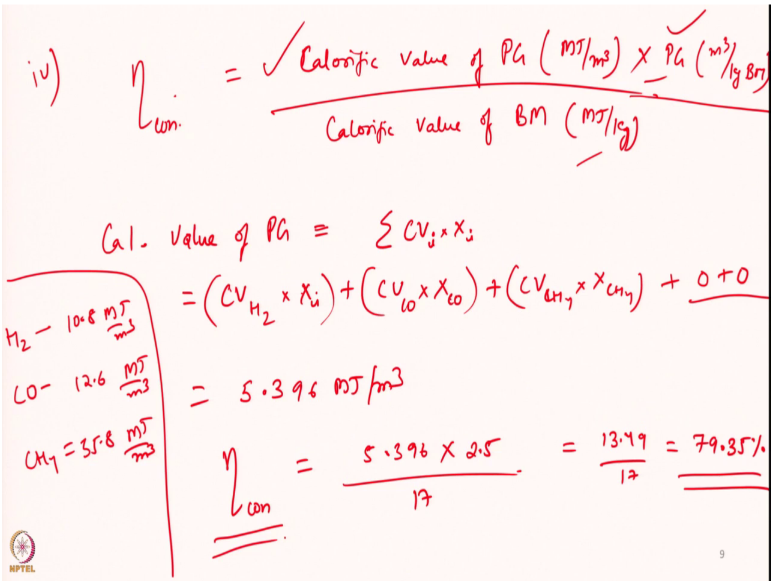

So, for the part four simple energy efficiency or we can just write it as efficiency of conversion is nothing but calorific value of producer gas in mega joule per meter cube divided by calorific value of biomass in mega joule per kg. But what is missing here is the producer gas in produced that is in the meter cube per kg of biomass. So, we get the right number here now.

So, first thing is to calculate the calorific value of producer gas. So, again calorific value is just like we calculate the mass fraction or the overall volume fraction that calculation we have done. Similarly, our value is also based on summation of the calorific value of individual gases, multiplied by the volume fraction, if we are looking for the meter cube. So now, this will be nothing but summation of calorific value of ith gas species multiplied by the volume fraction of the ith mass species or gas species.

So, this comes out to be calorific value of hydrogen multiplied by volume fraction of hydrogen, it is X i plus caloric value of carbon monoxide multiplied by volume fraction of carbon monoxide plus we will put bracket to avoid confusion plus calorific value of methane multiplied by calorific volume fraction of methane. We have two more gases in the fuel, that is carbon dioxide and nitrogen, but it does not have any calorific value right. So, we do not need to consider that.

So, we are only considering the fuel component of the gas. So, for nitrogen and CO2 it will be 0, no value for that. So, now, you can do it in mass fraction as well as in the volume fraction, whichever way you feel convenient. So, I am just denoting it with the mass fraction with mole fraction.

So, now from the data table we get hydrogen has a calorific value of 10.8 megajoule per meter cube, carbon monoxide is 12.6 megajoule per meter cube and methane is 35.8 megajoule per meter cube. So, putting all these values and the corresponding values of the volume fraction of the gas, we get the final number as 5.396 megajoule per meter cube. So, we have got this value and rest of the two we know. So, it is very simple.

So, efficiency of energy conversion from solid fuel to gaseous fuel, how much we are able to conserve the energy and that is 5.396 and the producer gas produced is 2.5 meter cube per kg that we already know and the calorific value of the biomass given in the problem 17 mega joule per kg.

So, this comes out to be 13.49 by 17 comes out to be 79.35 percentage. So, this is what is the conversion efficiency, 79.35 percent. So, very good reasonable number is 79.35 percentage. So, this gives you an overall a picture, not only a just editorial problem, but also gives you a picture like when we are going through gasification process, what is the potential of hydrogen, when we are doing the air gasification how much we can enhance if we do go for oxy stream gasification.

Hydrogen is present in biomass, it is also present in different category of fuels will have different amount of hydrogen, that also we have studied. So, we can calculate how much is the potential of the fuel itself to give you hydrogen, elemental hydrogen from the fuel and if we want more we need to use H_2O or the steam as a reactive media.

And also we get to know how much is the conversion efficiency, energy conversion efficiency around 80 percent, which is very good. So, it is just a thermo chemical process, but chemical energy is being transferred some of the heat loss is in the form of sensible heat, that goes out and some of the exergy losses that is because of the change in the entropy of the system.

So, that is about that. So, here we will finish this tutorial part and hope you will be able to solve a similar problem or a we will get a better insight of this particular portion of the course.

Thank you.