Fuels, Refractory and Furnaces
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Lecture No. # 03
Characterization of Fuels: Concepts

So, we continue our lecture with characterization of fuel, and I told you about calorific value and proximate and ultimate analysis of solid fuel. Now let us take fuel oil.

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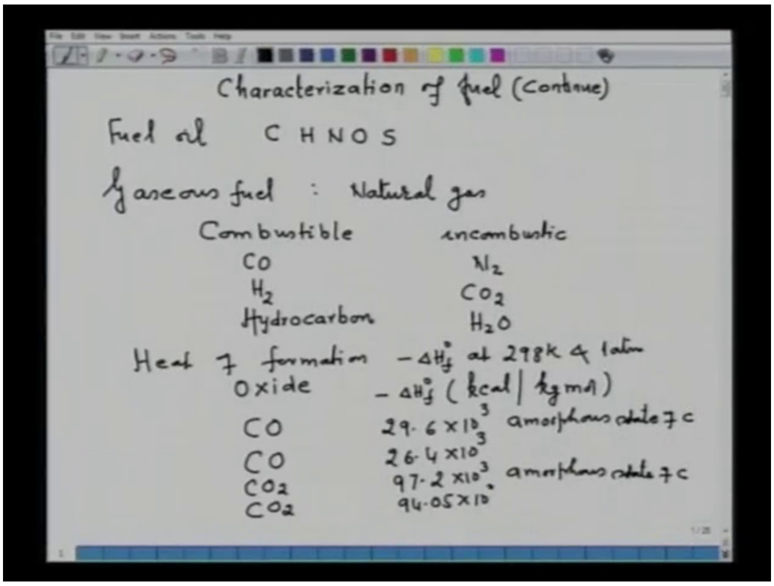

As regard fuel oil the analysis of fuel oil is given in terms of Carbon, Hydrogen, Nitrogen, Oxygen and Sulphur. The calorific value of fuel oil can be easily determined from the heat of formation of various oxides. For example, Carbon to CO 2, H to H 2 O and S to SO 2, and Nitrogen is an incombustible component. So, all combustible components are added together with their heat of formation that gives us the calorific value of fuel oil. Now in general, calorific value of fuel oil it does not change very much, it remains in the order of magnitude of around 9000 kilo calorie per k g to around 10000 or something to kilo calorie per kg.

As regard gaseous fuel, acid gaseous fuel natural gas is the naturally occurring resource let us say fossil fuel. There are other gaseous fuels also; in general all gaseous fuels have combustible component and incombustible component. For example, the combustible components of any gaseous fuel that consist of carbon monoxide, hydrogen, hydrocarbons; they are the principle, combustible component of any gaseous fuel among hydrocarbon there could be several. For example, C H 4 C 2 H C 2 H 8 or so on all these are the combustible component among incombustible component. We have say nitrogen, carbon dioxide, H 2 O so these are the incombustible component or you can also call them to be diluones that means they dilute the energy released by combustible component.

Now the calorific value of gaseous fuel it can be determined from heat of combustion values. Now I am giving here typical heat of combustion values of some gases. So, heat of so I am giving here, typical heat of formation values of some gases and from heat of formation one can also determine the heat of combustion. Say for example, heat of formation of some gases. Say I am giving here minus delta h naught heat of formation. I have given it 298 Kelvin and one atmospheric pressure. One can put oxide minus delta h naught f little more characters minus delta h naught f that I am giving in kilo calorie per k g m ole. So for carbon monoxide this value is 29.6 into 10 to the power 3 when the state of carbon is amorphous.

Amorphous state of carbon in fact the heat of formation that is also equal to heat of combustion when carbon reacts with oxygen and forms carbon monoxide so in that case heat of formation will be same as heat of combustion. C O in literature also you will find value to be 26.4 into 10 to the power 3 when carbon is not in amorphous state so that. is to be clear. Similarly carbon dioxide is 97.2 into 10 to the power 3 again here amorphous state of carbon. Amorphous state of carbon and in all other states c o two that is equal to 94.05 into 10 to the power 3 in all other states.

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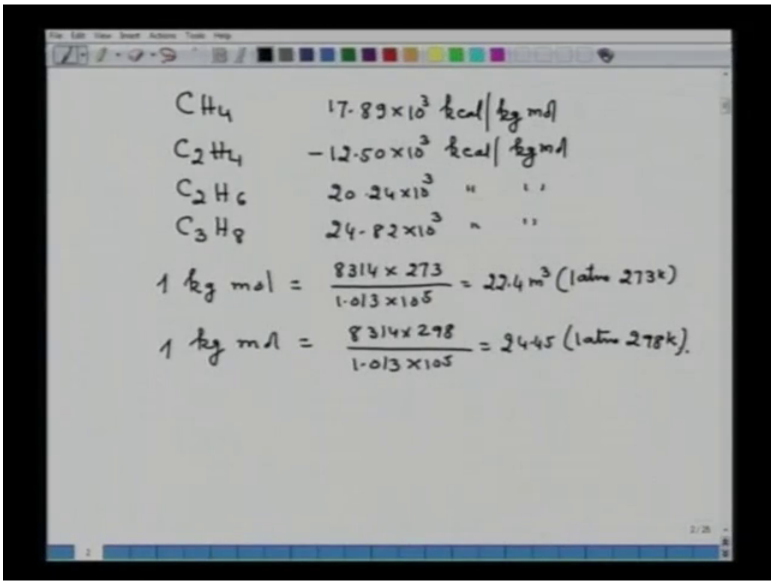

So, for methane the heat of formation is 17.89 into 10 to the power 3 kilo calorie per k g mole. Now note in case of C H 4 heat of formation is not equal to heat of combustion. Where as in case of CO C O 2 H 2 O the heat of formation will be equal to heat of combustion. So C H 4 17.89 into 10 to the power 3 kilo calorie per k g mole is the heat of formation in carbon reacts with hydrogen and it forms methane. C 2 H4 4 note its value is minus 12.50 into 10 to the power 3 kilo calorie per k g mole. Then C 2 H 6 this value is 20.24 into 10 to the power 3 kilo calorie per k g mole. C 3 H 8 value is 24.82 into 10 the power 3 kilo calorie per k g mole. About H 2 O vapor and H 2 O liquid I had already given in my earlier lecture.

Now one more thing is important to note that 1 k g mole one k g mole of any gas that is equal to upon 1.013 into 10 to the power 5 and that is equal to 22.4 meter cube at 1 atmosphere pressure and 273 Kelvin. Whereas 1 k g mole at 298 Kelvin into 298 divide by 1.013 into 10 to the power 5 that is equal to 24.25 at 1 atmosphere and 298 Kelvin.

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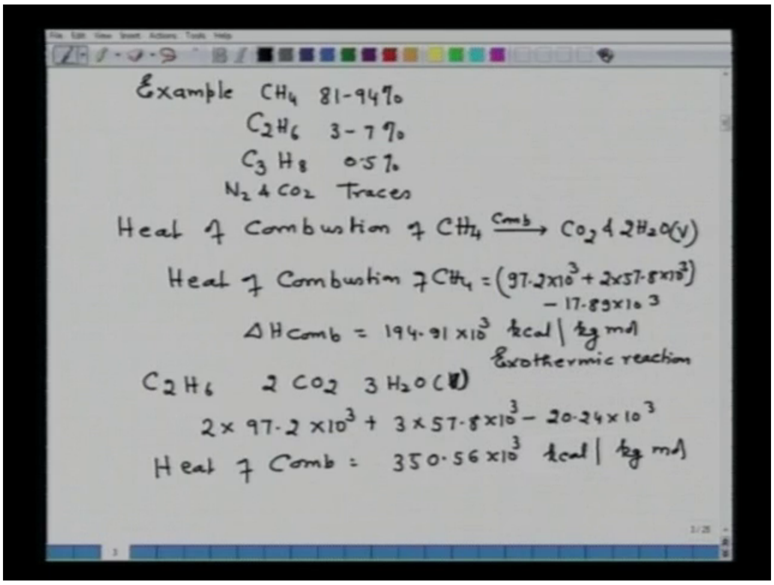

Now let us take an example to calculate the calorific value of say natural gas. So, I take an example of natural gas which has composition say methane it contains around 81 to 94 percent C 2 H 6, 3 to 7 percent, C 3 H 8, 0.5 percent and rest nitrogen and CO 2 they are traces. Now how to determine the calorific value of this gaseous fuel which is in fact natural gas? Now first of all we have to find out the heat of combustion of CH4, C 2 H 6 and C 3 H 8. So, once you find out the heat of combustion of the respective combustible component of the natural gas, we can add them together and we will get the heat of combustion of natural gas.

So, first of all you find out the heat of combustion of C H 4 so in order to find out say of heat of combustion of CH 4. Heat of combustion of CH 4, if we take say 1 k g mole of natural gas then CH 4 on combustion it forms CO 2 and 2H 2 O then heat of combustion of methane that will be equal to 97.2 into 10 to the power 3 plus 2 into 57.8 into 10 to the power 3 now mind you here on combustion H C 4 I had take C O 2 and H 2 O in the vapor state. If I take in the liquid state then I have to add theta of condensation this minus theta formation of methane that is 17.89 into 10 to the power 3. So, if I solve then I get the delta h combustion that is equal to 194.91 into 10 to the power 3 kilo calorie per k g mole. Now in fact they are in minus value so this is an exothermic reaction.

Similarly we can find out the heat of combustion of C 2 H 6. Now C 2 H 6 on complete combustion it gives 2 C 2 O and 3 H 2 O let us say 3 H 2 O as vapor. Then we can similarly, find out heat of combustion that will be 2 into 97.2 into 10 to the power 3 plus 3 into 57.8 into 10 to the power 3 minus heat of formation of C 2 H6 3. 24 into 10 to the power 3 so on solving we will be getting heat of combustion, heat of combustion that is equal to 350.56 into 10 to the power 3 kilo calorie per k g mole of C 2 H 6.

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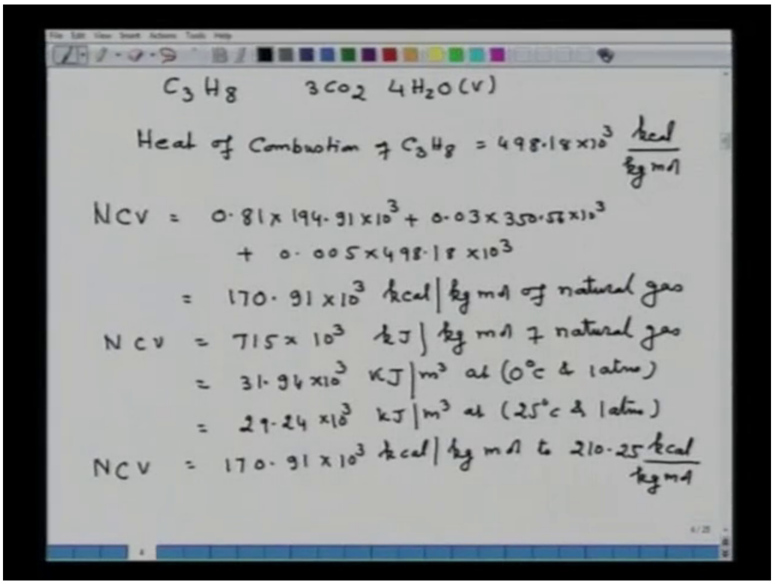

Now similarly, we can also find out another component C 3 H 8 doing same exercise say three C O 2 and 4 H 2 are the complete products or combustion. We take in the vapor state so again if I write down the heat of combustion of C O 2 heat of combustion of H 2 O subtract heat of formation of C 3 H 8. As I have done you can also do it because the values are given so we get heat of combustion of C 3 H 8 heat of combustion of C 3 H 8 that comes out to be equal to 498.18 into 10 to the power 3 kilo calorie per k g mole. Now we have the heat of combustion values of all the combustive components. Now note that these values belong when H 2 O is in the vapor state so we can call it to be net calorific value.

Therefore, the net calorific value of natural gas of the composition which I have given earlier, that will be equal to 0.81 taking the lower percentage of C H 4 that is .81 into 194.91 into 10 to the power 3 plus 0 .03 into 350.56 into 10 to the power 3 plus 0.005 into 498.18 into 10 to the power 3. So, this is the net calorific value of one k g mole of natural gas so we add them together we will be getting. 170.91 into 10 to the power 3 kilo calorie per k g mole of natural gas of natural gas.

Now we can convert in the different units also if you wish to do that then NCV that is equal to 715 into 10 to the power 3 that is kilo joule per k g mole of natural gas. We can also put that is equal to 91.94 into 10 the power 3 kilo joule per meter cube of natural gas mind you at 0 degree Celsius and 1 atmospheric pressure. Because when you want to express the calorific value in terms of meter cube then you have to express, what is the temperature and pressure? Because the expression of meter cube it has no meaning unless pressure and temperatures are specified that is an important thing.

Now this value is also equal to 29.24 into 10 to the power 3 kilo joule per meter cube at 25 degree Celsius and 1 atmospheric pressure. So, these are the calorific or net calorific value of natural gas. Now since the composition varies between 81 to 94. C 2 H 6 three to seven and so on. So, one can also determine taking other extreme composition that is 94 percent of methane 7 percent of C 2 H 6 then the calorific value or net calorific value. It varies in between 170.91 into 10 to the power 3 kilo calorie per k g mole to 210.25 kilo calorie per k g mole. So this is how the calorific value of gaseous fuel can be calculated.

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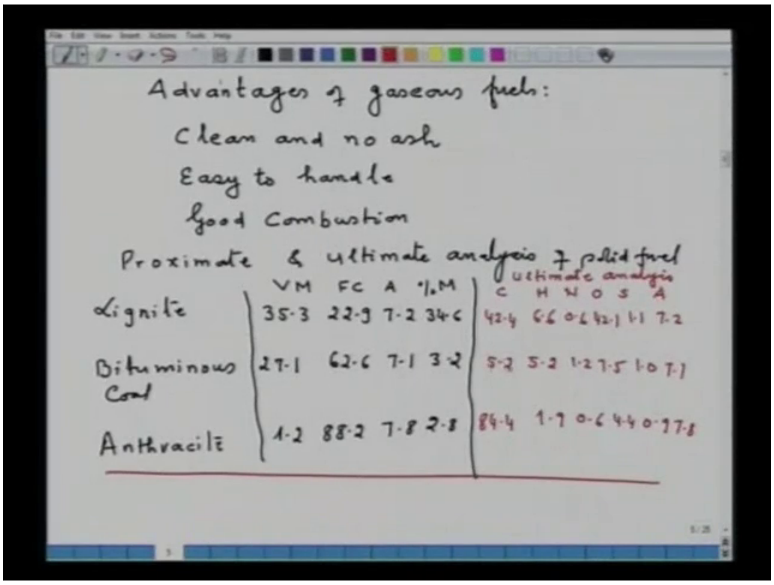

Now there are some advantages of gaseous fuels. The advantages of gaseous fuels are say one advantage they are clean and no ash. Gaseous fuel does not contain ash when you compare it with solid fuel which contains 10 percent, 15 percent or 20 percent ash. So, in that regard the gaseous fuel they are clean and do not contain any ash. Another benefit of gaseous fuel is they are easy to handle easy to handle. Third example good combustion can be obtained, because of the important condition for efficient or good combustion is the mixing of the combustible component of any fuel with the oxidizing gas. For example, air if it is good then combustion will be good, and one can easily expect when the fuel is a gaseous fuel then the mixing is very good compared to when you have the solid fuel and you are combusting with the air.

So, these are some of the advantages of gaseous fuels. Now after knowing this proximate analysis ultimate analysis and calorific value of different types of fuel, now we are in position to classify the fuels. And we will say that the fuel which has a high calorific value is a good quality fuel. Fuel which has a low calorific value is relatively not a good quality fuel. So, according to this we can classify the fuel in terms of say quality of the fuel, and defining by way of its composition and calorific value. So, first of all let us take the fossil solid fuel. So, I will give here some of the proximate analysis some of the proximate and ultimate analysis of the solid fuels. Say I take here lignite then I take bituminous coal and then I take anthracite. So, let me first of all give proximate analysis and all of us you know proximate analysis is given of volatile meter fixed carbon ash and percentage moisture.

Now lignite 35.3 volatile meter 22.9 percent fixed carbon, 7.2 percent ash and 34.6 percent moisture. Bituminous coal 27.1 percent volatile meter, 62.6 percent fixed carbon 7.1 percent carbon and 3.2 percent carbon note. The drastic decrease in the moisture as you go from lignite to bituminous coal that is the rank of the coal increases the moisture content drastically decreases. Anthracite volatile meter is 1.2 percent, 88.2 percent fixed carbon, 7.8 and 2.8 percent volatile meter percentage moisture.

Now interesting is to is to write down the ultimate analysis because if you want to find out the quality of the fuel then you have to find out how much energy it can release. That is what the calorific value of the fuel is and for that we need ultimate analysis. Now ultimate analysis says all of us you know is given in terms of carbon, hydrogen, nitrogen, oxygen, sulphur and ash. So, I am writing here carbon 42.4 and 84.4. Hydrogen 6.6, 5. 2, 1.9 Nitrogen 0.6 here it is 1.2, here it is 0.6. Oxygen 42.1 which drastically decreases to 7.5 and ultimately to 4.4 sulphur which is 1.1, slightly decreases not very much 0.9 and ash more or less it remains constant sort of thing.

So, this is what the proximate and ultimate analysis of the fuel. Now since we know that we can determine the calorific value of the fuel by the formula which I developed earlier. So, we try to determine the calorific value of the fuel and then we can say the quality of the fuel.

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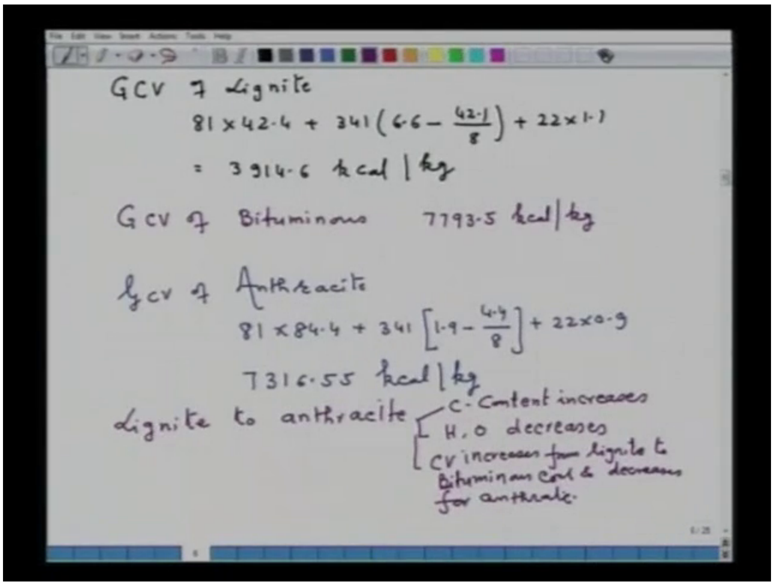

So, if I determine the say I determine the GCV of lignite. If I want to determine GCV of lignite then you know the formula that is 81 into 42.4 plus 341, 6.6 minus 42.1 upon 8 plus 22 into 1.1. So, comes out to be equal to 3914.6 kilo calorie per k g. Similarly I can determine GCV of bituminous coal and GCV of bituminous coal again the same formula you plug in the values of carbon, hydrogen and so on. And you will be getting the values are 7793.5 kilo calorie per k g. Similarly, I can determine now the gross calorific value of anthracite of anthracite again. I have to substitute say 81 into 84.4 plus 341, 1.9 minus 4.4 upon 8 plus 22 into 0.9. If I solve I will be getting 7316.55 kilo calorie per k g.

So, of all the three fuels if you want to analyze the calculation we see that the bituminous coal has a relatively higher quality than anthracite and lignite. Because the bituminous coal on combustion gives higher calorific value as compared to anthracite and to lignite. So, now s v go from lignite to anthracite that is if we proceed from lignite to anthracite then our calculations suggest the follows. And also the table shows follows that is carbon content increases carbon content increases. What is the reason for increase in the carbon content is obvious, because the anthracite which forms it is higher ranking of the coal and it forms at the last stage of coalification, and because of the because of the physico chemical reaction most of the volatile metals are removed and anthracite has higher carbon content also you can call it to be higher rank.

Another observation that you can make is that hydrogen and oxygen decreases. As we go from lignite to anthracite the reason is again in the coalification. Now third observation that you can make the calorific value it increases from lignite to bituminous coal and decreases to anthracite and decreases for anthracite. Do you know why if you see the analysis? You will find that the anthracite has lower percentage hydrogen as compared to bituminous coal. And therefore, in the anthracite the calorific value is slightly lower than that of bituminous coal.

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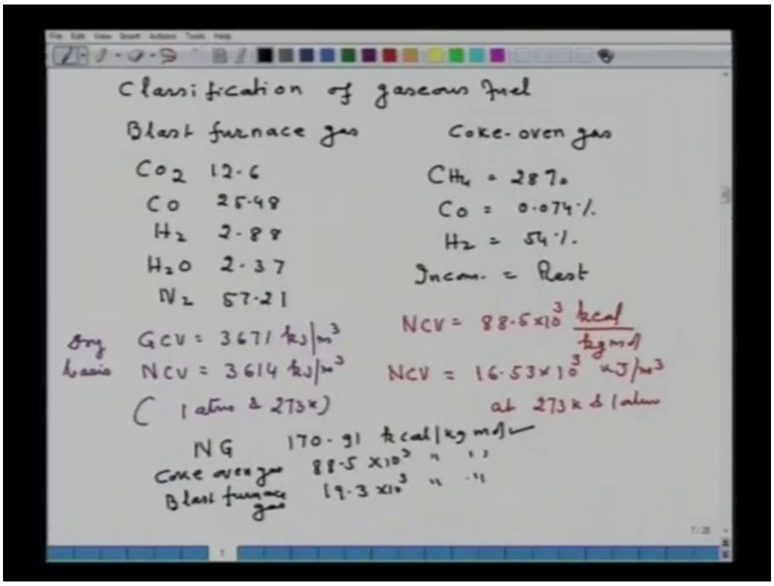

Now, then we can also classify in the same way gaseous fuel. Say classification of gaseous fuels. Classification of gaseous fuels. Now from combustion of view it is the calorific value that is important higher is the calorific value higher is the quality of the fuel lower, is the calorific value lower is the quality of the fuel. So, depending on the calorific value that a particular fuel has one can grade in terms of quality. So, there are several types of gaseous fuels are available. I will just quote one or two example now rest when you can find out from the books you can calculate the calorific value and you can grade them. So, I am taking one example as a blast furnace gas.

A typical composition which I have selected C O 2 12 .6, CO 25.48 hydrogen 2.88, H 2 O 2.37 and nitrogen 57.21. Another gas that I am selecting is the coke oven gas. Is the coke oven gas coke oven gas it is C H 4 28 percent CO 0.074 percent and hydrogen 54 percent and incombustible are rest. So one can determine NCV or GCV whichever you want to calculate again you calculate the heat of combustion of various combustible component add them together and you get the calorific value. So, for blast furnace gas on dry basis GCV it comes out to be equal to 3671 kilo joule per meter cube and N CV that is equal to 3614 kilo joule per meter cube and these values are at one atmospheric pressure and 273 Kelvin.

Now similarly, for coke oven gas NCV that is equal to 88.5 into 10 to the power 3 kilo calorie per k g mole and that is also equal to 16.53 into 10 to the power 3 kilo joule per meter cube at 273 Kelvin and 1 atmospheric pressure. So this is again the N C V. So, what we can conclude from here? So, if we have three different types of fuels in natural gas blast furnace gas and coke oven gas. Then the as per the quality of the fuel regarding the calorific value is concerned. So, one can say natural gas it has a higher quality followed by coke oven gas and followed by blast furnace gas.

So, I am just summarizing say natural gas calorific value is 170.91 kilo calorie per k g mole. Then coke oven gas as just now we have calculated 88.5 into 10 to the power 3 kilo calorie per k g mole. And then we have blast furnace gas value is 19.3 into 10 to the power 3 kilo calorie per k g mole. So, on these three fuels if you are required to classify you say natural gas is a higher quality fuel and related to natural gas coke oven gas is lower quality, and related to coke oven gas blast furnace gas is another low quality fuel so if you have another several fuels one can do the classifications.

Now another important thing in case of gaseous fuel it is gaseous fuels of range of properties. The calorific value varies the density also varies so a combustion system which is designed for a one particular type of gaseous fuel is not suitable for another type of gaseous fuel.

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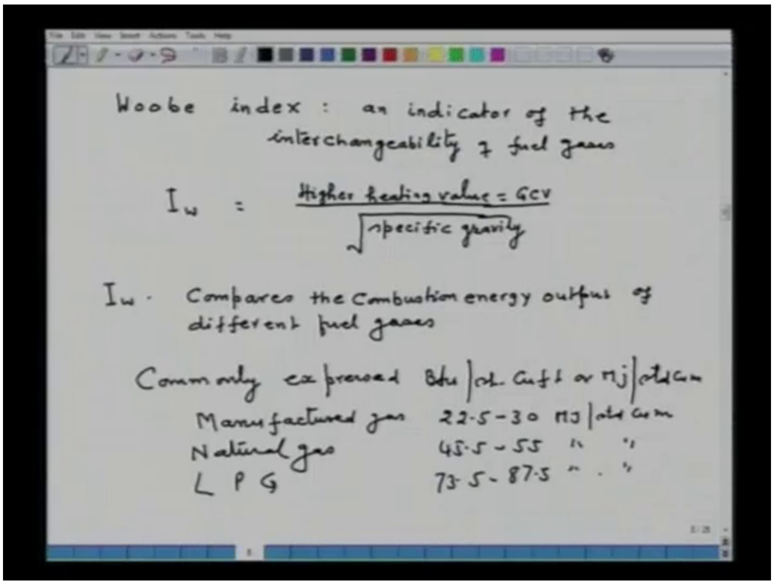

So for this purpose a Woobe index is defined. A Woobe index can be defined, and Woobe index is an indicator an indicator of the interchangeability of fuel gases, say like natural gas liquefied petroleum gas or whatever the gas maybe. It is defined as the Woobe index I w it is defined always on the basis of higher heating value, higher heating value which is also called GCV gross calorific value divided by square root of specific gravity. So, that is how an Woobe index is defined? So, this I w in fact it compares it compare the combustion energy output the combustion energy output of different fuel gases.

Now in fact while they are fuel gas or gaseous fuel they are one and the same thing. Now if the two fuels have identical Woobe index then for given pressure and mole settings the energy output will also be identical, that is what the concept of Woobe index. So, this Woobe index is commonly expressed is commonly expressed as B t u per standard cubic feet or mega joule per standard cubic meter. Now say some Woobe index of some gases say for example, if you have a manufactured gas some manufactured gas the Woobe index is 22.5 varies to 30 in mega joule per standard cubic meter for natural gas the value is 45.5 to 55 same unit. And for liquefied petroleum gas this value is 73.5 to 87.5. So, all these Woobe index are just that if you want to interchange a combustion appliance of one type of fuel to another then this Woobe index gives you a guideline.

So, now I will illustrate the concepts of proximate analysis ultimate analysis method of expression on the different basis and the calorific value by few problems. So, first so illustration.

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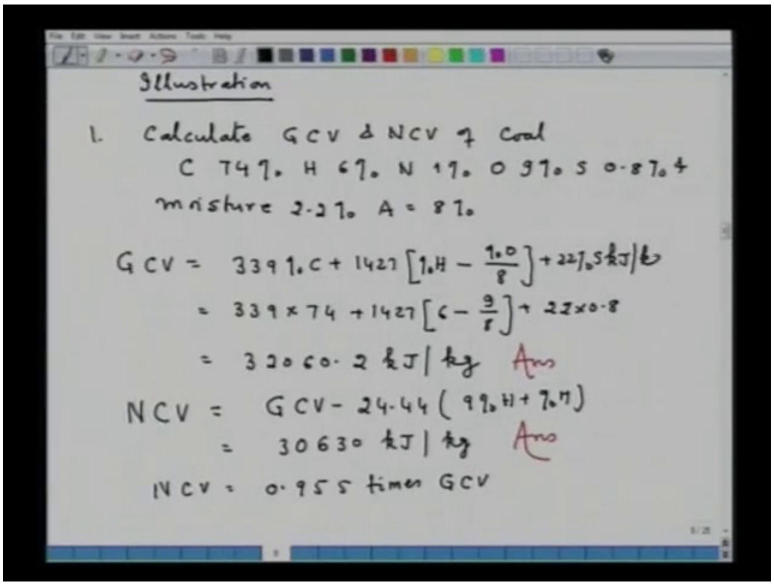

Let us take one problem say calculate GCV and NCV of a coal which analyses carbon 74 percent hydrogen, 6 percent nitrogen,1 percent oxygen, 9 percent sulphur, 0.8 percent and moisture, 2.2 percent and ash that is equal to 8 percent.

So, I required calculating gross calorific value and net calorific value of the fuel. So, I calculate gross calorific value straight away substituting the formula, you can calculate either in kilo calorie per k g or kilo joule per kg whichever way you want to calculate. I am calculating for kilo joule per k g that is formale 339 into percentage carbon plus 1427 percentage hydrogen minus percentage o upon 8 plus 22 percent is sulphur this value you will get in kilo joule per k g. So, I will be just substituting the value 339 into 74 plus 1472, 6 minus 9 upon 8 plus 22 into percent 0.8. Now all that you have to multiply and add them together so the value will be 32060.2 kilo joule per k g.

This is the, this is how you will be calculating. Now similarly, the NCV net calorific value they are the state of product of combustion is vapor of water then the net calorific value is equal to GCV minus 24.4, 49 percent h plus percentage moisture. So if you do that if you substitute the value of percent h that is equal to 6 moisture is 2.2 substitutes you will be getting 30630 kilo joule per k g. So, this is the answer. Now one of the important is to analyze the answer; now if you note from here you see that NCV is equal to 0.955 times gross calorific value in this particular case.

Why is it so? Because net calorific value considers H 2 O in the vapor phase, and this is very important from combustion of view, because the heat of vaporization of water will not be available for the heating of product in a furnace. So, it depends on the situation, where gross calorific value is to be calculated, and net calorific value is to be calculated. Now once again in the gross calorific value the state of H 2 O is liquid in NCV the state of water is vapor. So, that is why the difference is there, and the net calorific value is 95.5 percent of that of gross calorific value.

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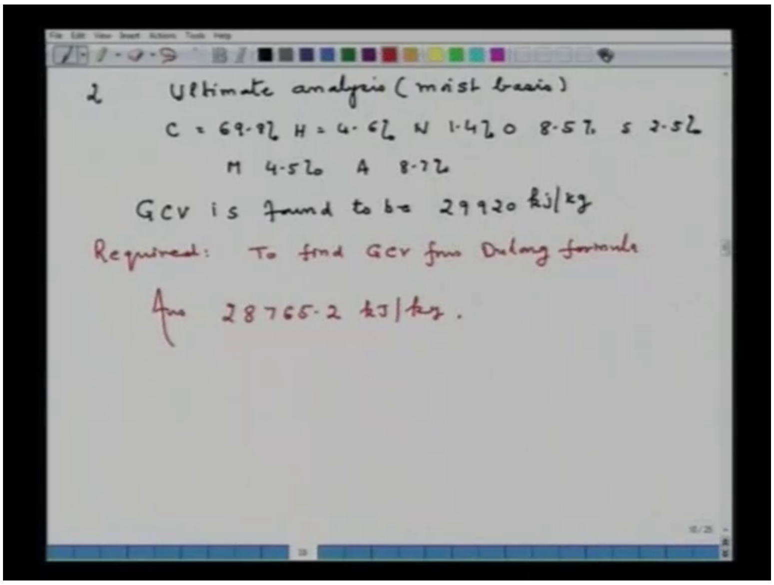

Now let me take another problem say the ultimate analysis of coal is given. Are given ultimate analysis it is given on moist basis given on moist basis say carbon 69.8, Hydrogen 4.6, nitrogen 1.4, oxygen 8.5 percent well they are all in percentage percent. Sulphur 2.5 percent, moisture 4.5 percent and ash is 8.7 percent. Now the gross calorific value is determined from experiment and gross calorific value is formed to be formed to be 29920 kilo joule per k g. Now you are required to find GCV from dulong formulas I had given earlier. And compare the values, and you have to find out the value of gross calorific value on moist basis so all that you have to substitute the composition as it is given and the value which the answer which you will be getting in this case that will be around 28765.2 kilo joule per k g therefore, your observation would be the Dulong formula calculates 0.96 times that of experimental one.

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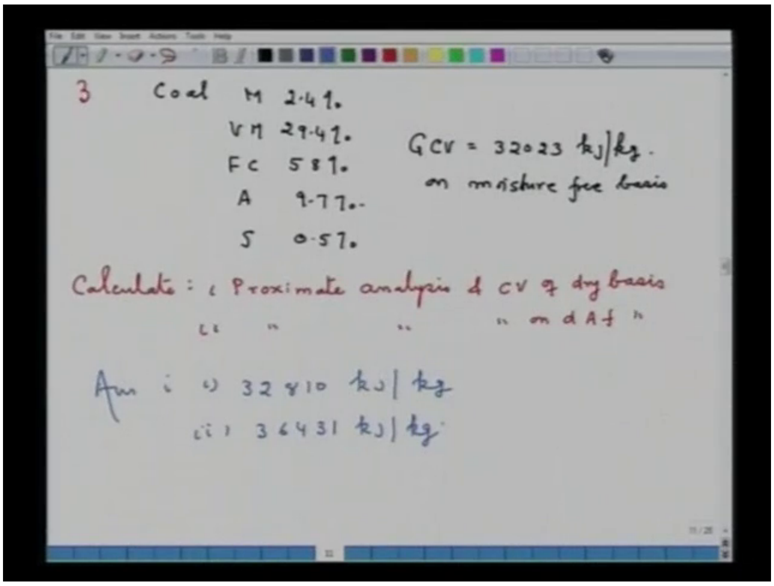

Now let us take the third third problem you have been given a coal of the following composition say coal the following composition. It has moisture 2.4 percent volatile meter 29.4 percent fixed carbon 58 percent and ash 9.7 percent. Sulphur 0.5 percent. GCV is given 32023 kilo joule per k g on moisture free basis. Now what you are required? You are required to calculate. So, calculate proximate analysis and calorific value on dry basis. And also calculate the proximate analysis and calorific value on dry ash free basis.

So, you calculate it. I am giving you the answer the answer for the answer for one that is equal to 32810 kilo joule per k g that is for the one, And for the second the answer is 36431 kilo joule per k g. So, that is what the answers. Now let us take another problem to illustrate further the concepts that are involving the calorific value.

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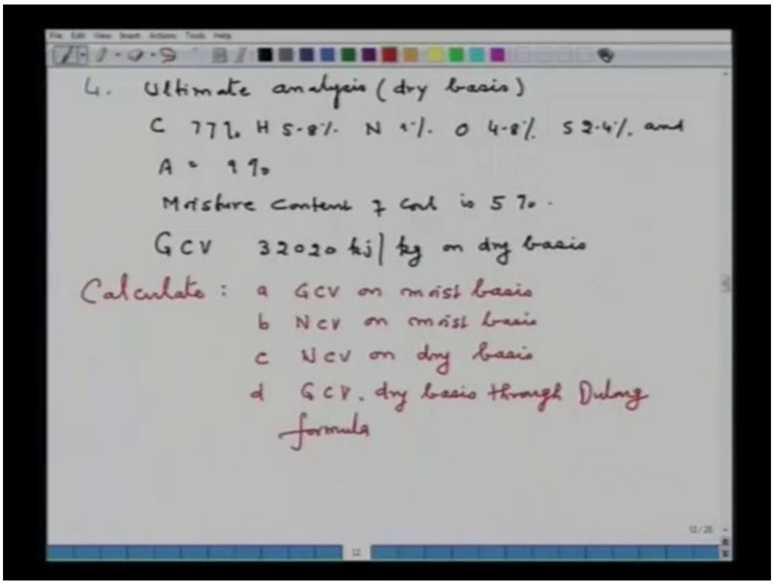

Now in a fourth problem, what I have done? Say ultimate analysis is given on dry basis. Now say carbon 77 percent hydrogen 5.8 percent nitrogen 1 percent, oxygen 4.8 percent sulphur 2.4 percent and ash that is equal to 9 percent. Now it is also said that th e moisture content of the coal that the moisture content of coal is 5 percent. GCV of this coal is 32020 kilo joule per k g on dry basis. What you have to do now? So, you n are required to calculate so calculate a GCV on moist basis, b NCV on moist basis, c NCV on dry basis, and d GCV dry basis through dulong formula.

Now in this particular problem the analysis is given to you on dry basis so the analysis it becomes hundred on dry basis and moisture is given to you separately. So, now you have to calculate gross calorific value on moisture basis. So, first of all this analysis from dry basis is to be converted on moist basis and then you can proceed for the calculation.

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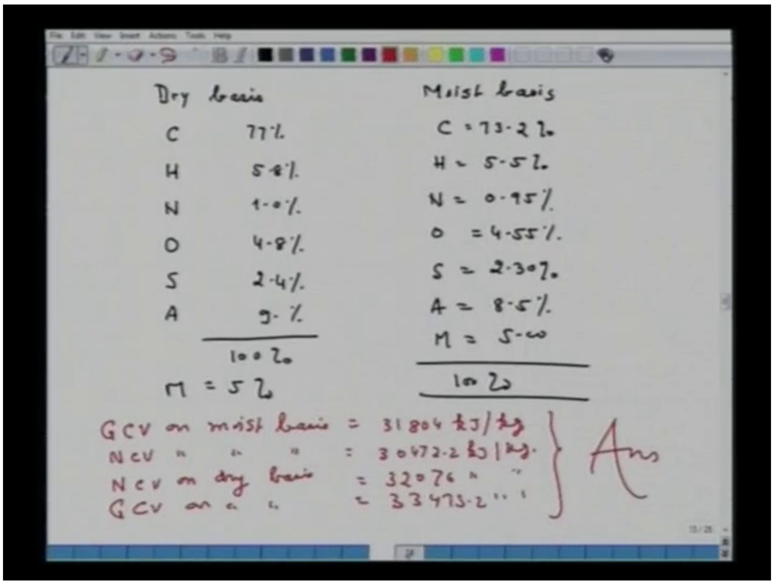

So, I just calculate I give you hint for calculation, say for dry basis the analysis carbon, hydrogen, nitrogen, oxygen, sulphur and ash, 77 percent, 5.8 percent, 1.0 percent, 4.8 percent, 2.4 percent and 9 percent. And if you can add them together it becomes 100 percent. So, moisture is given as 5 percent. So, on this composition you cannot calculate the gross calorific value on moist basis. So first of all this composition has to be converted to moist basis. So, how will you convert to moist basis?

If you convert this on a moist basis, then the hy then the moisture content it contains hydrogen and oxygen. So, you have to find out the H in H 2 O and O in H 2 O and subtract the respective H and O values and then you get the value on the moist basis. So, if you do that we have say carbon 73.2 percent, hydrogen 5.5 percent nitrogen 0.95 percent, oxygen 4.55 percent, sulphur 2.3 percent, ash 8.5 percent and moisture is equal to 5 percent, now it adds to100 percent. Now you can use the formula which I have given to you earlier.

So, if you use the formula, I am straight away giving the answer so GCV on moist basis that is equal to 31804 kilo joule per kg. Then NCV on moist basis 30472.2 kilo joule per k g, then NCV on dry basis that comes out to be equal to 32076 kilo joule per kg and GCV on dry basis by dulong formula that is equal to 33473.2 kilo joule per k g. These are the answers for the question which I have just given to you.

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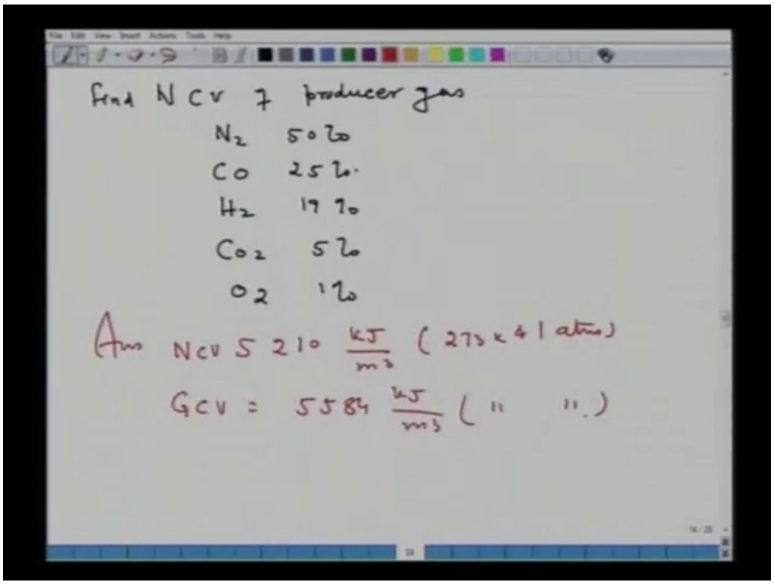

Now the last question that I will give you that you can solve yourself, you have to find out the cal the net calorific value, say find net calorific value of producer gas of composition nitrogen 50 percent, C O - 25 percent, hydrogen - 19 percent, C O 2 - 5 percent O 2 - 1 percent. And the answers for the problem would be the N C V, you have to calculate the NCV of producer gas and that will be equal to 5210 kilo joule per meter cube at 273 Kelvin and 1 atm. This is the answer for N C V. Now you can also calculate GCV and the answer for GCV that is equal to 5584 kilo joule per meter cube 273 Kelvin and one atmospheric pressure. Think why GCV is greater than NCV, because here the state of product of combustion is liquid. Thank you.