Energy Conversion Technologies (Biomass and Coal)

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Lecture 12

Practice problems (Part I)

Good morning everyone.

Welcome to part 1 of the lecture 3 under module 2. So, in this lecture we will practice few examples on the topic covered in this module. So, if you recall our discussion, so at the beginning of this module we discuss about the concept of solid and the liquid fuels.

In that first we discuss about the solid fuel, further we discuss about the characteristics of solid fuel followed by the structural composition of the solid fuel. While in the liquid fuels we discuss about the sources of liquid fuel followed by characteristics of liquid fuel further we discuss about the fuel component characteristics. So, here in this lecture we will practice few examples on some of the topics covered in this module 2.

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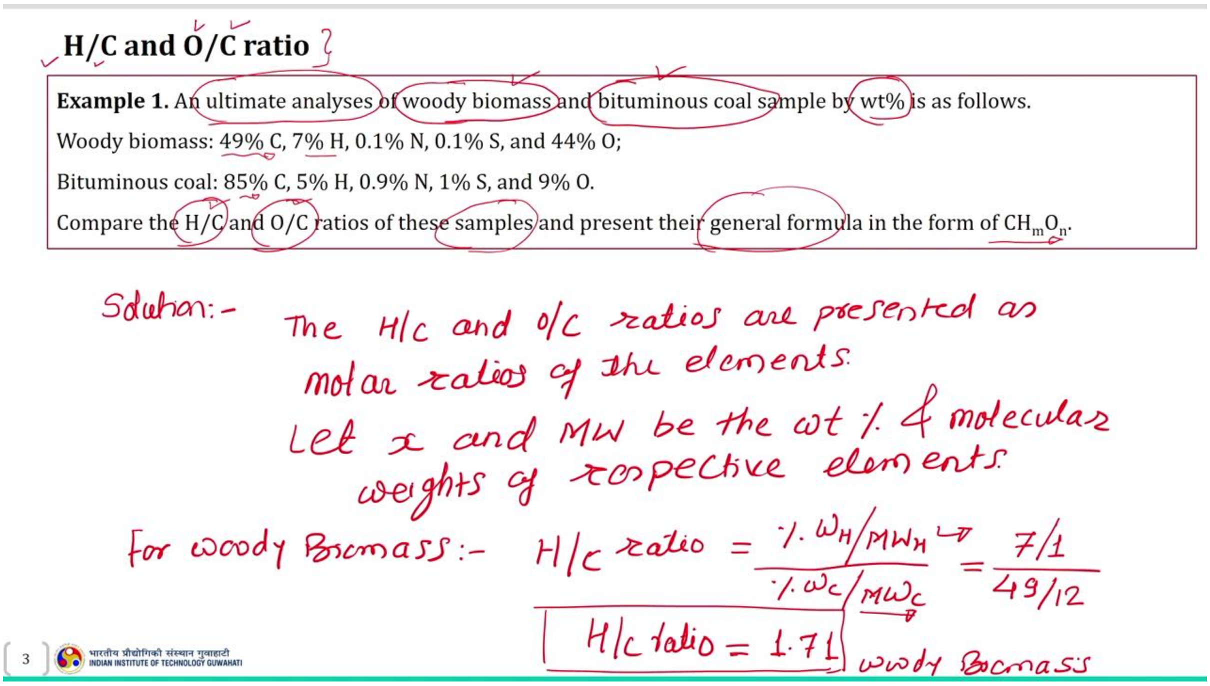

So, let us begin with the first example. So, this example is based on the concept of H/C ratio and O/C ratio. So, this particular concept we discussed while discussing the solid fuels and its characteristics.

So, if you remember in the solid fuel, we discussed about the estimation of the ultimate analysis of solid fuel and why it is essential. So, here in this example, we will be using this particular concept to just compare the H/C ratio and the O/C ratio of these two fuel samples. And will try to present their general formula in the form of CHO. As per the statement of example, an ultimate analysis of wood biomass and the bituminous coal sample by weight percent is given as follows. So, the wood biomass, it contains around 49% of carbon, 7% hydrogen, 0.1% nitrogen, 0.1% sulfur and 44% oxygen. While the bituminous coal contains around 85% carbon, 5% hydrogen, 0.9% nitrogen, 1% sulphur and 9% oxygen by weight.

So, with this given data we will try to just estimate the H/C ratio and O/C ratio of these two given fuel sample and then we will just try to represent their general formula in the form of CHO.

So, let us begin with the solution of this example. So, if you remember this particular topic when we discuss about this H/C ratio and the O/C ratio. The H/C ratio and the O/C ratios are presented as molar ratios of the elements. So, for this let us first consider x and MW be the weight percent and molecular weights of respective elements. Woody biomass, first of all we will try to solve this example for the woody biomass and similarly we will try to solve it for the bituminous coal as well.

So, for woody biomass if you have to represent this H/C ratio in the form of molar ratios then weight of the hydrogen in the woody biomass divided by the molecular weight of hydrogen and then percentage weight of because this is the ratio of H/C. So, this term represents the molar ratio of hydrogen divided by the molar ratio of carbon that is percentage weight of carbon by its molecular weight. Now, we know the percentage weight of hydrogen in the woody biomass which is given as 7% and the hydrogen we know the molecular weight.

Similarly, for the carbon the value is given as 49 and if you see the molecular rate of carbon, so once you solve this term, so we will get the answer in the form of 1.71, so the H/C ratio for the woody biomass is 1.71. So, similarly we will just try to find out the O/C ratio for the woody biomass.

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$$O/C \text{ ratio} = \frac{\%W_O/MW_O}{\%W_C/MW_C} = \frac{44/16}{49/12} = 0.67$$

for Bituminous coal :-

$$H/C \text{ ratio} = \frac{\%W_H/MW_H}{\%W_C/MW_C} = \frac{5/1}{85/12} = 0.71$$

$$O/C \text{ ratio} = \frac{\%W_O/MW_O}{\%W_C/MW_C} = \frac{9/16}{85/12} = 0.08$$

Thus, woody biomass observed to have higher H/C & O/C ratio than given coal sample.

In woody Biomass the molar proportion of C:H:O = 1:1.71:0.67

from this, we can represent the formula for woody Biomass as: $CH_{1.71}O_{0.67}$

||ly, formula for bituminous coal can presented as: $CH_{0.71}O_{0.08}$

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So, the O/C ratio again it is weight percent of oxygen by its molecular weight and weight percent of carbon divided by its molecular weight. And here the weight percent of oxygen is given as 44% in the woody biomass. And molecular weight as 16, we know and then the percent of carbon it is 49/12. So, once we solve this we will get the answer in the form of 0.67. So, now similarly let us try to solve it for the bituminous coal. So, again the H/C ratio equal to by %weight of carbon by its molecular weight. So, in bituminous coal if we see the percentage of hydrogen is given as 5 and the carbon percentage it is relatively higher than that of the biomass by its molecular weight. So, this ratio comes out to be around 0.71.

And this concept we already discussed that the woody biomass relatively have lower carbon compared to that of the coal. And hence the h by c ratio of woody biomass would be higher than that of the coal. And that is what we also obtained the value in the similar line that the H/C ratio of coal is relatively lower than that of the woody biomass, where the woody biomass has the H/C ratio of around 1.71 while for the coal the H/C ratio comes out to be around like 0.71. And that is mainly because it has more carbon content in its composition.

Similarly, the O/C ratio again it is percent weight of oxygen by its molecular weight and percent weight of carbon by its molecular weight. Here again the oxygen percentage in the coal is quite low compared to that of the woody biomass. While if you see the composition of the woody biomass it has around 44% of the oxygen while in the coal it is just 9%. So, once we do this calculation we will get the value in the form of 0.08.

So, in this case also the O/C ratio of coal is quite low compared to that of the woody biomass. And that is what we discuss also while discussing about the concept of woody biomass as well as the coal. And when we discuss about their H/C ratio as well as the O/C ratio we observed that the H/C and the O/C ratio of coal sample is quite low compared to that of the biomass and these two values also indicates the similar pattern. And thus after analyzing this value the woody biomass observed to have higher H/C and O/C ratio than given coal sample.

So, in woody biomass the molar proportion of C:H:O is 1:1.71:0.67. And from this we can represent the formula for woody biomass as $C\ H_{1.71}\ O_{0.67}$. So, in the similar line formula for bituminous coal can be represented as $C\ H_{0.71}\ O_{0.08}$. So, as these two formulas were asked in this example to represent in the form of CHO.

So, this is the representation of woody biomass and for the bituminous coal it can be represented in this way. So, I hope now this is clear how to calculate the H/C ratio and the O/C ratio from the given composition. I would say the ultimate analysis composition of the given fuel sample and once we know the H/C and the O/C ratio, then if it is asked to represent the formula in the form of CHO, then we can easily represent the formula of the given fuel in the form of the CHO. So, now let us move on to the next example.

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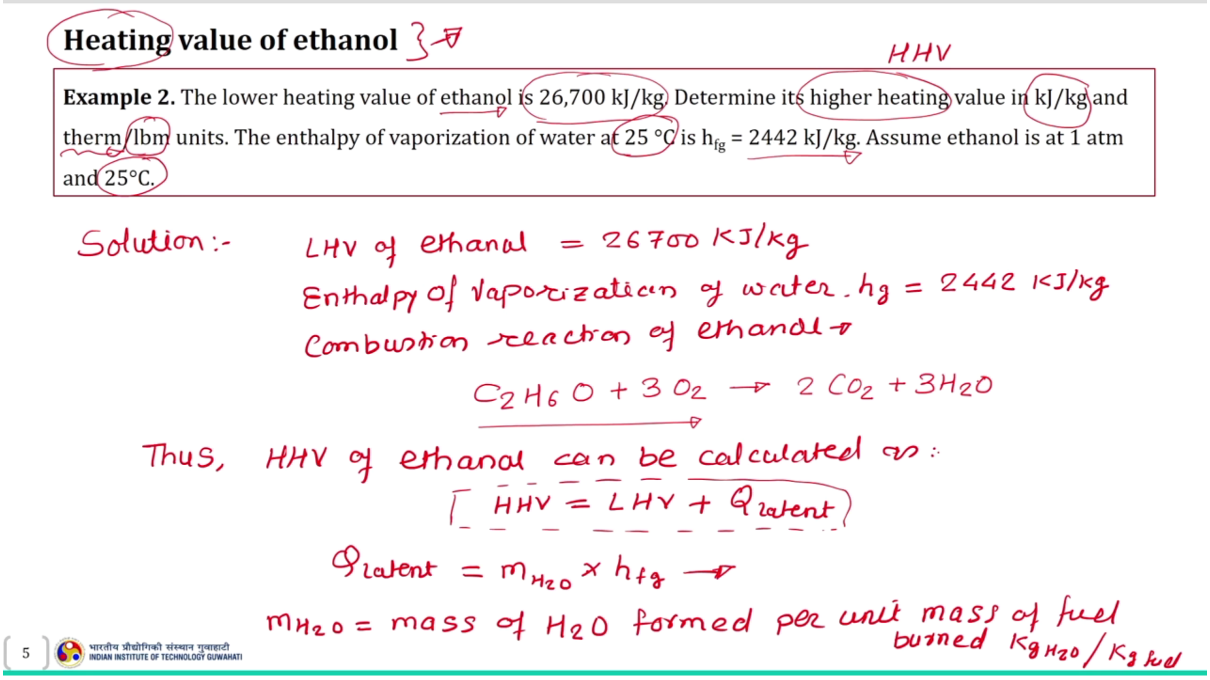

So, this example is based on the one of the topic discussed in the liquid fuel that is heating value of the liquid fuel and how to estimate this heating value from the given data. So, let us try to understand the given data in this example and then we will start solving this example. The lower heating value of ethanol, so here the liquid fuel is given as ethanol is 26700 and it is given in kilo joule per kg. So, with the help of this value we have to estimate the higher heating value of the fuel that is called as HHV as well. So, the higher heating value of the ethanol need to be estimated here and it is also in the form of kilo joule per kg.

And also this value we need to represent in the form of thermal unit per pound mass. And the enthalpy of vaporization of water at 25 °C is given as this much and we have to assume that the ethanol is at 1 atmospheric pressure and at 25 °C, so let us try to solve this example with the help of this given data. Lower heating of ethanol is given as 26700 kilo joule per kg and the enthalpy of vaporization of water that is represented in this form is given as 2442 kilo joule per kg. And if we write down the combustion reaction of ethanol, then it can be represented in this way. So, the ethanol is combusted will give the product in the form of right.

So, systematically now this equation is also balanced and we consider here that the complete combustion of the ethanol is taking place. So, HHV of ethanol can be calculated as so for this we know the expression that is HHV is equal to LHV plus Q latent and we also discuss this concept while discussing the heating value and how to estimate the heating value of the given liquid fuel. So, the Q latent can be calculated using this expression. So, here this term is the mass of H_2O formed per unit mass of fuel burned. And it can be represented in the form of kg of H_2O by kg of fuel.

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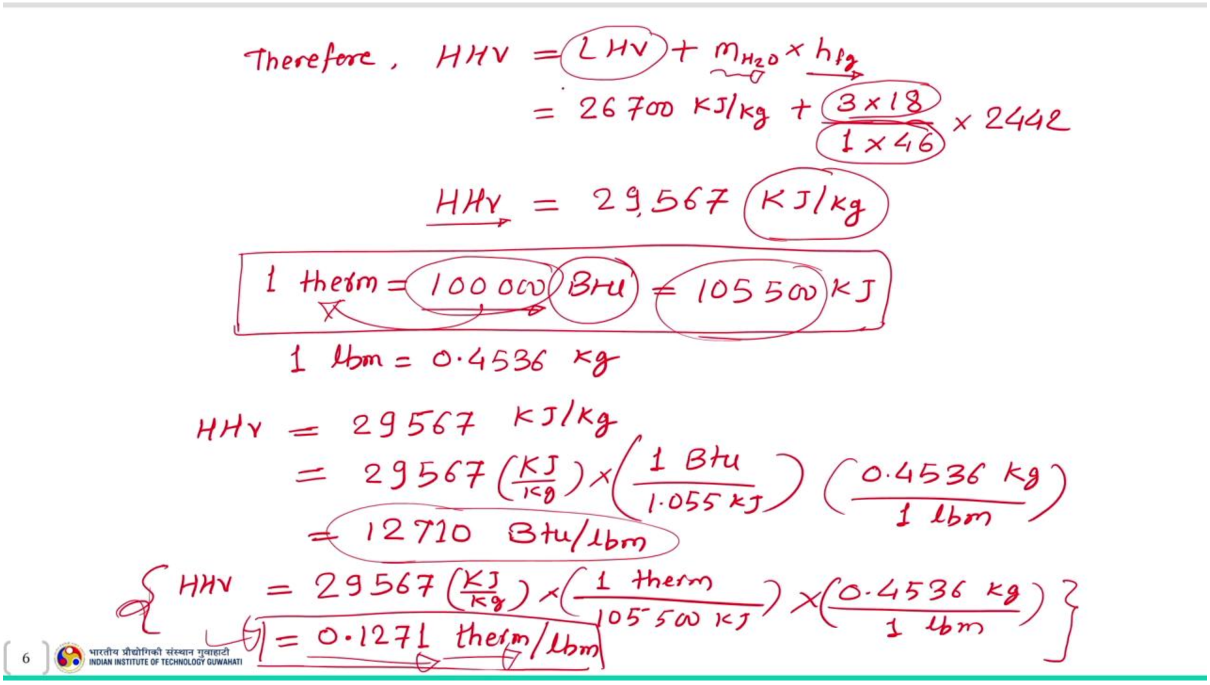

Therefore, HHV is equal to lower heating value plus the Q, latent now we will replace with this equation and we will just simply try to replace the value in this equation. Now, because the lower heating value of the ethanol is given as 26700 kilo joule per kg and this mass of water form will be represented in this manner where if you see the stoichiometric equation of the ethanol we have just written one slide before.

So, in this case when the ethanol is completely combusted then it is producing almost 3 moles of water. So, 3 moles of water are getting produced with the combustion of 1 mole of ethanol and the enthalpy of vaporization of the water which is at 25 degree C is given as So, once we just solve this term here 2442, we will get the value in the form of 29,567 kilo joule per kg because these are the value in the form of ratio of weight of the water to the weight of the fuel. So, this is high rating value of given fuel sample in the form of kilo joule per kg and also it has been asked to calculate this high rating value in the form of thermal unit per pound mass.

So, one thermal unit is equal to this many British unit and which is equal to 105500 kilo joule. So, this is also one of the concepts we discussed in one of the lecture where we discuss about the unit conversion system. So, that table can also be referred for this unit conversion and 1 pound equal to 4536 kg. So, now once we know this unit conversion, so we can easily calculate now the higher heating value in the form of thermal unit per pound mass. So, the heating value which is obtained from the given expression is in the form of 29,567 kilo joule per kg.

Now, if you just try to convert this in the form of one thermal unit. So, first we will try to convert it into the British thermal unit and then after that we will convert the value in the one thermal unit so that we can get the value of HHV in the required form 29567 which is kilo joule per kg and once we convert this into BTU. So, it is around 1.055 kilo joule as we know this many British thermal unit is equal to this much kilo joule and even the pound conversion is 0.4536, per pound and once we do this multiplication we get the value in the form of 12710 it is in the British thermal unit per pound mass.

Now we know the conversion of British thermal unit to the thermal unit. So, the HHV can be represented or can be calculated in the following way like 29567 kilo joule per kg into 1 thermal unit equal to 10550 kilo joule into again the pound the conversion is 0.4536 kilogram per pound mass. And once we do this calculation, so it will come in the form of 0.1271 thermal unit per pound mass.

Basically, this particular calculation is not again required here, but just to explain you about this unit conversion system, I have just repeated this calculation from the above step. Because once we know the one thermal unit equal to this many BTU and we already estimated the HHV in the BTU per pound mass. So, we can simply convert this into thermal unit and we will get the value in the form this answer. But just to explain you again about the unit conversion system like if the unit conversion system need to be utilized then how you can convert this value and we will get the answer in this form.

So, I hope now this is clear how to estimate the higher heating value if the low reading value and the latent heat of vaporization of the water is given. So, using these two terms you can easily calculate the HHV.

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Heating value of coal

Example 3. The composition of particular coal (by mass %) is as follows: 68% carbon, 6% hydrogen, 16% oxygen, 1.5% nitrogen, 2.1% sulfur, and 6.4% ash. What are the higher and lower heating values of this coal?

Fuel (Phase)	HHV, kJ/kg	LHV, kJ/kg
Carbon (*s*)	32,800	32,800
Hydrogen (*g*)	141,800	120,000
Sulfur (s)	9,160	9,160

Solution:-

The combustible components in coal are C, H, & S

Let x_i (m_f) be the mass fractions of C, H, & S present in coal

Using ultimate analysis (data) and heating values of standard components from table

$$HHV = x_C/m_{fC} \times HHV_C + x_H/m_{fH} \times HHV_H + x_S/m_{fS} \times HHV_S$$

$$= 0.68 \times 32800 + 0.06 \times 141800 + 0.021 \times 9160 \ \frac{kJ}{kg}$$

$$HHV = 31{,}004 \ kJ/kg$$

So, the next example it is also in the similar line. So, here we have to calculate the high reading value of the coal sample that is solid fuel. So, for the calculation of this high reading value of this given fuel the composition of the coal sample is given here. So, with the help of this composition we need to estimate the high reading value of the coal. So, let us try to solve this another example on the similar concept.

So, in this example the composition of particular coal sample is given as follows. So, it contains around 68 percent carbon, 6 percent hydrogen, 16 percent oxygen followed by 1.5 percent nitrogen, 2.1 percent sulfur and 6.4 percent ash. So, with the help of this given data we need to calculate the higher as well as the lower heating value of this coal sample. And if you remember in one of the lecture, we discussed about the estimation of higher heating value as well as the lower heating value of a given fuel if the composition of the fuel is known.

So, we will be using the same concept here to estimate the higher heating value as well as the lower heating value of the given fuel. And for that we required this table and if you recollect, while discussing this table also I mentioned there that this table would be quite useful when we will try to estimate the higher heating value as well as the lower heating value of a given fuel. Because for the estimation of this higher heating value as well as the lower heating value we need to know the heating value as well as the lower heating value of this fuel phase.

Let us try to solve this example. While discussing this concept, it was mentioned that the combustible components in coal are carbon, hydrogen and sulphur. Because once the combustion of the coal starts, so these components take part in the combustion process. And let x also represented as m suffix f be the mass fraction of carbon, hydrogen and sulphur present in coal. So, now using the concept of ultimate analysis, analysis and the data of this ultimate analysis is also given here in this example and heating values of standard components from the above table. So, these standard components and their heating values are already given here.

So, once we use these two data that is ultimate analysis data which is given in the example and the heating value data in the form of higher heating value as well as the lower heating value of the standard component from this table. We can calculate the higher heating value of this sample using this equation. So, if you remember this x suffix c also as I mentioned it can be represented in the form of mass fraction of carbon. And this also represents the mass fraction of carbon into the higher heating value of carbon plus x suffix h which we can also represent in the form of mass fraction of carbon into higher heating value of hydrogen plus into the higher heating value of sulphur. Because these three component will take part into the combustion process.

That is why this heating value is calculated using these three components. Now, once we replace the value of mass fraction of carbon which is 0.68, higher heating value of the carbon is given as 32800, and then the mass fraction of hydrogen is 0.06, into its higher heating value is 141000, and the mass fraction of sulphur into 9160. So, these values are given the unit terms of kilo joule per kg and after doing this multiplication the final answer comes out around 31004 kilo joule per kg.

So, this indicates the higher heating value of the given coal sample which is estimated using the composition of the coal as well as the heating value of the standard components.

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The lower heating value of coal sample can be calculated using following eqn. -

$$LHV = x_c/m_{fc} \times LHV_c + x_H/m_{fH} \times LHV_H + x_s/m_{fs} \times LHV_s$$

$$= 0.68 \times 32800 + 0.06 \times 120000 + 0.021 \times 9160$$

$$LHV = 29696 \text{ kJ/kg}$$

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Similarly, now let us try to calculate the lower heating value of the coal sample. Lower heating value of coal sample can be calculated using following equation. So, it is in the similar line as that of the high rating value. So, again it is mass fraction of carbon into the lower heating value of carbon plus mass fraction of hydrogen into the lower heating value of hydrogen and then lower heating value of the sulphur.

As the mass fraction of the carbon is known and the low heating value of carbon can be obtained from the above table which is plus the hydrogen and here the lower heating value of the hydrogen is given as and sulphur and its lower heating value is same. So, after doing this multiplication, the final answer is 29696 kilo joule per kg. So, this indicates the lower heating value of the given coal sample. So, this is another simple example using the concept of ultimate analysis how to estimate the lower heating value as well as the higher heating value of the given sample. So, I hope this is clear now how to estimate lower heating value as well as the higher heating value of the given sample if its composition is known.

And also the lower heating value as well as the higher heating value of these components needs to be given. So, once we know these values using this expression of LHV as well as HHV, we can easily calculate the HHV as well as the LHV value of the given sample.

With this we will end our lecture here. And in the next lecture we will practice few more examples on some concept which we could not able to cover in this lecture. So, we will practice few more example on the concept discussed in the module 2.

Thank you.