Energy Conversion Technologies (Biomass and Coal)

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Lecture 13
Practice problems (Part II)

Good morning everyone.

Welcome to part 2 of the lecture 3 under the module 2. So, in this lecture we will practice few more examples and this is in continuation to our previous lecture. If you recollect in the previous lecture we practice example on the estimation of H/C ratio and O/C ratio of a given fuel when the composition of the given fuel is known. Apart from that we also practice one example each on the estimation of heating value of solid and the liquid fuel respectively. So, this is in continuation to the previous lecture. In this lecture we will practice few more example on the concept that is heat of formation of a given fuel as well as how to estimate the emission from the ultimate analysis of a given fuel. Let us begin with the first example.

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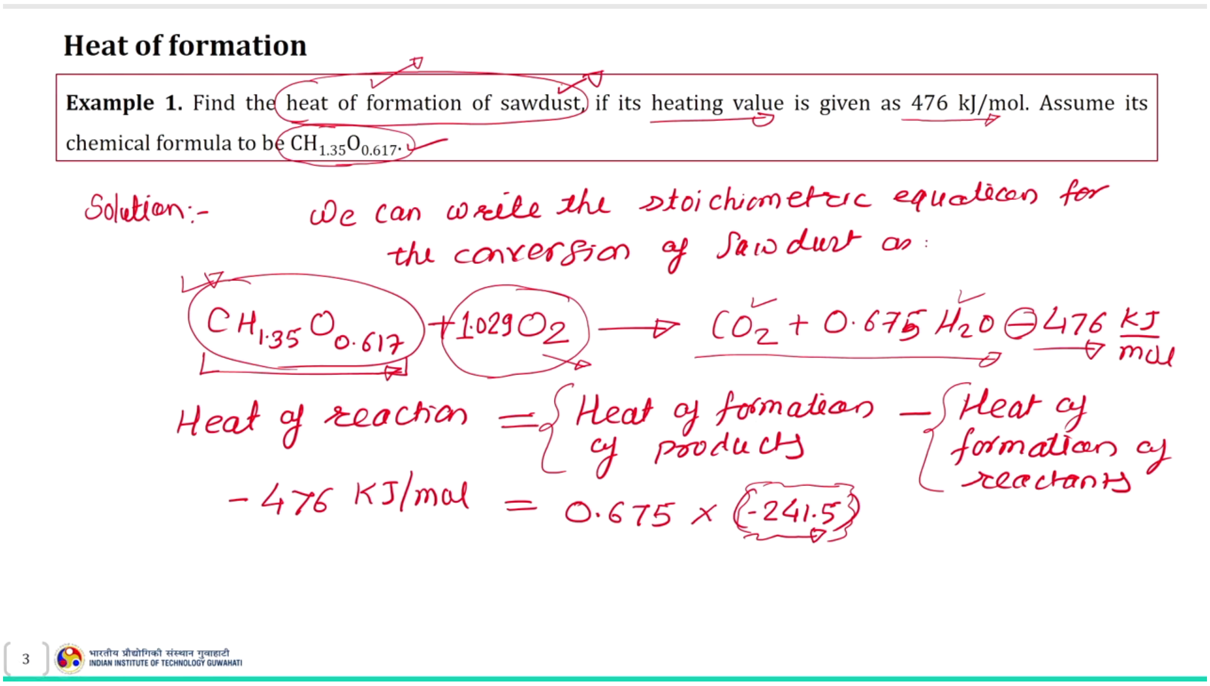

The first example is on the heat of formation which is also known as the heat of combustion. So, in this example we need to estimate the heat of formation of sawdust. So, the given fuel here is sawdust and its heating value is given as 476 kJ/mol and we need o assume the chemical formula of sawdust to be this one. So, with the help of this given data we need to estimate the heat of formation of a sawdust. So, let us try to solve this example with this given data. So, before we start solving this example, we need to write the stoichiometric equation for the conversion reaction of a sawdust.

And we can write the stoichiometric equation for the conversion of sawdust as because we know the chemical formula of sawdust which is given here in the example $CH_{1.35}$ and oxygen is 0.617. And once this particular fuel which is given here as sawdust is combusted. So, this particular formula here it represents the sawdust. Once it undergoes the combustion in presence of oxygen, it produces carbon dioxide and this much mole of water and this heat of reaction here because here given as the heating value as this one.

So, which is 476 kilo joule per mole and here we have mentioned as negative value because as we know the combustion is the exothermic reaction. So, it will evolve this much amount of the energy as per the stoichiometric equation and to balance this equation we need around like 1.0 to 9 moles of oxygen to combust this particular fuel completely to produce this composition of product. And now with the help of this stoichiometric equation, we have to estimate the heat of formation of a sawdust. If you recollect our discussion in one of the lecture, we discussed about the estimation of heat of combustion from the given reaction.

So, the same concept will be utilizing here to solve this example. That is the heat of reaction which we also termed as heat of combustion. So, that can be represented in the following way that is summation of heat of formation of products minus summation of heat of reactants. So, once you know the heat of formation of the product, so the product here is CO_2, water and the heat of formation of the reactant, so there are two reactants i.e. this is the given fuel. And this is termed as an oxidant.

So, sometimes we use air, sometimes we use pure oxygen. So, in general we termed it as an oxidant. Once we know the heat of formation of this reactant, then with the help of that we can easily estimate the heat of formation of the sawdust. So, here the heat of reaction it is given as minus 476 kJ/mol and heat of formation of the product. So, as I mentioned there are two products here like CO_2 and water.

Once we know the heat of formation of the product and the heat of formation of the reactant the difference between these two values will lead to our answer of the heat of formation of the sawdust. So, here if you see the heat of formation of the product it is represented as this much moles of water is getting produced and the heat of formation of the water is minus 241.5. So, this is the value which we have obtained from one of the table where the heat of formation of the different reactant is tabulated. And the values given in the same table are used here for the estimation of this heat of formation of the sawdust. However, for the convenience purpose, I will just reproduce this table here if required.

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Compound	H_2O	CO_2	CO	CH_4	O_2	$CaCO_3$	NH_3
Heat of formation at 25°C (KJ/mole)	-241.5	-393.5	-110.6	-74.8	0	-1211.8	-82.5

So, if you remember the table, there the name of the compound was given along with the heat of formation at 25 °C and the values were given in the kilo joule per mole and the different compounds like H_2O, CO_2, CO, CH_4, again calcium carbonate and NH_3. So, the heat of formation of the water was given as minus 241.5 here 393.5 minus 74.8 and for it is 0 minus 1211.8 and for NH_3 it was minus 82.5. So, we are just taking help of this table to solve this example.

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Heat of formation

Example 1. Find the heat of formation of sawdust, if its heating value is given as 476 kJ/mol. Assume its chemical formula to be $CH_{1.35}O_{0.617}$.

Solution:- We can write the stoichiometric equation for the conversion of sawdust as:

$$CH_{1.35}O_{0.617} + 1.029\,O_2 \longrightarrow 1\,CO_2 + 0.675\,H_2O - 476\ \frac{kJ}{mol}$$

$$\text{Heat of reaction} = \left\{\text{Heat of formation of products}\right\} - \left\{\text{Heat of formation of reactants}\right\}$$

$$-476\ kJ/mol = \left\{0.675 \times (-241.5) + 1 \times -393.5\right\} - \left\{\Delta H_{sawdust} + 1.029\,\Delta H_{O_2}\right\}, \quad \Delta H_{O_2} = 0$$

$$\Delta H_{sawdust} = -163.0125 - 393.5 + 476$$

$$\boxed{-\text{"}- = -80.5\ kJ/mol}$$

So, the heat of formation of the water as we just discussed before, so this value we have obtained from this given table plus the heat of formation of CO_2, here it is a 1 mole of CO_2 that is 1 into, so the heat of formation of the CO_2 is given as minus 393.5.

So, this is about the heat of formation of the product minus the heat of formation of the reactants. So, here there are two reactants that is the given fuel as well as the oxidant. So, we have to estimate the heat of formation of this given fuel that is right and then the heat of formation of oxygen. So, this is nothing but equal to 0 and once you do this small multiplication here. Then we will get the value of this term that is heat of formation of sawdust, as just after doing this small multiplication the value comes out to be around 163.0125 minus 393.5 and plus 476 because this will be equal to 0 totally and then the final answer would be in the form of minus 80.5 kJ/mol.

So, this is basically the heat of formation of the sawdust. I hope this is clear how to estimate the heat of formation of a given fuel for that this simple concept which we have discussed earlier in one of the lecture. The same concept can be used to solve this example of heat of formation of the any given fuel.

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Ultimate analysis to determine emissions

Example 2. Consider a coal with the following composition on a mass basis: 67% C, 5% H, 9% O, 2%N, 1.5% S, and 8.5% ash, and 7% moisture. This coal is consumed in a power plant at a rate of 2000 kg/day. To remove SO_2 emissions the limestone flue gas desulfurization process (with 98% efficiency) was used.
(a) Determine the amount of ash entering the plant per year. (b) Determine the annual amount of SO_2 emissions from the plant before and after the scrubbing, if all sulfur reacts with oxygen during combustion. (c) Determine the amount of CO_2 emissions produced from the SO_2 scrubbing process/unit.

Solution :→ ultimate analysis :- 67% C, 5% H, 9% O, 2% N
1.5% S, & 8.5% ash & 7% moisture
Coal consumption :- 2000 kg/day
Assumption :- Complete combustion of sulfur → $S + O_2 \rightarrow SO_2$
Efficiency of desulfurization process → 98%

The second example it is based on the estimation of emission from the ultimate analysis data of a given fuel. So, here the fuel is given as coal. And the composition of the coal on mass basis is given here and this coal is consumed in a power plant at a rate of 2000 kg/day. Therefore, to remove the sulphur dioxide emission the limestone flue gas desulphurization process was used and the efficiency of this particular desulphurization process was around 98 percent. So, with the help of this given data, we need to estimate the amount of ash which is entering the plant per year, because the daily consumption of the coal is given here.

So, based on that we need to estimate the amount of ash which is entering the plant per year, in the sense because this particular coal has ash content of around 8.5 percent. So, if this much amount of the coal is getting used in the power plant, so on that basis we have to just estimate like the amount of ash which is entering the plant on yearly basis. And second thing is like we need to estimate the annual amount of sulphur dioxide emission from the plant that is before and after this desulphurization unit, if all sulphur reacts with oxygen during combustion process. So, this is the condition here that all the sulphur which is present in the coal is getting combusted in presence of oxygen and it is forming sulphur dioxide as a product.

So, with the help of this condition we need to estimate the SO_2 emission from the plant that is before and after the desulphurization unit. And also we need to estimate the amount of carbon dioxide emission produced from the sulfur dioxide scrubbing unit or we can also say the process. So, now with the given condition as well as given data, we need to estimate these three terms. So, let us begin with the solution of this example. Here the ultimate analysis of coal is given as 67 percent carbon, 5 percent H, 9 percent O, 2 percent nitrogen, sulfur and 8.5 percent ash, and 7 percent moisture.

Along with that the coal consumption on daily basis is 2000 kg per day and the assumption is complete combustion of sulphur is taking place in the process. So, the sulphur is getting completely oxidized to form SO_2. So, this is the assumption and the efficiency of desulphurization process is given as 98 percent. So, with we need to estimate first the amount of ash which is entering the plant per year.

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a> To determine the amount of Ash entering the plant per year:-

$$\text{Ash entering}_{\downarrow \text{the plant}} \text{ per year} = \frac{8.5 \text{ kg ash}}{100 \text{ kg } \cancel{\text{coal}}} \times \frac{2000 \cancel{\text{ kg coal}}}{1 \cancel{\text{ day}}} \times \frac{365 \cancel{\text{ days}}}{1 \text{ year}}$$

$$\text{Ash entering the plant per year} = 62{,}050 \text{ kg Ash/year}$$

b> To determine the annual SO_2 emissions from the plant before and after the scrubbing process:-

from coal composition

$$\text{Annual consumption of S in coal} = \frac{1.5 \text{ kg S}}{100 \text{ kg coal}} \times \frac{2000 \cancel{\text{ kg coal}}}{1 \text{ day}} \times \frac{365 \text{ day}}{1 \text{ year}}$$

$$= 10{,}950 \text{ kg S}$$

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So, first we need to estimate the amount of ash entering the plant per year. So, ash entering per year can be estimated using the given data because we know the 8.5% of ash is present in the given coal sample. That means 8.5 kg ash per 100 kg of coal sample is here and on daily basis 2000 kg of coal is consumed in a plant. So, that is so per day basis it is around 2000 kg. So, on yearly basis means 365 days in a year, so once we do this multiplication here, we will get the answer in the form of 62,050 kg ash per year. So, the ash entering the plant per year is this much. So, here entering the plant right.

Second we need to determine the sulphur dioxide emissions from the plant before and after the scrubbing process. So, in this case basically 2000 kg per day of the coal is getting consumed in thermal power plant for the energy generation purpose. And with the help of that we need to determine the annual sulphur dioxide emission from this thermal power plant before and after the scrubbing process. So, from the coal composition we know the annual consumption of sulphur in given coal sample that is 1.5 kg of sulphur per 100 kg of coal. Because in the composition of the given fuel it contains around 1.5 percent sulphur and on daily basis 2000 kg of coal is consumed in the plant again on yearly basis, right.

So, once we do this small multiplication here we will get the value in the form of 10950 kilogram sulphur. So, annual consumption of sulphur is around this much.

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Complete combustion of sulfur :- $S + O_2 \rightarrow SO_2$

from stoichiometry, 1 kmol of S react to produce 1 kmol of SO_2

i.e. 32 kg of S burns to produce 64 kg of SO_2

Therefore, 10,950 kg of S burns to produce 21,900 kg SO_2 (before scrubbing)

Efficiency of limestone flue gas desulfurization unit = 98%

98% of SO_2 is removed by scrubbing

$= \frac{98}{100} \times 21{,}900 = 21462$ kg of SO_2

∴ 2% of SO_2 is emitted after scrubbing process :- $\frac{2}{100} \times 21{,}900 = \boxed{438 \text{ kg } SO_2}$ (after scrubbing)

And as per the assumption complete combustion of sulphur is taking place in this combustion process as a result the entire sulphur is getting oxidized to form SO_2. So, from this from this stoichiometric equation we know like 1 kilo mole of sulphur react to produce 1 kmol of sulphur dioxide. That is 32 kilogram of sulphur burns to produce 64 kilogram of SO_2. So, therefore, 10950 kilogram of sulfur burns on suppose yearly basis to produce 21900 kilogram SO_2. And this is before the scrubbing and this is before scrubbing process. So, here simply actually we have to do multiplication and the division then we will get the sulphur dioxide which is getting produced if this much amount of the sulphur is burned on yearly basis.

So, just by doing this cross multiplication and the division we will get this value of 21,900. So, just by simple the multiplication and the division we will get the amount of sulphur dioxide produced when this much amount of the sulphur burn in the plant. Since the efficiency of this limestone flue gas desulphurization unit is given here and it is around 98%. So that means around 98 percent of sulphur dioxide is getting removed during this scrubbing operation. Since we know the amount of SO_2 which is getting produced before the scrubbing operation, with the help of this value we can calculate the amount of the sulphur dioxide which is getting removed during this desulphurization process here.

Since 98 percent of sulphur dioxide is removed by scrubbing operation. So, we can calculate the amount of the SO_2 which is getting removed by this scrubbing operation that is 98% of sulphur dioxide and the value comes out to be around 21,462 kilogram of sulphur dioxide. So, this is the amount of sulphur dioxide which is getting removed in the scrubbing unit and as a result 2% of sulphur dioxide is emitted after scrubbing operation. Because 98 percent of the sulphur dioxide is getting removed in the scrubbing process as the efficiency of the scrubbing process is given as 98 percent. So, ultimately 2 percent of the sulphur dioxide is emitted after the scrubbing process that means 2 percent of the sulphur dioxide is observed in the exhaust emission and that can be calculated as 2 percent of the total sulphur dioxide which is produced in the plant. And which comes out to be 438 kilogram sulphur dioxide and this is after scrubbing. So, this particular value is before scrubbing and this represent the value after scrubbing.

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c> To determine the amount of CO_2 emissions produced from the SO_2 scrubbing process:

∴ SO_2 emissions reduces using limestone flue gas desulfurization process / as per the following mechanism:

$$(1)\quad SO_2 + (CaCO_3 + 2H_2O) + \tfrac{1}{2} O_2 \rightarrow (CaSO_4 \cdot 2H_2O) + CO_2$$

1 mole of SO_2 produce 1 mole of CO_2

therefore 64 kg SO_2 produce 44 kg CO_2

AS, SO_2 scrubbed/removed by scrubbing unit = 21462 kg SO_2

CO_2 produced after scrubbing of SO_2 $= \frac{44}{64} \times 21462$

$= 14755$ kg CO_2 {after scrubbing}

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Now, next we need to determine the amount of CO_2 emissions produced from the sulphur dioxide scrubbing process. Because we know the sulphur dioxide emissions can be reduced using limestone flue gas desulphurization process and this removal is taking place as per the following mechanism. And this concept of sulphur dioxide removal using this desulphurization process is discussed in one of the lecture in this module.

And we use the same concept here to find out the amount of CO_2 emission which is produced from the sulphur dioxide scrubbing process. So, if you recollect we saw this mechanism of sulphur dioxide removal using this desulphurization process in one of the lecture, where this sulphur dioxide is getting scrubbed in this limestone slurry in presence of oxygen and then it forms calcium sulphate dihydrate which is also known as gypsum along with So, basically here 1 mole of sulphur dioxide produces 1 mole of carbon dioxide. So, as per this mechanism 1 mole of sulphur dioxide produced 1 mole of carbon dioxide. Therefore 64 kg sulphur dioxide produce 44 kg carbon dioxide. So, here this is basically the molecular weight and this is the molecular weight of CO_2 right.

So, as we know the sulphur dioxide scrub or we can say removed by scrubbing unit is equal to 21,462 kg sulphur dioxide. So, this much amount of the sulphur dioxide is getting removed by scrubbing unit. So, now carbon dioxide produced after scrubbing of sulphur dioxide can be calculated directly here like 44 is a molecular weight of carbon dioxide into 21,462 because this much amount of the sulphur dioxide is getting removed in the scrubbing process. Once you multiply this term to carbon dioxide and then divided by the 64 that is the kilogram of sulphur dioxide, so we will get the answer in the form of 14000 kilogram carbon dioxide that is after scrubbing because here this much amount of the sulphur dioxide is getting removed in the scrubbing unit. So, as a result equivalent amount of the carbon dioxide is getting produced.

So, once we know that 1 mole of sulphur dioxide is producing 1 mole of carbon dioxide. And on kilogram basis it is like 64 kg of sulphur dioxide and 44 kg of carbon dioxide. And we know this much amount of the sulphur dioxide is getting scrubbed in the scrubbing unit. So, ultimately once this much amount of the sulphur dioxide is getting scrubbed. So, it will evolve this much amount of the carbon dioxide.

So, simply we are just doing the cross multiplication divided by this sulphur dioxide quantity here 14,755 kilogram carbon dioxide and that is after scrubbing. So, I hope this is clear like how to estimate the sulphur dioxide emission as well as the carbon dioxide emission from this particular mechanism. And this concept we have discussed in detail in one of the lecture in this module.

With this we will end our lecture here. In the next lecture which will be the first lecture of the module 3, we will discuss about energy from bio base feedstock. In that we will discuss about the availability of the feedstock material, composition analysis and the properties of the feedstock material and preparation of the fuel pellets using bio additives.

Thank you.