Energy Conversion Technologies (Biomass And Coal)

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Lecture 17

Practice problems (Torrefaction Mass & Energy Yield)

Good morning everyone.

Welcome to part 2 of the lecture 3 under module 3. In this lecture, we will practice few examples on the topic covered in the module 3. And this is in continuation to our previous lecture. In the previous lecture, we practiced example on the estimation of ultimate analysis of a given material. Followed by that, we estimated the net energy density of a purified product. This is in continuation to that. In this lecture, we will practice one or two more examples on the similar line.

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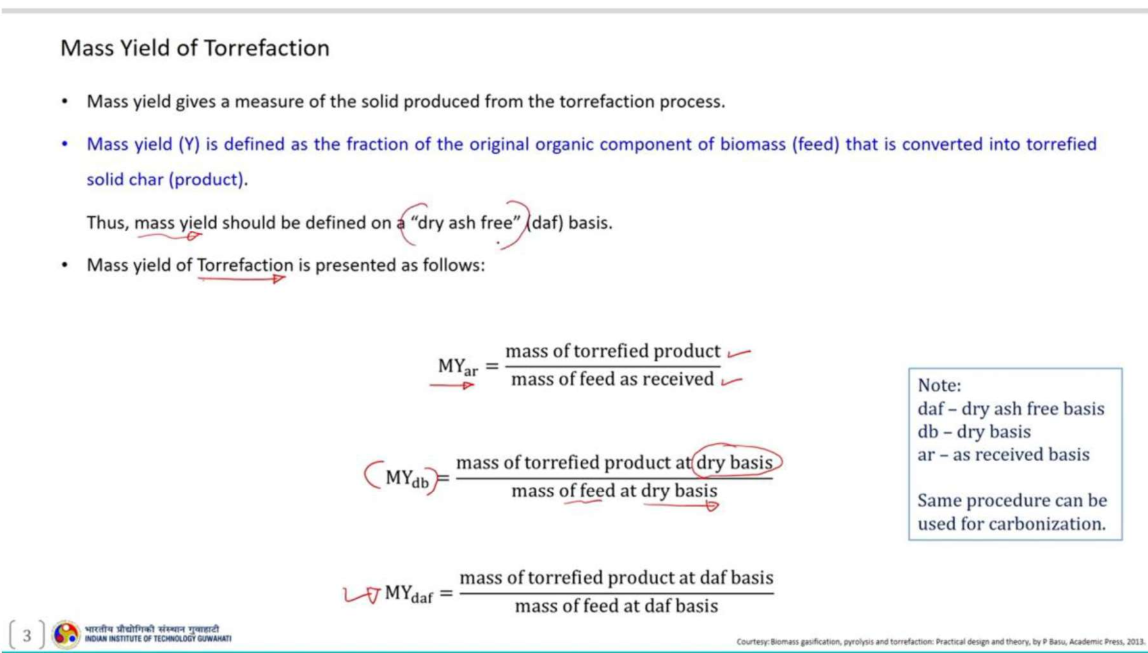

So, before we begin with the example, let us discuss in detail first about the mass yield and the energy density of torrefied product. And here the mass yield defined as the fraction of original organic component that is biomass which is converted into a torrefied solid product, that is char. And this mass yield should be defined as dry ash-free basis. The mass yield of torrefaction product is presented in three different ways. That is, mass yield on as received basis.

$$MY_{ar} = \frac{\text{mass of torrefied product}}{\text{mass of feed as received}}$$

So basically, it is a ratio of mass of purified product to the mass of feed as received basis. Similarly, it is presented in the form of mass yield on dry basis, that is mass of torrefied product at dry basis to mass of feed at dry basis.

$$MY_{db} = \frac{\text{mass of torrefied product at dry basis}}{\text{mass of feed at dry basis}}$$

And similarly, for the dry ash-free basis and as just mentioned before, this mass yield should be defined on a dry ash-free basis.

$$MY_{daf} = \frac{\text{mass of torrefied product at daf basis}}{\text{mass of feed at daf basis}}$$

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These three types of mass yield are correlated as follows:

Therefore, $MY_{db} = \frac{MY_{ar}}{(1 - M)} \Rightarrow MY_{ar} = (1 - M)\, MY_{db}$

$MY_{daf} = \frac{MY_{db} - Ash_{db}}{1 - Ash_{db}} \Rightarrow MY_{db} = MY_{daf}(1 - Ash_{db}) + Ash_{db}$

Abbreviations:
daf – dry ash free basis
db – dry basis
ar – as received basis
M – moisture fraction

In the similar line, these three types of mass yield are correlated in the following way. Suppose the mass yield on dry basis, it is correlated with the mass yield on as received basis using this equation.

$$MY_{db} = \frac{MY_{ar}}{(1 - M)}$$

$$MY_{ar} = (1 - M)\, MY_{db}$$

And detailed derivation about correlation of these three types of mass yield already discussed in one of the lectures in this module. And once we solve this equation, so it can be represented in this form. Similarly, mass yield on dry ash-free basis can be correlated with the mass yield on dry basis.

$$MY_{daf} = \frac{MY_{db} - Ash_{db}}{1 - Ash_{db}}$$

$$MY_{db} = MY_{daf}(1 - Ash_{db}) + Ash_{db}$$

So, once we know the mass yield on dry basis, then you can estimate the mass yield on as received basis as well as the mass yield on dry-ash-free basis. For that we need to know only the quantity, that is M (moisture) and ash content of the given material at dry basis. So, once you know these two quantities and the mass yield on dry basis, then you can easily calculate the mass yield on as-received basis.

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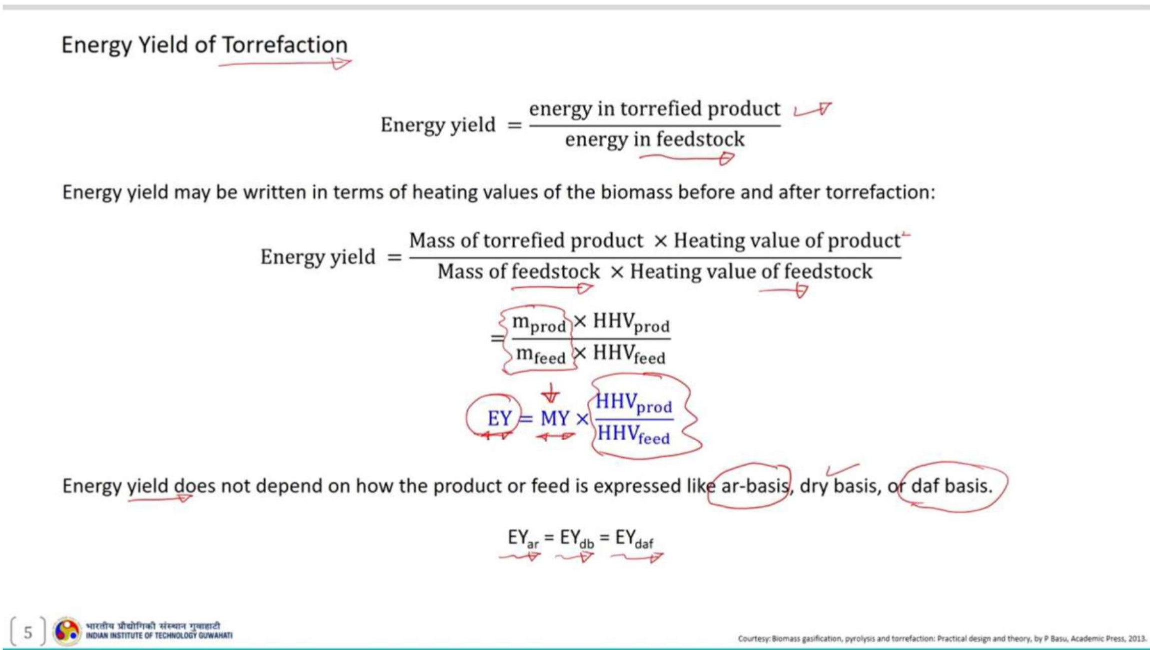

Similarly, we discussed one concept in this module that is energy yield of torrefaction. And it is the ratio of energy in torrefied product to energy in the feedstock.

$$\text{Energy yield} = \frac{\text{energy in torrefied product}}{\text{energy in feedstock}}$$

That means the energy content of the torrefied product to the energy content of the feedstock material. And this particular equation can also be written in the form of the heating value of these materials that is mass of torrefied product into its heating value.

$$\text{Energy yield} = \frac{\text{Mass of torrefied product} \times \text{Heating value of product}}{\text{Mass of feedstock} \times \text{Heating value of feedstock}}$$

Similarly, the mass of feedstock into its heating value. So, if you just separate out this term that is mass of product divided by the mass of feed, so this represents the mass yield of the product.

$$EY = MY \times \frac{HHV_{prod}}{HHV_{feed}}$$

And this way also, the energy yield is correlated with the mass yield of the specific material. And once we know the heating values of the feed and the produced product, then you can easily calculate the energy yield of the specific material. And there is one condition here that energy yield does not depend on how the product or feed is expressed like as received basis, dry basis, or dry-and-ash-free basis.

$$EY_{ar} = EY_{db} = EY_{daf}$$

So, here basically, the energy yield at as-received basis is same as that of the energy yield at dry-basis or to the energy yield at dry and ash-free basis. And I hope now this is clear to all of you, how to estimate the mass yield and the energy yield of a given material. So, in the similar line, we will practice one example in this lecture.

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Mass & Energy Yield of Torrefaction

Example 3

A commercial torrefaction plant set up in Northeast, India, to utilize the bamboo waste biomass containing 8% moisture on as-received basis. The composition of the biomass is as below:

Proximate analysis (db): Volatiles: 72.34%, fixed carbon: 25.53%, ash: 2.13%.

Ultimate analysis (daf): C: 42.80%, H: 6.35%, O: 50.40%, N: 0.35%, S: 0.10%.

Experimental studies shows that 20% of the dry biomass is converted into volatiles carrying 7% of the total thermal energy at an optimum torrefaction temperature and residence time for the biomass as 270 °C and 30 min, respectively. Calculate:

(a) Torrefaction mass yield on as received basis, dry basis, and dry-ash-free basis.

(b) HHV of the torrefied biomass (db).

So, in this example here, a commercial torrefaction plant is set up in the Northeast India, to utilize the bamboo waste biomass and it contains around 8% moisture, but that is on as received basis. And the composition of this biomass is given as the proximate analysis is given here as well as the ultimate analysis on dry and ash-free basis. And the details of the ultimate analysis and its composition is also given here. But, here if you remember, the proximate analysis is given on the dry basis. So, with this given information, it is also mentioned here, that the experimental studies show around 20% of dry biomass is converted into volatiles carrying 7% of total thermal energy. And that is at optimum torrefaction temperature and residence time for the biomass, and it is given as 270 degrees C and 30 minutes respectively. That means, this particular process, which is studied, is carried out at temperature of 270 degrees C and the residence time was 30 minutes. So, with the help of this given information, we need to estimate the torrefaction mass yield on as received basis, dry basis as well as on dry and ash-free basis. Apart from that, we need to also estimate the higher heating value of torrefied biomass, but that is on dry basis. So, with this given information, let us try to solve this example here.

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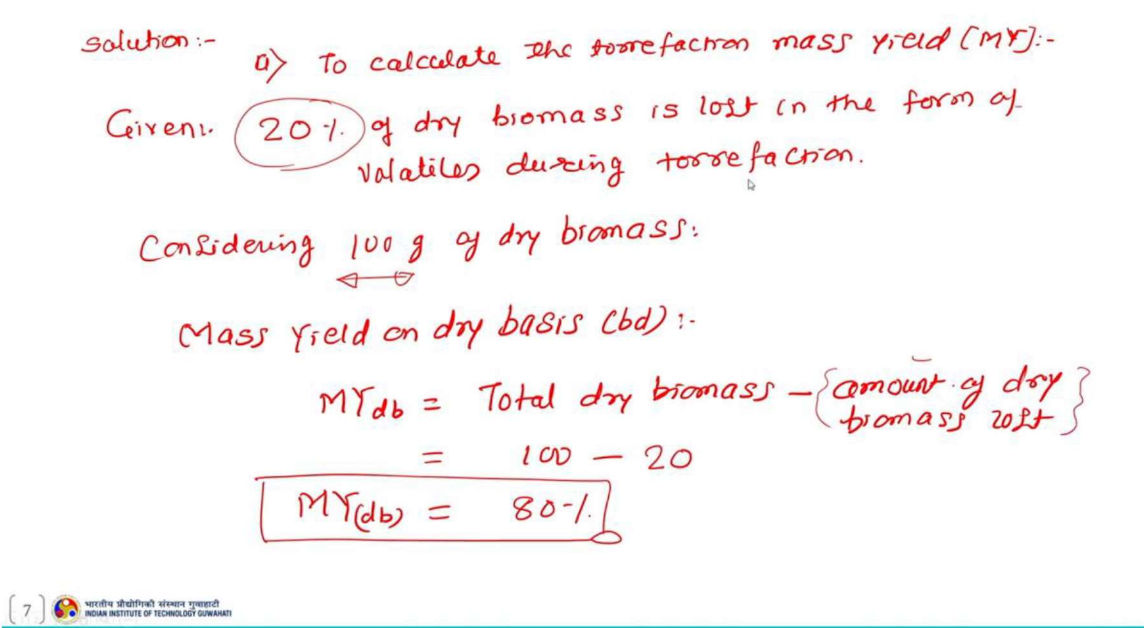

First, we will try to estimate the torrefaction mass yield and it is represented as MY. Because here, the given information is 20% of dry-biomass is lost in the form of volatiles during torrefaction operation. So now let us consider here, 100 grams of dry biomass. And then with the help of this information, we will try to estimate the mass yield on dry basis. So, mass yield on dry basis is equal to total dry biomass minus amount of dry biomass lost during this torrefaction operation.

$$\mathrm{MY_{db}} = \text{Total dry biomass} - \text{amount of dry biomass lost}$$

So, the total dry biomass as we have considered is 100 grams. So, it is 100 minus the amount of dry biomass lost. So, it is given here around 20% of dry biomass is lost in the form of volatiles during the torrefaction process. So, it is 20 here and mass yield on dry-basis would be around 80%. So, I hope this calculation is clear here. Because here the total biomass on dry basis is considered as around 100 gram and around 20% of the biomass is lost during the torrefaction process. And if you just take the balance of these two values, we will get the mass yield on the dry basis.

$$\mathrm{MY_{db}} = 100\ \mathrm{g} - 20\%\ \text{of}\ 100\ \mathrm{g} = 100\ - 0.2 \times 100 = 100 - 20 = 80\ g$$

$$\mathrm{MY_{db}} = 80\%$$

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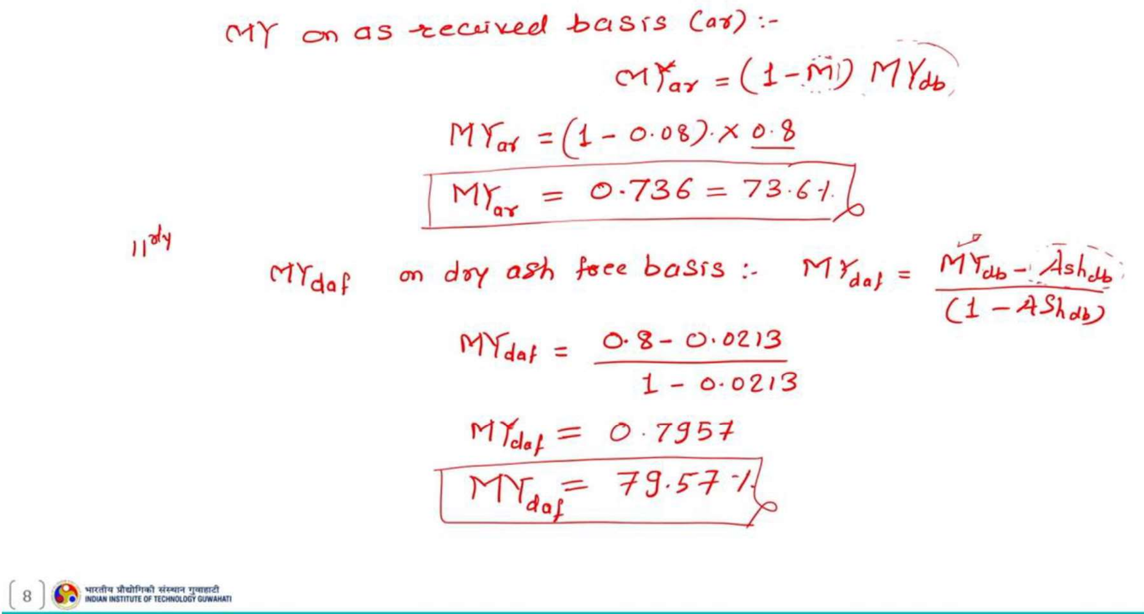

Similarly, we can estimate the mass yield on as received basis that is also nomenclature as "ar". And to do that we know the correlation, that is mass yield on as received basis equal to 1 minus M into mass yield on dry basis.

$$MY_{ar} = (1 - M)\ MY_{db}$$

So, once you substitute the values in this equation, 1 minus because here the moisture fraction of the given material is known that is 8%. So, that will be 0.08 and the mass yield here is 0.8. We have just estimated in the previous step. And once you do this small multiplication here we get the value like 0.736.

$$MY_{ar} = (1 - 0.08) \times 0.8 = 0.736$$

$$MY_{ar} = 73.6\%$$

That is mass yield on as received basis. Similarly, now we can estimate the mass yield on dry ash free basis. And further also we know one correlation, that is equal to mass yield on dry-basis minus ash content on dry-basis by 1 minus ash content on dry basis.

So, to estimate this value, although we know the mass yield on dry basis, but this value needs to be known. And the ash content on dry basis is given in the example and that is given as 2.13%. So, once you substitute this value here, so mass yield on dry and ash free basis, so this value is known, that is 0.8 minus ash on dry basis. It is given as 2.13% that will be 0.0213. 1 minus 0.0213. And after just taking the subtraction and solving this ratio, here we will get the value as 0.7957 that is 79.57%.

$$MY_{daf} = \frac{MY_{db} - Ash_{db}}{1 - Ash_{db}}$$

$$MY_{daf} = \frac{0.8 - 0.0213}{1 - 0.0213} = \frac{0.7787}{0.9787} = 0.7957$$

$$MY_{daf} = 79.57\%$$

So, the mass yield on dry-and-ash free basis would be around this much. And the mass yield on as received basis, if you just convert this into percentage as well so it will be 73.6%. And this is mass yield on as received basis. And the mass yield on dry basis is already estimated in the previous step. So, that is around 80%. So, this gives the details about the mass yield in different form and how it can be estimated from the given data.

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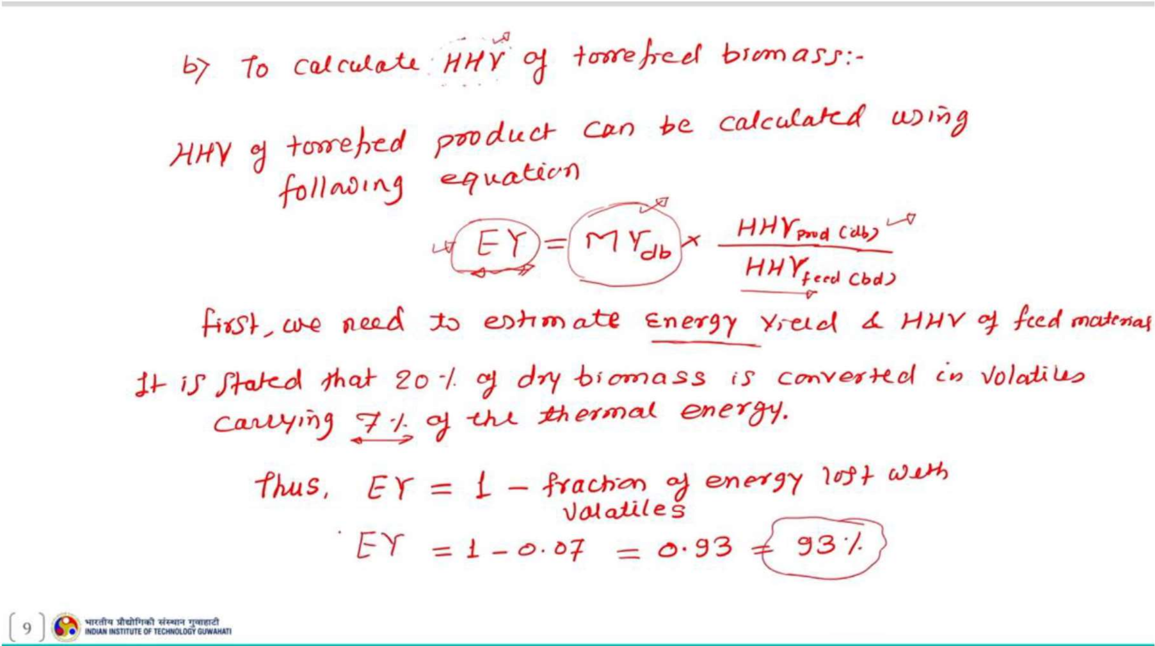

So, now next we need to calculate higher heating value of torrefied biomass. And if you recollect in one of the lectures, we discuss about the estimation of the higher heating value of the torrefied biomass. And there we discuss about the one equation. With the help of that equation, we can estimate the higher heating value of the torrefied biomass or torrefied product. So, the higher heating value of torrefied product can be calculated using following equation. That is energy yield is equal to mass yield, here it is on, here it is on dry basis, into higher heating value higher heating value of product on dry basis by the higher heating value of feed material at dry basis.

So, to calculate the higher heating value of the product, that means torrefied biomass, we first need to know the higher heating value of the feedstock material, and we also need to know the mass yield of the torrefied product that is on dry basis. So, we also need to know the energy density of the material. So, once we know these values, then we can estimate the higher heating value of the product, that is the torrefied biomass. So, now let us try to estimate at first the HHV of the feedstock and then we will try to estimate the energy yield because the mass yield on dry basis is already estimated in the previous step. So, first we need to estimate energy yield and higher heating value of feed material.

So how to estimate this energy yield? So, it can be estimated using the given data. Because in the example it is stated, that 20% of dry biomass is converted into volatiles, carrying 7% of the thermal energy. So, with the help of this given information we can estimate the energy yield.

$$EY = MY_{db} \times \frac{HHV_{prod(db)}}{HHV_{feed(db)}}$$

Thus, energy yield is equal to 1 minus fraction of energy lost with volatiles and it is given as 7%. So, once we substitute this value here, that is 0.07, that is 0.93 equal to 93%. So, this is the energy yield value.

$$\text{Energy yield (EY)} = 1 - \text{Fraction of energy lost with the volatiles}$$

$$= 1 - 0.07 = 0.93 = 93\%$$

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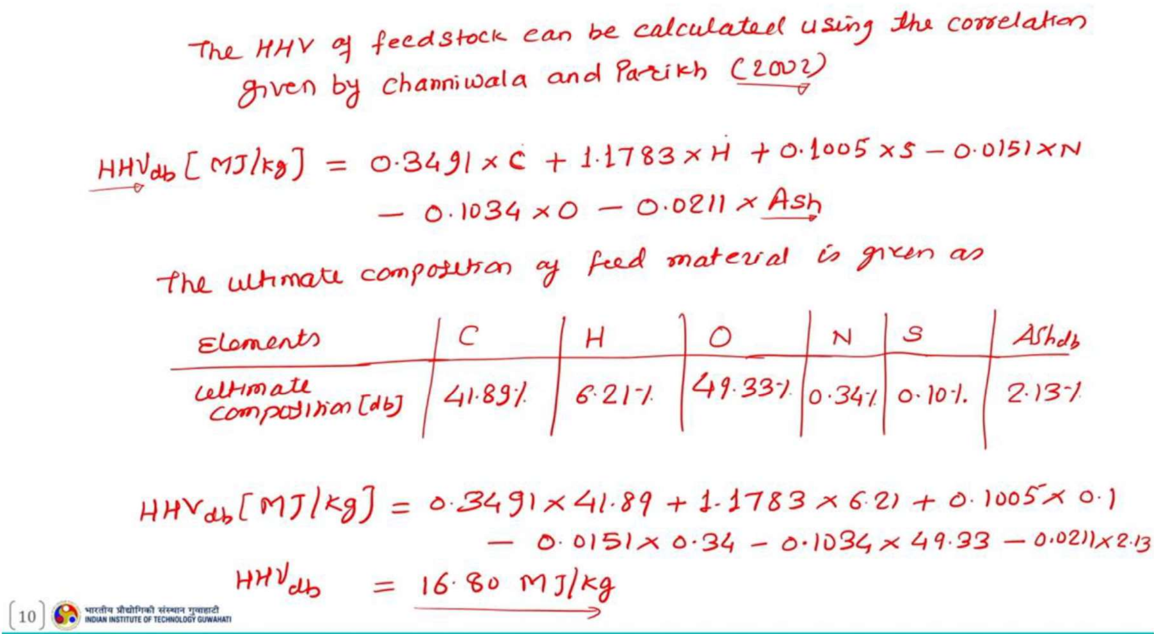

So, now we need to estimate the higher heating value of the feedstock, that is on the dry basis. So, the higher heating value of feedstock can be calculated using the correlation between the two variables given by this author: Channiwala and Parikh (2002). And the correlation is given as higher heating value on dry basis, that is in MJ/kg equal to 0.3491 into C plus 1.1783 into H plus 0.1005 into S minus 0.0151 into N minus 0.1034 into O minus 0.0211 into ash contained in the given material.

HHV_{db} (MJ/kg) = 0.3491 C + 1.1783 H + 0.1005 S – 0.0151 N – 0.1034 O – 0.0211 ASH

The ultimate composition of feed material is given as elements and then the ultimate composition and at dry basis. So, first carbon 41.89%, hydrogen 6.21%, O 49.33%, N 0.34%, S 0.10%, and ash on dry-basis as 2.13%. So, value of this component C, H, S, N, O and Ash is given here. So, with the help of this given value, we will try to estimate the high heating value of feedstock at dry basis. So, higher heating value at dry basis,

$$HHV_{db}\,(MJ/kg) = 0.3491 \times 41.89 + 1.1783 \times 6.21 + 0.1005 \times 0.10 - 0.0151 \times 0.34 - 0.1034 \times 49.33 - 0.0211 \times 2.13$$

$$HHV_{db} = 16.80\ MJ/kg$$

So, after solving this, we get the higher heating value at dry basis as 16.80 MJ/kg. So, after solving this, we get the higher heating value at dry basis as 16.80 MJ/kg.

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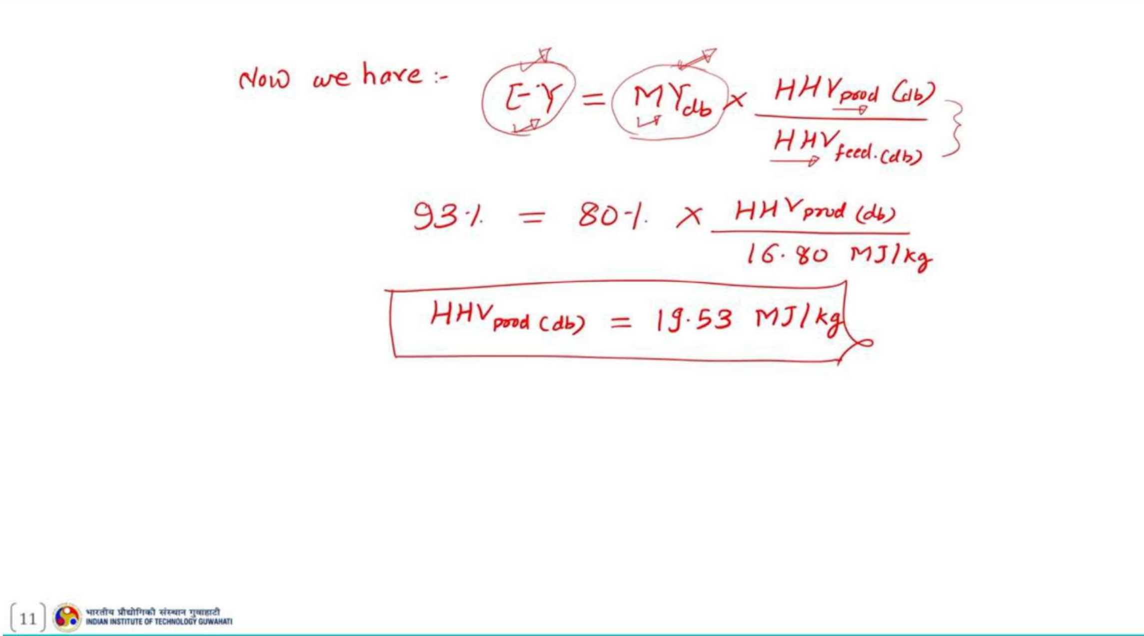

Now, we have energy yield equal to mass yield at dry basis into higher heating value of product at dry basis by higher heating value of feed at dry basis. So, here the energy yield value, energy yield is known that is 93%, mass yield 80% into high heating value of product dry basis. This we need to estimate but we know the high heating value of feed.

We have just estimated one step before, that is 16.80 MJ/kg. So just by rearranging this step, we will get the higher heating value of product, that is at dry basis and that is equal to 19.53 MJ/kg.

$$EY = MY_{db} \times \frac{HHV_{prod(db)}}{HHV_{feed(db)}}$$

$$93\% = 80\% \times \frac{HHV_{prod(db)}}{16.8\ MJ/kg}$$

$$HHV_{prod(db)} = \frac{93}{80} \times 16.8\ MJ/kg = 19.53\ MJ/kg$$

So, using this equation, we could able to estimate the high heating value of the product when the high heating value of the feedstock, mass yield, and the energy yield was known. And even this high heating value of the feedstock was estimated using the given correlation.

So, I hope now it is clear to all of you, how to estimate the high heating value of the product if the high heating value of the feed as well as the mass yield and the energy yield values are known. So, similar kind of example can be solved for the other feedstock material as well. Where we can calculate the mass yield of the material even if the high heating value as well as the energy yield values are known. Apart from that, we can also estimate the energy yield value, if the mass yield and the higher heating values are known. So, you may practice example in the similar line using different ultimate composition of the different materials and try to estimate the high heating value as well as the mass yield and the energy yield of the given material.

Examples of the similar type would be given in the assignment to estimate the high heating value or the mass yield or the energy yield of the given material. With this we will end our lecture here. In the next lecture, which will be the first lecture under the module 4, in that we will discuss about thermochemical conversion processes, that is simultaneous biochar and bio oil production and their application. Apart from that, we will discuss about the hydrothermal liquefaction of bio-based feedstock and at the end we will try to compare the biofuels with the conventional fuels.

Thank you.