Energy Conversion Technologies (Biomass And Coal)

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Lecture 16
Practice problems (Pelletization)

Good morning everyone.

Welcome to part 1 of the lecture 3 under module 3. In this lecture, we will practice few examples on the concept discussed in this module. So, if you recollect in this module, we discussed about the bio-based feedstock followed by the classification of the bio-based feedstock. In that, we discussed about the proximate analysis, ultimate analysis, and structural and compositional analysis of bio-based feedstock. Followed by that, we discussed about the thermochemical conversion processes. In that, we discussed about the physical processes and thermochemical conversion processes. However, we just learned two thermochemical conversion processes that is carbonization and torrefaction and remaining thermochemical conversion processes will be covered in the next module. So, based on the topic discussed in this module, we will practice few examples in this lecture.

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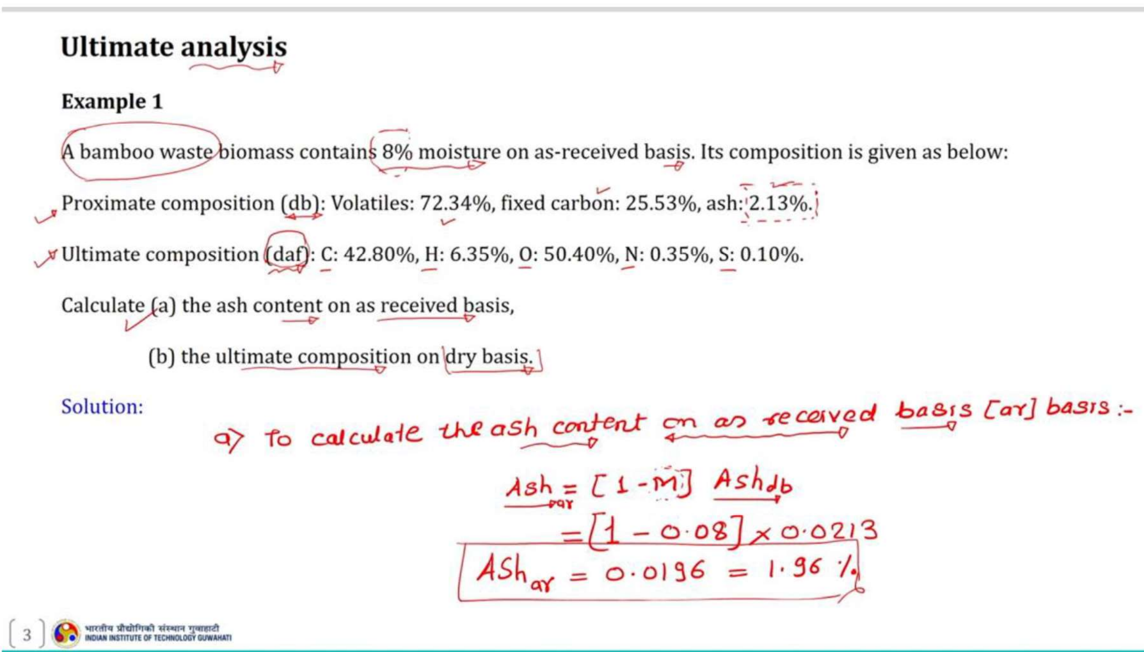

So, here is the first example which is on the ultimate analysis. So, a bamboo waste, it contains around 8% moisture on as-received basis and its composition is given as below, that is the proximate composition it is given on dry basis. That is, the volatiles content, fixed carbon content, and ash content. Also, the ultimate composition of this bio-based feedstock material is given, but it is on dry and ash free basis, which includes C, H, O, N and S. So, based on this given information, we need to calculate the ash content on as received basis. Similarly, we need to also estimate the ultimate composition on dry basis. For example, here the ultimate composition on dry and ash free basis is given. However, we need to estimate this ultimate composition on only dry basis.

So, let us begin with the solution of this example. So, here first we need to calculate the ash content on as received basis and it is also referred as "ar" basis. So, in this module, we discuss some correlation which correlate the ash content on dry basis with ash content on dry ash free basis as well. So, we will take help of those correlation while solving this example. And one such correlation if you remember is as mentioned here.

$$\mathrm{Ash} = (1 - \mathrm{M})\mathrm{Ash}_{\mathrm{db}}$$

$$\mathrm{Ash} = (1 - 0.08) \times 0.0213 = 0.0196$$

$$\mathrm{Ash} = 1.96\%$$

So, if you recollect our discussion. So, this indicates the ash on dry basis and this represents the ash on as received basis. And this M is the fraction of moisture in the given biomass. So, as we know, here the moisture value is given in the example as 8% and ash value on dry basis it is given here in the proximal analysis. So, if you just do this small calculation, we will get the value in the form of 0.0196 and this is the ash content on as received basis that is equal to 1.96%. So, this is the answer to this first term here, that is ash content on as received basis. Similarly, now, we need to estimate the ultimate composition on dry basis.

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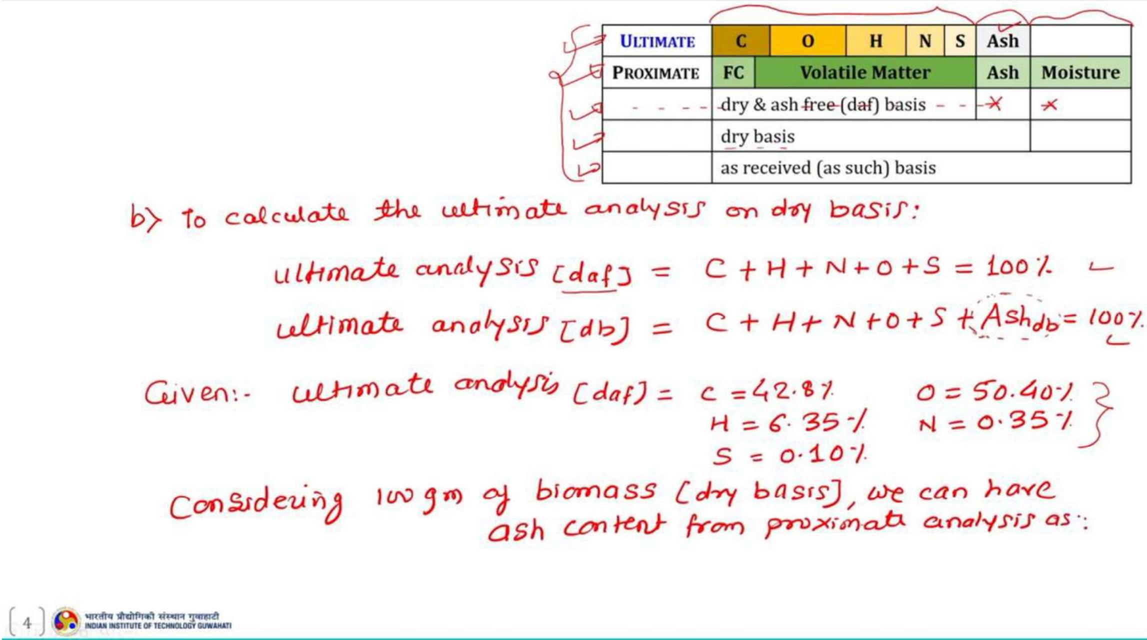

So, if you remember, this is the one concept we discussed in previous module as well as in the module 1. So, this particular chart indicates the ultimate and the proximate analysis and how this ultimate and the proximate analysis is represented in three different ways. So, this particular line indicates the dry and ash free basis. So, when you are calculating the ultimate analysis of any given feedstock on dry and ash free basis, so, it only accounts this composition. Because here we are not taking into account the ash and the moisture. If it is on dry basis, then it includes the ash in the composition. And if it is on as-received basis, means there is no preprocessing is done with this particular feedstock. So, it includes the moisture also. So, based on that now we have to estimate, we have to calculate the ultimate analysis. So, this particular line indicates the dry and ash free basis.

It can be represented in this way like C+H+N+O+S. It should be equal to 100% composition. Because this is on the dry and ash free basis where the moisture and the ash is not taken into consideration. And if you are representing the ultimate analysis on only dry basis then it includes C+H+N+O+S+Ash on dry basis and that equals to 100%. So, here since it is on dry basis, so, it takes into account the ash content of the given material. And ultimate analysis on dry ash free basis is given in this example, where it is represented in the form C = 42.8%, H = 6.35%, O = 50.40% and N = 0.35%, whereas S = 0.1%. So, with the help of these two equations and this given information, we have to now estimate the ultimate analysis on dry basis.

$$\text{Ultimate analysis (daf)} = C + H + O + N + S = 100\%$$

$$\text{Ultimate analysis (db)} = C + H + O + N + S + Ash_{db} = 100\%$$

Given: Ultimate analysis (daf) = 42.80% + 6.35% + 50.40% + 0.35% + 0.10% = 100%

So, considering 100 grams of biomass on dry basis, we can have ash content from proximate analysis, as ash content on dry basis which is given in the example as 2.13% of 100-gram biomass sample. So, it is around 2.13 gram.

$$Ash_{db} = 2.13\% \text{ of } 100 \text{ g} = 2.13 \text{ g}$$

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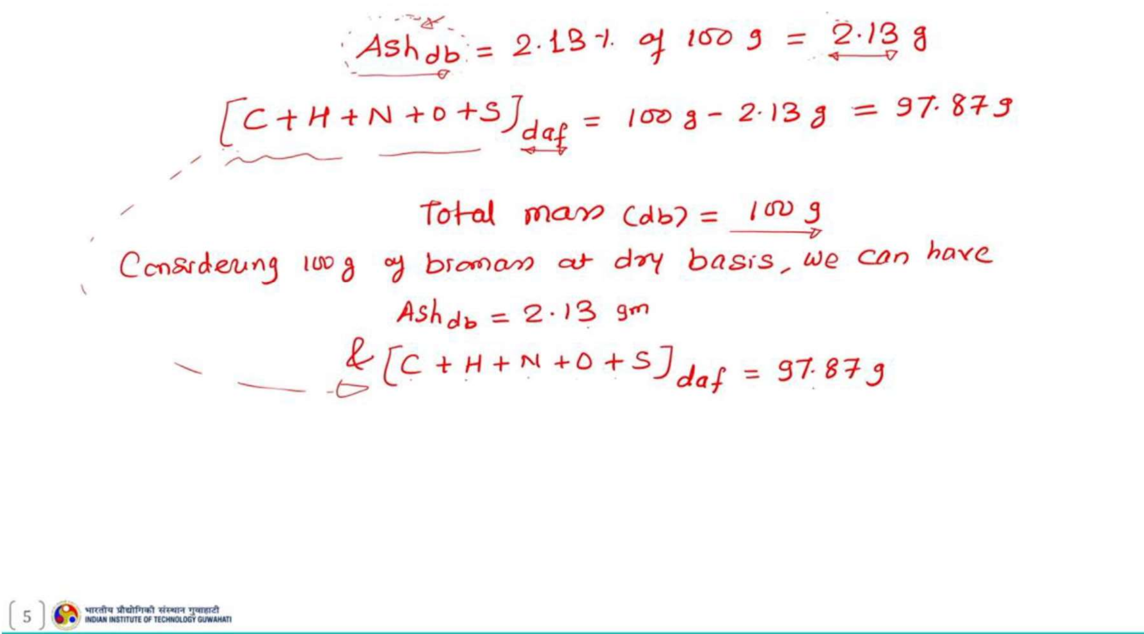

So now, we know the carbon, hydrogen, nitrogen, oxygen, sulfur on dry ash free basis is 100 minus 2.13 gram and it comes out to be around 97. 87 grams here.

$$(C+H+O+N+S)_{daf} = 100 \text{ g} - 2.13 \text{ g} = 97.87 \text{ g}$$

So, this indicates the ultimate analysis on dry and ash free basis. Whereas this particular value it indicates the ash content when the ultimate analysis was estimated on the dry-basis. So, it includes the ash of the specific material in the calculation of the ultimate analysis and that ash content on dry basis was found to be around 2.13%. But, when it is dry and ash free basis, so, this particular component that is ash is not considered in the ultimate analysis here. So, the total mass on dry-basis if you see here it is 100 grams. That is 97.87 gram, which includes the composition of these component and the remaining that is ash is 2.13. So, if you take the summation of these two quantities here, so, you will get the total mass on dry basis as 100 grams.

So, now, considering 100 grams of biomass at dry basis we can have ash content on dry basis as 2.13 g. And carbon, hydrogen, nitrogen, oxygen and sulphur that is on dry ash free basis equal to 97.87 gram. So, as if you see here, we are just using this information which is obtained from the previous step as well as the ash content on dry basis that is 2.13 gram. So, if you see now here, the total mass on dry basis is this term plus this term. If you take the summation of these two, so, we will get even the ultimate analysis on dry basis. That is C+H+N+O+S+Ash on dry basis, which is equal to the ultimate analysis on the dry basis and it will be equal to 100. So, now with this information, now we have to estimate the ultimate analysis on dry basis.

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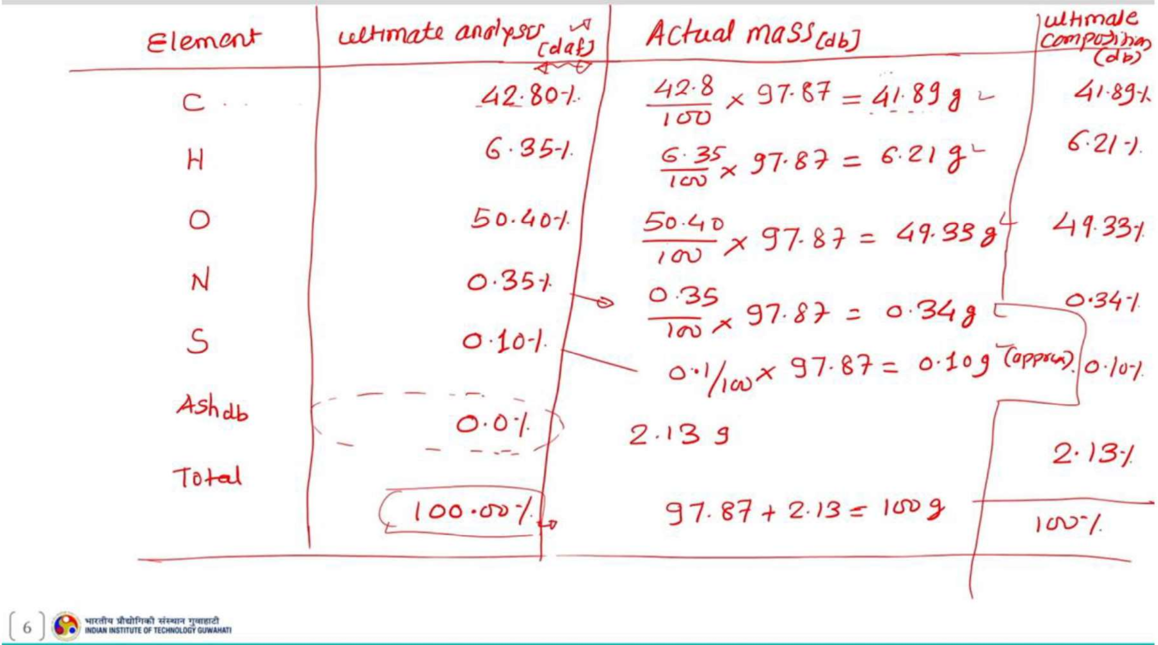

However, for that we know the element in the ultimate analysis that includes C, H, O, S, and then ash here on dry basis and finally is the total amount. Now, once you see here, the ultimate analysis on dry ash free basis is given as C is 42.80% H is 6.35%, O 50.40%, N is 0.35%, 0.1% and here the ash is 0%, because this is on the dry and ash free basis. So, ash is not accounted in the ultimate analysis here. And if you take the sum of these, so, this total %age is 100 %. Now with the help of this information, as well as information we have just obtained in the previous slide, so, we have to calculate the actual mass on dry basis. What is the meaning of that? For example, if you see here, so, this particular entire term indicates the ultimate analysis on the dry-and-ash-free basis and its total value is comes out to be around 97.87%. But here, the individual values of these terms are still unknown to us. So, we are just trying to find out the %age of this component in ultimate analysis on dry basis. Because these values are known to us on dry and ash free basis, but in terms of dry basis, it is still unknown to us. So, we are just trying to find out these individual values on dry basis. Because here if you see, this is actual mass on dry basis and this indicates the ultimate analysis on dry-and-ash-free basis. We know this value which is on dry and ash free basis. Similarly, we know the total of this component which comes out to be around 100 %. So, based on these two given information, as well as the information which is available here, we are just trying to estimate the actual mass on dry basis. So, it would be in this form:

$$C = \frac{42.80}{100} \times 97.87 = 41.89 \text{ g}$$

$$H = \frac{6.35}{100} \times 97.87 = 6.21 \text{ g}$$

$$O = \frac{50.40}{100} \times 97.87 = 49.33 \text{ g}$$

$$N = \frac{0.35}{100} \times 97.87 = 0.34 \text{ g}$$

$$S = \frac{0.10}{100} \times 97.87 = 0.10 \text{ g (approx.)}$$

$$Ash_{db} = 2.13 \text{ g}$$

C is 42.8 % here, which is on 100-gram basis. However, the actual mass which is available here is on dry basis 97.87. So, we just take the simple multiplication here. So, this final value will be 41.89 gram. So, this indicates, the C contained in the ultimate analysis on dry basis would be around 41.89 % because the total mass which is available here is on dry basis is 100 grams. But, when it is on dry and ash free basis, it is around 97.87% and we know the value of this component on dry and ash free basis. So, based on these given data, we are just converting these values into dry basis. Similarly, once you convert this H here into again 97.87, it will be 6.21 gram and O will be 49.33 gram, and this would be around 0.34 gram. And the sulfur, it would be roughly that is approx suppose. And ash here, because this is calculation on the dry basis, so, here the quantity of ash as we already estimated on dry-basis as 2.13. So, this value is known to us, so it is 2.13 gram. So, now, if you take the summation of all these terms, it will come out to be around 97.87 plus 2.13 ash on dry basis and roughly it would be 100 grams.

$$\text{Total} = 97.87 + 2.13 = 100 \text{ g}$$

So, I think this is clear now how to calculate this ultimate analysis or I would say the actual mass on dry basis. So, the ultimate composition on dry basis, it would be 41.89% here, 6.21%, 49.33%, here 0.34%, 0.10%, and here the ash would be 2.13. And this sum up to 100%.

I hope now this is clear to all of you like how we have estimated this ultimate composition on dry basis when the ultimate analysis composition was known at dry-and-ash-free basis. So, it can be done in the other way around also, if the ultimate composition on the dry basis is given, we can also estimate the ultimate analysis on dry and ash-free basis.

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Net Energy Density of Torrefied Biomass

Example 2

Calculate the net volumetric energy density of the torrefied biomass pellets, if its bulk density is 800 kg/m^3. The HHV at dry basis can be calculated using the following model equation, where C, H, S, N, O, and ASH are the mass per cent of carbon, hydrogen, sulfur, nitrogen, oxygen, and ash in the torrefied biomass at dry basis:

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

Elements	C	H	O	N	S	Ash_{db}	Total
Ultimate Composition (db)	48.9%	5.1%	42.5%	0.2%	0.1%	3.2%	100.00%

Solution: At first, we need to calculate the HHV(db) using ultimate

So, the second example here, it is on the concept of net energy density of torrefied biomass. If you recollect our discussion on the torrefied biomass, there we discuss about the calculation of net energy density of given biomass. So, this example is exactly based on this concept to calculate net volumetric energy density of the torrefied biomass pellets. If its bulk density is 800 kg per meter cube and the HHV value that is higher heating value at dry basis, it can be calculated using the following model equation.

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

So, we also discussed about this equation in the previous lecture, which is used to calculate the higher heating value for range of the fuels where C, H, S, N and O also the ash are the mass % of these components respectively in the torrefied biomass at dry basis and their values are given here.

So, with the help of this known data, we need to just estimate the net volumetric energy density. And to do that, we need to calculate the higher heating value on dry basis. So, let us begin with the solution of this example. At first, we need to calculate the higher heating value dry basis using ultimate analysis data to determine high heating value on dry basis.

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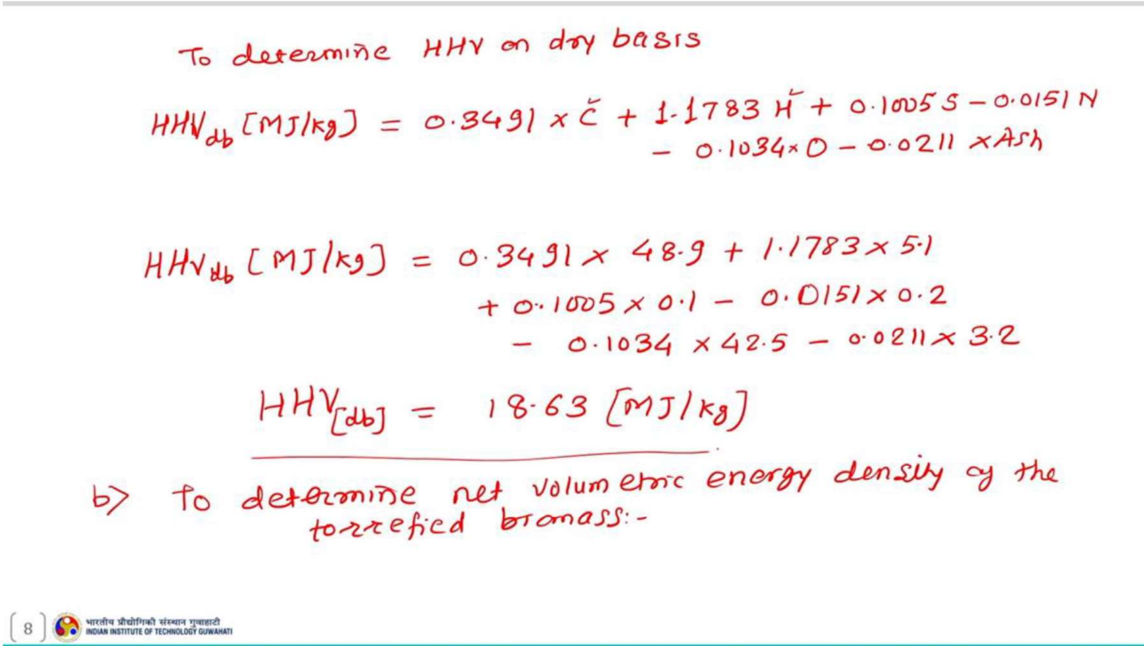

The equation is given here, which is in mega joule per kg.

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

$$HHV = 0.3491 \times 48.9 + 1.1783 \times 5.1 + 0.1005 \times 0.1 - 0.1034 \times 42.5 - 0.0151 \times 0.2 - 0.0211 \times 3.2$$

$$HHV = 18.63\ MJ/kg\ \text{(at dry basis)}$$

And the equation to calculate this high heating value on dry basis is 0.3491 into C plus 0.1005 into S minus 0.0151 into N minus 0.1034 into O and minus 0.0211 into ash content. So, as we know this component and their values, so once we replace these values in this equation, so the higher heating value on dry basis would be 0.3491 into 48.9 plus 1.1783 into 5.1 plus 0.1005 into 0.1 and then minus 0.0151 into 0.2 minus 0.1034 into 42.5 and minus 0.0211 into ash content which is 3.2. So, after just doing this multiplication and summation as well as a subtraction, so we will get the final answer in the form of 18.63 MJ/kg and this is the higher heating value on dry basis. Similarly, in this example, we need to calculate the net volumetric energy density of torrefied biomass pellet. Now, we need to determine net volumetric energy density of the torrefied biomass.

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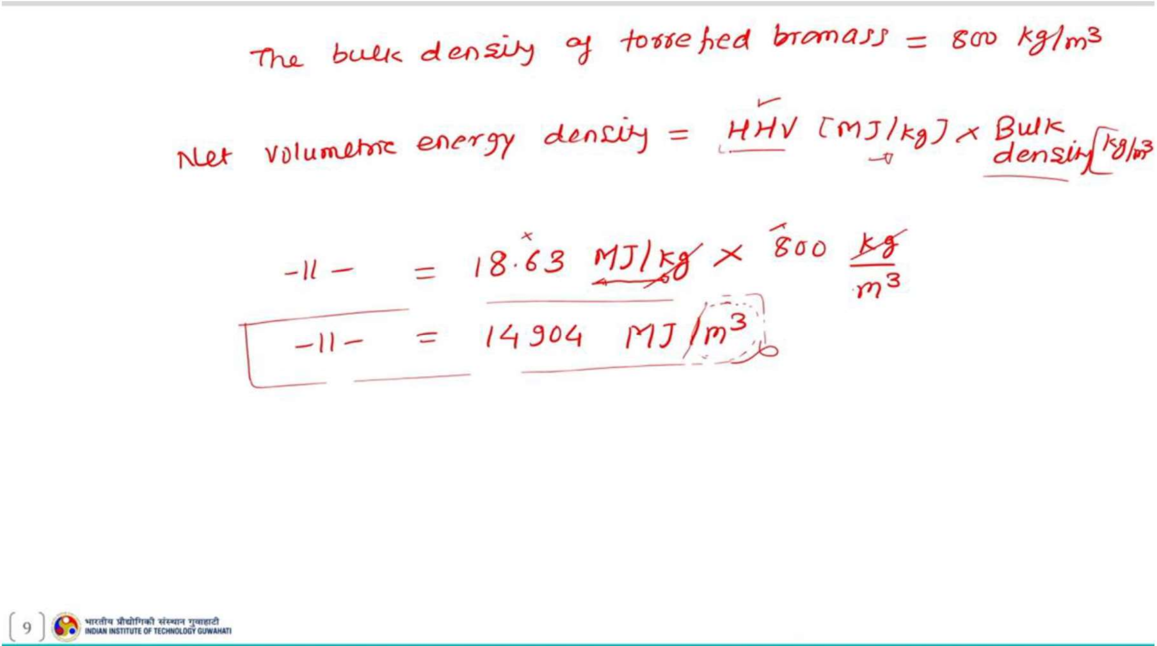

So, to estimate this net volumetric energy density, we need to know the bulk density of torrefied biomass. And it is given as 800 kg per meter cube. And if you recollect in one of the lectures in this module, we discuss about the expression to calculate the net volumetric energy density, if the higher heating value and the bulk density is known.

Net volumetric energy density = HHV (MJ/kg) × Bulk Density (kg/m^3)

$$= 18.63\ \frac{MJ}{kg} \times 800\ \frac{kg}{m^3}$$

$$= 14904\ \text{MJ/m}^3$$

$$= 14.904\ \text{GJ/m}^3$$

So, we will take the help of this equation here to estimate the net volumetric energy density. Because the high heating value of the sample is already estimated in this example and the bulk density is given. So, with the help of these two values, we can estimate the net volumetric energy density. And the high heating value obtained was 18.63 MJ/kg and the bulk density is given as 800 kg/m^3. So, once these two terms cancel out and after multiplication of these two quantities here, the final answer comes out to be around 14904 MJ/m^3.

And this is the net volumetric energy density of torrefied pellet. Because, if you remember this value is in terms of volume that is on meter cube basis. And the earlier value that is HHV, it was mega joule per kg. And we just estimated this value in the form of net volumetric energy density, using the help of this equation. I hope with this now, it is clear how to estimate the net volumetric energy density of a given bio-based feedstock.

It may be a bio-based feedstock, it may be a torrefied biomass or it may be a torrefied pellet. Whatever the feedstock and its composition which is available, based on that we can estimate the higher heating value for the specific feedstock. And if the bulk density value is known, then we can estimate the volumetric energy density easily. With this we will end our lecture here. And in the next lecture we will practice few more examples on the remaining concept discussed in this module.

Thank you.