Renewable Energy Engineering: Solar, Wind and Biomass Energy Systems

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Lecture – 17
Characteristics and Properties of Biomass

Good morning everyone and welcome to second lecture under model 6. In the previous lecture, if you just recall, we discussed about biomass, then we discussed about the definition of biomass, types of biomass in that we discussed about the broad classification of biomass, followed by the biomass structure. In that specifically we discussed about the component of biomass, the component includes cellulose, hemicellulose and lignin. So, in this lecture, mostly we will discuss on characteristics of biomass, properties of biomass and structural components of biomass. So, let us see this topic one by one in today's lecture.

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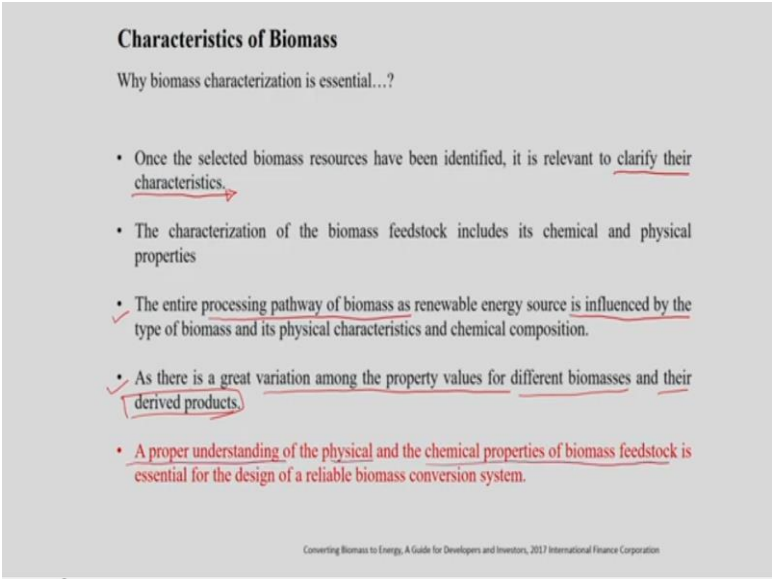

Characteristics of biomass, why biomass characterization is essential? Because, once the selected biomass has been identified, then it is relevant to clarify their characteristics. And as a result, it is very much essential to characterize the biomass before being utilized for any conversion process. Secondly, the characterization of the biomass feedstock mainly includes physical and chemical properties.

So, now, once we know the physical and chemical properties of the biomass, it becomes very easy to select the appropriate conversion process for the selected biomass. Third is most important point in case of characteristics of biomass is, because the entire processing pathway up of biomass as a renewable energy source is influenced by the types of biomass and its physical and chemical properties.

And that is the reason it is very much essential to characterize the biomass at first time. Similarly, if we just recall our discussion in the previous lecture, under types of biomass, there are also we discussed about different types of biomass. And there, we specifically mentioned that the composition of the biomass varies from biomass to biomass. Similarly, once the composition is varying, obviously it is going to have impact on the conversion process.

And that is the reason that characterization of the biomass is essential. Apart from that, as there is a great variation among the property value of different biomasses and their derived products. That means, as we just mentioned, there is a variation among property value of different biomass. As a result, obviously, the derived product obtained any conversion process will lead to different products. As a result, there will be again a variation in the derived product.

Lastly, a proper understanding of the physical and chemical properties of the biomass feedstock is also essential for designing a reliable biomass conversion system. So, this is also one of the important points which needs to be noted here that, unless we characterize the biomass, it is difficult to use a proper design system for the biomass conversion as well. So, if you try to see here, how the characteristics of the biomass affect the property of biomass as a fuel.

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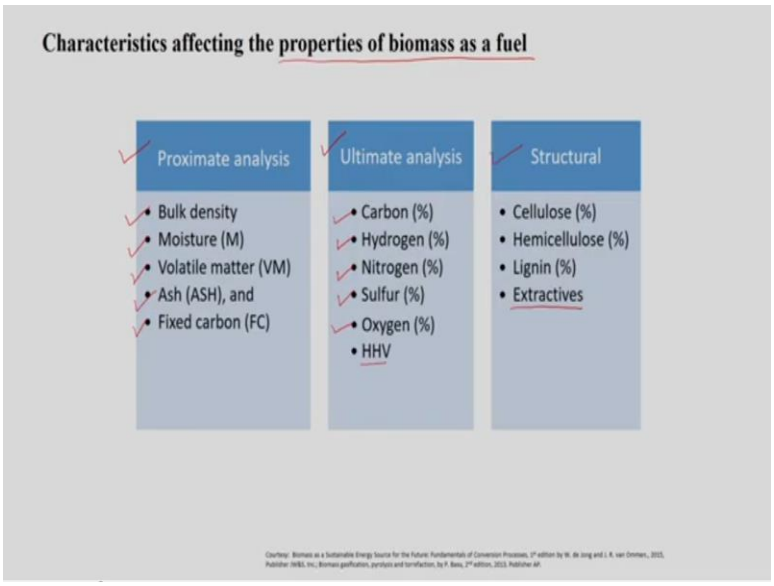

So, as a whole there are 3 different characteristics techniques, we try to use that is one is proximate analysis. Other one is ultimate analysis and structural properties of the biomass. The proximate analysis includes bulk density, moisture content in the biomass, volatile matter content in the biomass, ash content and the fixed carbon content in the biomass. So, this covers proximate analysis.

Similarly, in the ultimate analysis, we try to estimate carbon, hydrogen, nitrogen, sulfur, which is commonly known as CHNS analysis and oxygen is to estimate by difference and at the last is high heating value which is also called as calorific value of the biomass, and in the structural properties, we try to estimate the cellulose hemicellulose, lignin and extract use content of the biomass. So, all this together gives us an idea about the physical and chemical properties of the feedstock or I would say biomass. So, now, let us discuss about this proximate analysis and the properties include into proximate analysis one by one.

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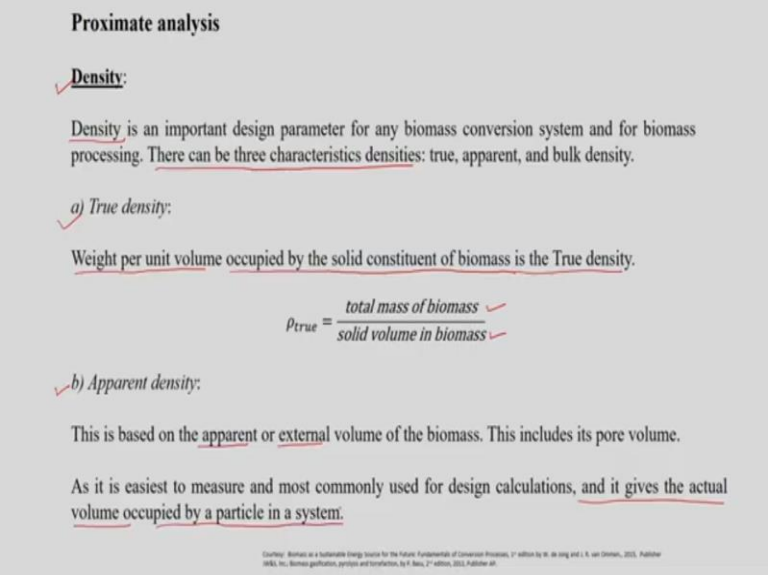

So, first of all let us discuss about the density. So, the density is an important design parameter for any biomass conversion system and for biomass processing as well. There can be 3 characteristics densities, that is true density, apparent density and bulk density. So, let us discuss first of all about the apparent density and then the true density. So, the true density is nothing but the weight per unit volume occupied by the solid constituents of biomass is called as a true density.

And it is the ratio of total mass of biomass to solid volume in biomass. It is very simple to calculate the true density of biomass samples. Similarly, if you try to see the apparent density, so, apparent density is based on the apparent or external volume of the biomass this also includes the pore volume of the sample the apparent density is easiest to measure and it is most commonly used for the design calculation and it also gives the actual volume occupied by a particle in a system.

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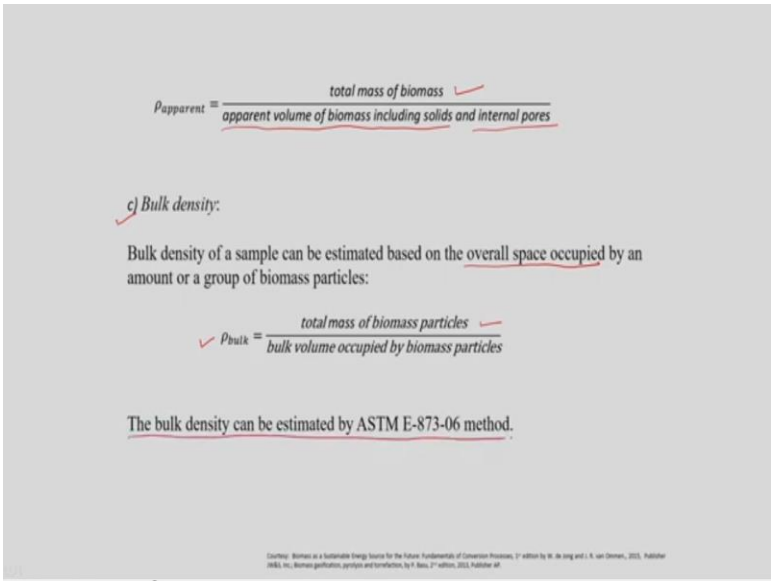

Now, apparent density is the ratio of total mass of biomass to the apparent volume of biomass including solids and internal pores this is termed as apparent density. Now, let us see about the bulk density, the bulk density of a sample can be estimated based on the overall space occupied by an amount or group of biomass particle. And it is the ratio of total mass of biomass particle to bulk volume occupied by biomass particle. And it is estimated as per this ASTM standard method and the standard protocol for the measurement of bulk density can be seen in this ASTM method.

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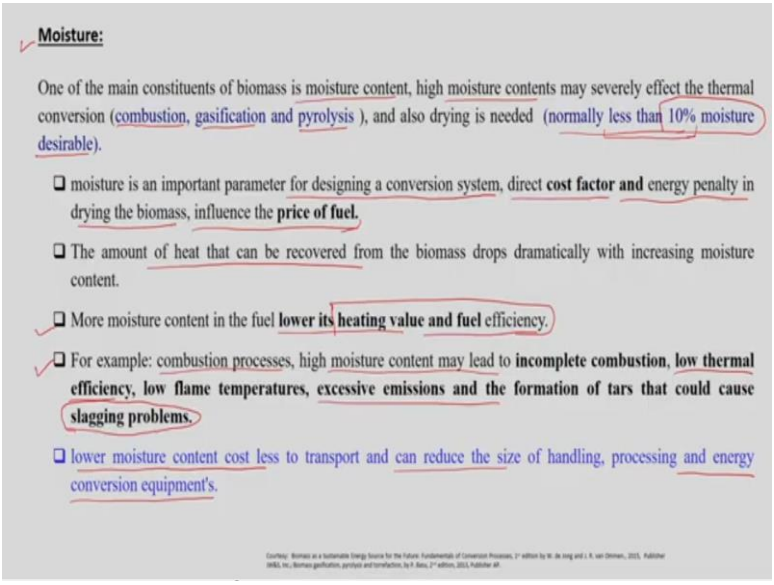

Next is moisture content. This is also one of the main constituents of biomass as high moisture content may severely affect the thermal conversion that means combustion, pyrolysis and

gasification process. The high moisture content in the biomass also needed a dryer as a result, one additional unit operation is required if the moisture content in the biomass is relatively high. So, that is the reason normally moisture less than 10% is desirable for the conversion processes.

So, this is very important point which we can note down, here if the moisture content is in the range of around 10% or less than 10%, so, this kind of biomass are desirable for the biomass conversion system mainly when you are talking about the thermal conversion that is combustion. Gasification and pyrolysis. Moisture is an important parameter for designing a conversion system because it impacts the direct cost factor and energy penalty in drying the biomass and also influence the price of fuel.

So, here feeling the sense after processing the biomass using a specific conversion system, it will lead to a derived product. So, derived product may be in the form of gaseous fuel or a liquid fuel. So, high moisture content in the biomass will have influence also on the price of fuel, the amount of heat that can be recovered from biomass also drop dramatically with increase moisture content.

This is also one important point which you need to note here that with increase moisture content, the heat recovery from the biomass sample also drop dramatically. The third point is which is very important here. Moisture content in the field also lowers its heating value and fuel efficiency. The meaning of this term here is, for example, if initial moisture content in the biomass is relatively high, as a result, while processing such biomass, the derived product will also have relatively higher or more moisture content.

And if the fuel contained more moisture, so, obviously, it will have impact on its heating value as well as the fuel efficiency. For example, here, let us take the example of the combustion process. In combustion process, high moisture content may lead to incomplete combustion, low thermal efficiency for example, low flame temperature and excessive emission and the formation of tar that can cause slagging in gasifier or boilers.

So, this is one important point also which needs to be noted that, if the moisture content is relatively high, so, the major problem it may happen in the thermal process is it could cause slagging problem in the boiler as well as in the gassy fire. Hence, low moisture content cost less to transport and can reduce the size of handling, processing and energy conversion equipments. So, it is very much essential and that is the reason at the beginning itself. I mentioned here that normally, moisture less than 10% is desirable, while we are talking about the thermal conversion system that is combustion, pyrolysis, and gasification.

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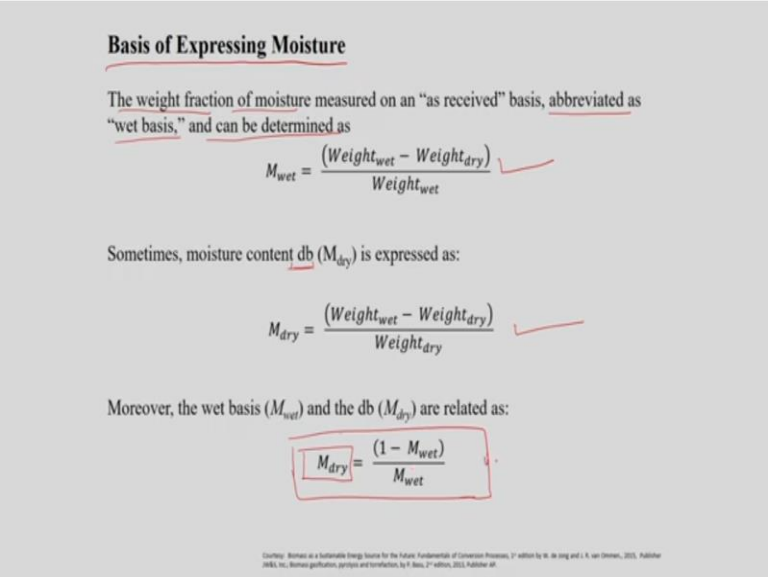

So, the next point is how to express the moisture in the biomass sample. Moisture in the biomass sample is expressed in 2 different ways. And it is termed as moisture on wet basis and moisture on dry basis. For example, the weight fraction of moisture measured on an as received bases abbreviated as wet basis and can be determined using this simple equation. Similarly, if we need to estimate the moisture content on dry basis, so, this is the short form I mentioned here that is moisture content on dry basis.

It is expressed as using this particular expression, which indicates the moisture content in the sample on dry basis and one can easily estimate the moisture content of the sample using this equation. Now, these 2 equations are these 2 terms are also related according to this following equation, which is moisture and dry basis equal to 1 minus moisture on the wet basis divided by

moisture on the wet basis. So, this gives the moisture content on the dry basis and how it is related with the moisture content on the wet basis.

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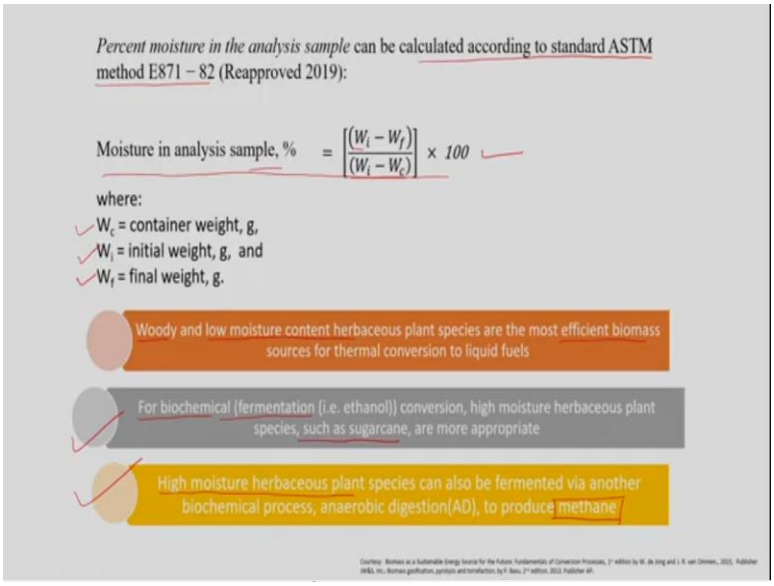

Similarly, the percent moisture in the sample can also be calculated according to the standard ASTM method, as mentioned here similarly, the standard protocol can be seen in this particular ASTM reference method and can be easily adopted for the estimation of moisture in wood or the biomass sample. So, the moisture in the analysis sample can be calculated using this equation, it is again the ratio of initial weight minus final weight by initial weight minus weight of the container.

So, this gives the moisture contained in the sample. Woody and low moisture contained herbaceous plant species are the most efficient biomass source for thermal conversion processes, as I mentioned in my previous slide as well. So, the low moisture content biomasses are always preferred for efficient conversion into a derived product using thermal conversion processes. Similarly, for biochemical that is the fermentation process here.

High moisture content herbaceous plants such as sugarcane are more appropriate for the conversion of feedstock into ethanol using the fermentation technique. However, high moisture content herbaceous plant species can also be fermented via another method, which is also called as a fermentation method that is anaerobic digestion which produce methane as a main product.

So, these 2 conversion techniques can handle relatively high moisture content herbaceous plant as well while in the thermal conversion processes, it is more appropriate to use low moisture content feedstock.

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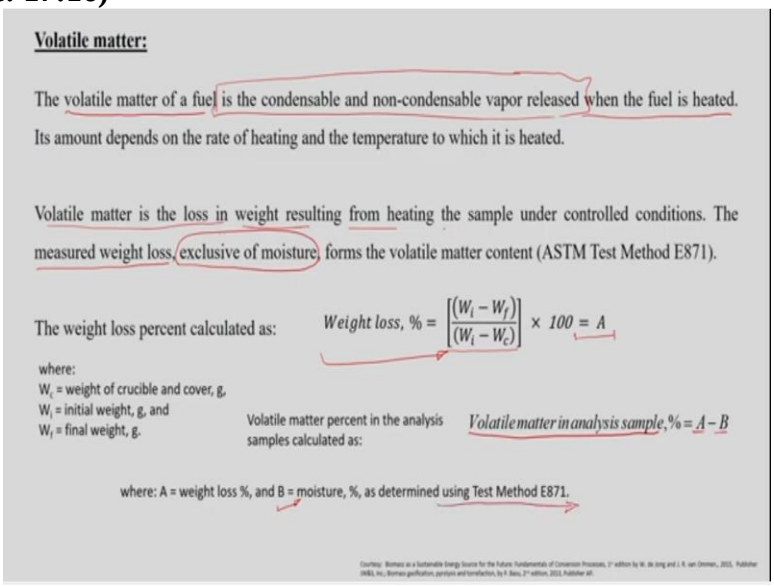

Similarly, the next topic in proximate analysis is volatile matter. Volatile matter of fuel is the condensable and non-condensable vapor released when the fuel is heated; its amount depends on the rate of heating and the temperature at which it is heated. So, this is very simple here the volatile matter is the condensable and non-condensable released vapor when the sample is heated.

Volatile matter is the loss in weight resulting from heating the sample under control condition and the major weight loss in this particular case, which is exclusive of moisture content forms the volatile matter of the sample. The percent weight loss in a sample can be calculated using this simple equation, which is the ratio of weight difference between the initial weight and the final weight by initial weight minus container weight, which is also we termed it here as A.

Because, when we have to estimate the volatile matter in the analysis sample, it is mainly different between the A and B, whereas A here is nothing but the weight loss percentage which is calculated using this equation, and here B is termed as the percent moisture content in the sample as determined according to this ASTM standard method, clear. So, different between these 2 gives us the volatile matter present in the sample.

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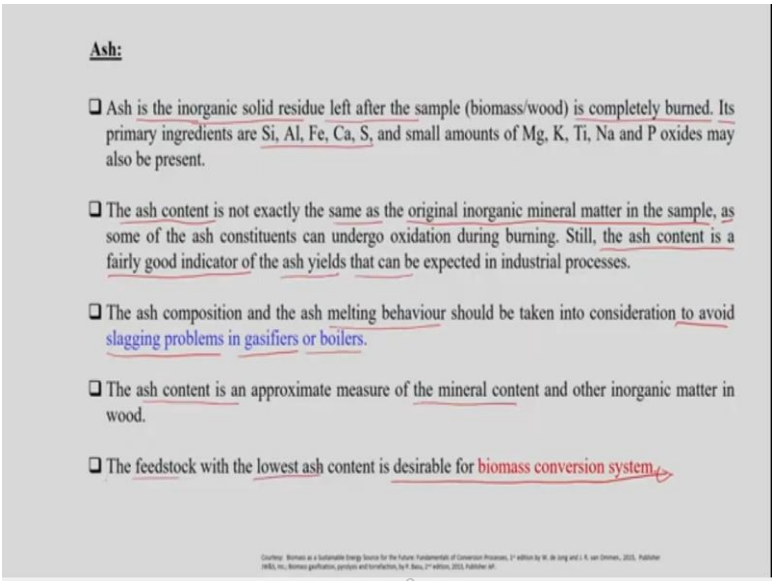

Similarly, the ash in the sample is also calculated using the standard ASTM method and ash is the inorganic solid residue left after the sample is completely burned. Its primary ingredients are as shown here. And it also includes a small amount of oxide, which may also be present in the ash when you try to burn the sample at relatively high temperature. The ash contained is not exactly the same as the original inorganic mineral matter in the sample.

Why because as some of the ash constituents can undergo oxidation during burning process, as a result, it may not represent exactly the original inorganic mineral matter present in the sample. Still the ash content is a fairly good indicator of the ash is that can be expected in any industrial processes. For example, if you see here, the ash composition and the ash melting behavior should also be taken into consideration to avoid slugging problem in gasifiers or boilers.

And that is what I mentioned in the previous slide as well, that the ash composition and ash melting behavior should be taken into consideration to avoid slagging problem in gasifiers or boilers. The third point is the ash content is an approximate measure of the mineral content and the inorganic matter present in the initial sample. The feedstock with low ash content is preferred for biomass conversion system.

So, this is another important point which needs to be noted the sample, whatever the sample which you are processing for the conversion system, it should have low ash content, either it can be a herbaceous plant, it can be a woody material, it can be a MSW, only concern here is, its ash contents should be low, so, that we can achieve a desirable conversion using the specific conversion system.

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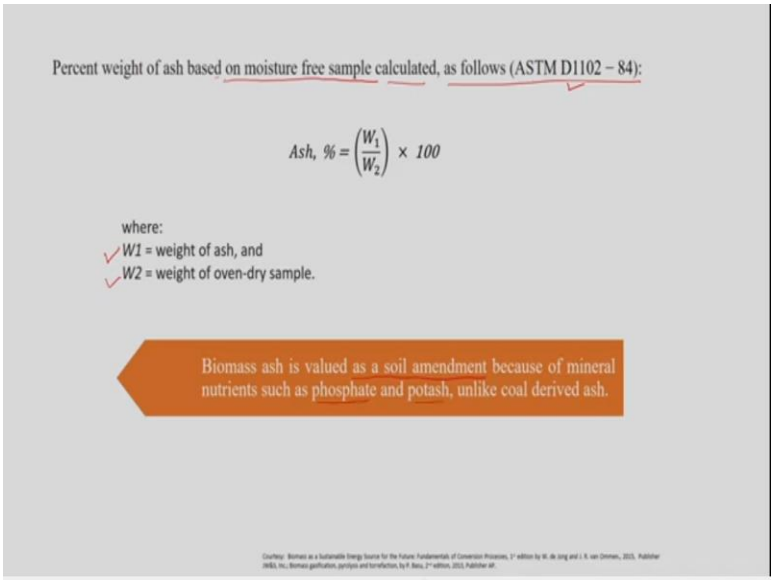

The percent weight of ash based on moisture free sample calculated according to the ASTM method mentioned here and it is simply a ratio of weight of ash by weight of oven-dry sample. Biomass ash is valued as a soil conditioner because mineral nutrients such as potash and phosphate are present in ash obtained from the biomass as a feedstock unlike coal derived ash, whereas, in the coal derived ash these nutrients may not be available in the sufficient amount.

Or it may not be available even in the coal derived ash. Hence, the biomass derived Ash is considered also as a soil conditioner. Now, let us discuss about another parameter which fix carbon content in the sample.

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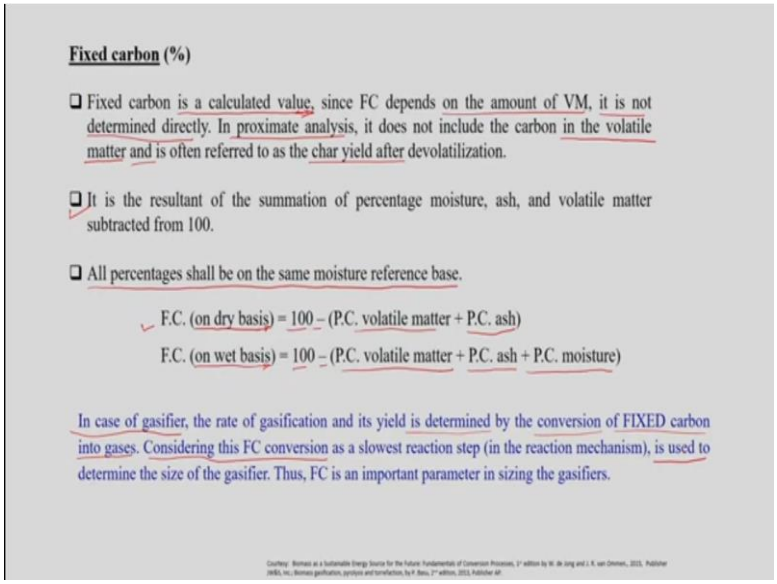

Fixed carbon is a calculated value, since fixed carbon depends on the amount of volatile matter in the sample and hence, it is not determined directly. In proximate analysis, it does not include the carbon in the volatile matter as I mentioned, and is often referred to as the char yield after devolatilization of the sample. It is resultant of the summation of percentage ash, percentage moisture, percentage volatile matter subtracted from 100.

So, it is very easy to estimate the fixed carbon content once we know the percentage moisture content in the sample, percentage ash content of the sample, and percentage volatile matter of the sample. So, all these percentages shall be on the same moisture reference basis, then it is very easy to calculate the fixed carbon content. So, as I mentioned here, the fixed carbon content on dry basis can be calculated.

As 100 minus summation of percentage volatile matter plus percentage as content of the sample, this gives us the fixed carbon content on dry basis. Similarly, the fixed carbon content on wet basis can also be calculated as 100 minus summation of volatile matter plus percentage ash plus percentage moisture content in the sample, which gives us the fixed carbon contained on wet basis. Hence in case of gasifier, the rate of gasification and its yield is determined by the conversion of fixed carbon into gases.

As a result, the fixed carbon conversion is considered as a slowest step in the reaction mechanism of the gasification process, which essentially used to determine the size of gasifier. Thus, fixed carbon content is considered as an important parameter in sizing the gasifier. This point is also very important, which needs to be noted here that the sizing of gasifier is mainly done considering the fixed carbon content of the sample.

And up till this point, if you see we discuss about the proximate analysis and how to do this proximate analysis using the ASTM method. In case suppose, these ASTM methods are not available to carry out the proximate analysis.

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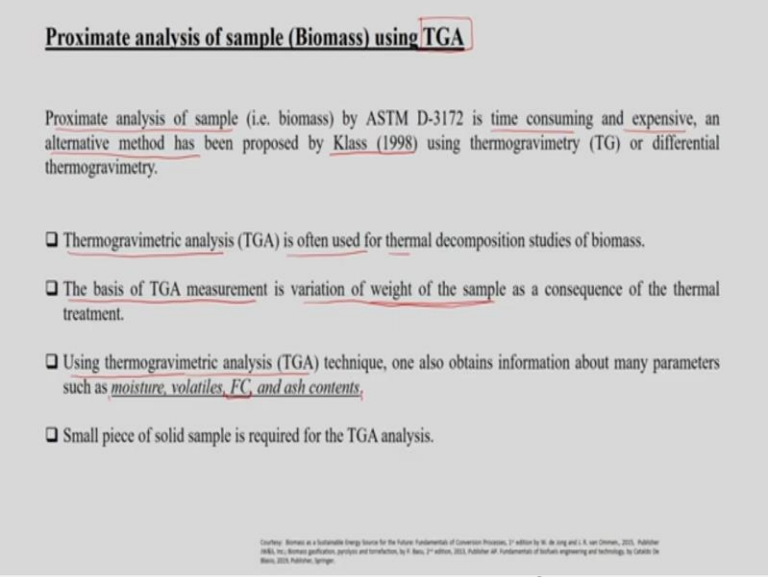

Then alternatively, proximate analysis can also be done using Thermo Gravimetry Analysis technique which is also commonly termed as TGA. Proximate analysis of a sample by ASTM method is time consuming first of all, and is an expensive also as a result, an alternative method has been proposed by Klass in 1998 using thermo gravimetry or differential thermo gravimetry technique, these are very simple technique.

By which one can also estimate the proximate analysis as well as we can also estimate the component of biomass from the specific analysis. For example, thermo gravimetric analysis is often used for the thermal decomposition studies of biomass sample and it is very widely used equipment nowadays to study the thermal decomposition of a biomass sample. So, while doing

the thermal decomposition of the biomass sample, we can easily estimate the properties in terms of proximate analysis.

And as well as we can also easily estimate the composition of biomass using this technique. The basis of TGA measurement is variation of weight of a sample as a consequence of a thermal treatment. So, this is a technique in which variation of the weight loss can be recorded as a consequence of the thermal treatment. using thermal gravimetric analysis technique, one also obtains information about many parameters such as moisture percentage, Ash percentage, volatile matter percentage and the fixed carbon content in the sample.

So, as I mentioned, this is a very good technique to estimate all these properties, which can be extremely estimated using the ASTM technique as well. Compared to the conventional technique, small piece of biomass sample is required for the TGA analysis. However, if you try to compare the amount of sample which is required, while doing the ASTM analysis is relatively high whereas, in case of TGA analysis, even small amount of sample is sufficient to perform the analysis.

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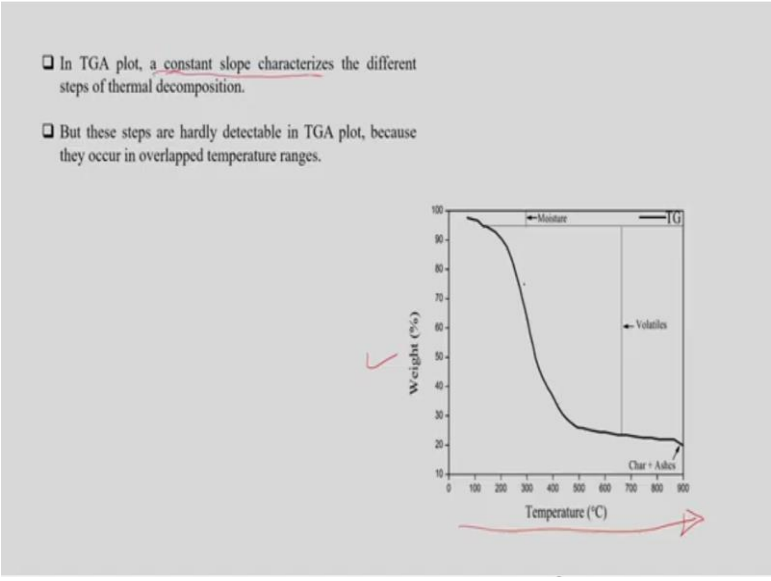

A TGA plot which is weight percentage with respect to temperature. If you see a TGA plot, a constant slope characterizes the different steps of thermal decomposition. However, from the TGA plot, it is very difficult to detect exactly the steps and how the decomposition is happening

in this particular range. Why because there is an overlap of temperature changes happening in the TGA plot hence it becomes very difficult to exactly find out the steps of decomposition and how it is happening in the TGA plot.

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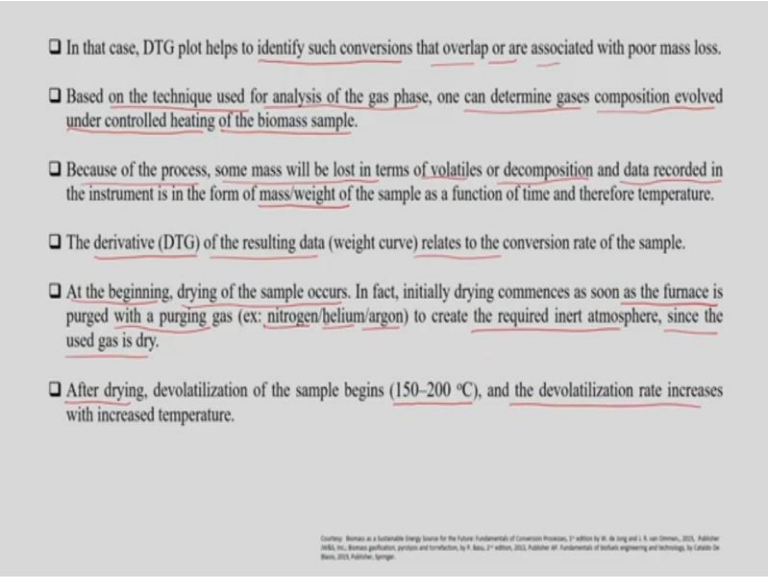

As a result, in that case DTG plot helps to identify such convergence that overlap or are associated with poor mass loss. So, DTG here is termed as Differential Thermal Gravimetry analysis, by which we can easily distinguish the steps of decomposition of the compounds in the sample very easily. Based on the technique use for analysis of a gas phase, one can also determine gas composition evolved under control heating of the biomass sample.

So, if the TGA is coupled with a gas chromatography equipment, so, one can easily find out the gaseous composition of the sample evolved, when the sample is heated under controlled heating rate, we can easily estimate the gas composition of that particular sample. Similarly, if we can couple this TGA with the FDIR, still you can easily estimate the gas composition of a specific sample using FDIR analysis as well.

So, that is the reason it is a very good technique to estimate the composition of gases as well as to estimate the approximate analysis of the sample. Because of the process, some mass will be lost in terms of volatiles or decomposition and the data recorded in the instrument is in the form of mass loss or we can say the weight loss of the sample as a function of time therefore, the

temperature. The DTG curve of the resulting data relates to the conversion rate of that specific sample.

As I mentioned, the DTG plot helps us to identify the number of steps and by which the conversion is happening in the sample. At the beginning of this particular analysis of sample in the TGA drying of the sample occurs, in fact, initially drying start as soon as the furnace is purged with the purging gases like nitrogen, helium or argon to create the required inert atmosphere since these are considered as dry gas.

So, once we start this analysis to initially, we purge the furnace with the inert gases, either it can be a nitrogen, helium or argon. So, that to create the required inert atmosphere in the furnace and hence, it gives us the dry condition in furnace. So, which also helped us to find out the moisture content in the sample, after drying and that is why we term it as a drying process, because then you can easily find out the moisture content in the sample during this process.

After drying devolatilization of the sample begins between 150 to 200 degrees C and the de volatilization, rate increases with increased temperature. So, if you just increase the temperature obviously, the devolatilization rate of the sample is increases. And hence, we can even the specific analysis in a faster rate.

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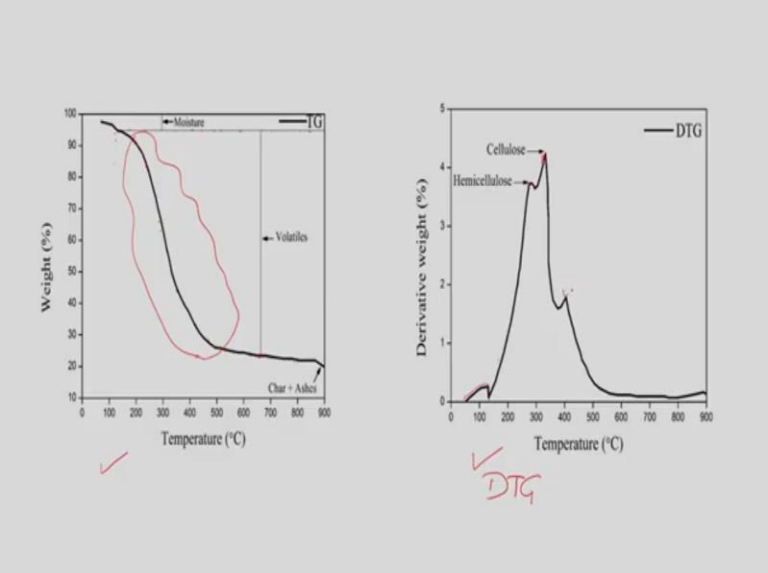

If you see here the 2 diagram which shows here the first is nothing but is a TGA plot and the second is nothing but here the DTG plot of the same data. Now, from the TGA plot if you see here, it becomes very difficult to identify the convergence step as here there is an overlap of temperature ranges happening hence it becomes very difficult to evident or to find out the number of steps by which the decomposition is happening in the process.

Similarly, if you see in the first stage itself here, have to say for example up to 120 degrees C; we can see that the moisture is getting removed from the sample. This particular weight loss is considered as the moisture percentage in the sample, softer moisture percentage as I mentioned devolatilization start between 150 to 200 degrees C. So, after this particular temperature, we can see that the devolatilization of the sample starts and it continues till up to even 500 degrees C.

Then after we can see there is a sharp decrease in the rate of devolatilization. And once you see here that it is almost or close to a constant, then up to that point we can consider that the weight loss is nothing but equal to the volatile matter present in the sample. And at the end, the char and inorganic matter which is present in the pan can be used to quantify the char content as well as the ash content of the sample that we will discuss in the subsequent slide.

So, based on this TGA plot, if you try to convert the data into a DTG form that is nothing but the differential thermal gravimetric form. So, you can see here this particular peak, again it represents the first stage where the moisture has been removed from the sample and when the devolatilization begins, you can see here it gives some separate peaks which appears in the graph. Similarly, you can see another peak here. So, this peak clearly distinguishes and clearly shows how the decomposition of the compound is happening in the sample, by which we can also estimate its percentage very easily.

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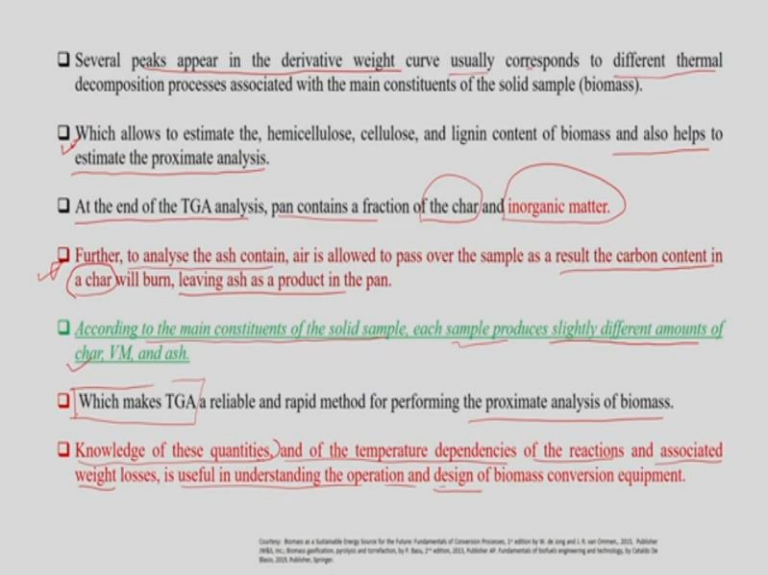

As I mentioned, several peaks appear in the derivative it curves usually corresponds to different thermal decomposition processes associated with the main constituents of the biomass sample. So, which also allows us to estimate the hemicellulose content, cellulose content and the lignin content of specific biomass sample and also helps to estimate the proximate analysis, that is what I mentioned, once the char and the inorganic matter is left in the pan, we can also estimate the remaining parameter very easily using this technique.

So, at the end of the TGA analysis pan contains a fraction of the char and inorganic matter. Further if we need to estimate the char and ash content of the sample to analyze that as contained air is allowed to flow over the sample as a result, what happens is the carbon in the sample that is nothing but a char will burn leaving ash as a product in the pan. So, basically now, we got 2 parameters here, 1 is char and another is ash content of the sample.

According to the main constituents of the solid sample, each sample produces slightly different amount of char volatile matter and ash. And this is obvious, as we already discussed this point several times, that the composition of the biomass varies from biomass to biomass as a result, we can also experience slight difference in the amount of ash volatile matter and the char content of the sample.

Which altogether makes TGA reliable and rapid method performing the proximate analysis of biomass sample. Knowledge of these quantities and of the temperature dependency of the reaction and associated weight loss is useful in understanding the operation as well as design of biomass conversion equipment. So, all this analysis can be done in a single equipment and the knowledge of these quantities along with the temperature dependencies of the reaction helped us to find out the exact design of a biomass conversion equipment.

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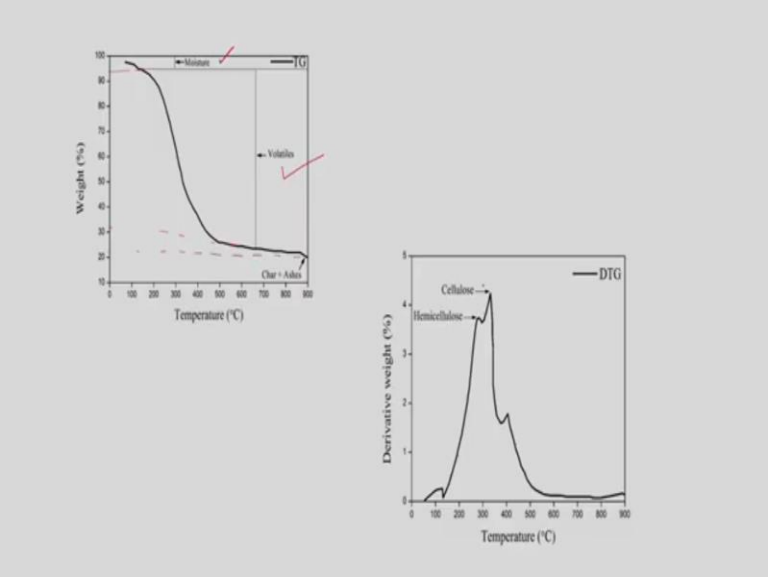

So, as I shown here again in the same graph, you can easily estimate the moisture content in the sample. Similarly, we can estimate the volatile matter present in the sample because these particular weight differences give us the sample. And from the remaining fraction, we can estimate the char and the ash containing the sample. The DTG curve easily gives us the understanding of the hemicellulose content, the cellulose content and the lignin content in the sample.

Because these compounds are getting decomposed in a specific temperature zone, or you can say specific temperature range. There might be a small overlap between the 2 compounds, but you can easily distinguish it using the DTG curve. So, it also gives us the composition analysis of the biomass. And that is the reason this is one of the most preferred technique nowadays, to carry out the proximate analysis as well as the compositional analysis of a biomass sample. So, today, we will just end our lecture here.

In the next lecture, we will discuss about some remaining properties of biomass as well as structural component of biomass. For any queries related to this lecture, feel free to contact me at vvgoud@iitg.ac.in. Thank you.