Renewable Energy Engineering: Solar, Wind and Biomass Energy Systems
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Lecture - 28
Gasification Process

Good morning everyone, welcome to part 2 of lecture 2 under module 8. In the previous lecture, in that we initiated our discussion on the torrefaction and combustion processes. So, in this lecture, we will continue our discussion in a similar line. So, we discuss another thermo-chemical conversion process here that is gasification. So, the content of this particular modular thermo-chemical conversion of biomass that is a gasification process.

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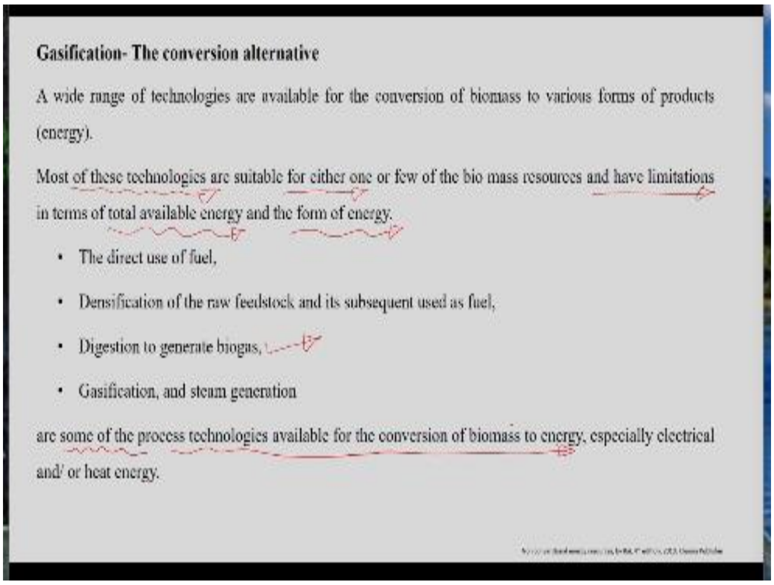

So, as discussed earlier a wide range of technological options are available for the conversion of biomass to a suitable kind of product for example, the energy. So, most of these technologies are suitable for either 1 or few biomass resources and have limitation in terms of total available energy and the form of energy. Like, if you consider the example of use of firewood as a direct fuel for production of the heat.

Whereas, in case if the firewood can be converted into a denser pellet and can subsequently be utilized as a fuel for heating purpose can give more energy efficiency rather than utilizing the firewood as such, because the firewood has high moisture content. Whereas the denser pellet has relatively low moisture content in the range of around like 4 to 5% only. As a result, the energy efficiency of utilization of the denser pellet will be relatively high compared to that of utilizing firewood as such for the heating purposes.

So, apart from that, if the material can be stirred into slurry and then digested to yield biogas as a product. So, this is also one of the technological options which is available for the biodegradation of the raw material to produce the gas. Or alternatively, the feed material can be gasified using a thermo-chemical conversion technique that is a gasification or it may be incinerated to produce the heat and produce heat can be used for the steam generation.

So, these are some processes, which are available for the conversion of biomass to energy, especially, electrical energy or the heat energy. So, we already discussed about these techniques in the earlier lecture. However, in this lecture, the main focus is on the gaseous fuel from the biomass. So, there are 2 most widely used technologies are available for the conversion of biomass to a gaseous fuel that is a biochemical method and thermo-chemical method.

To biochemical method involve the anaerobic digestion of the material to produce the biogas as a product. Whereas, the thermo-chemical method, it involves the gasification of the material in a gasifier to produce syngas as a product.

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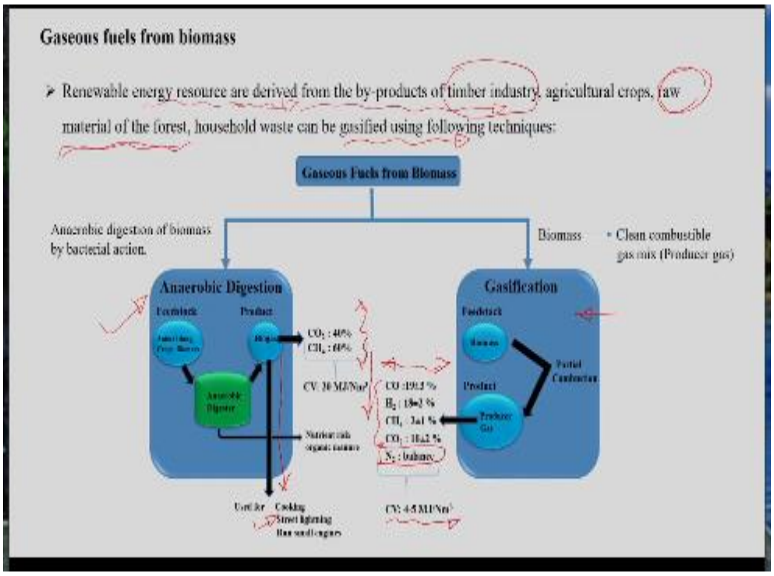

From the competitive analysis of these 2 techniques that is a biochemical method and a thermo-chemical method, it appears that the renewable energy resources like derived from the by-products of timber industry, agriculture residues, raw materials of the forest, household waste can be gasified using following techniques that is a biochemical method and thermo-chemical method.

So, if you look at the anaerobic digestion process, as we discussed earlier about this particular technology as well, because of the heterogeneous nature of the feedstock material, this particular materials first need to be converted into a slurry and then it will be digested in the digester to produce the gas. And the gas obtained from the gasifier is mainly consist of the CO 2 and the CH 4 in its composition along with the traces of other gases, it also contains the H 2 S as a gas.

And the calorific value of the gas produced from the anaerobic digester is around 20 mega joule per meter cube. And the gas produced from the gasifier can be used for the cooking purpose as well as for street lighting purpose, but for engine application, further processing is required. Whereas in case of thermo-chemical conversion process, so, the feedstock material is thermo-chemically converted into a gasified product that is called as a syngas.

And the main constituents of the seam gas are CO, H 2, CH 4 and CO 2 and the balance is nitrogen. And the gas produced from the thermo-chemical conversion processes has the heating value of around 4 to 5 mega joule per meter cube and the produce gas is relatively clean gas can be used for the burning purpose. So, for IC engine use, further processing is required for this kind of gas as well.

So, based on these 2 particular technology, it appears that still the gasification is the best suitable alternative for the conversion of biomass to a gaseous fuel because of its following importance.

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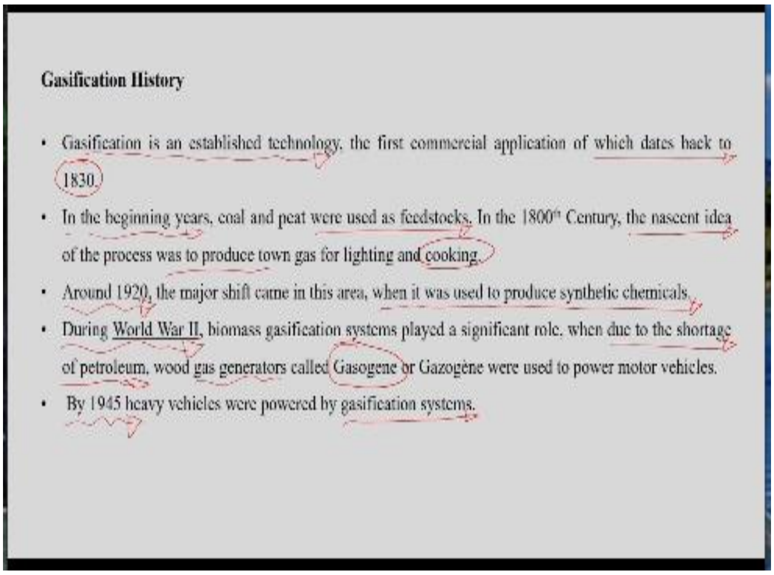

The gasification, it offers high flexibility in terms of various biomass material as the feedstock. So, in case of gasification, it is not limited to any specific kind of feedstock, the material which contain high moisture can also be utilized for the gasification purpose in the thermo-chemical gasification process. Apart from that the MSW can also be gasified to produce the seniors.

So, this is what is the meaning of this sentence here that it offers a high flexibility in terms of various biomass materials as the feedstock. And the second important point about this technology is the thermo-chemical conversion efficiency of a gasification, it is in the range of 70 to 90% and which is highest among various alternative technologies, which are discussed in this lecture as well as in the previous lecture.

And the output capacity of this particular process, it especially in the high output range. It is controlled by the availability of the adequate feed materials rather than other technical consideration. Apart from that, the output obtained from the gasifiers are suitable as a fuel to all types of internal combustion engine with capacity derating in the range of around like 15 to 30%.

So, because of these advantages, this is considered as the best suitable technology among the available technology for the conversion of raw material to a gaseous product. If you just look at the history of gasification process, so, the gasification is a well established technology and the first commercial application of which dates back to year 1830. So, this is a very well established technology and it is being used for the production of the seam gas from date back to even 1830.

And in the beginning years, the coal and the peat were used as a feedstock material. In the 18th century, the nascent idea of the process was to produce down gas for the lighting and the cooking purpose. Around 1920, the major shift came in this area where it was used to produce synthetic material. And this is what is the main shift happen in this particular technology, where the producing gas was used to produce the synthetic chemical as well.

And during World War 2, the biomass gasification system, it played an important role and when due to shortage of petroleum feedstock, the wood gas generator called gasogeneous were used to power the motor vehicle. And even by a 1945, heavy vehicles were powered by the gasification system. So, if you see the development happened in the gasification technology, so, it is evident from this particular slide that how the technological development happens in the gasification process.

And hence, because of this advantages and technological importance of this process, it is widely being used for the production of the gas from the solid material. So, these are talks about the history of the gasification and how this particular technology is evolved for the production of the syngas from the waste material.

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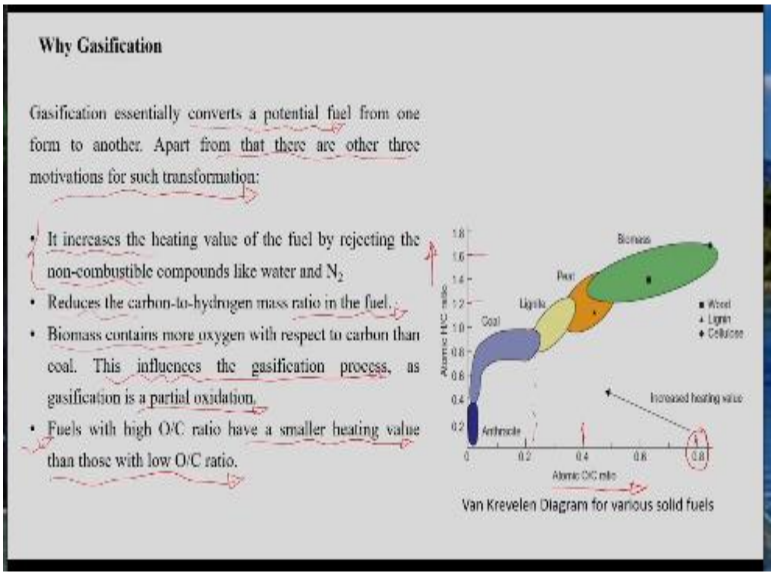

Now, apart from the advantages which are discussed in the previous slide, the gasification is essentially converts the potential fuel from one form to the another. And apart from that, there are other 3 motivation for such transformation of waste material to a high value or high quality product. So, the first is, it increases the heating value of the fuel by rejecting the non-combustible compound in the form of water and nitrogen.

So, this is what is the advantage of this particular technology where the low quality materials can be converted into a high quality fuel. So, it reduces the carbon to hydrogen ratio in the final product as well. And the biomass, it contains more oxygen with respect to carbon than coal. And this influences the gasification process as the gasification is a partial oxidation process. Hence, the oxygen which is required for the process can be supplied by the oxygen containing material itself.

Apart from that, the fuel with high oxygen to carbon ratio have a smaller heating value. And then those with the low oxygen to carbon ratio which can be seen from the graph, which is shown here. If you look at this particular graph, this indicates the oxygen to carbon ratio whereas, the y axis, it indicates the hydrogen to carbon ratio. So, in this case, the biomass has oxygen to carbon ratio, it varies from even like 0.4 to 0.8. So, it has a vast range of oxygen to carbon ratio.

And if you talk about even the hydrogen to carbon ratio, it is relatively high in case of biomass as a material. Whereas, in case of coal, if you see here, so, coal has relatively low oxygen to carbon ratio whereas, low hydrogen to carbon ratio, thus the material which contain higher oxygen to carbon ratio, which has a relatively smaller heating value can be converted into a high density material by converting this particular material using a thermo-chemical conversion process that is a gasification.

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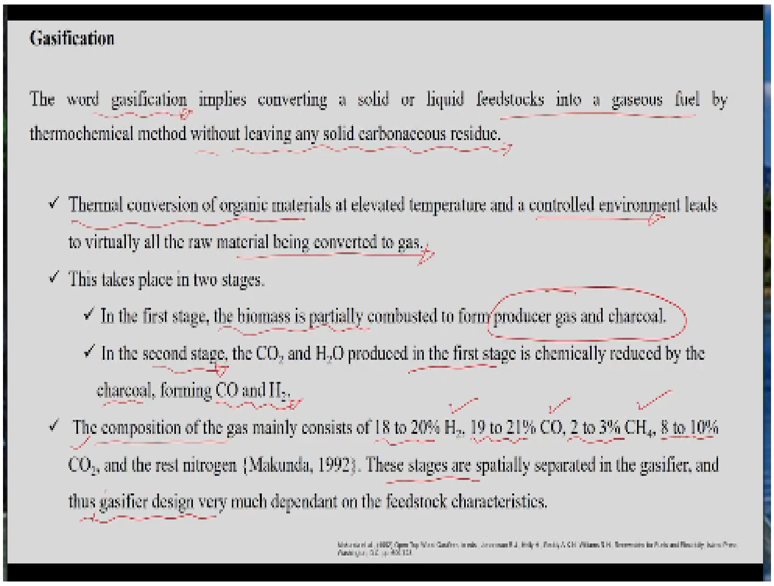

So, let us discuss about this gasification technology in more detail. So, what is gasification? The word gasification, it implies converting a solid or liquid feedstock into gaseous fuel by thermo-chemical method without leaving any solid carbonaceous residue inside the reactor. And the thermal conversion of organic material at elevated temperature and control environment, it leads to virtually all the raw material being converted to gas.

And this particular process, it takes place in 2 stages. So, in the first stage, what happens is the biomass is partially combusted to form the producer gas and charcoal and this is called as a primary zone. Whereas, in the second stage, the CO 2 and H 2 O produce in the first stage is chemically reduced by the charcoal forming CO and H 2. And the CO and H 2 is the major constituents of the gas producing the gasifier.

The composition of the gas, it mainly consists of 18 to 20% hydrogen, 19 to 21% carbon monoxide, 2 to 3% is methane and 8 to 10% is CO 2 and the rest is nitrogen. These stages are specially separated in the gasifier and thus, gasifier design is very much dependent on the feedstock characteristics. What kind of feedstock is being used for the gasification purpose? Based on that, the gasifier need to be designed to achieve a high process efficiency.

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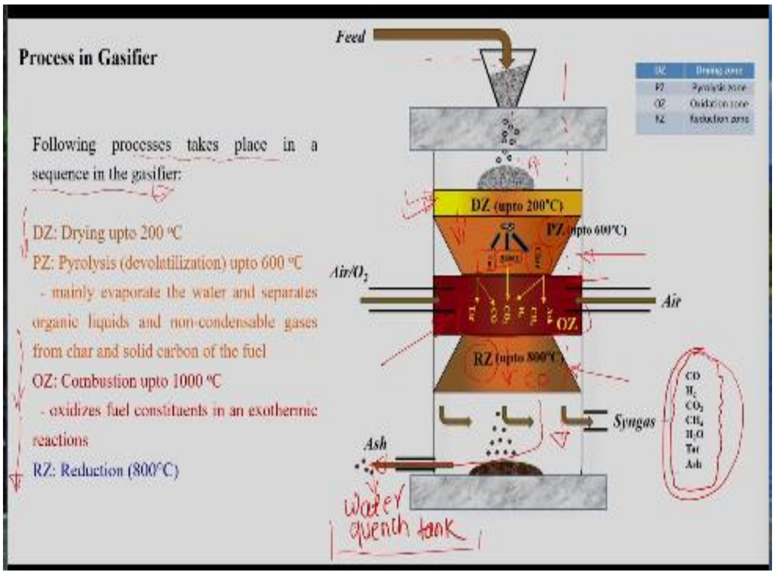

After understanding the gasification, let us see how the process of gasification it takes place in the gasifier. So, if you see this particular schematic here, the gasifier is divided into 4 zones that is dry zone, pyrolysis zone, this is the oxidation zone and this is the reduction zone. So, the producer gas in the gasifier is formed by partial combustion of the solid biomass in a vertical flow back bed.

So, this is a vertical flow back bed reactor. In the conditional producer gas theory, following processes takes place in sequence in the gasifier that is drying zone then followed by the pyrolysis zone, where the material is get pyrolysed inside the gasifier and then the produce material is oxidized in the oxidation zone followed by the reduction of the produce material in the reduction zone.

So, that is why as mentioned the gasifier is sequentially divided in the 4 zone in the gasifier. So, if you see in this particular process, the function of the drying zone in the gasifier is to remove the moisture from the incoming feed material. So, if you see here, this is the biomass, which is fed inside the gasifier and the function of this drying zone here is to remove the moisture from the incoming feed material, below the dry zone is the pyrolysis zone, where the draft feedstock material is converted into a residual carbon as a char.

So, if you see here, this is a residual carbon as a char, which is getting converted into a pyrolysis zone, followed by it also produces some combustible gases along with the tar as the product. So, the heat for the pyrolysis and the drying zone is supplied by the partial combustion of this product in the oxidation zone. So, in the oxygen zone, the oxygen in the air as well as in the steam, it reduces the carbon which is coming from the pyrolysis zone to hydrogen and carbon monoxide.

And the CO 2 form in the oxidation zone, it gets reduced to carbon monoxide in the reduction zone. Therefore, the final composition of the producer gas, it mainly depends on the water gas shift reaction, which approaches the chemical equilibrium corresponding to the exit gas temperature. And because of that, this particular composition of the producer gas, it also varies in the gasifier.

Apart from that if you see in this case, the heat of combustion in the oxidation zone, it also transforms to a non-combustible material and it gets converted into molten slag. The molten slag along with the ash is drained out continuously from the seals slack tap into the water quench water quench tank. So, as a result, the all the ash along with this particular slag is drained out continuously from this particular aid, which is called as a seal slag tap. So, this is how the gasification takes place in the gasifier.

So, now, as we discussed the gasification of the biomass is a very complex process. And it mainly consists of consecutive heterogeneous and homogeneous reaction. So, if we look at the type of reaction, which are taking place in the gasifier.

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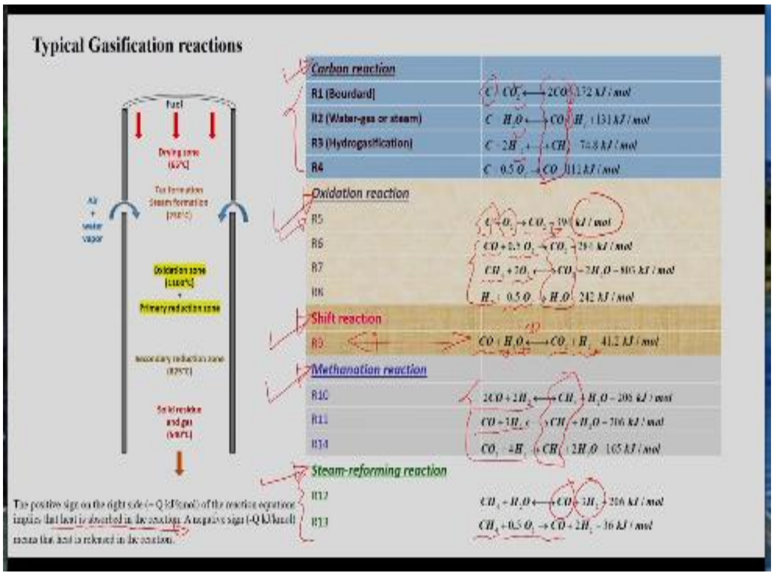

If you see here, the first is carbon reaction, followed by the oxidation reaction and then shift reaction, methanation reaction and steam reforming reaction, where the entire methane is getting converted into CO and the H 2. So, if you see in this case, the first 4 reactions are mainly the heterogeneous reaction, where the carbon in the char is getting reacted with the gases like CO_2, H_2O, hydrogen and the oxygen and producing these gas composition.

So, in oxidation reaction, the first reaction also is a heterogeneous reaction, where the carbon in the char is getting oxidized with the oxygen in the air or the steam to produce CO_2 as a gas. And all the remaining reactions are in the gaseous phase that is what is called as a homogeneous gas phase reaction, because here the C O gas is reacting with the oxygen.

Here, the methane is reacting with oxygen and hydrogen is reacting with oxygen and producing corresponding gases as the product in the oxidation reaction, followed by the shoot reaction. Here also the carbon monoxide is reacting with the water which is in the gas phase producing CO_2 and hydrogen as a gas. So, that is why this is also homogeneous reaction in the gasifier, followed by the methanation reaction, where the methane formation is taking place by the reaction of CO with the hydrogen.

And forming methane is the product, followed by the steam reforming reaction, where these methane which are formed in the methanation reactions are getting converted into a CO and the H_2. These are talks about the conjugative heterogeneous and homogeneous reaction, which are taking place in a gassy fire. Here, in this case, the plus Q, it represents the amount of heat absorb in the reaction.

So, if you see here, where in all these reactions, the plus Q, it represents the amount of heat absorbed during the reaction. Whereas, the minus Q, it represents the amount of heat which is released during the reaction. Now, after understanding the process of gasification as well as understanding the reaction which are taking place in the gasifier, let us try to understand the equivalence ratio and its importance in the gasifier

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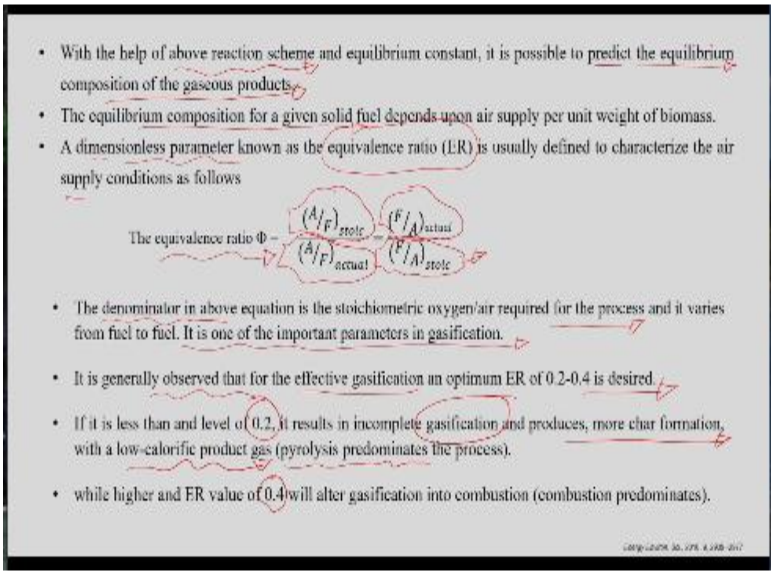

With the help of the above reaction scheme and the equilibrium constant, it is possible to predict the equilibrium composition of the gaseous product in the gasifier and the equilibrium composition for a given solid fuel. It depends on the air supply per unit weight of the biomass of the feedstock fed into the gasifier. And the dimensionless parameter, which is known as a equivalence ratio is usually defined to characterize the air supply condition as follows.

So, this is the concept which are already discussed in the previous lecture that is in the combustion, the same concept, we will be discussing here again. So, the equivalence ratio as we know, it is the ratio of air to fuel ratio, which is in the stoichiometric amount to the air to fuel ratio, which is actually required for the gasification reaction to takes place in the gasifier. Because the stoichiometric amount is nothing but the exact amount of oxygen which is required for the solid material to get gasified.

Whereas in the practical, it may not be so, and hence, excess air or the oxygen need to be supplied. So, that the complete oxidation of the material will take place in the gasifier and will achieve a high process efficiency. So, if you just rearrange these steps here, you will get fit to air ratio which is actual, divided by fit to air ratio in the stoichiometric amount.

And the denominator in the above equation, this particular term here in the equation, it represents the stoichiometric quantity of oxygen or the air is required for the process and it varies from fuel to fuel. It is one of the important parameter in the gasification process. As I mentioned, because of the diverse composition of the biomass, the air to fuel ratio in the gasifier also varies, it all depends on the fuel to fuel basis.

It is generally observed that for the effective gasification and optimum equivalent ratio of around 0.2 to 0.4 is desired. If it is less than or equal to 0.2, so, in that case, it results in incomplete gasification, because of insufficient supply of oxygen in the gasifier. As a result, the incomplete gasification will take place in the gasifier. And then it produces more char and low calorific value product gas.

And it is termed as a pyrolysis dominant process. Because in this case, because of partial supply of oxygen and that too is a incomplete gasification process. So, the pyrolysis will dominate the entire process. If the value of this equivalent ratio is higher that is 0.4 or higher than 0.4 or equal to 0.4, then in that case, it will alter the gasification into the combustion. And the predominant process in this case is a combustion process, because of increasing the oxygen supply in the gasifier.

So, what happens is like, the complete oxidation will take place and because of the excess supply of the oxygen in the gasifier. There will be a combustion which will be happening with the feedstock material. So, rather than producing the producer gas, it will produce the flue gas as the product. So, this is all about the equivalence ratio and how it is important in the gasifier.

So, once you understand the process of gasification as well as the importance of the equivalence ratio in the gasifier, so, next point is like, how to classify the gasifier?

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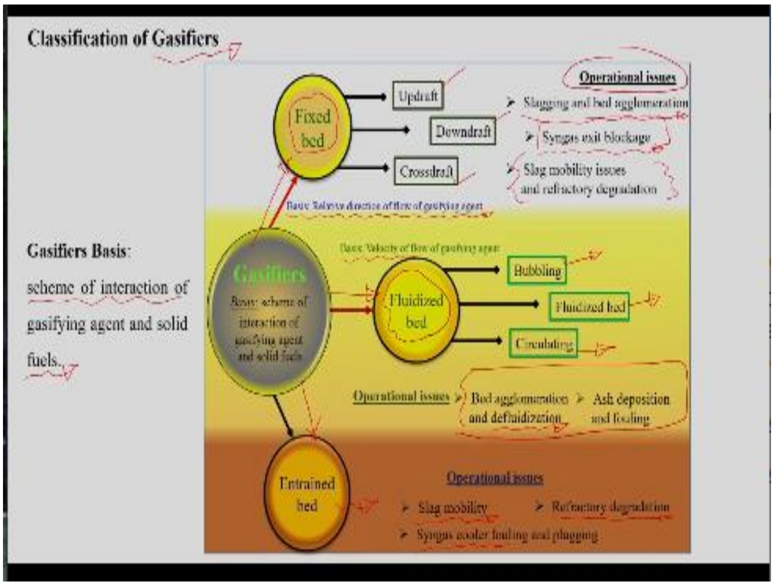

So, the gasifiers are classified based on the scheme of interaction of gasifying agent and the solid fuel. The gasifiers are classified as the fixed bed gasifier, fluidized bed gasifier and then entrained bed gasifier based on the scheme of interaction of the gasifying agent and the solid fuel. So, if you first talk about, the fixed bed gasifier the fixed bed gasifiers are further sub-classified as up draft gasifier, down draft gasifier and the cross draft gasifier.

And the basis of classification is direction of the flow of the gasifying agent in the gasifier. But the issues involved, in this particular gasifier are the slagging and the bed agglomeration. This is one issue in the fixed bed gasifier. Syngas exit blockage is another issue in the fixed bed gasifier. And the slag mobility followed by the refractory degradation is another issue in the fixed bed gasifier.

As we mentioned in the earlier slide that the heat of combustion in the oxidation zone, it transforms to the non-combustible material in the gasifier, which results in the formation of the molten slag. And the molten slag, which produced in the gasifier, it often blogs the path of the producer gas in the gasifier as well as the mobility of the slag is an issue. Apart from that, it also degrades the refractory in the gasifier.

So, the another class of gasifier is a fluidized bed gasifier and the fluidized bed gasifier further sub-classified into a bubbling fluidized bed gasifier. This is a fluidized bed gasifier and circulating fluidized bed gasifier. Even in this case, the basis of classification is velocity of flow of the gasifying agent and operational issue involved in the fluidized bed gasifiers or bed agglomeration and the defluidized of the material and ash deposition and the fouling. So these are the operational issue in the fluidized bed gasifier.

And the last classification is entrained bed gasifier and the operational issue involved in the entrained gasifier is slag mobility, again, the same issue of that of the fixed bed gasifier. The refractory degradation in the gasifier and syngas cooler fouling and plugging. So, these are the operational issue in the entrained bed gasifier. After understanding the classification of the gasifier, now, let us discuss about this gasifier in detail.

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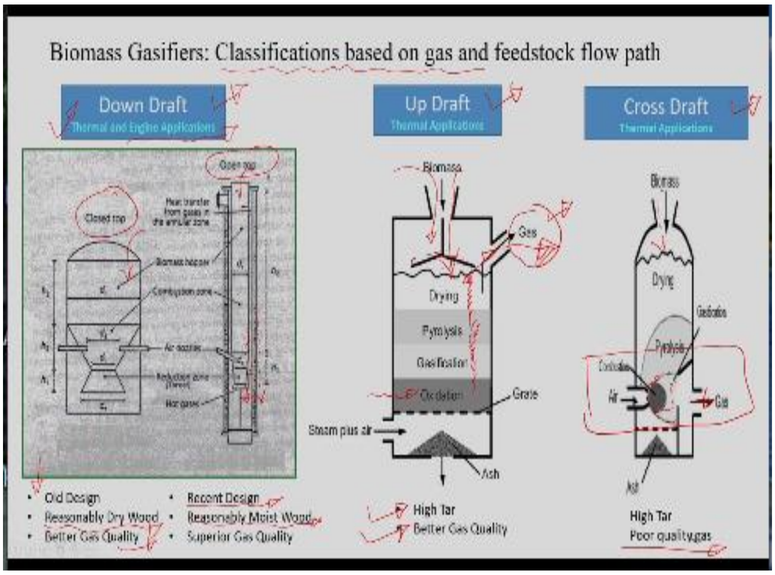

So, first is fixed bed gasifier. So, the fixed bed gasifier here is classified based on the flow of the gasifying medium inside the gasifier. And it is sub-classified as down draft gasifier, up draft gasifier and the cross draft gasifier. So, in the up draft gasifier, it is further subdivided into a closed stop gasifier and open top gasifier. So, in this case, the biomass is fed from the top and the produce gas is forced to pass through in high temperature zone where the on bed pyrolysis material can be cracked to produce the gaseous hydrocarbon as the fuel.

And mostly a clean gas is obtained from the down draft gasifier and it finds its use in thermal and the engine application, but there are sudden issues also with the open and the close top gasifier. So, in case of the close top, this is relatively old design, whereas open top is a reset designed for the gasification of the biomass material. Similarly, reasonably dry wood is required in case of the close top gassifier, whereas in case of the open top, reasonably moist wood is also sufficient.

So, in case of the open top, even the reasonably moist wood can be gasified to produce the gas. Better quality of the gas can be achieved in the close top. Whereas, in case of the open top, superior quality gas can be achieved, as I mentioned, because the gas is forced to pass through this high temperature zone here. And as a result, the unburned pyrolysis material undergoes the cracking to produce the gaseous hydrocarbon as a fuel.

So, as a result, this particular material well passing through the gasification chamber, it also get clean and then produce more or less a clean gas from this kind of gasifier. Similarly, if we just talk about the up draft gasifier, so, in case of up draft gasifier, the biomass is also fed from the top and the product gas is drawn off from the top of the gasifier as well.

So, as a result in this case, because of the movement of the gas from high temperature zone to a low temperature zone along with that, it also carries significant amount of the tar and the moisture because of the passing of the gas from the high temperature zone to the low temperature zone. Where the outgoing gas, it also carries away the tar and the moisture present in the feed material and relatively low temperature gas is obtained in the up draft gasifier.

But, the issue with this particular gasifier is, it produce high tar, as I mentioned, because it carried away the tar in the incoming material. Along with that, even the moisture content in the producer gas is relatively high, although better quality of the gas can be also obtained from the up draft gasifier. And if you look at the cross draft gasifier in case of cross draft gasifier, the biomass is also fed from the top here.

Whereas in case of the cross draft gasifier, the oxidation of the feed material it takes place just opposite to the exit of the producer gas. As a result, because of the short path of the producer gas inside the gasifier, it produces a poor quality gas and even high tar quality gas also, it is produced in case of cross draft gasifier. As a result, this kind of gasifiers are not in common use.

Now, once you understand the mechanism as well as the process of the down draft, up draft, and cross draft gasifier, let us, discuss about this gasifier in more detail.

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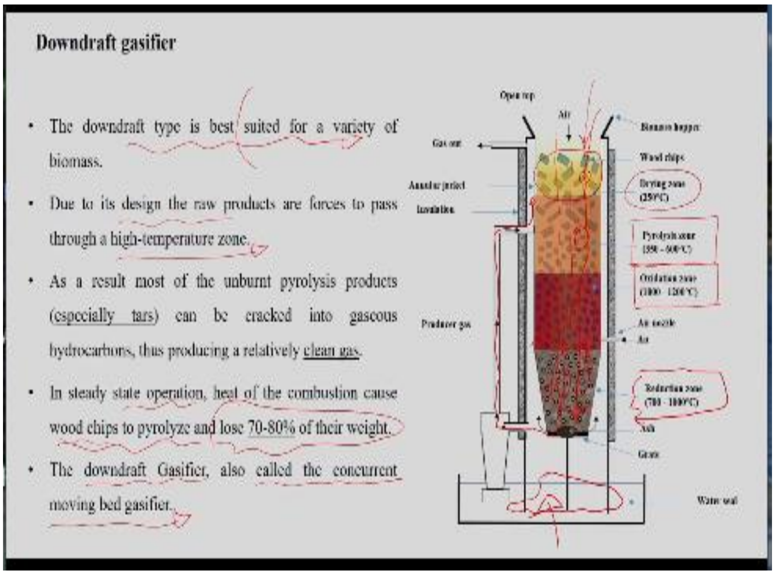

So, first is the down draft gasifier. So, if you see here, this is the schematic of the down draft gasifier where the biomass is fed inside the gasifier from the top. And if you see here, this particular gasifier is divided into 4 zones that is the drying zone, pyrolysis zone, this is the oxidation zone and reduction zone. So, as I said, the gas produced in this particular gasifier is forced to pass through the high temperature zone.

And then as a result, the unburned pyrolysis products are cracked in this particular zone here to produce gaseous hydrocarbon as a fuel. So, in this case, the temperature in the drying zone is around 350 degrees C, whereas, the temperature in the pyrolysis zone if you see here, it is in the range of 350 to 600 degrees C. And in the oxidation zone, it reaches to around 1000 to 1200 degrees C where the oxidation of the pyrolysis product is taking place to form the CO hydrogen and CO 2 as a product.

The CO 2 which is produced in this particular oxidation zone is further reduced to carbon monoxide in the reduction zone where the temperature is in the range of 700 to 1000 degrees C. So, if you see the operation of this particular gasifier here, so, exit gas from the gasifier is allowed to pass through the annular jacket. So, that the efficient transfer of the heat will take place to the gasifier and heat will also be transferred to the incoming solid material.

As a result, the drying of the solid material will take place in the gasifier so, that to achieve high thermal efficiency. So, the down draft gasifier is best suited for varieties of the feedstock material ranging from MSW to high moisture containing material as well. So, dry wood materials can also be gasifier in the down draft gasifier. Due to this design, the raw products are forced to pass through the high temperature zone. As I discussed, all the product gas are forced to pass through the high temperature zones.

If you see here, these are the high temperature zone and all the product gases has to pass through this high temperature zone. So, as a result, what happens is like in this case, the unburned pyrolysis products are getting cracked in this particular zone to produce a relatively clean gas with a more hydrocarbon content. And that is what is the advantage of the down draft gasifier.

So, in the steady state operation, the heat of combustion caused would shift to pyrolysis and lose around 70 to 80% of their weight. The product of the pyrolysis chamber which is mainly consist of the CO, hydrogen, CO 2 and fraction of the methane, it gets oxidized in the oxidation zone here to produce mainly CO and hydrogen as a product. And the CO 2 produced in the oxidation zone, it gets reduced in the reduction zone to produce carbon monoxide.

As a result, it produces relatively clean gas in the down draft gasifier. The down draft gasifier also called the concurrent moving bed gasifier. And the ash as soon as the slag material, which is produced during the gasification process is collected in the water quenching tank here. This is a water quenching tank. So, after understanding the down draft gasifier, let us discuss the importance of the up draft gasifier as well.

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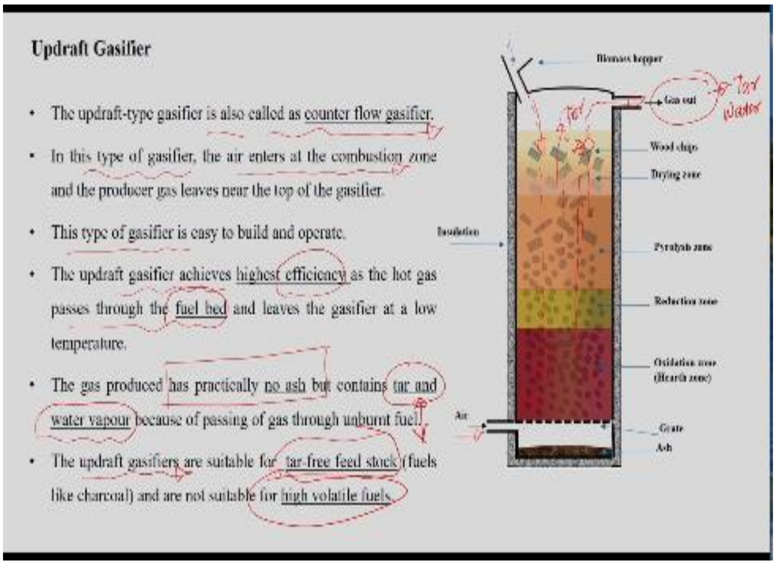

So, the up draft gasifier is also called as a counter flow gasifier. Because in this case, the biomass is also fed from the top and the producer gas is drawn off from the top of the gasifier here. So, in this type of gasifier, the air enters at the combustion zone. So, this is the entry of the air in the combustion zone here and produce gas leaves from the top of the gasifier as shown here.

So, the produce gases coming out from the top of the gasifier here and this type of gasifier is easy to build and operate. The up draft gasifier, it achieves higher process efficiency as the hot gas pass through the fuel bed and it leaves at relatively low temperature from the gassy bar. As a result, the gas produced from the gasifier practically has no ash, but it contains tar and water vapor because of passing of gas through the unburned fuel.

Because when this gas is passing through the unburned fuel, so, along with the gas, it also takes away the tar and water vapor, which are or you can say the moisture present in the unburned fuel. As a result, it contains more tar and water vapor in the exit gas. The up draft gasifier are suitable for tar free feedstock material and are not suitable for highly volatile material, because the gas is allowed to pass through the top of the gasifier.

So, the incoming feed material, if it contains the high volatile material, so, most of the volatile materials will be lost in the exit gas and will not take part in the reaction. That is why these kind of gasifier are not suitable for the high volatile material. So, after understanding the up draft gasifier now, let us discuss about the cross draft gasifier and how the operation of the cross draft gasifier takes place.

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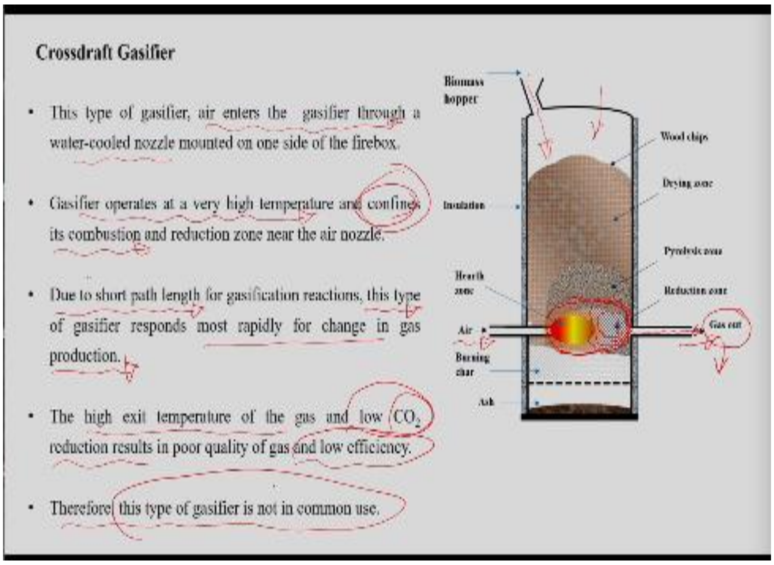

So, this is a schematic of the cross draft gasifier. In this case, as the biomass is allowed to enter inside the gasifier from the top and this is the air inlet to the gasifier and this particular portion is the gas outlet from the gasifier. So, in case of cross draft gasifier, air enters the gasifier through a water cooled nozzle, which is mounted on one side of the firebox. So, the gasifier which is operating at a higher temperature, it confines its oxidation and reduction zone, just next to the air nozzle.

And due to a short path length for the gasification reaction, these type of gasifier respond most rapidly for changing the gas production, because there is hardly any residence time for the produce gas in the gasifier. As a result, because of the short path lane of the gasification reaction, this type of gasifier response most rapidly for change in the gas production. Because there is no sufficient time for the gas to remain inside the gasifier.

After oxidation, it will undergo a reduction reaction here and immediately the gas will be exit out from the gasifier. The high exit temperature of the gas and low CO 2 reduction, it results in poor quality gas and low efficiency as well. Because the gas produced from this particular gasifier will have relatively high temperature and it will not undergo the CO 2 conversion as well. As a result, this particular gasifier and the product produced from this particular gasifier will have poor quality as well as low efficiency.

And therefore, these type of gasifier are not in common use. As I said earlier, that is the reason the cross draft gasifiers are not in common use for the gasification process. So, after understanding the fixed bed gasifier, let us discuss about the fluidized bed gasifier.

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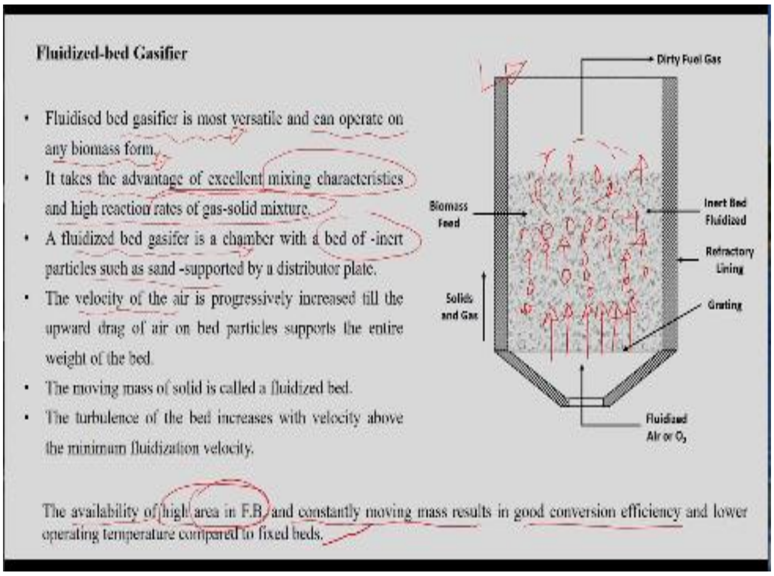

So, this is the schematic of the fluidized bed gasifier. So, the fluidized bed gasifier is considered as the most versatile and it can operate on any biomass form. And that is what is the advantage of the fluidized bed gasifier. It takes the advantage of excellent mixing characteristics and high reaction rates of gas solid mixture in the gasifier. A fluidized bed gasifier is a chamber with a bed of inner sand particles, which are supported by the distributor plate.

The velocity of the air is progressively increase till the poor drag of air on the bed particle support the entire weight of the bed here. And this moving mass of solid in this bed is called a fluidized bed and the turbulence of the bed in this particular gasifier; it can be increased with velocity which is about the minimum utilization velocity. And the availability of the high area in the fluidized bed and constantly moving mass, it results in the good conversion efficiency.

And lower operating temperature compared to that of the fixed bed gasifier and this results in the good conversion efficiency in the fluidized bed gasifier. Moreover, it also gives clean producer gas as the output from the fluidized bed gasifier. Now, once you understand the fluidized gasifier, let us discuss about the circulating fluidized bed gasifier as well.

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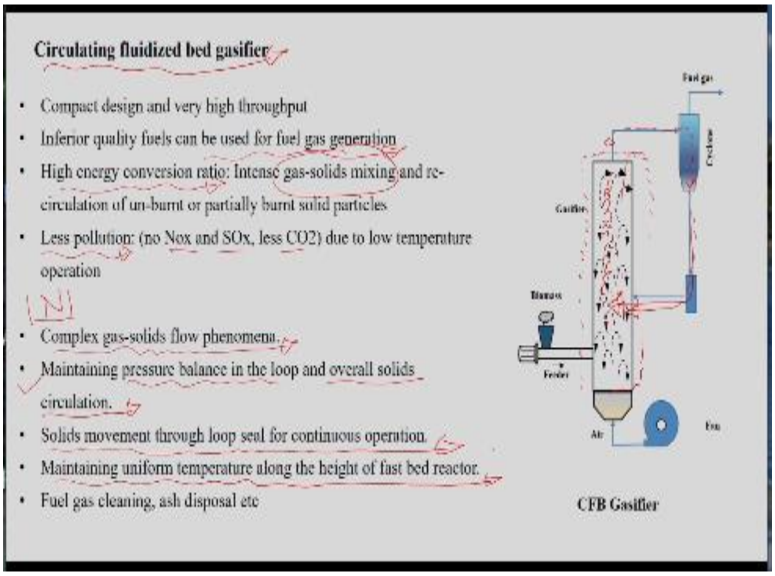

So, this is a schematic of the circulating fluidized bed gasifier. Where if you see here, the circulating fluidized bed design is a very compact and it achieves a high throughput as well. And inferior quality fuels can also be gasified to generate the fuel in the circulating bed fluidized gasifier. High energy conversion ratio because of the intense gas solid mixing which is taking place in the circulating fluidized bed gasifier recirculation of the unburned fuel back into the gasifier.

It also results in the high conversion efficiency, because of the circulating nature of the raw material, the unburned material will be collected in the cyclone will be recirculated back into the gasifier for the oxidation purpose. So, as a result, it gives relatively high conversion efficiency. The less pollution in terms of the NOx, Sox and the CO 2 due to the low temperature operation in the circularity fluidized bed gasifier.

But there are also certain challenges in the circulating fluidized bed gasifier in terms of complex gas solid flow phenomena. Another is like maintaining pressure balance in the loop and overall solid circulation is another challenge here. The solid movement through the loop seal for the continuous operation is one of the challenge of the circulating fluidized bed gasifier.

And maintaining the uniform temperature along the height of the fast bed reactor is also a challenge. So, the fuel gas cleaning as well as the ash disposal is also an issue in the circulating fluidized bed gasifier. So, after understanding the circulating fluidized bed gasifier, let us discuss about the bubbling fluidized bed gasifier.

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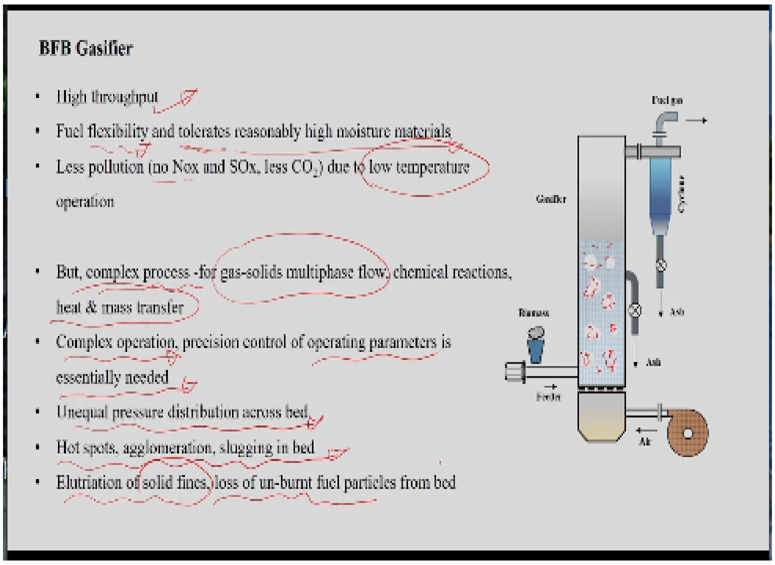

These represent the bubbling fluidized bed gasifier and this particular part here it represented the bubbles which are formed in the gasifier. So, in this case, if you see here, this kind of gasifier also achieve a high throughput and can operate on any kind of biomass material and tolerate reasonably high moisture material as well. The less pollution again in terms of NOx, SOx and CO 2, because of the low temperature operation in the bubbling fluidized bed gasifier.

More or less in this case also, there are certain challenges while operating this kind of gasifier because of the complex process of gas solid multi phase flow and the chemical reaction and the heat and mass transfer, this kind of gasifier need to be operated very effectively. And the complex operation in terms of the precision of control of the operating parameter is essentially needed in the bubbling fluidized bed gasifier. This is also one of the challenges in the bubbling fluidized bed gasifier.

And unequal pressure distribution across the bed. Moreover, the hotspot and the agglomeration and the slagging is taking place in the bed, which is another challenge in the bubbling fluidized bed gasifier. And the elutriation of the solid fines and the loss of unburned fuel particles from the bed is another major challenge of the bubbling fluidized bed gasifier. So, these are talks about the different types of gasifier, which are used for the gasification purpose.

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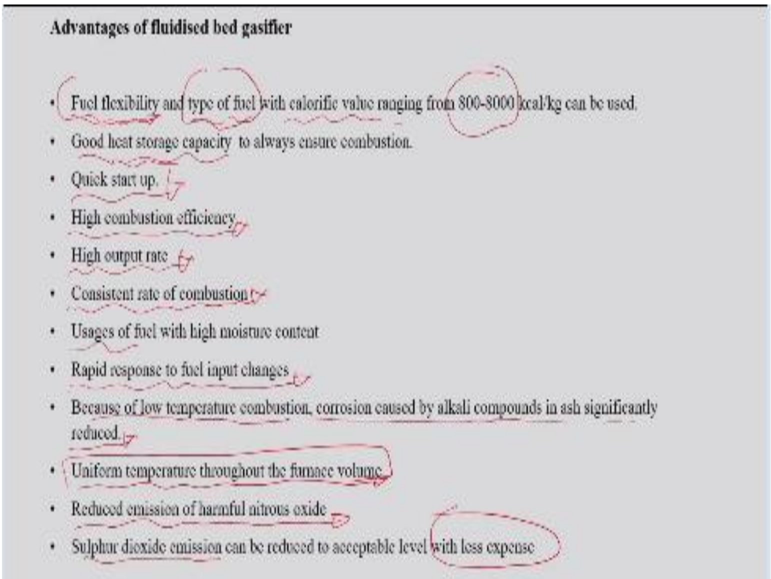

So, after understanding the fluidized bed gasifier, let us see what are the advantages of this fluidized bed gasifier. So, fuel flexibility is one of the advantage of the fluidized bed gasifier and the type of oil with the calorific value in the range of say 800 to 8000 kilo calorie per kilogram, can also be used to produce the syngas in the fluidized bed gasifier. Apart from that the good heat storage capacity to always ensure the combustion inside the gasifier is the major advantage of the fluidized bed gasifier.

Quick startup and high combustion efficiency is another advantage of the fluidized bed gasifier. It also has high output rate. The consistent rate of commercial is another important advantage of the fluidized bed gasifier as I mentioned, because of the uniform distribution of the solid biomass as well as the gasifying medium in the fluidized bed gasifier, it ensures the consistent rate of combustion in the gasifier.

The uses of fuel with high moisture content can also be preferred in the fluidized bed gasifier. The rapid response to fuel input changes is another importance of the fluidized bed gasifier and because of low temperature commercial corrosion caused by alkali compounds in ash, significantly reduced in case of the fluidized bed gasifier. Because this kind of gasifiers, it relatively operate at a lower temperature than the fluidized bed gasifier.

The uniform temperature throughout the furnace volume provides the high process efficiency and reduced emission in the form of harmful nitrous oxide. Because the process is carried out at a lower temperature range as a result, it reduces the emission of harmful gases from the gasifier in the form of nitrous oxide. Sulphur dioxide emission can be reduced to acceptable level with less expense as well and this is one of the important advantage of the fluidized bed gasifier.

So, after understanding the different classification of the gasifier as well as the advantage of the fluidized bed gasifier, if we just compare the gasification process with that of the combustion.

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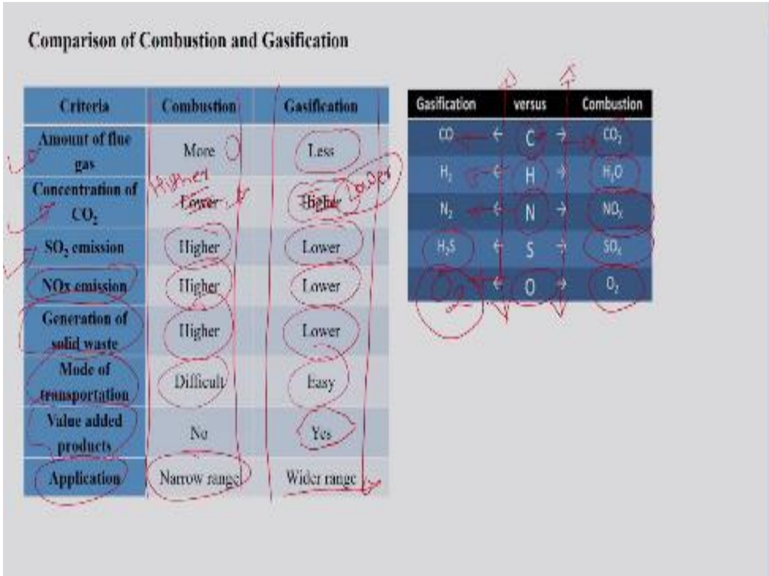

So, if you see here on small table has been tabulated, which shows the comparative analysis of the combustion with the gasification process, in the terms of amount of the flue gas. So, in case of combustion, the amount of the flue gas obtaining is more, whereas in case of the gasification, it is less concentration of CO 2. In the combustion, produce gas is lower, whereas, in case of the gasification, it is higher.

The SO 2 emission in the form of SOx is higher in the combustion process whereas, in case of gasification it is lower, as we already discussed just now. The NOx emission is also higher in case of combustion whereas in gasification, it is lower because the temperature in the gasification is relatively lower than that of the combustion process. And the generation of the solid waste, it is higher in this case.

Whereas in case of the gasifier, it is lower because most of the carbon in the solid fuel is undergoes the gasification that is oxidation and reduction process. As a result, it does not produce any unburned carbon in the gasifier. **(( )) (45:17)** without leaving any carbonaceous residues material, the entire material takes part in the reaction and produces into the gas as the product.

The mode of transportation in this case, it is difficult here, but it is very easy in case of the gasifier product and the value added product cannot be generated from the combustion product because it is mostly a flue gas. Whereas, the gasified product can be further process to produce valuable chemical as well as convenient product. The application of the gas produced from the combustion process has very narrow range.

It can be used either as a heat source or can be used to produce the steam. Whereas, the gaseous product produced from the gasification process has wide range of application, it can be used as a heat source apart from that it can be used in IC engine after further processing, more or it can be further converted into a valuable product or a valuable chemical as well.

So, let me correct this point here because the carbon dioxide production in the combustion process is relatively higher than that in the gasification process. Whereas, the carbon dioxide production in the gasification process is relatively lower. Now, if you look at the gaseous product produced in the combustion as well as in the gasification process, so, the carbon in the solid fuel material is getting converted into CO in the gasification and CO_2 in the combustion process.

Whereas, the hydrogen is getting converted into H_2O as a stable product in the combustion process because of the complete oxidation of the hydrogen in the combustion process. Because of the reduction reaction, the hydrogen in this case is getting reduced to H_2 in the gasification process and the nitrogen is coming out as such without taking part in the reaction, whereas, in this case, it is forming as a NO_x.

In this case, it produces H_2S, if the sulphur is present in the some of the biomass, then it will result in the formation of the H_2S here. In this case, it will form SO_x because of the complete oxidation of the sulphur compound in the biomass if any. And the oxygen if it is in excess, then it will come out as it is from the combustion chamber whereas, it is a partial combustion process.

So, as a result the un-utilize oxygen will not come out from the gasification process, because this entire process is carried out in the limited supply of the oxygen. So, this is how the composition of the gaseous product varies in the combustion and gasification process. So, with this I guess it is clear now, how the gasification operation takes place in the gasifier. So, with this we stop here.

In the next lecture, we will discuss about another thermo-chemical conversion process that is pyrolysis and chemical conversion processes.

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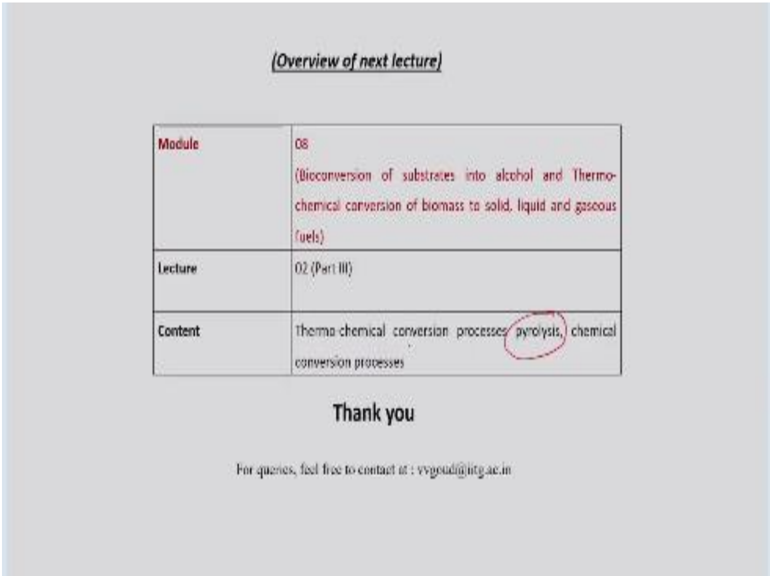

Thank you. Regarding this lecture if you have any doubt, feel free to contact me at vvgoud@idg.ac.in. Thank you.