Waste to energy conversion

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Lecture - 10
Gasification

Good morning everyone, in the last module, we have discussed on incineration, the most important thermal process for the waste to energy conversion. And in this module, we will discuss on gasification another thermal process for waste to energy conversion; unlike incineration in gasification we supply controlled amount of oxygen, and this process is also old process particularly for coal gasification. And this coal gasification process is a commercial process and liquid fuels like gasoline and diesel is produced from the coal through this gasification route.

However, the gasification of wastes and biomass is relatively newer concept. The difference between coal gasification and the gasification of waste and biomass is basically the nature of the feedstock, the coal is less reactive and this biomass and wastes are relatively more reactive. So, the avoiding conditions will be slightly different, but the basics of the gasification the mechanism, the energy requirement or say efficiency etcetera will be of similar. So, we will divide this whole module into two parts.

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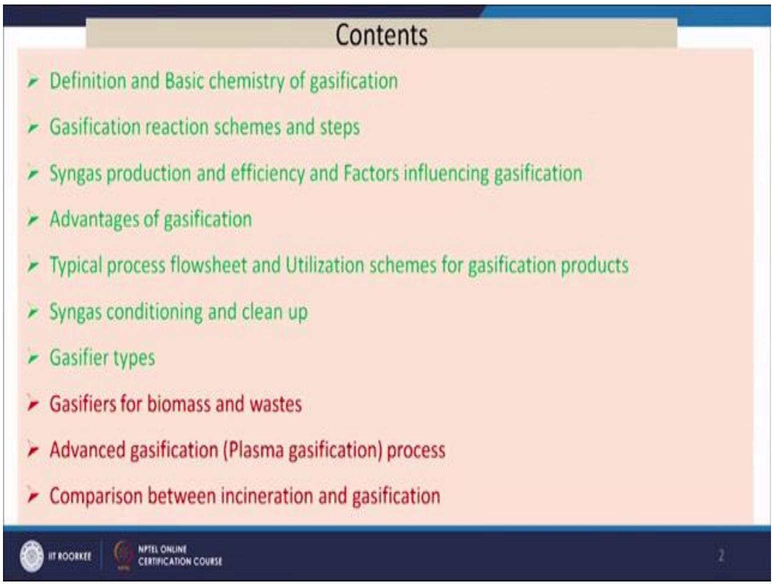

In the first part we will discuss about the definition, and the basic chemistry of gasification, mechanism and different steps for gasification, and then oxygen requirement and syngas productions and efficiency and factors influencing gasification advantages of gasification typical process flowsheets and the need for the cleanup of the syngas and its conditioning as well as some gasifier types. So, all of these will be applicable for coal gasification as well as biomass and waste gasification. And their second part will discuss on gasifiers for biomass and wastes, and advanced gasification that is plasma gasification process which is very, very important for the processing of hazardous solid wastes. And we will comparison of different incineration and gasification process, we will make in the second part.

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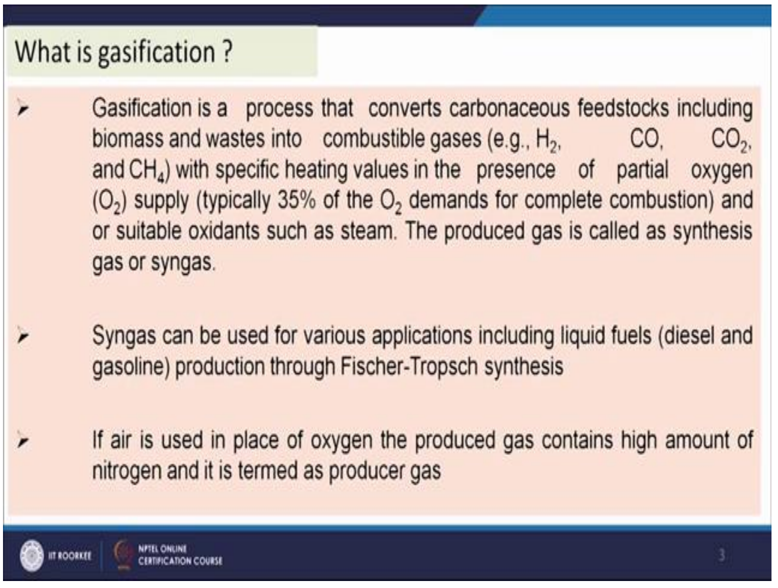

Now, we will say the what gasification is gasification is a process that converts carbonaceous feedstocks into combustible gasses including H 2 and CO mainly carbon monoxide and hydrogen dioxide gas, and it will with a specific heating value in the presence of partial oxygen supply that is typically say 35 percent of the oxygen demands of a complete combustion, and or suitable oxidants such as steam. The produced gas is called as synthesis gas or syngas, but if air is used in placed of oxygen then large amount of nitrogen is also present in the produced gas, and the gas is named as producer gas. Syngas can be used for various applications including the liquid fuel synthesis through Fischer-Tropsch synthesis routes.

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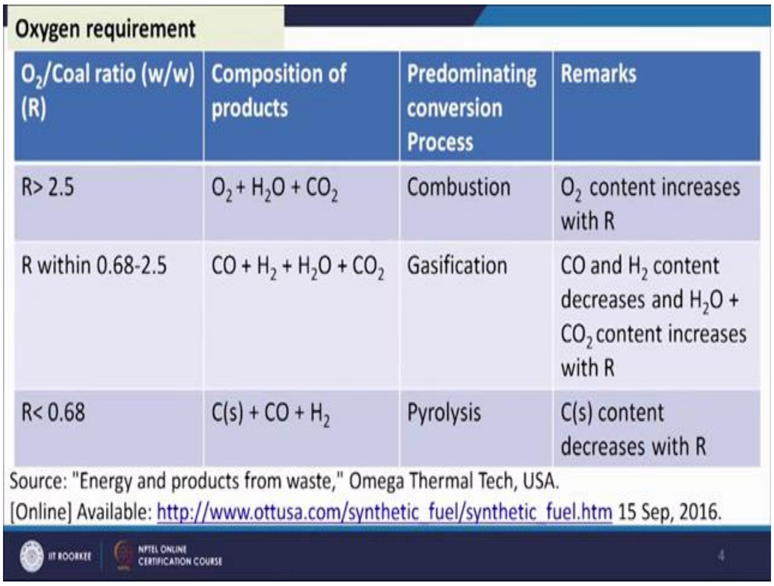

Oxygen requirement

O_2/Coal ratio (w/w) (R)	Composition of products	Predominating conversion Process	Remarks
R> 2.5	$O_2 + H_2O + CO_2$	Combustion	O_2 content increases with R
R within 0.68-2.5	$CO + H_2 + H_2O + CO_2$	Gasification	CO and H_2 content decreases and H_2O + CO_2 content increases with R
R< 0.68	$C(s) + CO + H_2$	Pyrolysis	C(s) content decreases with R

Source: "Energy and products from waste," Omega Thermal Tech, USA.
[Online] Available: http://www.ottusa.com/synthetic_fuel/synthetic_fuel.htm 15 Sep, 2016.

In the earlier module, we have discussed that incineration that is combustion and gasification and pyrolysis are main three routes under thermal processing of solid waste. In the incineration, we need excess oxygen; in gasification, we need controlled oxygen; in pyrolysis, we do not need oxygen. So, if we put some solid waste and say air or oxygen, so when under which ratio of oxygen and your feedstocks, what type of process will predominate that one guidance has been given in this energy and products from waste, this is the source I have mentioned here. So, in this source, it is mentioned that for oxygen to coal ratio weight by weight ratio.

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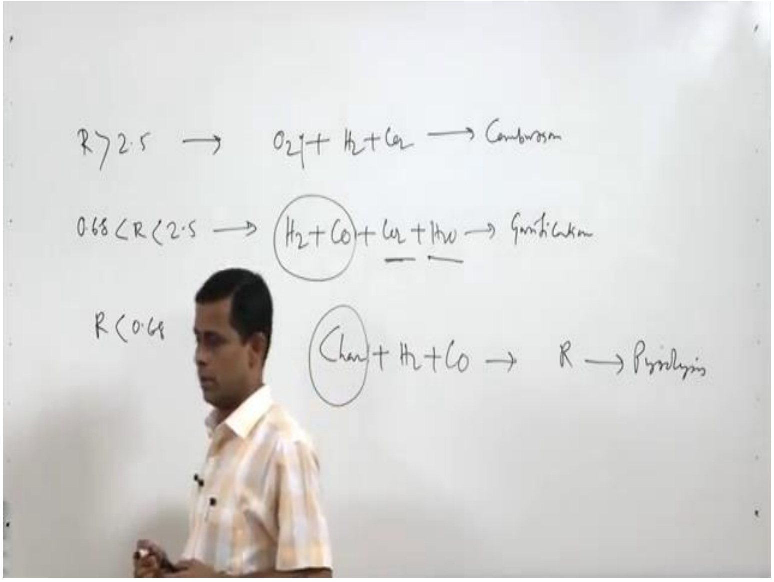

If it is greater than 2.5 the ratio, we have defined as R, if it is greater than 2.5 then the produced gas will be containing oxygen H 2 O and CO 2 and the process will be combustion process. Interesting to note that if the R value increases, the oxygen will also increase excess oxygen will also be available in the produced gas. If R value 0.68 less than R less than 2.5 then this the produced gas contains H 2 CO CO 2 and H 2 O, these are the major components other impurities may be, and this is your gasification process. Predominating process is gasification. If we increase the R value then CO 2 and H 2 O will increase and CO and H 2, CO and H 2 will decrease, CO 2 and H 2 O will increase with the increase of R. And if R less than 0.68, then we will get char, we will get H 2 and we will get CO. And the char value will increase, if R decreases; if R decreases, char value will increase. And in this case, pyrolysis process is the predominating route for the conversion.

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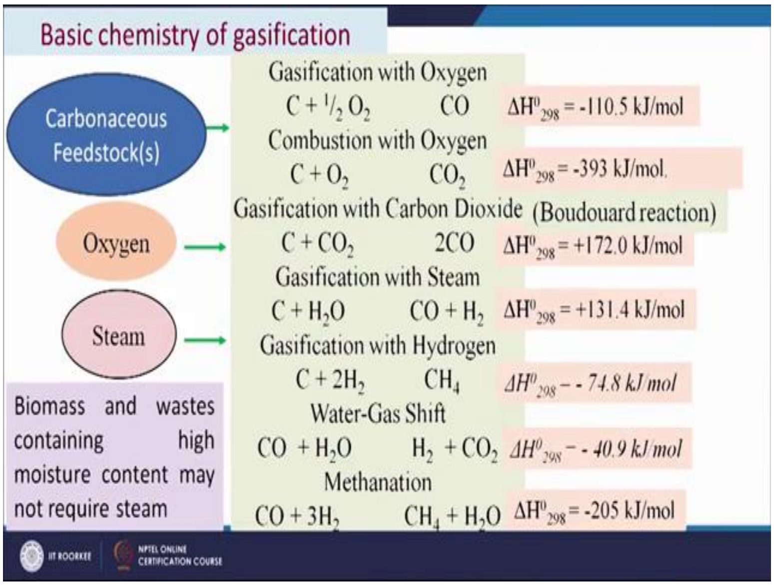

Now, we will see the basic chemistry of gasification. This approach or this chemistry basic chemistry involves the reactions with elemental carbon present in the feedstock with different agents like say oxygen, carbon dioxide, H 2 O and H 2.

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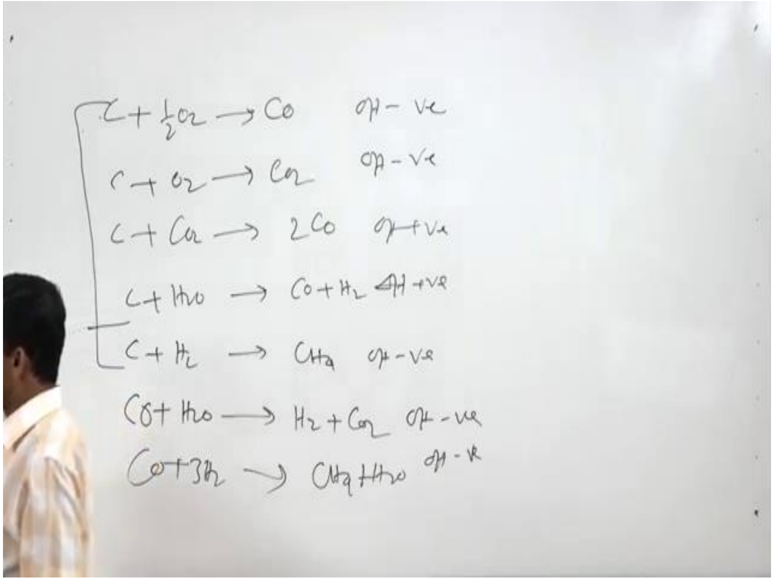

So, carbon will react with oxygen, it will give CO with negative del H is equal to negative this is called gasification with oxygen or partial oxidation. Then combustion with oxygen C plus O 2 that will give us CO 2 del H is negative C plus CO 2 that will give us CO del H is positive. C plus H 2 O that will give us CO plus H 2 del H is positive. Now, gasification with hydrogen C plus H 2 that will give us CH 4 del H is negative. And apart these are the four, five basic reactions basically four basic reactions, this also takes place they are methane formation as if side reactions. And other two reactions that is methanation and water gas shift reaction takes place in the gasifier that is CO plus H 2 O that reacts and converts H 2 into H 2 and CO 2 and del H is negative. Another reactions that is methanation CO plus 3 H 2 that gives us CH 4 plus H 2 O del H is negative. So, these are the major and minor reactions which involve in the gasification of carbonaceous feedstocks in presence of oxygen and steam.

Now, if coal is used where the oxygen is less, then the steam is required because this also has. So, coal has less amount of moisture, but waste and biomass, wastes and biomass normally contains higher moisture content and oxygen content, so that is why the steam requirement is also less. And in most of the cases steam is in many cases steam is not used. So, this is the elemental reactions we have expressed when oxygen is used. Now, if air is used, so the same reaction will be going on, but additional nitrogen will also be coming out to their gasifier, and it will be present in the produced gas, so that will give the producer gas. So, it will reduce the heating value of the produced gas as well as it will increase the nitrogen content in the produced gas that is called producer gas. Now we will see the difference between these two gases, one is syngas when oxygen is used, and one is producer gas when air is used.

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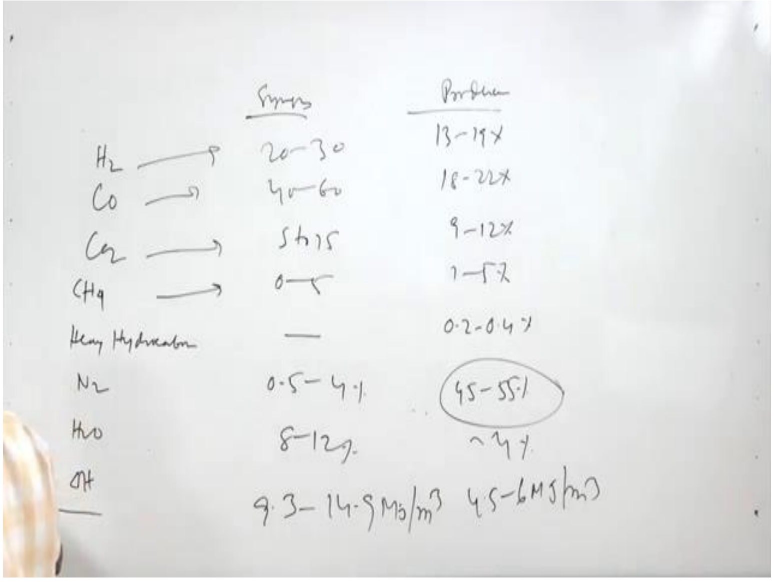

So, if we think about the composition say hydrogen, it is CO, CO 2, CH 4, heavy hydrocarbon, nitrogen, water vapor and heating value, these are the compositions and heating value del H So, if it is a syngas, this is typically 20 to 30 percent, this is typically 20 to 30, percent and this is for producer gas oh 13 to 19 percent, this is 13 to 19 percent. For carbon monoxide, this is say 40 to 60, and this is only 18 to 22 percent. And for carbon dioxide, this is also very less 5 to 15, and this is also say 9 to 12. C H 4 less 0 to 5, 1 to 5; heavy carbon, this is 0.2 to say 0.4.

Nitrogen, nitrogen in this case is very less. So, 0.5 to 4 percent, and it is say 55, 45 to 55 percent. So, this is very, very interesting, and mane a highly difference this nitrogen content. And H 2 O is 8 to 12 percent and this is around 4 percent, and del H, del H value in this case is higher that is say 9.3 to 14.9 mega joule per normal metric cube per meter cube whereas, this is only 4.5 to 6 mega joule per meter cube. So, the heating value of this producer gas is less with respect to syngas. Now, we will see reaction schemes. So, far we have discussed that is a very basic chemistry on the basis of elemental conversion that also only taking only pure carbon, no impurities are considered.

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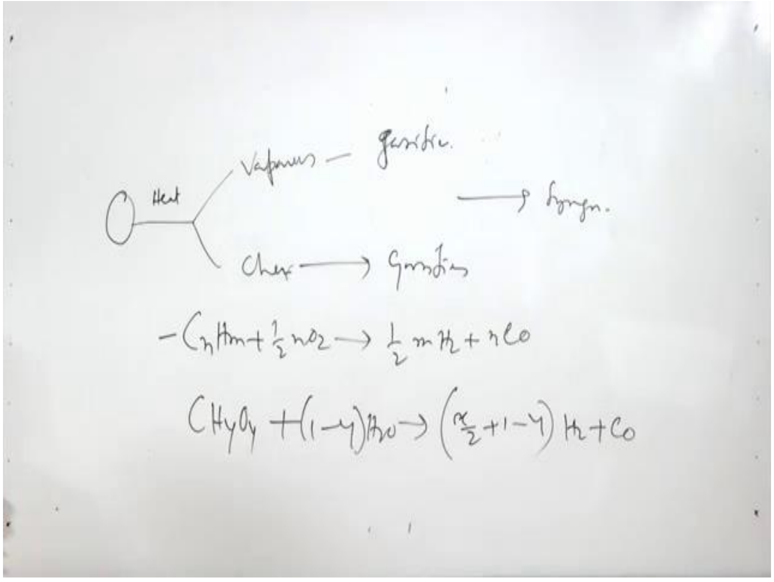

Here we will be discussing some more representative schemes that is at first feedstock comes in contact with hot gas. So, devolatilisation takes place. So, it gives some vapors and char. So, then char further gasifies this is gasifies and it gives the syngas. This is application of heat. Volatiles gasification reactions for this, it is Cn Hm plus half N O 2 that gives us half m H 2 plus n CO and char gasification C H x O y, this is char plus 1 minus y H 2 O that will give us x by 2 plus 1 minus y into C 2 plus CO. So, this was proposed in since 1989. So, here the similar phenomenon happens in case of incineration at first the material comes in contact with hot gases, and then volatilization takes place and then in case of incineration the volatiles oxidizes or combustion takes place with the secondary air, but here we are not providing any secondary air. So, controlled amount of oxygen is provided. So, the reductions or the gasification reactions proceeds on.

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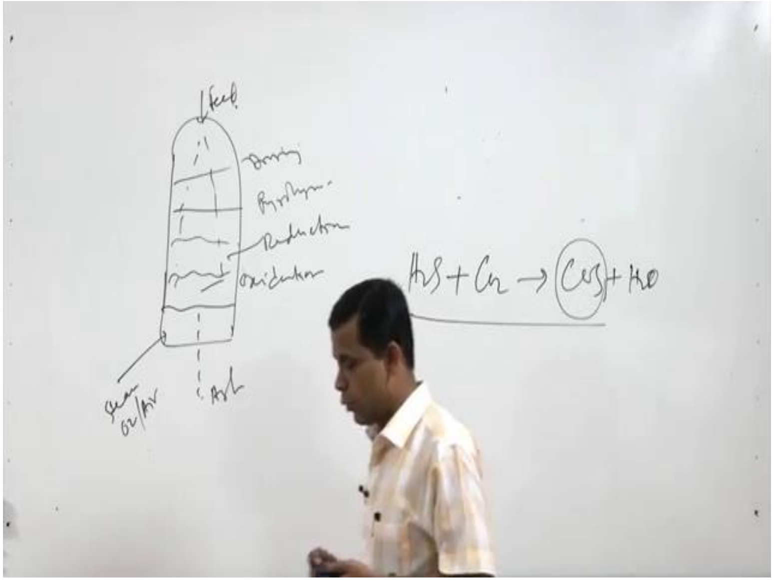

If we take one say a reactor or say gasifier, how the different joules will be distributed that is shown in this figure if we take one fixed weight gasifier say and from the bottom we will send steam, oxygen or air then from the top we will put feed and that will be great. So, ash will be collected here. So, this material is falling down. So, there will be some combustion zone. So, oxidation highs temperature, then reductions then it will be reductions, then it will be having pyrolysis, and this is drying. So, these are the processes or regions in the gasifiers we will get. This is very similar to incineration methods, but only difference that here the vaporized or the volatiles component do not get completely burnt, because oxygen is not there and char gasification takes place in place of char oxidation.

So far which we have discussed from this it is not clear how the H 2 S is produced and COS is produced during gasification which is present in the syngas and make serious operational issues. So, Valero et al in 2006, they has proposed one chemistry for the gasification. They have presented the molecular formula of the material carbonaceous feedstocks and shown the reactions of oxygen, CO 2, H 2 O and H 2 with that molecular formula. And they have shown that it is possible to produce H 2, H 2 S, N 2, CO, CO 2 CH 4 etcetera, etcetera. And it is also proposed that H 2 S which is produced during the basic reactions that also reacts with CO 2 and converts COS plus H 2 O. So, this is the reactions through which COS is present in syngas which requires to be clean because those components are not desirable, we have to remove these things.

Now, we will see how can we calculate the amount of syngas produced and the thermal efficiency of the gasification process. Gasification is the high temperature process, so it is governed by the equilibrium. So, through equilibrium modeling and its simulation, we can predict the compositions and the composition of syngas and production rate etcetera, many people tried on it on it and predicted the composition.

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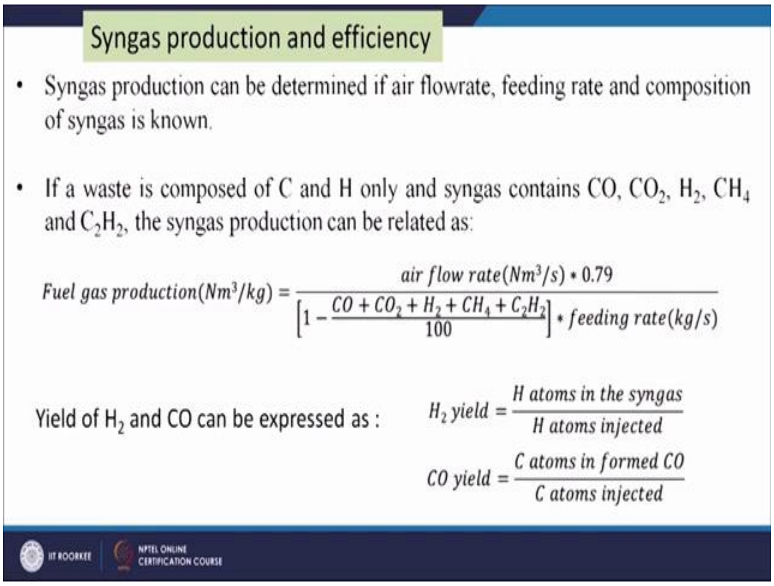

Here some formula is given using which we can calculate the fuel gas production rate if the material the raw material or feedstock contains only hydrogen and carbon and the product gas contains CO, CO 2, H 2, CH 4 and C 2 H 2, then fuel gas or syngas fuel gas or producer gas whatever it may be depending upon the situation.

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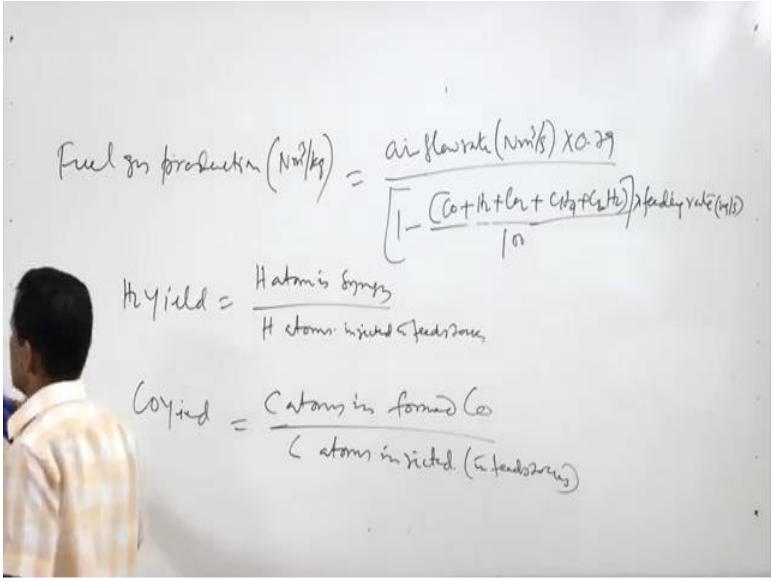

So, fuel gas production fuel gas production in case of what that is normal meter cube per kg of normal meter cube per kg of waste or carbonaceous material that is equal to air flow rate normal meter cube per second into 0.79 divided by 1 minus CO plus H 2 plus CO 2 plus CH 4 plus C 2 H 2, this is the composition of this. This is divided by 100 into feeding rate into feeding rate kg per second. Now, hydrogen yield and carbon monoxide yield is also two important parameter, so and this has been determined by hydrogen yield is equal to hydrogen atoms in syngas divided by hydrogen atoms injected; that means, in feed that is in feedstock in terms of feedstocks. And CO yield is equal to C atoms in CO formed CO divided by C atoms injected means in feedstocks. So, this way we can calculate the gas production rate and the yield of hydrogen and CO.

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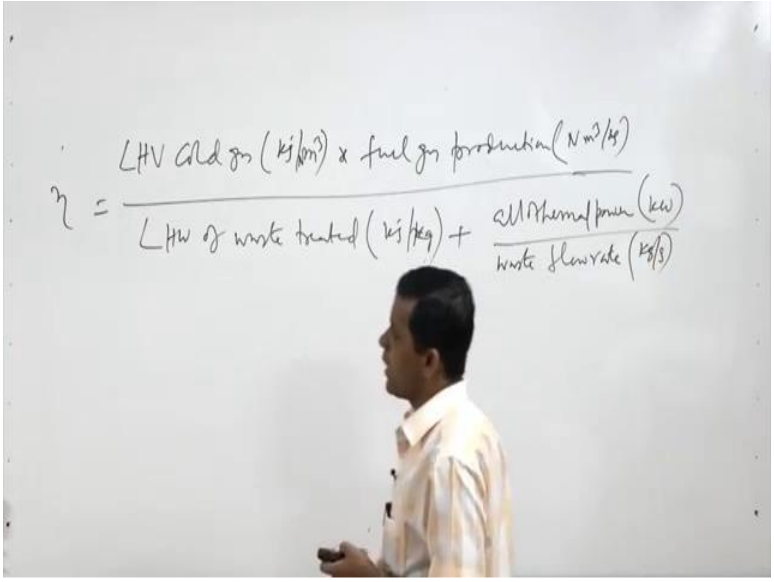

Now, we will see how to calculate the thermal efficiency. Thermal efficiency of this gasification process can be determined as the thermal efficiency is equal to heating value lower heating value LHV of the produced gas of the coal gas that is equal to in which unit kilo joule per normal meter cube into fuel gas production. What is the unit normal meter cube per kg normal meter cube per kg divided by how much heat available in the waste? So, LHW of waste heated that is equal to kilo joule per kg plus additional energy required for the process that is called allothermal power kilo watt allothermal power in kilo watt divided by waste flow rate waste flow rate that is equal to kg per second. So, this is the equation through which we can calculate the thermal efficiency of the process whole gas efficiency.

Now, generally conversion if it is a thermal power plant is between 30 to 40 percent for a single cycle steam power plant. And it can be increased up to say 60 percent per a combined cycle gas turbine power plant. Now, we will see what are the factors that influence the performance of the gasifiers or the gasification process see in combustion process also we have seen that time temperature turbulence feedstocks size etcetera influences this the rate of combustion. The similar way the performance of gasification also will be dependent on those parameter.

Here, in addition to these the type of heat injection whether we are feeding the feed from the top from the side like this, so that will also influence the performance of this. So, gasification agent whether we are using air or oxygen that will also influence the performance of the process. And then the types of heating whether we are using direct heating or indirect heating, so that will also influence the type of reactors which we are using fixed weight or say moving air flurised weight that will also influence the performance temperature range and pressure is also important in this case .

Now, what is the advantage of gasification this reduces CO 2 in the emission. So, CO 2 emission is reduced. We get some intermediate state to control the CO 2 emission. This is the one major advantage of this gasification process. Apart from these, it requires compact equipment with a relatively small footprint, accurate combustion control and high thermal efficiency. Now, we will see the flow sheet and utilization schemes of gasification products. Similar to incineration or combustion methods, we will be using waste and biomass or any carbonaceous materials after pretreatment. So, if the carbonaceous material is waste and biomass, the pretreatment is must.

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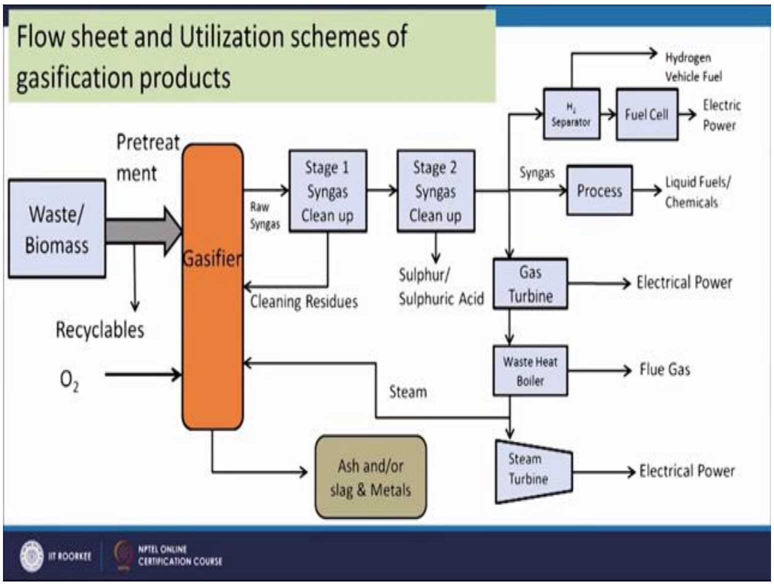

So, segregation your sorting, homogenization is required, and then the material will come to gasifier.

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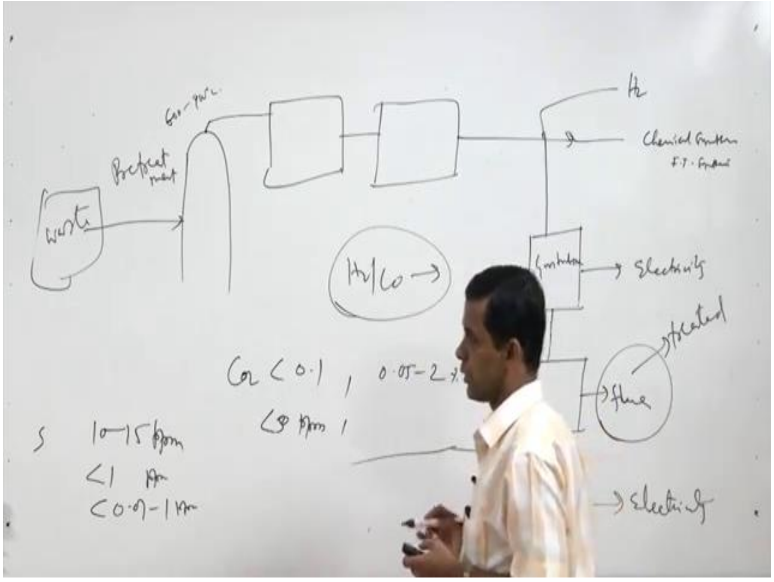

If we have our waste, after pretreatment it will come to gasifier. So, gasifier will supply oxygen or air and steam if required in this depending upon the moisture content in this waste. Then it will give us syngas, but here the temperature is high. So, high temperature that will vary from say 600 to say 900 degree depending upon the type of gasifier we are using, so that will go out. We need to clean it. So, our first step is syngas cleaning is done by using cyclones. So, particles which are carried over those are settled down and that can be recycled. So, this is your first step of cleaning. Then second step, we will clean the acid gases present it. So, SO 2 H 2 S, but and COS, SO 2 will not be present here unlike your incineration methods this will not be present in this case we will be using H 2 S and COS. So, we have to remove the H 2 S and CS in this case.

Then after acid gas removal, we will be getting the syngas that syngas can be used into different purpose. So, after the cleaning of the acid gas components from the syngas, this will be ready for utilization. Now, these can be used for various applications. It can be used for hydrogen productions, it can be used for chemical synthesis, it can be used for Fischer-Tropsch synthesis for liquid fuel. Then this can directly be used in gas turbine, so that will give us electricity; and then the gas will ooze and this can be heat recovered and we will use this gas for the steam formation. So, it will give us fuel flue gas after combustions, it will be water will be converted to steam, and that steam can be further used for steam turbine.

The steam can further be used in steam turbine which will again give us electricity. And this steam which is produced here part of the steam can be used in this gasifier if it is required. And from the bottom of the gasifier, we will be getting a slag and ash. These can be recovered or these can be managed in a proper way. Now, this flue gas which is generated here that has to be treated. And we will be discussing these things in other module. And we will also discuss the scopes for different applications in detail in other module. If we think about different applications then out of those applications three important applications are hydrogen productions and for hydro processing second is chemical and third is your power production. So, power production hydro processing and chemical productions. So, these routes are major route for the application of syngas, but for the downstream applications of syngas in these three routes the quality requirement is different.

So, if it is for power point power applications then quality requirement basically on sulfur that is equal to it should be less than 10 to 15 ppm; for hydro processing, the sulfur content should be less than 1; and for chemical, this should be less than 0.01 to 1, this is in ppm, so that has to be very pure. But for carbon dioxide and carbon monoxide for power application, there is no limitation, it can have any value. But for hydro processing the carbon dioxide for hydro processing it should be less than 0.1 percent; and for chemical, it will be less it will be using 0.05 to 2 percent. And for carbon monoxide if it is for hydro processing less than 50 ppm wet basis; and for chemical synthesis, what will be the CO that will depend upon the process because different processes requires different H 2 is to CO ratio in the syngas. Somewhere it is required is 2 is to 1 like say isotope synthesis somewhere say 1 is 2 1 there is DMA synthesis.

So, depending upon the nature of the chemicals we are going to produce the H 2 by CO ratio is required. To maintain this ratio we need to condition the syngas; that means, some other reactions are carried out with the syngas to monitor the H 2 by CO ratio. And pulling is required because syngas will be very high temperature I have mentioned, so for different applications the temperature has to be reduced. See this is the flow sheets we have discussed.

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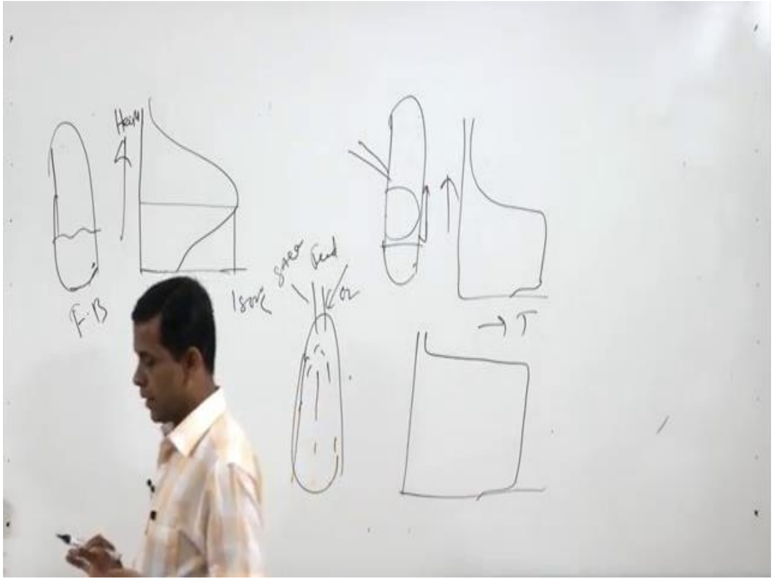

And now we will see some important type of gasifiers used in coal gasification fixed weight, fluidized weight and entrant weight gasifiers. If we think about the three gasifiers, if we see their temperature distribution for fixed weight, the temperature distributions along the height of this. So, this is the height of the gasifier this is the temperature. So, this is the combustion zone. So, maximum temperature will be here. So, it will be here and that will be reduced, this is ash zone, this is the combustion zone maximum temperature. So, this is around say 1800 degree centigrade this is for fixed weight. If it is say fluidized weight, so fluidized weight, we will put material from the side. So, here the temperature is less. So, here the temperature is less maximum temperature is inside. So, here width height the temperature distribution will be like this.

It will go uniformly this part will be having the uniform temperature distribution same temperature will be available throughout. And if it is entrant weight means the reactor we are putting from the top, the feet, the air the oxygen and steam. So, in this case, it will be distributed throughout the length, the temperature will be uniform, but this will be very high temperature from the beginning, from the beginning the temperature will be very high. So, this is the mean three type of gasifiers which are used for the gasification of different type of carbonaceous feedstocks. These are particularly applicable for coal and pet coke, the entrant weight gasifier is most suitable for the less reactive material. The same type of gasifiers are applicable for the gasifications of waste and biomass, but operating conditions will be different. So, up to this in this module; so, in the second part of this module we will start with the gasifiers for biomass and waste.

Thank you very much for your patience.