**Clean Coal Technology**

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**Week-10**

**Lecture-47**

Hi, I Professor Barun Kumar Nandi welcome you in NPTEL online certification course on clean coal technology. We are at module 10 discussing coal gasification. So, in this module we are discussing different types of reactors used in gasification like fixed bed, moving bed, fluidized bed, entrained bed gasifier. And we will also be discussing product gas cleaning, energy utilization, removal of H2S, NH3, tar, suspended particulate matter, etc.

So, let's start lecture 2. In this lecture, we will be discussing working principle of Lurgi gasifier. Lurgi gasifier is one of the oldest and very well proven gasifier being used for long time. So, Lurgi gasification process is one of the several processes for which commercial technology has been fully developed. This technology is being used in Germany before World War II. So, this technology was developed by the scientist Lurgi. So, he has developed in before the world hour during 1930s era. So, from that time this gasifier is used to supply syn gas for different industrial as well as domestic applications. So, this process has been used in large number in commercial plant throughout the world.

So, after that, this plant has been well accepted by people around the world. So, in different regions of the world, we can find this Lurgi gasifier. It is used in different industries directly for coal gasification or in some industries where the coal gasified product, syngas, is used for further heating in different applications. So, this process produces low to medium calorific value gas. So as this The Lurgi gasifier mostly uses air, and the calorific value of the gas is not significantly high, like if we compare it with LPG or CNG gas. So compared to that, its calorific value is on the lower to medium side, not the same as that So, this produces low to medium calorific value gas as a product. And in this older version of the Lurgi gasification process, we get ash produced in a dry form, which differs significantly from the more recently developed slagging gasification process. So, the major difference between its later versions or upgraded versions or similar other types of gasifiers is that in this gasification process, we get dry ash, meaning ash released from this gasification unit is in the dry phase, not in the molten or slag phase. That means the temperature at this exit point is not significantly higher; it is well below

the ash fusion temperature. So as a result, the ash produced from this gasifier is in the solid phase, in the dry powder phase, whereas in the recently developed there are various methods where the ash comes out in the slagging phase at high temperatures around 1400 to 1600 degrees centigrade.

So, this gasifier is a pressurized reactor that works above atmospheric pressure, and it is also a moving bed gasifier. So, from the top part of the gasification unit, from this side, the coal will fall and be fed from the top side. So, effectively, it is a top charging unit, and from the bottom side, we will send the air or reacting medium. So effectively, it will be a counter-current coal gasification unit, and the coal bed or these coal particles will move from the top and remain in this bed for a longer time. That's why it is called the moving bed gasifier, meaning the gasification bed moves from upwards to downwards and produces syngas from lump coal. That means the coal used in the reactor is not in smaller sizes; they are in the crust form, approximately 1 inch to 0.5 inch or 1.4 inch, that size is taken, meaning 3 mm to 12 mm or 18 mm, that similar size of coal is used.

As well as here, we use steam as a gasification medium as well as oxygen or air as a gasification medium. And it accepts coal only of the non-coking type. As this gasification technology or this gasification medium takes a lot of time for gasification. So, any coal having a coking tendency, that means if it has the caking tendency, if it is a coking coal, then the Swelling properties may appear here. So such coal is not suitable for this reactor. So only non-coking coal is suitable, and we can use this coal in a much bigger size. Only crushed coal can be used. It does not need any powder-sized fine coal particles. So, as this temperature is around 1000 degrees or below 1000 degrees centigrade, it can accept only non-coking coal. If the reactor temperature is significantly higher, like 1400 to 1500 degrees centigrade, in such cases, typically the reaction takes place very quickly, and accordingly, the caking properties will not have any impact on the reaction. So, any reactor that works at a very high temperature of 1400 to 1500 degrees centigrade can accept any type of coal, either coking or non-coking.

However, if the reactor operates at a lower temperature, in such cases, the residence time for the conversion is long, and as a result, only non-coking coal can be used in this reactor. So, the Lurgi gasifier accepts crushed coal; it does not need any further grinding of coal, and it accepts only non-coking coal. So, this is typically the This is the design or schematic diagram of the Lurgi gasifier. So here, this part is the top part where we store the coal in this coal bunker. So, we store this coal, and this is one of the semi-batch mode operations that happens. That means

coal will be stored here. So it will be feed at this top and depending on the requirement, depending on the coal requirement, this is the coal feeding point. We will open this knob or that means gate so that this coal lock will be opened and that coal particle will enter the reactor. So, this is a semi-batch mode where coal is stored in these systems. That means coal here we can use coal from 1.5 to 4 mesh. That means approximately 1 inch to 1 fourth inch size. That coal we can use along with the steam and oxygen in a slowly moving bed reactor. Coal will move very slowly continuously. But not in a very rapid space. Coal bed will move very slowly. in slowly it will move and after this reaction it will move and create the ash. So that's why it operates in a semi-continuously. Because the temperature of the reactor is not very high. It is below 1000 degree centigrade or similar to that. So, it will take lot of time for the conversion.

That's why we cannot go for very fast process. So, it is a one of the semis, it is one of the processes like semi-continuous process. This gasifier equipped with the hardware parts like coal lock hopper. This is the point where coal lock will be there. That means we can open and close the gate so that coal can be fed to the main reactor and it can be stored in the top side. So that is the purpose of this coal lock hopper. Then coal distributor. At this point coal is, when it is fed to the reactor, so we have to ensure that coal particles distribute to the entire area of the gasifier, not to any particular location. That means whatever the coal is there, that should be entered at all the points.

That is the purpose of this coal distributor. So, this coal distributor ensures that coal particles fed to the entire reactor, not to a particular region of the reactor. As it is the lump bigger size coal this coal distributor is an essential part of the reactor. Then it is the coal distributor then revolving grate which will continuously here it will continuously rotate in this way so that the coal particle distributes to the entire reactor. And ash lock chamber here depending on the requirement we can take out some of the ash particle once this conversion is complete. So, this ash lock or chamber also ensure that the coal particle stays here for the longer time or as per the desired time based on the reaction. This is the purpose of the ash lock chamber as well as the gas scrubber. Here the gas particle here the produce syn gas comes to at this region. So, whatever after the reaction is there the syn gas produced from this region and this syn gas has different type of impurities. So there has to be cleaned. That is why this that is the purpose of the gas scrubber. An automated coal lock chamber for feeding coal from the coal bin to the pressurized reactor.

This device is open called the coal lock hopper. Purpose of the coal distributor is that a coal distributor through which coal is uniformly distributed through the moving bed. That is the purpose of the coal distributor. It will uniformly distribute the coal particle through the moving bed. A revolving grid through which steam and oxygen are introduced in the reacting joule and thus ash is removed. At this bottom part here, a revolving grate is used so we have to ensure that the air or oxygen steam whatever the reacting medium is there they go to the entire reactor and all parts of the reactor not that means it will go to the all the part it will distribute the air or the reacting medium and from that zone also we can get that ash particle is removed. The ash lock chamber for discharging the ash from the pressurized reactor into an ash bin. This is the location of the ash bin. Which ash is cooled by the water quenching.

Because the ash will come at high temperature. It has to be cooled down for taking out of the reactor. And it is washed before it passes through a waste heat boiler. So, waste heat boiler it will recover the heat released from the ash. And it will be used for further discharging utilization in any other location. Coal enters at the top of the gasifier through the lock hopper and handled by a rotary distributor as it begins its descent through the gasifier so from this top side also that gasifier that coal distributor is there which will ensure that coal particle goes through the entire part of the reactor and from the bottom side also this distributor is there which will ensure that the gas particles goes throughout the reactor there is that so that there is no particular channeling of the ninth coal particle not the ash particle that there is proper and suitable mixing of solid coal as well as the reacting steam and air Coal feed is supported at the base reactor by revolving grate through which steam and oxygen mixture is introduced and ash is removed. So, this is another picture which shows that how coal and a more detailed picture of this Lurgi gasifier.

So, from this side, coal particle is there, is charged. So, it will stay here, that is the coal lock is there. So, in this coal lock, coal will be stored here and depending on requirement, coal particle will enter here. And at this point, this is the particularly the coal distributor which will distribute the coal, coal particle to the entire reactor. And this is the entry point for the steam and oxygen which will enter through this reactor here. And here it will distribute through this perforated place of ash where it will ensure that this entire oxygen or steam goes through all this zone. And whatever ash particle is there; it will come in this particular zone. So as a result, from all the sides of this reactor air and oxygen will go and as well as from all the sides of this reactor whole particle will come here. And further whatever ash is there it will be collected. at the ash hopper from this is the point where ash particle will be collected and it will to stay there for

some time with contact with liquid water to make it some waste recovery unit through the steam generation and this is the location where product gas, syn gas will go which will further go for purification and treatment and we can get the crude syn gas as well as we can recover other impurities like water oil and etc. that is as per the requirement of the syn gas cleaning as per the requirement of the reactor. This is the steam generator which will that gas liquid separator which will operate here, so that liquid water it can enter here So, inside this reactor also, we can see that there are the different zones available as we have discussed in our previous lecture. That is the co-current and counter-current, up-draft and down-draft reactor. So, this is basically the up-draft reactor. Your steam is entered here.

So, initially, it is the ash zone or it is the combustion zone is there. Further, this is the reduction zone or the gasification zone. This is the pyrolysis zone. This is the drying zone. So, coal particles enter here. So, hot air enters here. It passes through this ash. So, this ash gets cooled down at this particular location, and it transfers the heat to the oxygen and steam. And in the combustion zone, the combustion of Coke particles occurs, which means coal particles that have been converted to coke after the release of volatile material will react and be converted to carbon dioxide and other products as per the reaction there and further, this gas will go there, which will proceed to the reduction zone. Here, in most cases, carbon monoxide will be generated. As these are the same reaction schemes we discussed in our previous class. Then, it will go through the pyrolysis zone, where volatile material will be released, and then it goes through the drying zone. So, that is the same process as with coal.

Initially, it dries here at around 100 degrees centigrade. This is the pyrolysis zone, where its volatile material will be released. Then, it is the gasification zone or reduction zone, and in this zone, there is no oxygen present. So, it will undergo gasification reactions using carbon dioxide and steam, and further, it will enter here, where it will be exposed to the fresh oxygen entering it. So, this is the entire reactor. It is a counter-current reactor or updraft reactor, as we have discussed in our previous lectures. So, if we describe the entire process, steam and oxygen enter from the bottom, while the ash is removed at the bottom by a rotating grid and log hopper. This process takes place at around 24 to 31 atmospheric pressure and in the temperature range of 620 to 760 degrees centigrade. So, in the combustion zone, the temperature is about 600 to 800 degrees centigrade, and the residence time of the reactor is about 1 hour. As we are using larger coal particles of 1 inch to 1.14 inch, that means about 4 mm, 5 mm to about 20 mm coal particles are used. So, it takes a lot of time for the gasification reactions to complete. So, overall, this reaction means the coal particle residence time is about 1 hour. During this 1 hour, the coal

particle will move slowly from the top to the bottom of the reactor. That is why it is called a moving bed reactor.

The entire coal bed moves from the top side to the bottom side of the reactor. Steam is introduced from the bottom of the reactor, which provides the necessary hydrogen species—that means in the steam, there is hydrogen present as H2O, which contains H2. So, it supplies the necessary hydrogen species and heat generated by the combustion portion of the char. There is a combustion zone here; heat will be supplied, and if we see the pictures, the details show the concentration of different types of gases. As we can see, with increasing atmospheric pressure—like 5 bar, 10 bar, 15, 20, 25, 30, 35, 40—we observe that if we increase the pressure inside the reactor, the production of methane gas increases. In such cases, the steam will react much more efficiently. As a result, in the syngas, the concentration of hydrogen and methane gas will be on the higher side, while the concentration of carbon monoxide will be on the lower side. Whereas, at low pressure, we can see that the concentration of hydrogen is on the higher side, the concentration of methane is on the lower side, and the overall calorific value of the syngas is on the lower side. So, overall, from this picture, we can see that above 30 to 40 bars, the heating value of the syngas is significantly higher, and it also has a significant amount of methane and hydrogen and a very small quantity of carbon monoxide. This can produce a syngas which is rich in methane and hydrogen, so the overall heating value or calorific value of this syngas produced is on the significantly higher side. That is the reason why this Lurgi gasifier is well accepted and very popular in worldwide utilization. It can use High-ash coal; it can accept crushed coal. It does not require further crushing or grinding of the coal. Also, it can produce syngas which is rich in methane and hydrogen. The product from the high-pressure reactor has a relatively high methane content compared to a non-pressurized reactor.

As this reactor operates at high pressure, according to the reaction kinetics at that high pressure, methane concentration will be significantly higher, whereas the carbon monoxide concentration will be less. Basically, at this high pressure, the carbon monoxide will convert to methane, as per the reaction we have discussed in our previous lectures. So, the high methane content of the product gas is a result of relatively low gasification temperature. And if oxygen is used as an injecting and gasifying medium, the exit gas can have a heating value significantly higher, like 450 BTU per standard cubic foot. So, if we are using, we can use air as well as oxygen.

If we are using oxygen, in such a case, the calorific value will be significantly higher. But if we use air, in such a case, the calorific value will be less because nitrogen gas will be present in the and that will reduce the calorific value of the gas. A high ratio of steam to oxygen helps to moderate temperature because we are using the steam at a higher ratio, so we can reduce the temperature of the combustion zone. If we are using pure oxygen, in such a case, the combustion zone temperature is significantly higher. But if we use steam, the steam also takes part in the reaction, and those reactions are endothermic. As a result, the temperature of the bed gets decreased. So, the use of steam actually helps to reduce the temperature of the reactor and ensures that the ash does not melt.

It does not reach to its aspersion temperature which is around 1200 to 1300 degree centigrade for most of the cases and as a result this ash will be removed as in the dry phase as in the solid phase not in the liquid phase as a molten slag. The crude gas leaving the gasifier contains a substantial amount of different type of condensable product including tar, oil, phenol, etc. As we have seen our previous plots here also, in this particularly if we see in this picture, so here we can see that Then after this drying and pyrolysis zone, whatever the VM is released, those VM directly goes to the syngas. It directly gets mixed to the syngas and it does not get adequate time or temperature for further reaction with the steam or oxygen so that it can convert to carbon monoxide, methane and other gas.

So, as a result, whatever the volatile material components are present there, most of them are reposed to the or they go to the along with the syngas. As a result, this syngas produced, it will have higher quantity of tar, similar type of oils and organic compounds, phenols, etc., which are separated or which has to be separated in a further next unit. a devolatilizer where gas is cleaned to remove unsaturated hydrocarbon and naphtha. So, if we are using this counter current reactor, in such case always the syngas will contain such type of organic compounds and further we have to clean syn gas as per the requirement. So that this material does not go to the syngas and does not create problem to the consumer exit raw syngas is about 550 degrees centigrade which has significantly higher temperature. So, heat has to be recovered from this which is further cooled down quench using the recycled water to as well as if we quench this or if we reduce the temperature of the reactor. Some of the oil tar will also get condensed and water jacket pulls the gasifier vessel and generates the part of steam need by the reactor whatever this water is used some part of this water is converted to steam and used during the inside the reactor for the gasification Further, this gas is subjected to the methanation as per the requirement that is CO plus 3H2 equals to CH2 plus H2O to produce high CO2. calorific value

gas. If we want to go for high calorific value gas, in such case, we have to ensure that this gas contains higher amount of methane and less amount of carbon monoxide because calorific value of the carbon monoxide is on the lower side. So, this gas is further subjected to methane reaction in a further reactor.

So, if we want to get a high calorific value gas for the industrial applications. Overall if we see major advantage or major characteristics of this Lurgi gasifier is that it has a very high cold gas thermal efficiency. What is this cold gas thermal efficiency? It is a measure that how much chemical energy from solid fuel is retained by the product gas. If we see the gasification process that means from coal. We produce CO and H2 and maybe some amount of CO2 and others. So, whatever the energy available at this coal how much energy we are retaining in this product gas which are the desirable product because in this process some of the energy is converted also to get product like CO2 and others. So, in such case energy is not efficiently transferred from coal to the syn gas as if we convert it to the carbon dioxide, so all the energy will be released at the gasifier itself so in such case energy available in the syn gas will be less. So, in this process as we are product is mostly constituted of carbon monoxide, hydrogen, methane and etc. and very less amount of carbon dioxide is there. So, whatever the calorific value or chemical energy is available in the coal, most of that energy is transferred to the product gases. That's why this energy is retained in the product gas. That means whatever the calorific value of the coal is there.

A substantial amount or a higher amount of this higher percentage of this chemical energy is available in the syn gas. So, there is no energy loss during this gasification. That is the main advantage of this Lurgi gasifier that it has a higher amount of cold gas efficiency. Simplicity of the gasifier configuration operation and it has a very high equipment efficiency and it has very low oxidant requirement like either we use oxygen or air. It needs less amount of oxygen or air as the steam is there and it does the major part of the gasification reaction as well as controlling the temperature and it can accept less feedstock, complex feedstock preparation because it can accept with the bigger size coal particle. As we are using coal particle of bigger size, we do not have to even grind and further process the coal particle so that they meet reactor requirement. As it uses the bigger size coal particle, our coal handling section or CHP units in the Plant will not be too much extensive. One very small CHP units will be adequate to meet the required coal size and coal quality required for the gasifier.

Product gas is at relatively low temperature as the product gas is about low temperature of about 600 degrees centigrade. So, it does not need any expensive high temperature heat recover unit. If the product gas comes out at 1000 degree or 1200 degree centigrade, a significant amount of our mass more expensive heat recovery unit is required to recover all the sensitive heat as well as the other type of heat is available in the syn gas. As the temperature is on the 500 to 600 degrees centigrade we can use low-cost heat recovery units for this plant and we can use the feedstock flexibility they are suitable to handle coal with high reactivity moisture. It can use coal with different type of reactivity whether it is a slowly reactive or high reactive. That means it is poor reactivity is less or high. All these types of coal can be accepted because the retention time or reactivity The space time for the reaction is about one hour and higher. So even the coal reacts very slowly, it can get adequate time for conversion to the carbon monoxide and other to the syn gas. So, it can accept any type of coal with respect of their reactivity.

It is their highly reactive or low reactive, all these are accepted in this reactor. And more reactive feedstock is preferred as they will do this reaction very quickly. And we can increase the coal gasification rate. And they will react at maybe at the low temperature operation. As their operation is low temperature, it is preferable that the reactive feedstock should be highly reactive. And even if the feedstock is low reactive, it will take lot of time for the reaction. But it can convert it. and if we see the other advantages it has a higher methane content in the product gas so whatever the product gas is there methane concentration is on the significantly higher side, that's why it can be used as an fuel gas to the other consumer industries and limited ability to handle coal fines, as it cannot handle the coal fines because the coal finds can block the inside the locations pores and others and it can create a solid bed through which oxygen and other gases cannot move. So that's why it needs the bigger size or lump size coal of 2 mm 4 mm 10 mm etc. not in the final size like 0.5 mm or 200 micron it cannot handle the final size coal Coking coal cannot be used there because the temperature is 500 to 600 or 1000 degree centigrade. So, swelling of the coal will occur and that will create problems in the gasifier. So, coking coal is not suitable for this gasifier. It has to be non-coking coal. If it has to use any coking coal, so at the in any other units, this caking property has to be removed by heating it or by any other way. Long feedstock residence time in the gasifier and slow characteristics, overall, it takes the longer time in the gasifier, so overall if we want a very high flow rate gasification, we need a very bigger plant or bigger size gasifier or many three four units or ten units has to be operated in parallel to meet the required gas demand and there has to be control for field size distribution for proper operation.

So, hydrocarbon liquids such as tar and oil are produced as it is a counter-current reactor, and all these volatile materials get mixed with the product gases, syngas. So, their percentage, like tar, oil, other materials, and organic compounds, will be significantly higher in the syngas, and they have to be cleaned accordingly. So, there needs to be increased efforts to clean these. Produced gas, if it is used for applications other than direct heating—if we use these gases for direct heating in the next unit—then all this tar and oil is acceptable. But if it is used in other plants where they are not acceptable, or if we are to transport syngas over long distances, then tar, oil, etc., must be removed, or this syngas must be cleaned; otherwise, it will create different types of corrosion and erosion problems in the pipeline. and explosion hazards without carefully monitoring the system. As coal particles stay there for a long time—about one hour at temperatures of 500 to 700 or 1000 degrees centigrade—it can have explosion hazards.

Although we can monitor it, we can avoid it by continuously monitoring it. So, overall, this unit must be monitored continuously so that it does not create any explosion hazard. So, overall, if we summarize and see the advantages and disadvantages of this Lurgi gasifier. This Lurgi gasifier is a very well-proven technology. It was developed successfully. Before World War II in Germany, and it is well accepted worldwide. It can accept bigger-sized coal particles, which is the major advantage. Coal particles do not have to be crushed and ground, so any coal having high ash content or any coal with high. HGI value is very low, meaning if B coal is very hard. All types of coal can be gasified in this unit, irrespective of their calorific value and other factors, and that is the main reason this Lurgi gasifier is used. Also, the methane concentration in the product gas is higher, which makes the syngas with high calorific value suitable for different other units like thermal power plants, cement plants, or other units. So, they can use this Lurgi gasifier. for their gas requirement or fuel gas requirement if they want to use gaseous fuel in their reactor.

Thank you.