Clean Coal Technology

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Week-10

Lecture-48

Hi, I am Professor Barun Kumar Nandi, welcoming you to the NPTEL online certification course on clean coal technology. We are at module 10, discussing coal gasification. In this module, we are discussing different types of gasification reactors as used in different industrial practices, like fixed bed and moving bed reactors. In this lecture, I will be discussing the fluidized bed reactor. So, let's start lecture 3 on fluidized bed and other similar types of gasifiers. If we see the fluidized bed reactor, the fluidized bed reactor or fluidized bed gasifier works on a similar principle, in a similar way to how fluidized bed combustor units operate. We have discussed fluidized bed combustion units in our previous lectures in the combustion chapters. So, the fluidized bed gasifier is also the same or a similar unit, with the only difference being that in the case of a fluidized bed combustor, we use only air for combustion. Here, we have to use air, steam, and other materials as per the requirements of gasification, as well as the bed medium or other materials like limestone, depending on our needs. So, overall, the working principle of this fluidized bed gasifier is exactly the same or similar to that of a fluidized bed combustor or a fluidized bed dryer. So, in this case, for a fluidized bed gasifier, we use air or steam as the fluidized bed medium and as the reactor. In this case, air or steam is used to fluidize the solid fuel. This solid fuel can be any type of carbon-based feedstock or hydrocarbon feedstock, such as coal, different types of biomasses, or waste coke particles obtained from steel plants or other similar industries, and similar types of other feedstock. We can gasify all of them in the same unit simultaneously, which is the major advantage of the fluidized bed gasifier over other types of gasifiers. So, in the same unit, we can simultaneously use coal, biomass, other hydrocarbon feedstock, and even a wide variety of biomass, including agricultural waste, municipal waste, garden waste, etc. Here, we also use bed material to control the reactor's temperature and improve the gasification reaction, as this bed material helps maintain the temperature and remove ash particles generated from the coal particles during the gasification reaction. We can also use limestone or similar materials to capture sulfur-related gases. We can use limestone, dolomite, or similar white materials as per our requirements.

So, they can also be added in the gasifier unit. And in this fluidized bed gasifier, we can also use high-ash coal. Particularly, the problem with other types of gasifiers is that in those gasifiers, depending on the temperature and pressure operated, in most cases, high-ash coal cannot be used. They have other types of limitations also. Like if we go for very fine particle gasification units, in such cases, we cannot grind the coal to a very small size. And if we use other high-temperature reactors also, in such cases, the ash fusion and ash melting can create some problems. But in the case of fluidized bed gasifiers, we can use high-ash coal irrespective of its ash percentage. So as a result, any type of coal, like in the similar way we have used during fluidized bed combustion, in fluidized bed gasification also, we can use any type of coal irrespective of its ash percentage, like low-ash coal, high-ash coal, adversary rejects, tailings—all can be used in the coal gasifier. Along with the biomass and others, and particularly the addition of biomass improves the hydrocarbon structure and the hydrogen sources in the feedstock. So as a result, product gases will be rich in hydrogen and other methane-like gases. Gasification happens in a bed of inert material, which is usually hot, typically made of sand and alumina, as we have discussed earlier, and is supported through an upward movement of the gasifying medium.

And as the flow rate of gas increases, this bed material starts rising and becomes fluidized. As we have seen in our previous fluidized bed combustion chapters, like here on this side, we charge the bed material, oxygen, and others from these three inputs. So, from this location, all the coal particles will be fluidized in this medium and they will react with the steam, oxygen, and other gaseous reactants. And they will be gasified, and this product gas will go to this unit. Here, the cyclone separator recirculates the unburned carbon and other materials, and the flue gas. In such a case, it will be the syngas, which will go to further purification units. So different designs of reactors are there, depending on the design, type of feedstock, and others and accordingly, we can use the bed material, other materials, and fluidization gases at different locations. So, minor variations in the design may exist. But overall, this is the fluidized bed where the primary air or reactant medium, like air and steam, is used to fluidize the coal particles, biomass particles, all in this zone. And they will perform the gasification reaction here. And further, they will go to the cyclone separator.

The cyclone separator recycles some of the unburned carbon particles and unburned fuel particles, which still require gasification. As well, it recirculates some of the unburned ash, bottom ash, and other materials to maintain the reactor's temperature. And the product gas, which is mostly syngas, will go to further purification units. So, overall, if we examine the operating principles of the fluidized bed gasifier, this fluidization process increases the reactivity between the bed material, inert material, and biomass. The reason we prefer fluidized bed gasification in some cases compared to Lurgi gasifiers or other types of gasifiers is that in the case of high-ash coal or if the coal reactivity is low, meaning the coal has very little reactivity, it requires a longer residence time inside the reactor. This is sometimes available in the Lurgi gasifier but may not be available in all cases. And even if its ash percentage is significantly higher, in such cases, the Lurgi gasifier cannot operate efficiently. In such cases, we can opt for the fluidized bed gasifier, where this fluidized bed The coal particles will be present, and the bed material will continuously have friction and collisions with these coal particles, continuously removing the generated ash layer or ash particles from the coal surface.

Every time the coal surface gets freshly exposed with the hydrocarbon layer, which will react with steam and other elements. So, even if the reactivity of the coal is less, the overall yield of the reactions can be significantly higher. Similarly, if there is a wide mixture of hydrocarbon feedstock like coal, biomass, and others, each of them has individual residence time, reaction medium, and reaction time. The material can even be reacted in the same reactor, where biomass reaction can be very fast, whereas the coal reaction can be slow. However, we can blend them in the gasifier, and all can be co-gasified in the same unit, yielding a constant amount of syngas with relatively stable composition from the output. So, the rate of reaction is higher in the case of fluidized bed gasification compared to fixed bed or moving bed gasification.

Here, the ash layer is continuously removed from the coal surface, so the reactivity and rate of reaction are relatively higher compared to fixed bed or moving bed reactors like the Lurgi gasifier. Due to the enhanced performance of the fluidized bed system over the fixed bed, it can operate with a wider range of biomass feedstock materials even at a large scale, potentially yielding gas with a high calorific value. However, fluidized bed systems are quite costly, requiring a fluidization medium and many control equipment, with a more complex structure compared to other reactor types. This is actually the schematic diagram of the fluidized bed reactor, where the feedstock or feed is introduced here.

It is kept in this lock hopper, where it stays for a longer time, and as per requirement, it is sent to the feed screw and then to the fluidized bed as needed. From the bottom side, oxygen and air flow enter at this location. Here, air, steam, and other gaseous mediums enter, while coal particles and fluidized bed material are inserted and fluidized in this reactor. All these gases then proceed to the cyclone separator, where heavy particles are recycled back. After the reaction is complete, the generated ash particles move to the cooling chamber, where heat recovery units operate to recover heat. The cooled ash then exits at the bottom through the lock hopper and is released in dry powder form as needed. The syngas is obtained through the cooling units for heat recovery and can be further purified before being sent to consumers. In a similar way, there are other types of reactors, one of which is the Winkler gasifier. This is the oldest fluidized bed gasifier and has been commercially used for many years.

Depending on its operation condition we can group Winkler gasification under low temperature gasifier and high temperature types also. Here, in case of such gasifier operates at the atmospheric condition and it is a refractory line shift reactor and it can use coal particle of about 10 mm size. So, this gasifier uses the bigger size coal particle of about 10 mm and it operates at the atmospheric condition. Coal is continuously feed by screw conveyor. From a pressurized hopper and fluidized by a primarily blast off immediately above the primary grate and a secondary blast ash above the fluidized bed serves to gasify any of the unreacted char in the product steam. Ash is not leaving with the steam and is removed as an external cyclone is withdrawn to the base. of the reactor by mean of a rotating scraper. So, this is a typically schematic diagram of a Winkler gasifier. Here we can feed the biomass, coal and other from this unit. It will be kept as the lock hopper and this is the charge being from here coal particle and other material will get charged.

It will charge to this location. This is the location for the feed screw conveyor which will charge the material here and from this location it will get gasified. Gasified reaction will occur. It will again go to the cyclone separator and will return back and it will go to the ash discharge system and here it will go to the syngas will go to this system for the further cooling and we can get the product gas.

So overall, it is the fluidized bed gasifier, but somehow an older design is present in this gasifier. So, depending on whether producer gas or steam gas is to be mixed, either an air-steam or oxygen-steam blast is used. If we want to produce only steam gas without any hydrogen gas, in such cases, only oxygen or air is used. If we want some amount of hydrogen and methane gas to be on the higher side, which is known as water gas, in such cases, oxygen along with the steam blast is also used. And the output can be varied over a relatively wide range without appreciable loss of efficiency.

Typically, syngas will contain about 36 to 37% hydrogen, 45% carbon monoxide, and about 16% carbon dioxide. However, owing to the construction of the reactor, the maximum temperature does not exceed 980 degrees centigrade. So, it is as it is the fluidized bed reactor. It does not use temperatures above 1000 degrees centigrade. So, the reactor temperature is similar to other types of fluidized bed reactors, which operate below 1000 degrees centigrade, and these restrict fuel gasification to ignite and sub-bituminous coal only. As this gasifier temperature is low, it operates only under atmospheric conditions. So, very difficult hydrocarbons or very long-chain hydrocarbons, which require high temperatures for gasification, cannot be gasified in this unit. So, this is the typical drawback of the fluidized bed gasifier or similar types of gasifiers. If we gasify coal at lower temperatures below 1000 degrees centigrade, there can be many types of hydrocarbons that will not react with steam because they are for their reaction, their activation energy will be high. They have to break their bond between the hydrocarbon. We have to operate it maybe at higher temperature above 1000 degree centigrade. So, in such case, in such this type of gasifier. Only low maturity coal which does not contain any complex hydrocarbons, only those can be gasified. But if any coal has very high maturity like anthracite coal or any similar type of material which needs only high temperature for the reaction so that it can react with oxygen and steam, those material cannot be gasified in this system.

In the low molecular weight material, biomass material like lignite, sub-Bituminous coal, biomass and municipal solid waste, they all can be gasified in this same unit. Typically, high rank coal is as of rule insufficiently react to such comparatively low temperature and at atmospheric condition. But now with the use of pressurized reactor they can be used. So, typically if the reactor is operated on atmospheric condition, they cannot gasify any complex molecules which are typically present in high rank coal. But if we use the highly pressurized reactor maybe with some catalyst or other medium, they can be used even in this type of reactor. But it is always better that we should go for high temperature reactor for the high rank coal. This is the typical schematic diagram of the such gasifier. It is similar with that of other type of fluidized bed gasifier where we feed the oxygen and steam at this point. It will gasify in this way. We get the raw gas here. Here we go for the heat recovery and any fly ash particle recovery, and further it will go for any modification like shift reaction, purification, methanation reaction, dehydration, and we can get all the natural gas or synthesis gas at this point. This circuit is very similar to that of any other industrial circuit units, and this is the location where we will get the ash or bottom ash particles. Another type of gasifier is the KRW gasifier. In this KRW gasifier, it is a pressurized reactor where the feed is dry, and it is a fluidized bed but in the slagging reactor, which can work even at high temperatures. The gasifier was developed by the scientist M.W. Kellogg company. This KR gasifier can gasify all types of coal as they use high temperatures, including high-sulfur coal, low-rank coal, and highly swelling coal. If we use high temperatures, then we can use swelling coal, which means we can use both coking coal and non-coking coal because, at extremely high temperatures, these swelling characteristics will not create any problems and can easily be overcome in this reactor. Crushed coal and limestone, typically less than one-fourth in (about 6 mm in size), are fed into the bottom of the gasifier with air and oxygen entering through the concentric layer at high-velocity jets. This ensures thorough mixing of fuel and steam. The coal immediately releases volatile material after entering the gasifier, which oxidizes rapidly, producing heat for the gasification reaction.

This is the typical reactor design. Here, we send the oxygen, recycled fines, recycled gas, and we can send the feedstock here. They will immediately gasify at very high velocity at this point, and in this particular zone, all of the coal will release volatile material and burn there. In this particular zone, they will undergo reduction and combustion reactions, and we can get the steam gas from this location. Another method for gasification is the Kopper-Totzek gasifier. In this gasifier, which has been commercially used since long time in 1938, it is an entrained solid-fuel gasifier where we use the coal fines at atmospheric pressure. This reactor uses typically relatively small cylindrical and refractory line coal burner into which coal oxygen steam are injected through two or four tangentially disposed burner head. So, this gasifier is very much similar to that of pulverized coal combustor where we feed the powder size coal from the different point in a reactor. From the different points it can be four points or it can be two feeding points that is it can be a two four two or four tangentially disposal point or burner head steam is introduced around these heads to cover the reaction zone and protect the vessel wall from excessive heat product gas is taken up through the collector pipe at the top and ash leaves at the bottom as molten slag through the bottom. So overall if we see this reactor is typically use powder size coal of 200 mesh or similar size. So, they can be charged from different either two or four charging point at similar to that of any pulverized coal combustor. So, the powder coal will charge here. They will react in this gasification zone and this gasification will occur at extremely high temperature.

So, at this high temperature all this particle will get immediately gasified within a shorter span of time as the temperature is excessively high. And as this temperature is excessively high all the ash particle will come as a molten slag through this reactor and we will get the product gas at this particular point. This is the bigger image. So, we can send the pulverized coal and oxygen here. We can send the steam from this point. So they will enter at this particular location. This is the main gasification zone and molten slag will come to this path and product gases will go to these locations and where we can use the boiler and other material which can use the generated heat during the gasification. So main advantage or major aspects of this gasifier is that the feed coal from the process is typically crushed and they are passed, 70% of the particle will pass to the 75-micron size that is 200 mesh which is same with that of any of the pulverized coal combustion unit. They mixed with oxygen and low-pressure steam. injected into the gasifier through a burner head. The heads are spaced either 180 degree or 90 degrees apart depending on the two feed or four head. If it is the two head, they will have gap of 180 degree because in such case they will start release from this point. If they are four head, they will start from four different point so that there is a difference of 90 degree of each of the burner locations. So, they will be either two headed or four headed proposed burner arrangement and they are designed such that steam envelops the flame and protects the reactor wall from excessive heat as they will be charged here. So, the very outer side of this area may be at very high temperature to avoid that at excessively high temperature refractory wall may get damaged.

So, this steam is charged from this location. So that they will maintain the temperature on the lower side so that the overall the outside zone of this main flame zone which will be of the lower temperature and it will not damage the refractory material this reactor typically operates at an exit temperature of about 1480 degree centigrade and the pressure is maintained just slightly above the atmospheric condition. So, this reactor operates at excessively high temperature of 1480 to a higher temperature even at one atmospheric pressure. Only about 85 to 90% of the total carbon may be gasified in a single pass. Now at this high temperature even at this high temperature depending on the hydrocarbon structure and their component.

In a single pass, about 85 to 90% of the material will get gasified, and further, they have to be recycled back so that the remaining amount of gasified material can be gasified. So, if this carbon per person is totally functional, it depends on the reactivity of the coal, and if we use low-rank coal, this reactivity can be 100%. As this entire reaction between coal particles, steam, and oxygen is a chemical reaction, it all depends on the reactivity. If the molecular bonding between the hydrocarbons is excessively strong, in such cases, they need high temperatures. So, even at very high temperatures, about 85 to 90 percent of the bonds will break and undergo gasification. So, we have to recycle this material for further gasification so that all the material can be gasified. But if we use low-rank coal like lignite or semi-bituminous coal, it can achieve 100% in a single pass. So, if we use biomass and other types of materials in this reactor, they will be gasified immediately in a single pass. But if we use high-rank coal, it will take some more time. But overall, if we see that in this reactor, we can operate even at very high temperatures of 1500 to 1900 degrees centigrade in this chamber. This product gas leaves the gasifier at about 1400 to 1500 degrees centigrade and is passed through a radiation boiler, which recovers the heat, and a waste heat boiler for the recovery of sensible heat. An appreciable amount of coal dust is carried out with syngas as we are using pulverized coal, and they are released at just slightly above one atmosphere. Some of the dust particles will also go with the syngas, so this is removed in the dust catchers, and the coal is used once again. Half of the ash is deposited on the gasifier wall as a fluid slag because, at this temperature of above 1500 degrees centigrade, coal ash fusion will occur. So, the ash will get fused and stick to the wall of the refractory material. It flows down and is finally removed at the bottom wall.

This process generates no tar and yields a substantially methane free synthesis gas. Particularly if we see the other gasification process where temperature of the gasification is on the lower side. Now if we operate the coal gasifier or coal combustor at lower temperature, some of the hydrocarbon which is very complex in nature, they may not react. So, in such case, probability of having some amount of tar or unburned hydrocarbon will be there, which will create impurity in the syn gas as well as the yield of the gas will be less. But as this reactor operates at a very high temperature, all the tar and other material will react very fast and they will all get converted to syngas component either methane or hydrogen or similar type of gases. So at this temperature there will be no organic compounds or very less amount of organic compounds, VOC compound will be there in the syn gas and depending on the temperature and reaction kinetics, there can have very less amount of methane in this gas and typically it will contains most of the material 30 to 32 percent will be of hydrogen, remaining 55 percent of carbon monoxide and about 12 percent of carbon dioxide The heat of the reactor causes formation of slag as this temperature is excessively high, always the ash will get molten, it will create some slag and it is removed from the bottom of the gasifier through a water seal which will reduce the temperature of the slag and we can collect it. gases and vaporized hydrocarbon produced by the coal immediately passed a very high temperature which they decompose rapidly very rapidly so that the coal particle in the plastic says do not get agglomerate so if we can see that the entire coal particle they are exposing to very high temperature at very high velocity and their particle size is very less So, even if the coal has the caking tendency or they are having the swelling tendency, they will not get adequate time to show their fluid properties or to get it swelled.

So, all these properties will not have any impact because within the shorter time all the hydrocarbon will be converted to gaseous product. So, all the plastic properties will not have any impact. during the inside the reactor typically if we use the coking coal in a combustor. The coal will show the caking properties it will swell increase its volume and creates lots of operation difficulty. That's why the coking coal is typically not suitable for combustion applications as well as some of the gasifier applications but in this case as we are operating it at very high temperature and with a very shorter residence time at a very small particle size of 75-micron coal particle will not be able to show any of their plastic properties they will immediately react with the oxygen and steam. So, we can use any type of coal can be classified irrespective of their caking tendencies, ash content, ash fusion temperature and others High operating temperature ensures that the gas product does not contain any type of ammonia, tar, phenol or any condensable hydrocarbon as it is operating at very high temperature.

So even if ammonia is present, it will also get oxidized to form nitrogen and similar compounds. The tar and phenol will also get oxidized and react with the steam. Similarly, any type of condensable hydrocarbon will also react with the steam. As a result, we get highly pure syngas without any major impurities from the coal. The raw gas can be upgraded to synthesis gas by reacting carbon monoxide with steam to produce additional hydrogen and carbon dioxide. If we want the raw gas to be free from carbon monoxide, we can further react it with other reactants as per the coal gasification reaction scheme, so all carbon monoxide reacts with steam to produce H_2. That means this reaction will occur. It will produce CO_2 and H_2. These reactions can occur depending on the reaction kinetics and the conditions provided. The major advantage of this reactor is its ability to accept all types of coal without prior treatment, other than pulverization, and some flexibility in ash removal.

The major advantage of this reaction is that it can accept all types of coal, whether caking or non-caking. Highly mature coal, high-rank coal, low-rank coal, or biomass—whatever is present—it can accept all types. Even if the coal has a high or low ash fusion temperature, all can be gasified in this reactor. The only requirement is that they must be pulverized to 75 microns. That is the only requirement coal preparation once in this unit, instead of being trapped as slag ash, can also be desired as the fly ash with the raw single, then separated from as an external cycle separator. The high operating temperature also allows very fast gasification as it works at very high temperatures. Gasification can occur at a very high rate or very fast rate. In view of the exceptionally high capacity and modest cost of the Kopper-Totzek reactor, its relatively low carbon inventory and consequent above-average oxygen consumption are generally not serious disadvantages. Overall, they are very good. And they don't consume a very high amount of oxygen, and they don't have any major disadvantages. The disadvantage is only that it can have some amount of loss of sensible heat with the raw syngas as they are going at a relatively higher temperature of 1200 to 1480 degrees centigrade. So, there needs to be a cooling down, and some heat recovery units have to be there. Further, they have to be cleaned as per the requirement. As per the requirement of the downstream chemical synthesis process.

Thank you.