Clean Coal Technology

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Lecture-44

Hi, I am Professor Barun Kumar Nandi, welcoming you to the NPTEL online certification course on clean coal technology. We are in module 9, discussing the fundamentals of coal gasification. So, in the previous lectures, we have covered the fundamentals of coal gasification, including different types of chemical reactions and types of gasifying agents like oxygen, air, steam, etc. So, in this lecture, I will be covering the effect of coal properties on coal gasification. So, let's start the lecture on fuel properties and gasification.

So, whenever we see the major differences as well as similarities between coal gasification and coal combustion, it is that the same chemical reactions or similar types of chemical reactions happen where the coal hydrocarbons react with the gasifying agents or oxidizing agents, depending on whether it is gasification or combustion. So, overall, it is again the chemical reactions between the coal hydrocarbons and the gaseous reagents. Those reagents can be oxygen, steam, carbon monoxide, carbon dioxide, hydrogen, etc. So, overall, it is like a solid plus gas-phase reaction where coal or any such feedstock like coal, biomass, or other feedstocks are in the solid phase, and oxygen, carbon dioxide, carbon monoxide, or steam—whatever is there—is in the gaseous phase. So, overall, it is the solid and gas chemical reaction, whether it is in combustion or gasification. Overall, it is a chemical reaction between a solid and gaseous material. So, whatever the impact of other parameters is, we have seen during coal combustion that a similar impact or similar parameter effect will be here also in coal gasification. Like we have seen that during coal combustion, we have the TGA and DTG analysis. Its reactivity analysis includes ignition temperature, peak temperature, and burnout temperature. At a certain temperature, the rate of reaction is significantly high.

At a certain temperature, the rate of reaction is low. Some of the coal reacts very fast, while some reacts very slowly. The ash layer, the impact of moisture, the impact of mineral matter composition, and its percentage all play different roles during coal combustion. All these parameters will again play a similar role. That role may not be exactly the same, but it will be similar during gasification, as it is the same solid-gas reaction. Here, the coal reactivity is the main parameter. The types of hydrocarbons present in coal also matter. These hydrocarbons react with reactant gases like oxygen or steam. This reactivity is the main parameter in determining gasification kinetics. If these hydrocarbons react easily with oxygen or steam, then the reaction rate will be significantly higher. If the hydrocarbons are inert in nature, they require higher activation energy for the reaction. In such cases, the rate of chemical reaction will be low. Thus, coal reactivity is the main parameter. It determines whether the reaction will be very fast or very slow. Here, we can also obtain similar TGA-DTG plots to identify why some coal reacts and why some does not. These TGA-DTG plots can also be obtained for gasification reactions under similar atmospheric conditions if maintained in the TGA analyzer.

Here, the mineral matter—its composition, its percentage, what materials are present in the mineral matter—is it silica or alumina? Is it sodium, potassium, calcium, magnesium? What oxides or salts are there? They will play an important role during the chemical reaction. Similarly, the volatile material and fixed carbon represent the different types of hydrocarbons present in the coal. So, if volatile material components like hydrocarbons are part of the volatile material, they are either highly reactive or non-reactive components. With oxygen or steam, the rate of reaction will vary, and accordingly, the product gas may have different compositions. In some cases, hydrogen will be high; in others, carbon monoxide concentration will be high. That all depends on the volatile material composition, its reactivity, and the same applies to the fixed carbon. So, they all play an important role during gasification.

As it is a chemical reaction among the hydrocarbons present in coal and reactant gases like oxygen, carbon monoxide, H2, etc., reactions occur at the individual component level. So, all reactions happen individually—like any particular hydrocarbon reacting with carbon monoxide, another hydrocarbon reacting with steam. A third hydrocarbon reacts with hydrogen. So, individual reactions happening with the hydrocarbons as well as the reactant gases will decide the rate of reaction as well as the rate of gasification. Reactions and types of products, volumetric yield, and other factors are also influenced. Similarly, mineral matter composition can have a positive or negative effect—whether any mineral matter acts as a catalyst or an inhibitor during the chemical reaction. So, they will decide whether the rate of reaction will be fast or slow. So, the mineral matter percentage and composition may or may not have a positive or negative impact during such chemical reactions.

So, all these chemical reactions are like combustion reactions. It is simply a reaction between hydrocarbons and reactant gases in the presence of some impurities. Hence, reaction kinetics and product composition will vary depending on the coal composition, reaction conditions, etc. Typically, during gasification, we can use coal as it is the most widely available hydrocarbon-rich material. But we can also use other types of coal, like lignite, maybe coke, maybe biomass, maybe municipal solid waste, which has a hydrocarbon residue part. So, all these materials can be part of coal gasification or the gasification process.

So, feedstock may contain either a single material like coal or it can be a blend of coal, coke, lignite, biomass, municipal solid waste, etc. as per the availability. And depending on this single fuel or blended fuel, the product gas composition will vary. If you are using solid waste material, in such cases, the municipal solid waste mostly contains agricultural waste and other waste. So those are typically highly rich in volatile material, so their reactivity is different, similarly with the case of biomass. But if you are using coke, it is a highly carbon-rich material, and the hydrogen percentage is less. In such cases, carbon monoxide concentration will be higher, and hydrogen and methane concentrations will be less.

Similarly, for lignite, its moisture concentration is significantly higher, and the hydrogen percentage is significantly higher, while the carbon percentage is less. In the case of coal, depending on rank, it may have different components. So, we can do this gasification with all these materials, either at a single source or as a blended source. This decision is made based on the availability, location, and purpose of these gasification plants. If we are only using coal, which typically happens in the case of single-source coal mines or near coal mines, we can use biomass and municipal solid waste where their availability is significantly higher. So, in such cases, the purpose of classification is only to utilize this municipal solid waste and biomass to get some of the energy or some of the product gases from the gasification. So, purpose and reaction kinetics will depend on the location—why we are doing this classification and where we are doing this classification and depending on the feedstock, there are different types of reactors available, like fixed-bed reactors or fluidized-bed reactors, which are similar to what we have seen in the case of pulverized coal combustion, fluidized combustion, fuel-bed combustion, etc. So here also, we can get different types of gasifiers. We have also seen co-current and counter-current gasification, etc. So, all these can accommodate different types of feedstocks. An overall fixed-bed gasifier can accommodate moisture content up to 35%. Here, the difference between coal combustion and coal gasification is that during coal combustion, moisture content is not required, as it acts as an impurity. But during gasification, even if moisture is present, it can also act as a gasifying agent. So here, we can use a certainly higher percentage of moisture in the coal.

So here in the fixed bed gasifier, we can take even up to 35% moisture in the coal, provided that the ash percentage is not significantly higher. If moisture is also higher and ash is also higher, then it will be very difficult to react that coal to gas. Started reacting that coal because high moisture content will take the entire heat release for the removal of moisture, and then mineral matter will also create problems during the reaction. So, in the case of gasification, we can accept even inferior quality types of coal. That is the purpose of why we do gasification. In the case of combustion, we typically avoid using such inferior quality coal where 35 percent moisture is present. So, the coal particles or coal which is not suitable for combustion purposes can be used here. By gasifying them, producing some syngas, and that syngas we can use for other purposes.

Pre-drying may be required if moisture and ash content are on the higher side. If all of them are on the extremely higher side, particularly moisture, because it is very sensitive to the heat requirement for the initial starting reaction. So, in such cases, drying may be required; otherwise, as such, drying may not be needed, and the entire feedstock may be charged to the reactor after adjusting the suitable particle size. The entrained flow reactor or fluidized bed gasifier needs moisture content to be reduced to lower than five percent because their temperature is on the lower side, as well as to improve coal hardenability, since in entrained flow we need fine coal particles. So, depending on the size requirement and other factors, the moisture content of the coal should be on the lower side. So that they can be handled and charged to the reactor. In the internal flow system, the residual moisture contributes to the gasification system but requires heat to evaporate it. The moisture content of the coal is significantly higher.

In such cases, the input heat required for evaporation will be significantly higher. But that produced moisture can also act as a gasifying agent or reactant to improve the gasification. Chemical composition may affect the reaction kinetics as well as the ash fusion, heat transfer, and temperature control inside the reactor. If we see the impact of ash. That ash or mineral matter is an impurity in the coal.

So, components of the ash, such as sodium oxides, potassium oxides, alumina, silica, or whatever is present, are there. They may affect the reaction kinetics. Some of the material can help in the reaction kinetics by providing a positive impact. Some can have a negative impact. Also, some of this material may improve heat transfer, as during the gasification reaction, coal particles need to be heated. So, if the heat is transferred quickly—as if the material is highly conductive of heat—the reaction can happen very fast, and the gasification rate will be significantly higher. But if that coal particle has a very poor heat transfer coefficient due to the particular composition of ash, then in such a case, it may take longer to reach higher temperatures and to react. In such cases, reaction kinetics will be different. Similarly, if the heat transfer coefficient is very low, the coal particle may not achieve higher temperatures, and if the temperature of the coal particle is on the lower side, even though the reactor temperature may be higher, the coal particle temperature may be on the lower side. The product gas may contain carbon monoxide or carbon dioxide, depending on the temperature of the coal particle. So, the composition of the mineral matter in coal or the composition of ash has a significant effect or a major impact during gasification. So, ash should be kept as low as possible so that its impact is minimized, since provisions must be made for introducing and withdrawing it from the system.

Another role of ash or mineral matter is that, as they are inert materials, they typically act or are used to control the temperature of the reactor. Any ash presents at high temperatures—1000 degrees or 800 degrees Celsius—can maintain the bed temperature or reactor temperature around that same 1000 or 800 degrees Celsius. If ash is not continuously removed at a higher rate, it is highly possible that the temperature of the reactor may fluctuate significantly. So, in such cases, it acts like a fluidized bed temperature control reactor here, ash also acts as a temperature-controlling medium to control or keep the temperature of the reactor fixed. That's why in a fluidized bed reactor or similar reactor; provisions are there where we can add ash material as an inert material to only control the temperature. Other purposes include using ash as a heat transfer medium, either as a flow counter-current to the product gasification in gasification fixed bed reactors and others. In fixed bed systems, ash accumulates at the base of the fuel bed and is withdrawn by mechanical systems. Typically, in the fixed bed after the gasification reaction occurs, whatever ash is there goes to the bottom side and is withdrawn as bottom ash through some mechanical arrangement using a mechanical grate or any similar condition. However, it is preferable that it should not reach the ash fusion temperature, like in an unfused stage. In such cases, we can get solid ash particles ash at a higher temperature.

If we reach the ash fusion temperature or if the reaction has to be conducted at very high temperatures, then ash fusion may occur. So, in such cases, we can get the liquid stage. In the entrained flow reactor, it is removed as liquid slag because, in entrained flow reactors, the temperature of the reactor is significantly higher. In such cases, ash fusion or ash melting occurs. So, this ash fusion temperature is a measure of when ash will melt and transfer from solid to liquid phase.

Temperature is an important parameter in the design and operation of gasifying systems for those that operate below the ash fusion temperature to avoid fusion, sintering, or clinkering of the ash, as well as for gasification systems that operate above the ash fusion temperature to promote slag formation. Also important is another characteristic of ash: the relationship between temperature and ash viscosity. Changes in the flow characteristics of the slag are critical. So, if we see here, ash fusion conditions in the reactor are extremely dangerous and undesirable in any reactor, whether it's a diesel combustor or a gasifier. The difference is that, in the case of a combustor, we can avoid utilizing this ash fusion temperature by controlling the combustion reactor at 1200 degrees or nearby temperatures. But in both the cases, the rate of reactions can be different. That in case of combustion, if we are operating reactions at lower temperature, rate of reaction can be different. But the product gas composition, it will always be having carbon dioxide. But in case of gasification, if we operate the gasifier even at lower temperature or below 12.8 degree centigrade, the product gas composition will be different. like if we operate at lower temperature carbon dioxide concentration will be higher, if we operate the reactor at high temperature carbon monoxide concentration will be higher. Similarly shift reaction methanation reaction and other reactions may happens may not happens depending on the temperature. So, in case of gasification, it is not that we can always avoid ash fusion.

Ash fusion may be there but we may have to operate this reactor even at high temperature to get the desirable product gas composition because in the gasification the product gas composition is important whether we need methane or we need hydrogen, otherwise if we operate slow temperature we can get CO and CO2. So, if we need methane hydrogen and other gases or if we need CO2, CO and other gases that depends on the reaction kinetics. So here we and if we change the temperature product may have higher amount of methane or higher amount of hydrogen So temperature we cannot avoid to keep it only on the lower side. Temperature is decided by the reaction kinetics and feed composition like coal or biomass. So, as we need the desirable product, we may have to operate the reactor even at high temperature. So, we cannot always avoid creating some ash fusion or slag formation from the reactor. So, this is not the possible in always cases that some of the cases we have to operate the reactor even at higher temperature only to get the desirable product in the composition. In the fluidized bed system, the ash is mixed with the char and this ash is separated by either in sintering or agglomeration of the ash and circulation from the weighed through a fully entrained combustor and milled on separate in the liquid slag. Ash constitutes are important at the selection of material of construction and particularly slagging combustor.

In addition, proper ash composition or chemical manipulation through the addition of a fluxing agent is also necessary for achieving desirable slagging operation. If we want ash fusion to occur—whether it is ash fusion or slagging—what are the characteristics, such as viscosity and other properties? To modify these, sometimes external chemicals or impurities are added, which are called fluxing agents. So, this fluxing agent will react with the material and may form some different compounds to modify the slagging characteristics, viscosity, and other properties. Now, if we discuss the role of volatile material. Volatile material from coal can contribute to the product of gasification without requiring steam recompositing or oxygen consumption. If we observe in co-current or counter-current flow reactors, this volatile material may undergo decomposition or thermal reaction with the gasification process, or it may not participate in the gasification reaction, depending on the reactor design. If the volatile material enters the gasification reactor, meaning these gases are again exposed to the high-temperature zone, they will decompose and form hydrogen and other gases. form hydrogen and other gases. But if these volatile materials do not reach the high-temperature zone and instead mix directly with the product gases, the volatile material can become part of the product gases. So, the volatile material from coal can have a major impact on the flue gas or gasification gas composition. If this volatile material passes through the reactor, then all of it will participate in the coal gasification process. In such cases, the concentration of hydrogen and other gases will be higher. And the product gas will be free from any impurities originating from the volatile material. But if the volatile material does not pass through the high-temperature zone in the reactor, it will directly mix with the flue gases or product gases.

In such cases, this volatile material will be part of the gasified gases, and they must be purified depending on their composition. So, volatile material, which can vary from less than 5% to 50% for sub-bituminous coal, can consist of carbon monoxide, hydrogen, and traces of nitrogen in the compound. Volatile material composition in types of coal. The conditions under which the volatile material is driven off affect the nature of the residual fixed carbon and the char that remains. If the volatile material percentage is high, once removed, the residual char or coke particle will be highly reactive. If the volatile material concentration is lower, then after, due to this volatile material, steel coal will have lower porosity and lower reactivity.

So, the percentage of volatile material and its composition also play a tremendous role during coal gasification. The composition of this volatile material may add impurities to the product gases if not gasified properly. So, if coal has a lower quantity of volatile material, we can use processes where the volatile material will not pass through the high-temperature zone. But if the volatile material content is high, it is desirable that all this volatile material should pass through the main gasification zone or high-temperature zone so that it undergoes gasification reactions and produces hydrogen, carbon monoxide, etc. as per the chemical reaction. Generally, if we consider the fixed carbon, it is the main material that determines the gasification product. That is, the nature of the fixed carbon—whether it is highly reactive or not. If this fixed carbon contains a higher amount of carbon, then the product gas will have a higher amount of carbon monoxide and other gases. But if the fixed carbon contains a higher amount of hydrogen, in such cases, the product will be rich in hydrogen, methane, and other types of gases.

Again, if it is highly reactive or non-reactive, that will decide the rate of the gasification reaction. So, this nature of fixed carbon, which is the major component of the char after the moisture and volatile material is driven off. It is important that the performance of the gasifier entirely depends on the physical and chemical properties of this char. Fixed carbon properties such as density, structure, strength, and reactivity all depend primarily on the coal, but they are influenced by the pressure, temperature, and rate of at which coal is heated and its final temperature. So, though all these parameters originate from the coal structure, depending on the fixed carbon composition and its properties, we can get different reaction kinetics as well as whether this fixed carbon is reacting or not. It can have different rates of reaction.

Similarly, if it has a caking tendency or non-coking tendency, because in the gasifier, we can use both coking coal as well as non-coking coal. Even the coking coal may not have the desirable properties for coke-making; they can also be gasified here. So, in such cases, if the coke has a coking tendency or a strongly coking tendency, or a swelling tendency, it can create problems during gasification, so that must be considered during the design of the gasifier. Some gasifiers can be designed to handle caking and swelling coals, but they require coal to be pre-treated so that these swelling or caking characteristics do not impact significantly during gasification. So overall, if we see that all these parameters like fixed carbon, volatile material, moisture, and other components, they have major impacts during gasification.

The composition of fixed carbon and the composition of volatile material are very important to decide the product gas composition. Particularly, if we see the history of gasification in our Indian context, earlier many fertilizer plants were operating on coal gasification initially, and that gasification product of carbon monoxide and hydrogen was used for the manufacturing of fertilizers and other by-products. But the problem with coal gasification is that once we change the source of coal or after 10 or 15 years of coal mining, that particular coal is not available. In such cases, we get different types of coal. So once the source of coal changes, the gasification kinetics change significantly, as a result, the product gas of the gasification may not have the same percentage of carbon monoxide, hydrogen, or methane. As a result, as we are using this gasification product for the next fertilizer plant or other chemical plant, in such cases, that chemical plant receives gases or syngas having wide variations in its percentage of carbon monoxide and other gases, and that may not be suitable for that particular chemical plant or fertilizer plant. So that is the major difference between coal combustion and coal gasification. In the case of coal combustion, the combustion rate can be different, but overall, we are getting some amount of energy, so that energy is utilized there. Any variations in the coal property are there, still the coal combustion plants can operate with some minor or major modifications, but in the case of coal gasification plants,

As gasification occurs, the product gas composition changes significantly depending on the source of coal or feedstock, and that particular product gas composition may not be suitable at all for certain plants. So, in that particular plant, the desirable composition in the flue gases may not be achieved, and their product will not be of the desired quality, preventing them from producing their intended product. Or they may not be able to produce the fertilizer itself. There is a major difference between coal gasification and coal combustion. And as the mineral matter composition, ash composition, volatile material composition, and fixed carbon composition all change, the rank and maturity of the coal also change. And with the change in rank and maturity of the coal, the reaction temperature varies. The product gas composition varies significantly. It can either be rich in carbon monoxide, rich in hydrogen, or rich in methane. That all depends on the reaction kinetics as well as the source of coal, but in the case of combustion, this does not happen. The product coal can be different, but overall, it provides some amount of energy, combustion kinetics may differ, but overall, since we obtain some amount of energy, it will have an impact, though that impact can be modified by changing the design. But in the case of gasification, we cannot do that because the product gas has a different composition and kinetics, depending on the coal composition as well as the temperature. So, if the product gas does not contain any carbon monoxide, hydrogen gas, or methane gas, then that gas may not be suitable for the consumers who are using those product gases. Therefore, for coal gasification, it is essential to maintain the quality, source, and other properties of the material or feedstock.

If we change this feedstock, its reaction kinetics will change. If the reaction kinetics are changed, the product gas composition will change. It may have higher impurities or traces from the volatile material. It can have a higher amount of carbon monoxide. It can have a higher amount of methane gas, a higher amount of hydrogen gas, or maybe steam or other gases may be present. So those gases may be suitable or may not be suitable for the consumer. So, during this gasification, it is desirable that we maintain or keep the required conditions. The required temperature, pressure, as well as consistent feedstock, are the main requirements for the successful operation of any gasification plant. If a consistent source of feedstock is not available, particularly when we are working with biomass or municipal solid waste, or municipal waste where the feedstock characteristics change every day. In such cases, it is very difficult to get the desired product composition in the flue gas, and that will be very difficult for the consumer to utilize such gases.

Thank you.