

Clean Coal Technology
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Week-09
Lecture-45

Hi. I, Professor Barun Kumar Nandi, welcome you to the NPTEL online certification course on Clean Coal Technology. We are in module 9, discussing the fundamentals of coal gasification. Different types of chemical reactions happen during coal gasification. Types of gasifying agents like oxygen, air, steam, and their role during gasification, the effect of fuel properties on gasification. In this module, I will discuss different applications of coal gasification. So, let's start lecture 5, the scope of coal gasification, after going through all the previous four lectures. It is very common or very genuine to ask why people go for coal gasification reactions, why coal gasification reactions are very important for our day-to-day life as well as industrial practice. So, if we see why we go for coal gasification in any coal industry, we can observe that the properties of coal vary from day-to-day mining, from different sources. The coal we receive on any particular day and the next day the properties are not exactly the same. Exactly the same means it is not 100% identical. It may be similar, maybe 90% or 99% the same, but it is not exactly 100% the same coal we can get every day in any industrial applications as well as domestic applications, as coal properties depend on the origin of the coal, their mineral and metal composition, and other coal parameters that we have discussed earlier.

So, when we utilize coal, we face a lot of difficulties during utilization as the properties of coal are different. So, their combustion characteristics are not the same or exactly identical. This is quite different from conventional liquid fuel or gaseous fuel. In the case of liquid fuel or gaseous fuel, typically the composition of the fuel remains broadly the same. So, there is not so much wide variation in liquid fuel properties like petrol or diesel from day to day or month by month. It is broadly remains same but in case of coal these properties vary. So, whenever we try to use coal in industrial as well as domestic applications as the coal properties are not exactly same. the products like when we are burning the coal and producing some steam in thermal power plant or producing some heat in the cement plant or blast furnace or wherever we are utilizing this coal we are not getting exactly same amount of heat or coal is not burning in the same way as what happens in earlier days. As a result, what happens is that there are

always some issues with the unburned carbon coal ignition coal burning etc. which impacts the product quality of the consumer. So to avoid this that if we do the coal gasification initially, that is before utilizing the coal, if we convert it to some of the gaseous products and this gaseous product quality we can verify, we can check and further this gasified product or this syn gas can be used as a secondary fuel for applications in such case when we can see that the quality of syn gas, its composition we can take it and further we can use it in different applications. So as a result, we can gasify wide varieties of coal with their wide varieties of their properties some coal can have high GCV. Some coal can have lower calorific value some coal can have higher ash content etc. whatever so different types of coal can be gasified in a same reactor and that reacted after the reaction whatever the syngas is produced that can have some quality control parameters and after that syngas we can use it for further heat generation where we burn carbon monoxide methane hydrogen and other gases. So during the gasification we can easily gasify wide types of fuel sources like there can have variations in the coal properties but if we know that the syngas has this composition and further when we utilize that syngas in a combustor we will know that we will have this type of properties will come out and we can easily adjust or monitor the gaseous fuel, feed rates and other as a result in a same reactor we can gasify different types of coal and we can use it for our actual purpose.

So, we can use different types of coal or wide varieties of coal in the same reactor. It is very difficult to do in a similar way in the combustor. If in the combustor we want to do this, in such case there will always have some unburned carbons and others. But in the gasification, some coal may take longer time, some coal may take lesser time depending on its reactivity. But all products will be gasified and these gases will be using it. So, they are the probability of having any type of unburned carbon, reactivity issues of the coal that can be minimized or that impact can be minimized when we will generate seen gas as gaseous fuel for utilization in further process. we can use wide varieties of coal here one thing is important that obviously the coal reaction kinetics will be different but we can adjust that coal kinetics parameter during the reaction so that at least there will not have any type of unburned carbon in the fry ash as well as in the bottom That part we can ensure, but that is a difficult in case of direct coal combustion. In case of gasification plus combustion, we are doing it in two stages. Initially gasifying the coal, then we are utilizing that produced thin gas in a combustor.

So, we have two stage control possible in case of gasification plus combustion. But if we directly burn it, there is only single stage control is there. And here any variations in the coal properties will have severe impact on the heat released as well as the final products. In the same

reactor or in the same gasifier, we can gasify multiple types of fuel. That is the major problem advantage of this gasification in present days if we can see there is wide variations in the coal properties is available some coal has a very good calorific value whereas some other coal has inferior calorific value some of the coal are Indian and we are also importing some foreign sources coal or imported coal to meet our energy demand so there is always some variations in the coal properties And when we are burning them in a combustor, as we have seen in our previous classes from their TGA, DTG curves and other data that there is wide variation in their combustion properties. So, there will always be a lot of difficulties in the plant side to utilize such coal. But if we can gasify the coal initially, so all these negative impacts we can manage and further we can use their produce in gas in that coal.

So, we can use multiple source coal. in the same gasifier and further if we can use the municipal solid waste like the garden waste where many type of agricultural waste or biomass is present. So, all these material waste materials also can be used for power generation if all these products are directly burned in the combustor. So, there are many harmful chemicals are present in all these wastes they can create some problem to the environmental but if we gasify them and if we can clean or if we can remove any of the undesirable polluted gases present in the gasified medium, then further that after removal of those harmful gases, we can burn it in the reactor. So, in this way, we can use multiple fuels like coal, coal biomass, coal biomass, municipal waste, etc. We can gasify them in a single reactor. Further, we can clean the product gases and others. and then we can use it for power generation or any other purpose. In the same way we can use any type of inferior type of coal or any type of unused coal like any high ash coal, coal rejects, coal tailings from different coal washeries, they all can be gasified in the same reactor and further whatever the residual calorific value or hydrocarbons are there. Those can be used during this gasification also. So overall if we see by this gasification, we can use wide various types of fuel, either different type of coal, different types of coal plus biomass and other mixture as well as any type of inferior quality coal we can use. and whatever the product gases are produced from the gasification plant that is the syn gas or the water gas if we are using steam. So, these gases have the multiple utilization this syn gas can directly be used as a fuel gas for further utilization. This syn gas can be used in a chemical factory or chemical plant to produce some variable chemicals. This syn gas can be used as a gaseous fuel for the domestic application where we are using presently we are using natural gas or LPG gas. So, all these gases can be used either for power generation or heat generation or any other purpose and further if we see that we can also get the advantage of gaseous fuel whenever we use the solid

fuel liquid fuel or gaseous fuel we can see that the utilization of gaseous fuel is very easy because gaseous fuel can be transported to any location through pipeline and pump. So even it can be lifted to a 10 storey or 50 storey or 100 storeys building to the pipeline but if we want to transport this coal to a 100-storey building Then it is very difficult. So, if we have converted this solid fuel to gaseous fuel, we can easily transport it to long distance, 100 kilometers, 1000 kilometers, etc.

We can easily transport it. But transporting solid fuel this way is very difficult. We need specialists. Railway tracks, road service, railway wagons, etc., are all required when transporting solid fuel. A lot of infrastructure support is needed when utilizing solid fuel like coal. But if you use gaseous fuel, as it can be transported through pipelines and pumps, we can easily transport it over longer distances. We can avoid transporting unnecessary ash materials or mineral matter present in the coal. So if any coal has 40% ash, we are unnecessarily transporting this 40% ash from coal mines to the location. But if we gasify this coal at the source in the coal mines or nearby the coal mines itself, we can save the resources used to transport this 40% mineral matter to the consumer. Further, this syngas can be used in different industries. The syngas has a wide variety of consumers. This syngas can be used directly as a fuel source.

Further, it can also be used as a source of different types of chemicals. Based on the individual gases present in the syngas, we can effectively use it as a gaseous feedstock for further industrial applications, as well as a fuel. For example, it can be used for iron ore reduction in metallurgical sectors. If we look at the commonly used blast furnace technology, iron ore is reduced to produce iron and further steel. There, we need coking coal, and the reserve of coking coal is very limited in India. Around 12% is available, and worldwide, the reserve is not significantly higher.

So, production of steel we need always good quality coal as this coal is not available. So, we can alternatively go for this reduction of iron ore using the carbon monoxide and hydrogen feed gas that is we could know as the direct reduce iron or DRI method. So in this method the syngas is used or hydrogen rich and carbon monoxide rich gas is used in the reactor for reduction of iron ore to do the iron producing and further steel producing reaction so in this way we can use the non-cooking coal or inferior quality coal or even the biomass or other similar type of carbon rich fuels for production of steel or reduction of iron ore and we can save lot of money short lot of resources for the coking coal So that's why this DRI technology is nowadays getting

very much popular compared to the blast furnace based technology where the availability of coking coal is not so much high and it is always doubtful whether we can get the good quality cooking coal for the blast furnace that's why many of the industries many of the plants are being installed or they are being converted or they are adding another units to going for the DRI based iron extraction unit or steel production unit Further, if we see the individual gases like present in the syn gas, there we have carbon dioxide, carbon monoxide, hydrogen, methane, etc. And now if we can separate these individual gases using suitable gas separation methods. We can extract pure carbon monoxide, we can get pure hydrogen, pure methane and other gases. And nowadays we can see that overall trend is going that we will go for the hydrogen fuel or hydrogen-based energy sources.

But if we see overall, where is the source of hydrogen? Hydrogen is not available in any of the mines or any of the earth sources like the way we extract natural gas. Natural gas is available because the earth surface is different location. Crude oil is available. Coal is available. But we will not find any mines or locations where we can extract pure hydrogen gas. So, whenever we consider hydrogen as a clean fuel, we must always search for a source to obtain it. Overall, hydrogen is primarily available in large quantities through steam reforming or gasification of hydrocarbon-rich materials. We need hydrocarbon-rich feedstock to perform steam reforming or gasification to produce hydrogen. Currently, industries use steam reforming of natural gas, LPG, or naphtha as the primary technology or coal and other hydrocarbon resources. If we want to use hydrogen as fuel, we must still rely on coal, biomass, or similar feedstocks. Even if we use biomass as feedstock, we can gasify it easily. We can produce hydrogen gas by modifying the reaction kinetics to maximize hydrogen yield, then purify it for use in hydrogen-based engines. Similarly, we can separate carbon monoxide, which can be used as fuel. Or as a chemical source for producing other chemicals.

Likewise, we can produce methane and other hydrocarbon gases through gasification. Gasification opens the door for converting coal into chemicals. With coal, we can produce various chemicals. By converting coal into gaseous products, we can produce high-value chemicals, improve the plant's financial viability while obtain hydrogen as a clean fuel. A suitable fuel for fuel cells and similar applications. Other advantages for coal gasification are that we can get syn gas can be easily transported through pipeline, tankers, etc. without transporting the mineral matter present in coal. And so, in this way, we can dispose the ash present in coal at the source itself. As we have discussed earlier, that whenever we are transporting coal, we are transporting the ash material from the origin to the consumer. At the

origin, there is a vacant space. We need material for landfilling. after extraction of coal whereas the consumer after burning of coal they have the waste solid material of fly ash or bottom ash so they have to again transport this ash to some other location for disposal but if we gasify the coal or if we gasify the biomass or other material we don't have to transport this ash material long distance and that can be disposed at the source or nearby source that can be used for landfilling or any other application at the source itself without transporting it or without utilizing so much other resources for transportation of this ash. Again, the production of hydrogen is possible only through the hydrogen generation methods from hydrocarbon. Overall, if we see that hydrogen we can also produce from the hydrolysis of water and other sources but they are not economically visible because we will extract hydrogen from water and after the reaction we will again produce water. So, it is not thermodynamically possible or acceptable cycle for utilization and production of hydrogen. So, best method or widely available method or industrially stable, industrially proven technology is that production of hydrogen from any type of hydrocarbon-based feedstock. So, even in this way, we can use either coal, we can use different type of biomass, different type of other feedstock for production of hydrogen. we can get hydrogen through this gasification also and it can it will further produce open it will further open the window for coal to chemicals through the physical chemical reaction after this gasification we are getting carbon monoxide hydrogen methane and those can again go for the physical reaction to produce methanol and from methanol we can produce many other organic chemicals. So, this entire feedstock, carbon monoxide, hydrogen, methane, etc. can be further used to synthesize different types of organic chemicals. And these organic chemicals are very costly. They are very high-value-added products. And in this way, we can go for the coal-to-chemicals route where coal will be used not as an energy source but as the organic feedstock for the production of different types of valuable chemicals like methanol and other types of chemicals, other types of feedstocks. If you see the different types of difficulties that these gasification-based plants face, that is the variation of coal properties on a day-to-day basis. So even if there are some variations in the coal properties, we can absorb these variations in the produced gas mixture because that will have a different composition. So, to ensure that the produced gases have the same composition, we always have to monitor the produced gas material or syngas, whatever its composition, whether the carbon monoxide or hydrogen percentage is higher or lower. We have to monitor it and check it on a day-to-day and year-to-year basis because the properties of coal vary. On a day-to-day and year-to-year basis. So always using this gasification, these particular properties, we have to

monitor very strictly. Otherwise, we may gasify the coal, we may gasify the biomass or other feedstock, but the product syngas composition will be different.

There can be a higher amount of carbon monoxide or a higher amount of hydrogen, a higher amount of methane, and others. So, which may not be suitable for a particular industry. So, we have to regularly monitor the properties of coal, and if there is some change in the coal properties, how it will affect the gasification kinetics. That is also important: we monitor the gasification kinetics, and we should also monitor the product syngas composition. If there is any major change in the syngas composition, we should alter the input fuel coal properties by blending with some other type of coal or other type of biomass or other type of material so that the input hydrocarbon composition is the same or nearly similar, and we can also control that reaction kinetics.

So, this is the most challenging part for the gasification plants to ensure that we always get the same or similar gas composition in the syngas. That is the main challenging task, and that is due to the difficulty in obtaining the design coal. Whenever we design any particular plant, it is very essential that we obtain the design coal for the specific applications. But if that design coal is not available in the combustion units, it is directly affected because it is only a one-stage method. We directly burn the coal and use it.

But in the case of gasification, we have time to monitor the syngas composition and can alter or modify it by blending with different types of coal, biomass, and others. So that at least the steam production rate and other factors do not vary significantly, and we can maintain the required temperature. The heat rate available for the combustor is affected, but if we use it directly, it is very difficult. And again, if this syngas is directly sent to any consumer, they will also face difficulties. If we send it on a day-to-day basis, we must regularly monitor it, as the gas composition may vary if the source of coal or feedstock characteristics change, making it very difficult to maintain product quality. So that is always the difficulty when handling this type of feedstock, like coal or any type of biomass. Even if we use biomass-based gasification plants, the hydrocarbon properties are present, and depending on the feedstock changes, the product gases may have different compositions. Some biomass can yield a higher amount of hydrogen, while others may yield less. So, we have to monitor all these feedstock characteristics. After initial analysis of all the feedstock—what their hydrocarbon characteristics are and what their expected gasification kinetics will be—we can adjust the source fuel properties by blending different types of fuel to ensure that the product gas

composition remains the same and does not vary significantly. Another disadvantage of gasification is that some heat is wasted during the process. During gasification, we can observe that the initial reaction, where carbon monoxide is produced, releases some heat, so whatever energy is available in the biomass or coal, about 30 to 40% of the heat is released during gasification, and that amount of energy is not available for utilization by the actual consumer. As a result, this is one of the drawbacks, Not the entire 100 percent of energy available in the coal is used by the consumer; rather, 70 to 80 percent of the energy will be used by the consumer, and the remaining 20 to 30 or 40 percent of the energy will be used during gasification. However, even after this energy is used during gasification, the product gases will have a lot of flexibility and advantages during utilization, and they can be used without any trouble. Getting any unburned hydrocarbon, fly ash particles, or bottom ash particles if they are directly using coal. Here, as they are using the gasified syngas, they will not have to face any difficulty in handling this solid waste material. Overall, if we summarize based on the gasification chapters, gasification or coal gasification helps to convert the solid fuel into gaseous form. As a result, we can obtain gaseous fuel from solid fuel, and we will use this gaseous fuel for different purposes.

The gaseous fuel's usability is far better. The usability or application of gaseous fuel or gaseous feedstock is far better. It is much easier and environmentally friendly compared to directly using any solid fuel. So, even this gasification technology can replace or compete with other gaseous fuels like syngas or natural gas available on the earth's surface if there is any shortage of natural gas. We can use this syngas from coal gasification plants to maintain their required gaseous fuel, and this syngas can also be used for domestic cooking and other applications. So, by converting coal into syngas or gaseous fuel, we can extend or expand the base level or consumer level for the coal industries. Similarly, air is mostly used in gasification, and if required or for particular plants requiring some hydrogen or methane gases, we can use steam and other materials. Water and steam addition improves the hydrogen or hydrocarbon-rich gases. If you are using only air, syngas will be rich in carbon monoxide. If you are using water or steam or similar feedstock, in such cases, the percentage of hydrogen or other hydrocarbon gases like methane or ethane will increase in the product gases. Reaction kinetics is the major parameter to be monitored and managed by the commercial plant, they have to continuously monitor the reaction kinetics if any change in the feedstock characteristics is there. Coal properties can modify the product gas composition if the coal has a different type of hydrocarbon structure, meaning if the coal has a different type of CHNSO composition.

Accordingly, the product gas may have different types of CO, N₂ gas, H₂S gas, and other compositions. So, coal properties can significantly modify the product gas composition and hence the profitability of the plant. So, overall, if we see for gasification plants or gasification-based units, the most important thing is that we should get consistent quality of coal, at least in their ultimate analysis. If the ultimate analysis properties are consistent, we are getting the same amount of carbon, hydrogen, nitrogen, sulfur, oxygen, etc. We can maintain the product gas composition, and we can easily maintain competitiveness with nearby available commercial gaseous fuels like natural gas or others. But if the coal properties or feedstock properties vary significantly, then the gasification plant will face a lot of difficulty in controlling the rate of reaction as well as the product quality. In such cases, they will face a lot of difficulty, and in such cases, the plant will face challenges, and they may not even meet the consumer requirements.

Thank you.