Clean Coal Technology

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Week-10

Lecture-50

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. So, in our previous lectures, we have discussed different types of reactors used in gasification, as well as the product gas cleaning from the syngas. In this lecture, I will be discussing different industrial applications or downstream plants of coal gasification units. So, let us start Lecture 5 on coal gasification downstream plants.

If we observe during coal gasification, some amount of heat is produced from the initial combustion reaction where coal is converted to carbon monoxide gases. Now, depending on the further process—whether we are using steam or any other material—some amount of heat is always released in the coal gasification process. That means, whatever amount of chemical energy or heat energy is available inside the coal, some part of that heat energy is released at the source or at the gasification plant itself, and the remaining amount of energy is transferred to the syngas. This is used by the end user or the consumer, which is called the cold gas efficiency. That means how much chemical energy of the coal is transferred to the product gas or syngas. Since some combustion reaction occurs during gasification, some amount of energy will always be released at the source itself. So, the syngas will not have the same 100 percent amount of energy or calorific value present in the coal. It may be 60 to 70 percent or 80 percent of the energy available in the syngas. So, this 20 percent or 30 percent of heat energy, which is released in the plant itself or during gasification, can be used for other purposes, such as similar downstream industries. Such practice is called the cogeneration of heat.

That means, during gasification, we will intentionally produce heat as well as syngas. So, syngas will be used for downstream industries, chemical industries, or whoever uses it, and the heat produced during this gasification will be used for other purposes—any useful purpose. So, that is called cogeneration. Cogeneration or coproduction, in the context of gasification, refers to the ability of a gasification plant to vary downstream processing of the produced gas depending on market conditions to optimize profit as well as sustain operations in difficult

situations. Now, why is this co-generation of heat and gas present? That means from the gasification plant, we can get some amount of heat as well as syngas. Now, why is this co-generation concept present? Because in the market condition, depending on the feedstock characteristics, sometimes produced syngas may not have any consumers. So, the market value of this syngas may be on the lower side.

It entirely depends on the coal-to-chemicals market and other markets. So, if that market is not accepting this syngas at a high value, then in such cases, the sustainability of the plant may be very difficult. So, to sustain this plant and to operate it in difficult conditions, the plant has to find other ways so that it can run. One of these processes is to produce heat, meaning from this gasification plant, in such cases, we will produce heat, and this heat will be used for other purposes. One example is the IGCC plants, what is called the integrated gasification combined cycle-based power plant. So, in this plant, coal gasification is initially used, and further, the heat is produced by the coal gasification as well as whatever syngas is produced, which is burned or used in the next unit or power-producing unit where electricity is produced by a combined cycle method using both a gas turbine as well as the conventional Rankine cycle-based method. So, effectively, in this method, we use coal as well as other types of biomass or other feedstocks to produce power. So, the entire coal gasification can be converted into a typical thermal power plant by this route. So, although its origin or its basis is the coal gasification plant, if syngas does not have any good market value or consumers, then the entire gas as well as the heat produced during gasification will be used for electricity production or power production.

So that is there in the integrated gasification combined cycle plants. We will be discussing this in our next module, Module 11, in detail. So, this is one of the applications where a gasification plant can also be converted to a completely thermal power plant in some difficult situations. Similarly, whatever heat is produced during this gasification. Like during this gasification, some amount of heat as well as some excess steam is released from the plant, so we can supply this waste heat to nearby chemical plants where steam is required for their operations. Maybe it can be a pharmaceutical plant, another type of fertilizer plant, or any other chemical processing plant where steam is required for the processing of chemicals. So, in such cases, the gasification plant can supply its waste heat or intentionally produce heat so that it can be supplied to nearby plants. For their manufacturing of chemicals or other processes, so by this way, it can sustain itself. As a result, we can see that the gasification plant operates to produce heat as well as syngas. Similarly, the steam generated from the heat released during gasification

can be supplied to other chemical plants. We can also install plants for converting syngas to chemicals, like producing different types of organic compounds or valuable chemicals, which will have significantly higher market value, or it can be converted to any type of liquid fuel. So, this is one of the routes that was typically used in the 18th or 19th century where Coal was used primarily to produce different types of organic chemicals or everyday chemicals like naphtha, naphthalene, benzene, toluene, and other chemicals used in daily life as well as in pharmaceutical industries.

In the 18th and 19th centuries, coal was used to produce all types of chemicals, but later the feedstock changed from coal to liquid fuels like crude oil as well as gaseous fuel sources. Still, from coal gasification plants, we can produce different types of chemicals, as coal feedstock is very cheap compared to other types of feedstocks. Also, we can use syngas to produce individual gases like carbon monoxide, hydrogen, methane gas, etc. So, if we can install some gas separation plants, using suitable technologies, we can separate pure carbon monoxide gas, pure hydrogen gas, and pure methane gas, as well as similar other gases from the syngas. All these individual gases have their own market value, and their combined market value will be significantly higher than that of syngas.

So, in difficult conditions, this gasification plant can also be used to produce individual gases like carbon monoxide, hydrogen, syngas, methane, etc. So, such an approach helps the gasification plant to survive as well as to increase its profitability. For example, if we consider the cogeneration of heat, how this can be achieved, and how cogeneration of heat and gas can be realized. Suppose we are operating any gasification plant. Now, in the gasification plant, the feedstock itself can include coal or biomass. We can use other types of feedstocks. So, depending on the availability of feedstock—whether it's the type of coal, biomass, or any other feedstock available at a lower market price—they can all be gasified in a single reactor. This depends on the design of the reactor. So, from these coal gasification plants, we can observe that some amount of heat is produced, as discussed in Reaction 1 in our Module 9 lectures: $C + 0.5\ O_2 \rightarrow CO$ + heat. So, if we consider this reaction,

This reaction is exothermic in nature. So, from the gasification process, some amount of heat is released. This heat can be used for different purposes, such as power generation or in chemical plants. This heat can also be supplied to nearby cement plants or other steam generation plants that require steam for their production. It can be used for plant operations as well as for day-to-day purposes.

So, coal gasification plants can supply heat as one of the sources to generate revenue, as well as utilize their products. Additionally, this syngas, which consists of carbon monoxide, hydrogen, and other components, can be used in various applications. It can serve as a fuel gas, a chemical feedstock, or for hydrogen production. It can also be used for carbon monoxide production, as well as for the production of different types of bioproducts from this syngas. Thus, we can co-generate heat, gas, and various chemicals from the same gasification blast unit. Overall, this gasification unit can be operated as a central hub for gasification. Nearby, many industries can benefit.

This coal gasification unit can serve as a primary hub, supplying various raw materials and energy to other industries. This is one example of the IGCC circuits, which we will discuss in detail later. Typically, in IGCC, we prepare the coal by crushing and grinding it. Subsequently, it goes to the gasifier, the gas cleaning plant, and the particulate material removal system. Thus, we obtain the raw gas. This raw gas can then be used to produce the shift gas reaction. We can remove sulfur and H2S. Thus, we can also produce sulfur or H2S. Sulfuric acid can be produced as a byproduct here. Additionally, the sulfur removal process can lead to CO2 capture, where CO2 can be used as a separate product for other industries. The remaining fuel gas, rich in hydrogen and other gases, can be directed to the gas turbine cycle. This cycle will produce electricity, and the exhaust gases can be used in a Rankine cycle-based plant to generate additional electricity. This combined cycle can also utilize exhaust steam from this unit, which can be supplied to the recovery shift gas reaction. Power plant units and for here also gasifier we can use in the air separation unit we can recover some of the amount of air argon and other gases we can get the nitrogen gas and others. So in case of IGCC it is a complete approach to produce electricity as well as different type of byproducts like sulfur, H2SO4, carbon dioxide, air or argon gases or other gases as in complete circuits and these are the some of the flow sheet what are the different materials we can produce we can generate from the coal gasification based plants like if there is a feedstock, there is an gasification plant after this gasification plant is there We can get the slag material which can be used as a landfilling or the construction material for cement industry as well as on others. This is one of the byproducts we can get from the coal gasification units.

Now whatever the inert gases are there in the air, they can be separated, they can be collected in the gasification unit. So, we can get argon, nitrogen, oxygen as one of the products from the gasification unit. This is the you can say this is the second product. We can also get carbon

dioxide as the third product. We can get sulfur and sulfuric acid and similar sulfur rich compounds at the fourth product.

So, in this way we can get so many products like we can get steam, we can get hot water as part of heat energy which can be used to produce electricity. So, from this gasification if we go for the syngas production plant and syngas can be used in this combined cycle plant. to produce hot water which is also required for the gasification unit we can also produce electricity in the plant itself and if we see the from the syn gas again it can be used for the chemical production during this chemical production we can produce hydrogen gas, carbon monoxide gas, ammonia based different type of gases as well as the different type of fertilizer like urea and others urea ammonium sulfates and others many fertilizers can be produced from this and synthetic natural gas that if we enrich this gas with the methane content so it can replace the natural gas available which is called the SNG or synthetic natural gas. It is not the pure natural gas whatever available from the earth surface but from coal we are manufacturing it, we are producing it that is why it is called the synthetic natural gas.

It will be rich in methane gas. It can produce different types of industrial chemicals through the chemical production route. It can produce methanol and others, and even this syngas can be used for the Fischer-Tropsch synthesis reaction, where carbon monoxide and hydrogen gas will react to produce different types of products like naphtha, high-cetane diesel oil, jet fuel, and more. All these chemicals can be produced, and all these products can be generated. Coal will be used as a feedstock. So, depending on the properties of coal, the process there, and depending on the catalyst, reaction kinetics, or the plant used, all these products can be possible or can be generated from the coal gasification units. So, this is another schematic picture that shows how coal can be used in different applications. Here, we can use either coal or pet coke, and if we gasify it, we get syngas. Along with coal, we can also mix pet coke, which is also a waste product or residual product in the crude oil distillation units or oil refinery units. From the syngas, we can produce pure carbon monoxide, which can be used for carbon monoxide-based chemicals as well as acetic acid. Further, this syngas can also be used for the IGCC units for electricity production, for Fischer-Tropsch units for diesel and naphtha production. The same syngas can be used for methanol production, and from methanol, we can get formaldehyde, gasoline, methyl acetate, and acetic anhydride. So, all these chemicals can also be produced if we can produce them.

We can go for gasification to produce syngas, followed by methanol. From methanol-based chemicals, we can produce dimethyl ether fuel for distribution or generation, ethylene, alpha-olefins, olefins, acrylic acids, and hydrogen-based chemicals like ammonia. Hydrogen can be used in fuel cells. It can be used in refinery processes for saturation reactions of fatty acids. Syngas can be used as a fuel gas or town gas in different locations. From ammonia, we can produce acrylonitrile, urea, ammonium nitrate, and similar types of fertilizers. Earlier, before natural gas was available to a higher extent.

Earlier this coal was used to produce all type of different type of ammonia-based fertilizer by the National Fertilizer Limited. But later the feedstock has been changed to the natural gas and methane gas. depending on the market condition similarly this coal can be used for different type of valuable chemicals as we seen it here so even if we see from one ton of coal if we can produce one kg of this type of product and their products are very highly valuable product even they are one kg or 10 kg cost is significantly on the higher side so as a result these roots of coal to chemicals Here coal is not used as a fuel but rather it is used as a chemical feedstock for producing different type of chemicals. So, in this route this gasification actually opens the window for utilizing coal to a high-end application.

If we use coal as a simply fuel to produce energy to burn it, we use it for the typically low-end application where we get only the heat energy. But if we use coal as a source of chemical feedstock and for the chemical feedstock if we produce different type of fertilizer, hydrogen gas, different type of chemicals and all these materials have very high market value. So as a result, this gasification route we make it that highly profitable for the any of the plant if they go for the coal to chemical routes. So typically, this coal gasification opens the window for utilizing coal in different applications. And some of the applications are still successful. Some of the applications have some of the difficulty. Due to variations of coal properties on day to day in mine life. that mine it will not it is not able to provide some fixed or suitable quantity of coal every day so the gasification plant is getting difficulty in this. As a result, the syn gas and methanol concentration or quality is not up to the mark. So that is the only difficulty at present with the coal to chemicals otherwise this coal to chemical route is very well-established route that was the process are very much well established and they can be used for production of different type of chemicals.

These are the different type of chemicals again if we see that is if we use some bituminous coal or high grade coal we can produce hydrogen gas we can produce carbon monoxide methanol

and from their derivative products we can get acetic acid formaldehyde olefins like ethylene propylene methyl acetate acetic anhydride and from the hydrogen in the refinery or the other routes we can produce in the refinery process hydrogen gas is required we can produce ammonia fertilizer, ammonium nitrate, acetic acid. We can produce from acetic acid. We can use household cleaning material, waterproof sealants, etc. Dyes also can be used.

We can use fuel. We can use the plasticizer for different type of material like methyl acetate. We can get different type of liquid shape detergent. Other we can get ethyl glycol fiber materials and other, so we can effectively we can get different type of feedstock also for chemicals we can produce it from the coal as well as similar material. So, if we summarize the entire coal gasification chapters we can see that coal gasification can be used as a center point for different downstream industries. So, from coal gasification plants we can operate many coals to chemicals plant other industrial application power plant and etc. So, coal gasification can be used as a hub for an industrial installation where there can have many downstream plants which will use feedstock or raw material products byproducts of the coal gasification plants, hydrogen and other gases can be produced from coal through the coal gasification route. And this route, if we say, nowhere natural gas is, natural hydrogen gas is available. So, in most of the cases, hydrogen is extracted or hydrogen is produced from any of the suitable hydrocarbon feedstock. This gasification route or steam reforming route is the main route where hydrogen is produced from the different type of hydrocarbon feedstock. So here we can use coal as one of the feedstocks to produce hydrogen gas.

Gasification opens the window for coal to chemicals. Gasification at lower temperature typically results in impurities. at syn gas but no slagging or of ash is occurred if we do the gasification reaction at lower temperature. Like in case of Lurgi gasifier which operates at 700 to 800 degrees centigrade. In low temperature it can have some thin gas can have different type of impurities but there will not have any type of slagging or fusion of ash will be there. So that is suitable but if we do the gasification at higher temperature The syngas quality yield everything is improved as the conversion of carbon monoxide, hydrogen, methane reaction ore are improved as well as the impurities present in the syngas will be on less. But in such case if the temperature is excessively high like 1400 degree centigrade, ash fusion may occur. So, which can create problem during utilization or handling of ash. Lurgi gasifier as well as the fluidized gasifier both can be used in gasification. At present both the gasifier is used, Lurgi gasifier is used from the more than 100 years we can say from the World War 2 in the 19th century 1930. It is almost 100 years that Lurgi gasifier is being used in different industrial

applications. And nowadays fluidized bed gasifier has become very much popular because it can handle different types of feedstocks in a single unit. It can be operated with the biomass as well as the coal.

There is concern about the utilization of biomass and waste biomass is available everywhere. So, many industries are trying to or they are operating with the fluidized bed gasifier where coal as well as biomass are gasified to get different type of products depending on the type of feedstock as well as the syngas quality requirement. And gasification can be used as an additional step for coal utilization in the power plant. If we go for the IGCC based unit or similar gas turbine-based unit where gas turbine is used for the production of electricity, in such case coal can be burned or can be utilized in two different steps. If we go for the direct thermal power plant, here coal is directly burned or combusted to produce heat as well as the steam. But if we gasify the coal and that product gas or syngas is used to produce heat, in such a case, it is a two-step process for power generation. But the major advantage here is that any variations in the coal properties will only impact the quality of syngas. So, the plant will have additional time or additional resources. to maintain the quality of syngas, so that the actual steam production rate or temperature in the boiler does not decrease significantly or vary significantly. So, if we go for a two-step combustion, like initially gasification followed by the combustion of syngas to produce heat, in such a case the power plant gets some opportunity to correct whatever drawbacks the coal has.

Otherwise, if coal is used directly, any variation in the coal properties directly impacts the boiler performance, its temperature, and other factors. So, gasification-based units can be used as an additional step for coal utilization. And here we can use different types of coal also, high-ash coal, low-ash coal, even biomass. Everything can be gasified. Typically, in a thermal power plant, only 5 to 10 percent of biomass can be directly burned in the combustor. But if we go for the gasification-based route, in the gasifier, we can even gasify 50 percent of biomass and 50 percent of coal in the same reactor, and that entire feedstock can be used for power production. So, if we go for the gasification-based route for power production, we can use a much higher quantity of biomass in a thermal power plant for power generation, and this is very suitable particularly for inferior quality coal or inferior quality feedstock. If there is coal of inferior quality, high-ash coal, or reject coal, or it is lignite-type coal, so the GCV or calorific value of the coal is on the lower side. Even from that coal, if we gasify it with the help of other biomass and feedstock, overall, we can maintain the quality of syngas, its hydrogen percentage, and others. So, this gasification route can also be used for power production. So overall, if we see,

gasification is a very good technology for utilizing coal in an environmentally friendly way. While sulfur, ammonia, and other materials can easily be removed from the syngas, further, that clean syngas can be used as a gaseous fuel in different applications. So, in this way, we can use coal in a much cleaner and environmentally friendly way.

Thank you.