

Clean Coal Technology
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Hi, I am Professor Barun Kumar Nandi, and I welcome you to the NPTEL online certification course on Clean Coal Technology. We are at Module 9. In this module, we will discuss the fundamentals of coal gasification. So overall, in this module, we will discuss different types of chemical reactions involved in gasification, types of gasifying agents like oxygen, air, steam, and the effect of fuel properties on product quality, their composition, blending of fuels during coal gasification, and their impact on syngas and fuel gas.

So, let's start Lecture 1. Now, coal gasification. This is one of the coal utilization methods where we utilize coal in a different way by converting it into a gaseous medium. Overall, this coal gasification or gasification of any type of similar solid fuel, such as biomass or others, is the process where we convert that solid fuel into gaseous form. In this gaseous form, there will be a mixture of different gases like carbon monoxide, hydrogen, methane, CO₂, nitrogen, etc. These produced gases will have a very good fuel value and can be used as gaseous fuel. Once this coal is converted to gaseous fuel, it will be advantageous for utilization because it is converted into a gaseous fuel, and there are different wide advantages of utilizing gaseous fuel compared to solid fuel. This process is a partial conversion of coal where we provide a limited amount of oxygen, about 25 to 40 percent, to gasify the coal. The solid fuel will be converted into gaseous media, which is also called syngas. In this process, as seen in this picture, we use air, oxygen, steam, or any combination of these materials to perform the gasification reactions. These react with the solid fuel, coal, and the reactions will occur at around a thousand degrees or similar temperatures, depending on the reactor design and other conditions. In this case, they will be converted into carbon monoxide gas, hydrogen gas, methane, carbon dioxide, nitrogen, or any other similar gases.

So, whatever is the coal is there, this coal will be converted to these gases. Now, these gases have some of the valuable chemicals like carbon monoxide, hydrogen, etc., which can be used as a gaseous fuel because these gases are also a gaseous fuel and they also can be used for other applications. And whatever the residue mineral matter is there, that will be remain as the residue

ash. So overall if we see in this process whatever the hydrocarbons are present in this coal, all these hydrocarbons they will be converted to nearby low molecular weight hydrocarbon gases. Now these hydrocarbon gases they will be used further. Now here the role of air, oxygen or steam is that they will react. Oxygen will react with coal but this reaction will not be allowed to 100% conversion what happens in case of combustion. Here we will provide less amount of oxygen like 25 to 40% of oxygen whatever is required as per the stoichiometric reaction. So, we will provide less 50 percent or less depending on the medium used if you are using only air or we are using only oxygen we can we have to give some higher amount of oxygen like 40 percent if we are using steam then in such case availability of oxygen is also from the steam is there so in such case we have to provide less amount of oxygen like 25 to 30 percent. So overall if we see in these reactions or during this gasification we can use only oxygen or air. Difference between this oxygen and air is that if we are using oxygen then it will have the produced gases will have only carbon monoxide, carbon dioxide and hydrocarbon gases. If you are using air in such case the nitrogen, which is part of air that is 80 percent nitrogen is there that will also be part of the product gases. So, in such case product gas will be in diluted condition where nitrogen concentration will be high. So apart from oxygen we can use also steam or H₂O that is high temperature steam around 1000 degree centigrade that can also be added during the gasification reaction. So, this reaction can happen using only as pure air or oxygen as well as using steam also. So, this product gas whatever we will get from the coal gasification that is known as the synthesis gas or very well known as the short term syn gas. This syn gas is typically mixture of nitrogen and carbon monoxide gas.

So, if you are using air product will be the sin gas where percentage of nitrogen will be on higher side that is about 80% will be nitrogen because this nitrogen originates from the air. remaining 20 percent oxygen whatever was there that will convert it to the different type of chemical gases like carbon monoxide carbon dioxide and other gases and there can have also other gases like hydrogen carbon dioxide methane depending on the reaction kinetics at what temperature we are doing this reaction what is the composition of the coal what type of hydrocarbons are present in the coal or biomass or whatever the solid residue we are converting it and there can have some amount of water vapors either generated or released from the coal by their evaporation or by the chemical reaction or can be the excess amount of water vapor that is added during the reaction so depending on the fuel material use like we are using coal We can use biomass, we can use lignite type of coal, we can use similar other type of

hydrocarbon rich feedstock. And this is most important that we can use any type of hydrocarbon rich feedstock.

In industrial scale, mostly we use coal. However, if some coke particles are there or a very low volatile material, coal is there. They can also be converted to gaseous form to get the different type of gaseous product. We can use biomass and wide type of biomass can be used. These biomasses can be agricultural waste, agriculture residue, forest residue, wood or sawdust or maybe any type of municipal solid waste which is rich in organic compounds or biomass. They can be any inferior quality coal like lignite, peat and others. or any type of similar hydrocarbon rich material like Petco or other material they can also be blended with this coal or they can be used to as a feedstock for the coal gasification along with coal. So, all these materials can be gasified so either we can call it like a coal gasification if you are using coal if you are using pure biomass which can be a biomass gasification it can be coke gasification or others. So, depending on the hydrocarbon which feedstock whatever is there we can call this process in different moment nature no different ways reactant, typically we use air as air contains 80% nitrogen and 20% oxygen. So, in such case the concentration of nitrogen in the product gas will be on the higher side. So, the percentage of the other gases will, by default, be reduced in the volumetric ratios. We can also use pure oxygen if required for high quality or any particular process where we need to use pure oxygen to obtain pure or high-quality hydrocarbon gases like methane, ethane, or hydrogen, etc. We can also use oxygen. We can also use carbon monoxide in some cases, and we can also use steam. To change the composition of the product gases. The product gases mostly consist of carbon monoxide, hydrogen, methane, carbon dioxide, water vapors, along with many other gaseous impurities. Typically, if we observe the different chemical reactions during coal gasification, they are as follows: if we consider coal as a carbon source, coal will react with a limited amount of oxygen, not the full amount. We provide a limited amount of oxygen, like $0.5O_2$, then it will be converted to carbon monoxide. Alternatively, if the coal feedstock or biomass feedstock or hydrocarbon feedstock reacts with steam, it will proceed to these reactions or similar reactions. The term 'similar reaction' is very important here because different types of similar reactions can occur depending on the concentration of the feed or reactants, as well as the concentration of the products, along with the temperature, pressure, and catalysts present under different conditions. All these reactions, like similar reactions, can occur in many ways. For example, $C + H_2O$ may produce $CO_2 + H_2$, or it may produce $CH_4 + H_2 + O_2$, and many other similar chemical reactions are possible. So, overall, if we consider the gasification reaction involving oxygen as well as steam, it will

be coal plus oxygen plus steam, which may produce carbon monoxide, hydrogen gas, carbon dioxide gas, and methane gas. The concentration of carbon dioxide and carbon monoxide can vary depending on the kinetics of the chemical reaction and the conditions under which these reactions occur, as several reactions are possible here that will produce either carbon monoxide or carbon dioxide. Again, carbon dioxide can react with coal to produce carbon monoxide. Carbon monoxide can also react with steam to form carbon dioxide and other products. Many chemical reactions are possible depending on the reactor conditions, temperature, and the presence of other catalysts.

So overall we can get product gas containing mixture of all these gases. So exact gas composition will depend on what condition or what temperature pressure catalyst etc., how we are performing this reaction in what direction we are doing this reaction like whether we are supplying oxygen initially or later steam or oxygen and coal are supplied in different locations depending on the design of the reactor. So, depending on all of this these gas compositions can vary and as well as the depending on the feedstock composition like if you are using a coal or if you are using any biomass as biomass has higher amount of oxygen and hydrogen in their structure compared to the coal. So obviously the percentage of hydrogen methane gas etc. will be higher in case of biomass Whereas if you are using coal as the carbon content is higher, product gases will have much more quantity of carbon monoxide, carbon dioxide, etc. So overall, by these reactions, if we summarize, like we can produce by this coal gasification we can get a gas mixture that may consist of all these materials. Now if we are converting coal to all these materials, all these gaseous compositions or all these gaseous materials has their own calorific value. So, overall, this gas mixture itself can be used as a gaseous fuel or a gaseous hydrocarbon rich gas which can replace or which can be used where we use a conventional LPG gas or CNG gases. So, this gas mixture itself is a gaseous fuel. So, wherever we are using coal and we are facing some of the difficulty in utilizing coal. In such case we can use this entire feedstock or gaseous product as a fuel and they will again convert it or react with oxygen further to produce carbon dioxide and water as per reaction happens in the gaseous field. So, this feedstock is having wide applications in different industries either it can replace the conventional gaseous fuel or it can be used as a feedstock individually for where we need pure hydrogen gas, where we need carbon monoxide gas, we need methane gas, etc. So, from this gas mixture, we can extract or we can separate these individual gases also, which can have individual applications in different industrial, either chemical industries or fertilizer industries or others. So, overall, if we see, this gasification is a partial oxidation process. This is an

oxidation process but not a complete oxidation process. It is partial because we are providing a lesser amount of oxygen. The difference between coal combustion and coal gasification is that in the case of coal combustion, we provide 100% oxygen or excess oxygen to ensure that all the coal or solid fuel is converted to carbon dioxide and steam or water, whereas in the case of coal gasification, we provide a lesser amount of oxygen. As we are providing a lesser amount of oxygen, it will not be completely converted to carbon dioxide. It will remain in an intermediate stage as carbon monoxide. Some of the hydrocarbon gases like methane, ethane, as well as hydrogen gases. So, the product gases are different. In the case of coal combustion, our product gas is carbon dioxide only. In the case of coal gasification, the product gas will have carbon monoxide, methane, hydrogen, and similar hydrocarbons, as well as some amount of carbon dioxide.

So, the term partial oxidation is a relative term, which simply means that we will provide a lesser amount of oxygen than what is required in the case of coal. Combustion process. So, in the case of the combustion process, we need a full 100% amount of oxygen. In the case of gasification, we will provide a lesser amount of oxygen, like 25 to 30%, 40%, or 50% oxygen, as per the requirement for complete conversion. So, in the case of gasification, we provide a lesser amount of oxygen.

So, we will partially burn it. So that's why it is called the partial oxidation process. So, whatever the total gases are there, we will be using them. And this is a complex, different type of oxidation reaction that occurs, and depending on the fuel composition, this product gas composition will vary. During this gasification, coal is typically blown or heated at high temperature with oxygen as well as steam. So, in some cases, these reactions are also conducted in a pressurized reactor. During this reaction, oxygen and water molecules oxidize the coal and produce a gaseous mixture that is rich mostly in carbon monoxide. Some amount of carbon dioxide may be there. It can have water vapor as a residue or may be released from the coal structure.

It can have hydrogen or similar other hydrocarbon gases like methane, ethane, or similar gases. Some of the byproducts, like tar, phenol, etc., are also produced during this reaction, as this coal has different types of organic compounds. Some of the organic compounds may not be completely converted to carbon monoxide, hydrogen, and other gases. Maybe they will remain as lower molecular weight materials like phenol, tar, and others.

And if the reactor temperature at the exit point is not very high, they can remain as they are, like whatever they are, as part of volatile material. So conventionally, this volatile material also contains some amount of tar, phenol, etc. So, this tar and phenols and other materials, if they do not get adequate reaction conditions to convert them to carbon monoxide and hydrogen, they can remain as they are. So, they depend entirely on the temperature of the reactor, reactor design, reactor feeding point, and exit temperature of the product. or produced gases, etc.

So, it all depends on the specific gasification technology and the temperature of the exit gas. If the temperature of the exit gas is low, this tar and phenol may not be converted to carbon monoxide or other gases; they will remain as they are because their thermal degradation conditions may require higher temperatures. And this process can also be conducted in situ in the coal mines themselves. We can carry out or conduct this coal gasification reaction in the coal mine itself without mining the coal. We can convert this hydrocarbon part of the coal to gaseous fuel, or we can conduct this entire gasification in the coal mines themselves. So, it can happen in the natural coal seams.

So, in such cases, we call it underground coal gasification, where in an underground coal mine, we can completely gasify the coal. Without needing or requiring any type of coal mining, these are used in some cases or can be used in some cases where conventional coal mining is difficult and there are other difficulties in operating mines and extracting the coal. We will discuss this underground coal gasification in later chapters. So overall, if we see that the chemistry of gasification is quite complex. Whether it will produce carbon monoxide or carbon dioxide, whether it will produce methane or hydrogen. Whether this product gas will have some amount of tar and other materials or not. That depends on the entire reaction kinetics of this gasification. It depends on the temperature, pressure, reactor design, etc. And this is a quite complex series of reactions. And there are different types of parallel reactions as well.

So, it will happen through a series of physical transformations and chemical reactions within the gasifier, depending on the gasifier design, temperature, pressure, and many other factors. Several chemical reactions can occur, producing carbon monoxide, carbon dioxide, and others. We need a carbonaceous feedstock—the main feedstock required for gasification is the carbonaceous feedstock. Any carbon-containing feedstock or hydrocarbon-rich feedstock can be gasified to produce such gases. That can be coal, different types of coal, or byproducts of coal like coke and others.

It can be biomass, or it can be wood. It can be municipal solid waste. It can be any type of petroleum industry residual product, etc. It can be any type of carbonaceous feedstock. That means we need feedstock containing carbon and hydrogen or any type of hydrocarbon. And they undergo several types of chemical reactions to produce the methane, ethane and other gases. Some of these chemical reactions happens in series. Whenever we convert or whenever we do this gasification, there are several stages of reactions are there. And there are several stages of reactions changes in coal is there that can be initially the dehydration where moisture will be released from the coal surface. So, this moisture will lose out initially then it can go for the pyrolysis or release of volatile material stages where volatile material will be released from the coal surface. we call it like paralysis or body volatilization then it can have the oxidation and combustion reactions as per the reactions there it can have the main gasification reaction there it can have further reaction like water gas reaction shift gas reaction methane reaction etc. so all these reactions happen or all these changes happens to the coal or the feedstock So depending on the temperature, pressure, composition of hydrocarbons and other all these reactions happens in series and depending on the temperature some of the stages may happen some of the reactions may not happen. Now particularly if we see why we conduct this coal gasification or what is the major purpose of converting coal to a gaseous fuel or what is the major purpose of coal gasification in industrial way.

So firstly, here we convert coal to a gaseous fuel. As we all know that if any gaseous fuel is there, they can be easily transported through pipelines, through compressor, through tankers and others. so there are many inherent advantages of utilizing any of the gaseous fuel compared to any solid fuel that is in general the solid fuel has there are different difficulties in utilizing it either transportation either storage etc. so if we use gaseous fuel we can get many advantages like we can simply transport it through pipelines We can easily compress it, we can easily increase its concentration as well as these gaseous fuel or these hydrocarbons or materials, they easily react with oxygen. So, combustion of gaseous fuel like CNG or LPG is very much easy and they always go for 100% complete combustion quickly compared to solid fuel, coal or biomass.

So, this is in general that gaseous fuel has so many advantages over the solid fuel. So major purpose of this coal gasification is that if we can convert this solid fuel coal to gaseous fuel, so you will get all the advantages of utilizing or handling the gaseous fuel over the coal. So, they are easy to transport. We can easily transport it to pipelines and others. Ash will be disposed in a coal.

If we see for Indian context, it is 30%, 40% or 50% ash is there. And when we transport this coal to other location, we also transport this mineral matter of 40 to 50%. And this mineral matter doesn't give any calorific value. So unnecessarily it increases the transportation cost, mining cost as well as the material handling cost. So, if we gasify the coal at the source at the mines or nearby the mine's location, we will be transporting only the hydrocarbon rich part which will be converted to gaseous fuel and we will be disposing the solid residue as at the source itself.

So we can save a lot of money as well as the other advantages by not transporting by not handling this high amount of ash itself and on the other way this ash whatever is generated from the coal that can be easily utilized in the coal mines land filling or other application at the source itself because wherever we doing this coal mining that mining locations need some landfilling material whereas if we are burning the coal at other location they will have the same problem with the disposal of this ash so At the source, there is a shortage of material because coal is mined and there is a vacant space. Whereas in the utilization sector, there is an excess solid residue or solid waste called the ash.

So, if we gasify the coal, we will generate all this ash material in the source itself. So that can be utilized again for landfilling and other purpose. So, we can have saved a large amount of money as well as the advantages in terms of transportation and the combustion efficiency of syn gas or any of the gaseous fuel is always higher because this gaseous will always have Brownian motions, when we utilize them for combustion reaction. As they are the gaseous material they will easily mix with the oxygen. So, we can burn this gaseous fuel with less amount of excess air typically if excess air requirement for gaseous fuel is very less 100 or 105 percent is adequate there because they are better mixing with the fuel gas as well as oxygen. However, in case of coal as it is a solid material. So solid and gas mixing is not very easy it always has challenge of proper mixing. So as a result, there will be always some difficulty in combustion and we always need a higher amount of excess air like 20 percent excess air 30 percent excess air is always required in case of solid fuel combustion. So, if we convert it to the gaseous fuel like syn gas it will be easily burned in a reactor. So, we can have advantage of using gaseous fuel in a particular reactor if we convert it to a syn gas. The product gases, it can have production of fuel, for production of electric power generation units. In the thermal power plant, it's also, there are so many parameters involved where the coal combustion rates largely affect the electricity output in the plant.

But if coal combustion has difficulties and it has some many, many problems in coal combustion, in such case, power plant will face lot of difficulty in maintaining the required power output. However, if we initially convert this coal to fuel gas and then further fuel gas is burned to produce steam and others, so there can have much more stability in power generation. So thermal power plants can also be operated by converting coal initially to gasifying through gasification and that can be used to produce electricity. and in other cases, for low value applications like we can produce this fuel gas for domestic and you know industrial applications where low heating value gaseous fuel is required. We can also supply this syn gas for industrial applications to the industries where the low calorific value gaseous fuel is required and where the availability of natural gas or LPG gas is not there. So, by this coal gasification overall if we see that we can easily convert this coal to a gaseous fuel and that gaseous fuel can be utilized in different industries like thermal power plants or any other similar industries.

Industries that need low-calorific-value coal can use it as a source for carbon monoxide, carbon dioxide, hydrogen gas, and feedstock, which can be utilized in other industries as a source of chemicals and other products. We can also benefit from not transporting coal over long distances, saving transportation costs and reducing the need for landfilling at the coal mine site itself. Overall, coal gasification is a process similar to coal combustion, but the amount of oxygen supplied is limited. Thus, not all the coal or hydrocarbons will be converted into carbon dioxide. It will be partially converted. It will produce carbon monoxide and other hydrocarbon gases, which we will utilize as gaseous feedstock for further processes.

Thank you.