Clean Coal Technology

Prof. Barun Kumar Nandi

Department of Fuel, Minerals and Metallurgical Engineering

IIT ISM Dhanbad

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Lecture-26

Hi, I am Professor Barun Kumar Nandi, welcoming you to the NPTEL online certification course on clean coal technology. So, we are at module 6. In this module, we will discuss various industrial coal combustion methods, like different techniques used in burning coal at various particle sizes and others. These are the various topics that will be covered under this module in different lectures. First, we will cover fuel bed combustion, then pulverized coal combustion, followed by fluidized bed coal combustion, including atmospheric fluidized bed combustion, circulating fluidized bed combustion, pressurized fluidized bed combustion, and similar methods.

So, let's start with lecture 1 on fuel bed combustion. Now, if we examine coal combustion theories and their applications in domestic and industrial units, there are different methods available. In some cases, we can burn low-ash coal, while in other applications, we may burn high-ash coal. Sometimes, we need lower temperatures. For domestic cooking and similar applications, the fuel bed temperature or coal burning temperature will be on the lower side, maybe 400, 500, or 600 degrees Celsius. In other cases, we may need to burn coal at 900 or 1000 degrees Celsius, and in cement plants and other units, we may need to burn coal even at 1400 or 1500 degrees Celsius, depending on the requirement. The temperature required for combustion or utilization, the types of coal available, or whether there is co-firing or co-combustion of different types of coal or coal along with biofuels, biomass, or other similar materials, such as industrial waste, all play a role.

So, there are several ways industries burn coal. Based on their requirements, each method has its own merits and demerits. It is not that one particular method is bad or another is good. Each has its own advantages and disadvantages depending on the situation. For example, some methods are very good for high-ash coal or low-volatile coal, while others may be better suited for high-quality coal with lower ash content and very high gross calorific value (GCV). Accordingly, these coal combustion methods are categorized into three different types. The first one is fuel bed combustion. The second one is pulverized coal combustion. The third one is fluidized bed coal combustion. In fuel bed combustion, typically bigger size or lump coal is used. They are known as, or broadly, they are known as the grate firing method. As they are fired over a particular grate, in such cases, we use bigger size coal particles. In the case of the pulverized method, we use very fine size coal particles. In the case of fluidized bed, we use crushed coal, which will be of some particular size. So, if we see all these three different methods—fuel bed combustion, pulverized bed combustion, and fluidized bed combustion methods. As we have seen, in the fuel bed, we need to burn or we can burn bigger size coal. So, for coal or that particular type of coal which is difficult to crush, or if we need low temperature, we can use the fuel bed combustion. Whereas, in the case of pulverized coal combustion, we need very fine powdered coal. So, coal should be easily crushed. Powdered easily, not facing any major difficulty, not requiring any major equipment infrastructure, or not causing any major wear and tear in the coal circuits.

So, only those types of coal are suitable which can be easily powdered to the desirable size. Similarly, in the fluidized bed, coal which is very good for crushing but may not be suitable to make into powdered coal, those types of coal are used in fluidized bed combustion. So, these are the broad different methods of how coal is burned based on their coal properties and coal particle size. So, in the case of industrial coal combustion, we have the fuel bed combustion. In fuel bed combustion, this is the typical structure of how this coal is burned. Like this is the coal grate or support material over which the coal particles are placed. So, this is the location coal particles are placed. This is the actual support is given called grate. That is why it is called the grate firing. And through this grate these have some openings through which oxygen gas or primary air enters so this is the main support material will have some holes or openings through this oxygen will enter and coal can be stayed or coal has spread over the this entire top of this grate so This coal can be charged either from the top of this bed or it can be charged from the bottom of this bed depending on the particular requirement or particular type of design. either coal can be charged from this top then it is called like then top charging top charging coal or top feed coal or over feed coal combustion whereas in other design in some of the design it may charge from the bottom side also so if it is charged from top side so press coal will be charged here and it will move towards this direction and finally it will release an ash in case of bottom charging Coal will be charged from here and it will be moved to upward direction and here it will release as an ash particle. So, these are the two broad way grate firing is done. And if we see this great firing, this is particularly suitable for the bigger size coal particles. So here we don't have to cross the coal to very smaller size. We can use like 50 mm size coal or 30 mm size coal. Maybe some bigger coal also we can use.

And in this design, particularly if we see, there is no particular constraint on the residence time. So, coal particles will get adequate time for burning, ensuring there is no unburned carbon or unburned combustible material. So, this is the particular requirement where top feed or bottom feed, or this grate-firing coal combustion, is mostly used in domestic as well as some low-temperature industrial applications. Now, what happens to the coal when it gets charged at the grate? Here, we can see from the different nomenclature mentioned or different symbols in this picture, typically the green coal means it is the freshly charged coal, whatever is charged just now or within a very short span of time.

This is the part where the green coal, or the freshly charged coal, is present. This is the location where we can see the coal burning with some flame. So, this flame will be above the coal surface layer, and above it, we will place our desired material or get the heat released. So, this is the zone where the green coal, or you can say the freshly charged coal, is present. And further, this green coal, once it gets heated, will move downward.

So here, initially, it will form some coke. Then it will form ash. So, these are the corresponding reactions happening at each individual layer. And primary air is fed from the bottom of these grates. So, through these grates, Primary air is supplied and will react with the coal. So depending on the top feed or the bottom feed, there are these different layers, and accordingly, this gas composition will change. That means whatever chemical reactions are happening. At different layers, it will be different depending on how the gas is flowing—that means how the primary air is flowing and how the coal particles are coming down. If we observe the primary air and how it flows initially, we can see here that five different layers are present in this fuel bed combustion. Freshly charged coal is known as green coal. Now, after this coal is charged here, it is like freshly charged coal. It contains all the parts of volatile material, fixed carbon, moisture, as well as the mineral matter.

So, all these materials will be present in the coal at this particular layer. What will happen once this coal is charged at the top part? The coal will initially face the heat. Once this coal starts getting heated, all the moisture content present in it will be released. That's why this initial zone is known as the drying zone—meaning whatever moisture is present in this coal, it will get released. The coal will dry, so if this coal is drying, some amount of moisture will be released from its surface. Accordingly, this moisture will also be present along with the flame.

Whatever role this moisture plays—if it reacts with coal or other gases—it will take part in all these chemical reactions. Similarly, after entering, meaning once it loses its moisture, it is further exposed to high-temperature heat. Once it is exposed to high-temperature heat at the initial layers of this coal, it will again start losing the volatile material.

At the first stage, they have released or lost their moisture content. At this stage, they will lose their volatile material. So, this volatile material will get released and will move upward as part of the volatile gases. That's why this VM part will be present. And in the top part, as some moisture is present, it will be part of this moisture, which originates from the coal as well as any moisture coming from the air. So this final gas product will always have some moisture, whereas at this layer it will have some volatile material. Once this volatile material is released, we can say that the coke from coal is converted to coke. The difference between coal and coke is that volatile material is not present in coke. If we remove the volatile material from coal, we call it coke. So, we get a coke layer at this particular layer, which means it is basically a mixture or it contains fixed carbon and mineral matter. This coke layer, which is here now, will have its entire fixed carbon burned, and accordingly, it will release different gases and most of the energy. So, in the coke layer, fixed carbon combustion occurs. And we call it the combustion zone. Here, combustion is taking place. In the previous layer, volatile material is being released.

It is called the distillation zone, similar to the terminology used in oil refineries when distilling crude oil. In the case of crude oil distillation, we heat the material and extract some of the components. We call it distillation when, by heating, some of the material—such as hydrocarbons—is released. Generally, we name or classify them as distillation. So here, the same nomenclature is used, and we call it the distillation zone. So we can identify three different zones. The first one is the drying zone, where the coal particles lose moisture. In the second zone, the coal particles lose volatile material. Here, coal particles lose moisture and volatile material, and the main coal combustion takes place, where fixed carbon is burned in the combustion zone. In the last part of this section, all the coal particles are burned. So, what remains is the residual ash that we obtain in this section. So we call it like an ash zone where ash will get cooler as combustion goes on. So, this is the way how this coal particle is exposed to heat and how different type of physical and chemical reactions occurs with the coal particle now if we see in terms of primary air or gas composition what is happening here so if we see the primary air it is entering at this section. So here it will be at atmospheric temperature of 25 degree centigrade. So, this primary air getting preheated to this ash layer So whatever the primary air is entering air, so that primary air will get preheated. That means whatever the temperature or heat available in this ash layer, that will be taken or that will be transferred to the nearby primary air. So, ash will get cooled and we can recover some amount of heat from this ash.

As well as that heat will be recirculated or reused in the system. So, there is no major heat loss. That is why this primary air is sent from the bottom. So that whatever the heat is available that can be transferred to this primary air. So as released from this system can be having lower temperature may be 100 degree or 150 degrees centigrade if they are released. So primary air will be preheated at 150 degree or 200 or 300 degree centigrade so they will get heat or collect heat or recover heat from the waste material or solid waste ash so once this is there so this primary air get heated and at this particular zone when It is the coke is available as we have known that this is the combustion zone here this coke is available and when this coke is there that means in the entire carbon is exposed to the oxygen. Now once this entire carbon is exposed to this oxygen that means it can form carbon dioxide or carbon monoxide. So, depending on the residence time it is getting as well as the amount of oxygen it is getting. If it is getting adequate amount of oxygen and if rate of reaction is slow or produced carbon monoxide gas staying there for longer time. So, depending on the amount of oxygen or air supplied, the location, whether it is getting adequate residence time or whether immediately carbon monoxide getting released, it can be able to come out of the reactor as we have discussed in previous chapter.

So, it will create both carbon monoxide as well as carbon dioxide. So, some amount of carbon dioxide may form as some of the coal particles or some of the carbon monoxide may be converted to carbon dioxide if they get adequate residence time otherwise they will always convert to the initially carbon monoxide. So initially they will be getting converted to carbon monoxide and if additional oxygen is available or if residence time is there then only it will be converted to carbon dioxide. So similarly, when carbon monoxide is there from the coal surface if any other hydrocarbon is also there they will be released in the form of hydrogen gas or nearby any of the hydrocarbon lightweight hydrocarbon gases like methane and other gases. So, they will be released from this coke layer the theory you have discussed in previous a module like that as this is the limiting reactant. So, whatever the coal is there, so this will be the oxygen will be the limiting reactor because their adequate amount of carbon is there so until unless carbon gets finished completed they will form carbon monoxide and nearby hydrocarbon gases if some of the carbon monoxide converted or they get adequate time they will be converted to carbon dioxide and there will always be some nitrogen gas originating from the primary air. So, this gas will go and at this level what we can see that green coal is there where it is losing volatile material. So, this entire gas mixture it will get mixed with the volatile materials present in coal. So, at this level gas mixture will contain volatile material carbon monoxide carbon dioxide nitrogen and hydrogen that means this part plus volatile material will get mixed at this level. So, if these gases are released from this surface it will contains volatile material, carbon monoxide as well as hydrogen gas. Now, as all these materials or gases are there, that means entire coal has been converted to some gaseous form or gaseous fuel containing volatile material, carbon monoxide and hydrogen.

So, to ensure that all these volatile materials, carbon monoxide, hydrogen and any other hydrocarbons gets converted to the finer form like carbon dioxide that means they needs to further burn or further oxidize we have to supply secondary oxygen or secondary air at this location. So, from this top surface secondary air is charged here. So, this secondary air will ensure that all the volatile material all the carbon monoxide and all the hydrogen and hydrocarbons present in this gas mixture they get further burn and they further burn with some flame. So, once they further burn with the flame they will be finally converted to final product of coal combustion like carbon dioxide excess oxygen if it is there from the secondary air nitrogen gas and any hydrogen or hydrocarbons converted to the water. So overall if we see that Primary air will get heated in the ash layer as it passes through the coke layer where temperature can be around 1200 degree centigrade or 1000 degree centigrade here combustion takes place major reactions will be C plus O_2 but here can have some CO also in the upper zone excess oxygen makes CO gas which is further mixed with volatile material and moisture. So final gas mixture will contain CO_2, CO, H_2O and nitrogen so there needs to be supplied some secondary air at this stage to ensure complete combustion of the coal in case of under feeding case coal is filled from the bottom and through the same mechanical arrangement like the screw conveyor or others but in this case primary air passes through this hole mixed with fresh coal but in this case what will happens is that the reaction mechanism will be somehow different and the temperature profile will be somehow different so what will happen there in this Whenever air is supplied, it removes the moisture and volatile material. Later, this gas mixture passes through this coke zone. So entire volatile material and other gases will pass through this coke zone.

And so, in that zone, if we charge coal from the bottom, so in the same zone, in the coke zone, both cokes will get combusted as well as volatile material will also get combusted. So, some amount of CO will be produced. which will be burned by the secondary air. And in the presence of secondary air, some amount that combustion of carbon monoxide and residual volatile material will be done there. But what we get different is that we will get differentiate in their heat recovery or heat thermal efficiency because whatever the ash is there that will be released at higher temperature because primary air is heated directly from the coal whatever heat is getting released. So, there will not have any heat recovery system that means ash will be released at high temperature maybe 900 or maybe 1000 degree centigrade. So, there will be major heat losses from the ash as it is not mixing with the primary air. So, if we see the top charging and bottom charging broadly similar reactions will occur but the reactions happening location it will get changed if we charge coal from the bottom if we charge coal from this bottom side ash will be generated here. So, in such case ash will be generated here. So, this ash will be released at high temperature whereas this primary air will get heat or it will take heated it will get heated from the coal surface. So, in such case overall temperature profile will be different so there will have less thermal efficiency if we charge coal from the bottom and also if we see the gas composition here as here temperature will be on higher side as in the nearby flame as temperature will be on higher side. So, there will not have any amount of volatile material in the flue gas or gas going out of the system. So, if it is charged from the top at the top layer it is getting secondary air. So, there can have probabilities that still in the presence of secondary air some of the volatile material may not get desired residence time for burning. So, there is some probability or possibility is there along with this gas some amount of or trace quantity of very smaller quantity of other hydrocarbons and carbon monoxide may be there that means this is some probability is there if we charge coal from the top because whatever that your volatile material is released and they will directly go out. So, within this short span of time, it has to get converted or it has to get burned but if we charge coal from the bottom side, volatile material is released at this surface. So, it is getting adequate residence time for combustion. So, in the flue gas, there will not have any major unburned hydrocarbon or carbon monoxide because all will get adequate time for burning. So, there will be some differences in the flow gas composition as well as the thermal efficiency in both the case if we charge the coal from top or if we charge the coal from the bottom and even in this design if required we can arrange or we start this ash layer to reduce the impact of ash layer formation to ensure that all the bigger size coal particle gets completely burned. So that arrangement also can be possible in similar grade design by externally using any mechanical scraper or any other device. We can also remove the ash layer if required. So, these are the some of the Real time mechanical stokers or combustion equipment used in or coal firing system used in high temperature applications in industrial scale.

Like in this scale, whatever we can see is that this is the conveyor belt or that grate. This is actually the grate. Through which coal combustion takes place, this is the surface where coal particles will stay. From this surface, coal is charged as per the requirement. From this hopper, coal will be charged, and this is the final point where coal will ignite. We can control the flow rate of coal here. So once this coal is there, coal particles will travel across this distance. So, coal particles will travel through this path. These coal particles will travel, and by this distance, coal particles will get completely burned. So, coal particles will get residence time. That corresponds to the speed or rotational movement, whatever the speed is there, and based on the distance, it will get the time required for combustion. Initially, coal particles will be here, and they will go across this distance. At this location, they will fall like ash after combustion is completed. From the bottom side, through this grate, but through this opening, primary air will be supplied. So, this entire section will be working, or they will be burning coal as per the picture shown here.

So, whatever the reactions are showing here, that means this entire bed will be in a moving bed. So, this entire bed will move in this direction, and combustion will take place. So that happens in the case of a mechanical stoker where coal particles of bigger size are charged. They will go through this. So, this is the motor or some mechanical arrangement is done to rotate this grate. So, this grate will rotate continuously in this way and it will release ash particle here and at this time location. they will release all the ash residue present in the grate. So, and from this side we will we will be supplying the secondary air that whatever was required in this design whatever the secondary was air was required in this design they will be supplied at this location. So, from this side we supply the primary air and from this location we supply the secondary air. So, this air will get burnt they will get it heated and flue gas will be of high temperature depending on the type of coal and properties of coal. So those flue gas will be useful for further utilization as per the requirement. This is the Mechanical stoker almost in the similar way that coal how it is get burned like this is the different equipment's like hopper, coal grate, front grate, chain grate etc. which are part of this coal that mechanical stoker and from this bottom side we are feeding the primary air. And this is the mechanical stroker when we need to supply some bigger size coal.

So, in this coal hopper, coal particle stays there and they will be fitted to a hand or in a thrower which will throw the coal particle based on their mass and other requirement. So, this will throw, this will rotate or we call it like a mechanical spreader. this spreader will throw the coal particle or to different distance so in this distance at so here we will get the required amount of fuel bed and from this bottom side we can get the primary air supplied and from this location we can get the secondary air supply and using this particular lever we can discharge or we can disturb the whatever the ash layer is there, we can remove it and we can finally also remove the ash layer from this. So, this is a mechanical stoker also used in different industries where bigger size coal particles are typically burned. So overall if we see all these mechanical stokers different designs are there in most of the cases they are used for the low temperature applications where we can we have to use some bigger size coal particle and this bigger size coal particle particularly if the ash content is on the higher side so any high ash coal Maybe 45 or 50% mineral matter is there. So those coal typically takes lot of time and their calorific value is less. So here temperature requirement is on lower side. That means 600, 700 or 800 degree centigrade heat is required or their temperature is required for processing of their material or any similar purpose.

This type of fuel bed combustion is used. The advantage of this fuel bed combustion is that we can use any of the larger-sized coal particles, and it can allow the coal particles a longer residence time. So, if any coal takes a lot of time to burn, it can burn such coal. Also, we can use different blends of fuel as well as other types of solid fuels, like municipal solid waste and others that have some combustible material in this type of mechanical stoker coal combustor. So, we can burn or co-fire them also in this particular system. This system is mostly used for low-temperature applications, and in such cases, there may be some possibility that the coal has some unburned carbon particles inside this coal, and there may be some amount of unburned hydrocarbon gases or carbon monoxide in the combustor.

So, there are needs—maybe some secondary air is there, but in some cases, tertiary air may also be required. This picture has been taken from the Power Plant Engineering book by P. K. Nag, and you can also use it for reference purposes.

Thank you.