

Clean Coal Technology
Prof. Barun Kumar Nandi
Department of Fuel, Minerals and Metallurgical Engineering
IIT ISM Dhanbad
Week-04
Lecture-20

Hi, I am Professor Barun Kumar Nandi, welcoming you to the NPTEL online certification course on Clean Coal Technology. We are discussing coal combustion fundamentals in Module 4. So, we have already covered various aspects of combustion fundamentals, the shrinking core model, and the burning profile of coal. Heat release rate and burning time. In this lecture, I will discuss the impact of burning profile parameters on real-time coal combustion utilities.

So, let's begin Lecture 5 on coal combustion. So, as we have seen, coal particle density and coal particle diameter also have a major impact during coal combustion, as well as the burning profile parameters of different source coals or coals of different origins. They also vary widely. Now, let's see how the particle density of coal and its diameter or size affect coal combustion. So, this is one of the images. This image represents the typical coal combustion process that occurs in a boiler. In the boiler, these are the different input points where coal—pulverized coal—is burned or charged, along with the primary air. They are fed from this side and burned in this air because the coal particles used here are pulverized coal of 75 microns or smaller. These very fine coal particles burn in the air phase itself, and after burning, they precipitate as bottom ash at the bottom of the boiler and are released as bottom ash. Some of the coal particles will also get burned if they are lighter in nature. They may report or go to the upward side as they are of light particle density. They will report to the fly ash or go along with the flue gas in the combustor. There are different control mechanisms, crushing, and grinding, everything is there in the backside which makes or pulverizes the coal to the desirable size based on the other coal characteristics. So, if we see what are the forces acting on the coal particle. During this combustion, whenever coal particles enter this particular chamber, like if it is getting or entering at this particular point, it gets residence time corresponding to this until it falls to the bottom as bottom ash. So, this time, Whatever this coal particle gets, like 4 seconds or 5 seconds or more than that or less than that, depending on the velocity of air and other conditions.

So, it gets a very small amount of time inside this boiler to burn. So, its residence time is very important. This coal particle has to get completely burned within this short span of time. So, if

the coal particle gets adequate time for combustion, it will completely burn, and in the bottom ash, There will be no unburned hydrocarbons or unburned coal particles. But if this coal particle needs much more time for combustion, if it has some delayed combustion or its rate of combustion, rate of heat release is not matching with the design of this boiler or this burner, it will not get adequate time for burning. So, although it may reach or may have gotten its activation energy for combustion, it is already at a high temperature. But it is not getting adequate space time or residence time required for its burning. It will not release heat in the main chamber. The zone where it is expected to release the heat, rather it will burn or release at this bottom phase. So, if it releases heat at the bottom phase, whatever the previously deposited ash particles are there, they will get heated up, they will reach their melting point or fusion point, and a lot of other consequences occur. So, if we see how this coal particle density and coal particle diameter affect, like if we see any coal particle is like this.

So, what are the forces acting on this? Typically, coal particle try to fall downwards due to gravity force as well as due to velocity of air and other flow rates, other parameters, it faces some drag force. So that this drag force keep this particle in the air phase not allow it to precipitates. So, it has to get these two drag force as well as the gravity force. Now if we see mass of coal particle that is corresponding to the density of coal particle as well as the particle volume. Now this particle volume again corresponding to the particle diameter like $4 \text{ by } 3 \text{ pi} \cdot d^3$ to the power cube. so, this is the volume formula for volume. So here what we can get is that if this particle diameter is on higher side like any coal particle is there it has been grinded to the desirable size but if this particle diameter is there. So, if any particle diameter is either 75 micron or if it is 200 micron. Or if it is 10 micron, like it is this size, this is bigger size, whether this is in smaller size. If there is change in the particle diameter, depending on the grinding efficiency of the mill, if particle is of bigger diameter, like 200 micron. Obviously the particle volume will be on the higher side. So, if particle volume is on the higher side even the particle size the density of particle is same. Overall mass of particle will be on the higher side. So that downwards force mg force gravity force will be on higher side. So, this particle will easily or quickly precipitate or quickly drops to the bottom that means it will remain in the air for less time or its space time will be less that time duration for which it is staying in the air phase it will be less if they are of bigger size particle or they are of bigger diameter particles. So, for optimum efficiency or desired temperature heat release coal particle must be grinded at their suitable size as per the design or there should not have any oversized coal particles in the pulverizer. If there is any oversized coal particles in the pulverizer, then

this particle will not get adequate time for burning, adequate time for combustion as its settling velocity will be on higher side. So, it will always create some unburned carbon in the bottom ash. Similarly, if we see the density of coal particle. If coal particle has specific gravity of 1.3 1.5 or 1.9 if there is variations in the specific gravity of coal particle. So, if they are higher density coal particle like if the coal particle density is a specific gravity is about 1.9.

In such a case, what will happen? As their particle density is on the higher side, their mass will also be on the higher side. So, if their mass is on the higher side, in such a case, it will again settle or come to the bottom ash very quickly. Quickly or within a shorter span of time. So, if particle density is on the higher side, it means it has a higher settling velocity. So, it will have less retention time or less time duration for which it can remain in the air. Similarly, if the particle has a larger diameter, its settling velocity will be high. And it will stay in the air for a longer time duration. So what is its actual significance? If we see it like this, what actually happens with the coal particle? Like this is a Dimension of that boiler, which we have shown in this picture. So, if we see in this picture, the particle is falling from this side. If we consider this picture, we can understand it like this. So here we are sending all the particles of 75 microns. If any particle has more than 75 microns or if that pulverizer is not working properly, we can get coal particles even larger than 75 microns. So, if any coal particle has higher particle density, like if this coal particle has a particular mass or mg on the higher side, if mg is high, it can either have higher particle density or higher particle volume. So, as the mg force is on the higher side, basically here it will have this Momentum force, which will act here as well as the gravitational force, which will act here, and combined, the particle moves in a tangential way due to this force. So, if this force is on the higher side, the heavier coal particle will not travel a longer distance; it will try to precipitate in this way. Whereas the lighter coal particles will go for a much longer duration and will precipitate here. So, the space time or residence time it gets to react or burn depends on the particle density. Now, what will happen? Even though their particle size is similar in nature, if we see the black particle, as it is getting less time for crossing, its time duration is less, so although it is burning slowly. But when it is falling below, it may not get completely burned. As a result, we can have some fine coal particles which may contain unburned carbon. Whereas if we see the red curve, the red curve particles, it is just getting, but here the amount of this percentage is less. Whereas these blue particles are almost completely burned by this length. So, there are no unburned coal particles here.

So, if coal particle density or their gravitational force is different, they will have different residence times for burning. So, their particle density and particle volume, etc., must match or

must align with the design or dimensions of the boiler. If they settle very quickly or if their particle density is on the higher side, there will always be some probability of unburned carbon here. Similarly, if coal particles are very lightweight in nature, That means in such a case, if this force is on the higher side, their velocity is higher, but their gravitational force is very low.

In such a case, it will move in this way, and by this time, it must finish burning before it is expelled or goes along with the flue gas. as fly ash. So, if we use very light coal particles, like those with a specific gravity of 1.2 or 1.3 or maybe 1.1 or others. So, in such a case, all the coal particles will go with the flue gas as fly ash, but before leaving this combustor, they must finish their combustion so that there is no unburned carbon or other gases in the flue gas. Now, what all these parameter differences mean—like if we see coal with higher particle density, as we have seen that coal of 1.5 or 1.9 They may have their GCV value is on the same side because gross calorific value depends on the hydrocarbons present as well as the origin of coal. They can have coal particle where ash percentage is less but their calorific value is also less. but there can have opposite side there can have some coal particle where density percentage is on the higher side whereas GCV is also on the similar level. So, there can have probability that two coal of having same gross calorific value but there is significant difference in the particle density. So, if coal has some higher particle density what it will see it will have higher settling velocity that means it will have less space time for reaction if it has less space time for reaction it will not may not be able to completely burn or it may burn that depends on the that inherent hydrocarbon properties of that coal that burning profile parameter. So, in most of the cases it will result in unburned carbon along with lower heat release because it has higher settling velocity it will have less space time it is that highest probability is that coal particle will not get adequate time it is not that coal particle doesn't have adequate GCV value. It may have GCV value, but we are not allowing it to remain in the air for sufficient time. So that it can stay in the air for longer time and it finished combustion within that time. Whereas in the opposite scale, if we use the light mass coal particle where the particle density is very less, as their settling time is on higher side as they can stay in some longer time. So, most of the cases like this particle they will finish their burning. Similar phenomena will occur if we use different sizes of coal particles like if we use bigger size bigger size coal particle but lighter coal particles like they can have size is bigger but they can be lighter and they can be smaller coal particle size but they can be heavier coal particle size so we have to consider all these aspects whether these coal particles are getting adequate space time for reaction or not whether they are burning profile temperature that their minimum time required to complete combustion they are getting

it or not we have to use coal in such way that we can avoid all these aspects of creating unburned carbon either in the bottom as well as in the fly ash. If we use very fine coal particles or if we use biomass where density of particles is very less, so they will just remain in the air and even they may leave directly the combustion chamber without getting burned. without getting ignition because they are so much lighter in nature so they will not get their adequate time duration for burning. So, they we may burn we may charge them there but they will not actually get burned because they are so much lighter in nature. So that they will directly goes out within a very short span of time this is also undesirable condition or if we are using coal which may have good GCV or which may have their design GCV value but their particle density is on the higher side. So, in such case they will enter and immediately they will fall to the bottom of the combustor without getting burned. So, we have to consider all these aspects that's why always we have to use the design coal and we have to use we have to analyze all the properties whether these properties After verifying all these properties whether it can be used or it can burn inside the combustor efficiently or not. If we do not consider all these aspects, we will not achieve total combustion of coal particles, only due to the failure of the design or, you can say, a mismatch of coal properties as well as the design of the boiler. And if we see, typically, what happens in the case of tangential coal-fired pulverized combustion like these particular units, in the actual burner, this type of burning coal is fed from all four sides. It is a three-dimensional image; we are seeing only the left side. So, from all four corners, typically, coal is fed—they are coal-fired in this boiler. So, if we see a tangential coal-firing unit, if we see its top view, Like from this side, one coal stream is getting fed; from another side, another coal stream is getting fired. So, from all these four sides, coal is typically fed, and we get all the coal particles to burn in this zone, which is known as the fireball, as we have discussed in the previous class. So, in real-time boilers, coal particles or pulverized coal are fed from all four corners, maybe at different heights. So, this is only the four-point; it can even have other heights. It can have other feeding or charging points like this one. So, this is only for one side; similarly, we can have coal particles charged from the other four sides at some other height, another set of coal particles also charged, and from the third height, sometimes coal particles are also charged. So, in real-time boilers or real-time pulverized combustion units, typically, coal is fed from the 4-point or 8-point. or even up to 12 points. This can be more, depending on the capacity or heat requirement in the boiler.

So, if we see these tangential firing units, here we can see how or what actually happens in these tangential firing units if there is a change in the coal particle density, heat release rate, as

well as the combustion characteristics or burning profile parameters are different. Typically, coal and biomass particles have different densities, and their heat release rate controls the temperature profile inside the boiler. So, if you see, these are the four points from where coal particles are getting fed to this boiler. So, we have considered here only one point to discuss what happens, and the same thing happens with all four corners—all the remaining three corners. So, if we see any coal particles charged from this—this is actually a three-dimensional image—so if we see only from this and this side, what happens to the coal particle? So, inside this, the temperature is always higher. So, this particular temperature zone, it is known as the fireball where the temperature is different may be inside those temperature is high and at this temperature location temperature is less. So overall this boiler has to maintain this temperature profile as well as the location. So that this temperature profile if it is there it should remain inside this zone not like it is shifting to this particular zone or it is shifting to this zone or it is shifting to this zone or this particular fourth zone. So, it is always desirable that it should remain in the center zone not shifting towards the left nor right or any other side. So, it is desirable that it should maintain its temperature profile inside it which is monitored from the control units or the control room of any of the thermal power plant. So, they can see in their computer screen there this image. This image correspondence to the temperature profile inside this boiler, so if we see what happens actually so whenever coal particles are charged from this point. It is expected that by this length or in this case this for this length they will get ignited that means It is expected that they will reach their ignition temperature or their ignition should occur by this length so that in between this length, it will release its peak combustion heat release or peak combustion rate will occur so that it can release its highest temperature. So, in this zone, There should have some that DTG max whatever we have read there that temperature profile or heat release corresponding. So DTG max that should occur at this zone. It is expected. So, if it is crossed like this whole particle will move through this. So, by this length it will finish burning and it will fall as a bottom ash.

So, it is the actual requirement that by this curve. Coal particle should enter here, it should ignite latest by this point, it should travel by this way and by ending this point, it should fall there as a bottom ash. If this happens, that means it is releasing heat just center of this boiler and it is in such case we can easily maintain the desirable heat release and as well as the temperature profile of the boiler. Now what will happen if any coal particle has higher particle density that means is density of this coal particle is on the higher side or overall coal particle mass is on the higher side. It can have some from higher bigger size coal particle or it can have

bigger or higher particle density. So effectively as is settling velocity will be higher. So, it will travel to this path not following this path, rather it will follow this path. If it is followed this path, so it will release heat at this location. That means temperature profile will shift towards this location as coal particles are having higher density. So, they are traveling across this path, not following this particular trajectory. They will follow in a shorter distance. So, they will release entire heat by this path. so, in such case that fireball temperature will leave shift towards the either left similarly if it is from this part path it will shift toward the other side so effectively fireball temperature profile will shift from the center to any of this side and if also as it is getting less time it must finish combustion whenever it reaches at this particular point If it reaches this particular point, then it will release all the energy. If it is not burned by this point, it will fall here as the bottom ash. So, if it is released here as a bottom ash, that means although we have charged the coal particle, It has partially released 60, 70 or 80% of energy and remaining 20% of hydrocarbons are not burned because we have not allowed it to desire residence time to get it burned here.

So, what aspects will be there or what phenomena will be there? That fireball characteristics we are not being able to maintain. as well as we are getting unburned carbon here. Similarly, if coal particle has lower particle density, their particle density is very less. So, in such case, it will travel to this path to report as a fly ash. So, if it reports by fly ash, again temperature profile will shift towards this side. If temperature profile shift towards this side, again there will be Stability of the fireball will not be there as well as we will get fly ash. So, if that coal particle doesn't get completely burned because it is getting less amount of residence time. Residence time is much more if it travels by this corner.

But if it is taking this short route in such case residence time will be very less. So as a result, in both the case we will get unburned carbon either in the fly ash or in the bottom ash and other. So if we typically blend the biomass as the particle density of the biomass is on the lower side biomass doesn't have higher particle density compared to coal they are typically lighter in nature if biomass percentage is smaller we can able to maintain this fireball temperature but if the biomass percentage is on the higher side we will not be able to maintain that burning profile temperature because biomass particles will finished burning by this way so it will seep to this location and it will go in this way whereas coal particle will be there so effectively if we see the profile this will be the location for fireball location corresponding to biomass whereas this will be the fireball locations corresponding to the coal particle so there will be unstable combustion or we will never able to maintain the desirable temperature characteristics across

the boiler so what will happen if it releases more temperature here nearby refractory material may not have adequate temperature stability to sustain this overheating if this temperature zone is 1200 here if it is suppose in this temperature zone it is 1200 degree centigrade and it is 1000 degree centigrade this refractory material limitation that they can survive at 1000 degree centigrade but if temperature here is 1300 degree centigrade refractory material will get damaged. Similarly, boiler tubes and other material will get damaged they will get overheated same thing will happens to this side also. So overall this is an extremely undesirable condition that's why when we charge the coal particle there we have to see all these aspects so Overall, if we see coal and biomass particle density, their heat release rate, they entirely contours the temperature profile inside the boiler. Early ignition results in wider and lower temperature fireball. If it is some delayed combustion or higher peak combustion results in concentrated fireball like they should burn at this location we should get concentrated firewall in both the case if entire the heat is released only at some particular zone and if that means if DTG max value is significantly high or if there is DTG max peak value is like this or DTG value DTG profile parameter is like this. So, there is two different cases if DTG profile is like this That means it will release energy at this point and if DTG profile is like this. Here, that means if this curve is on wide in nature, so it will release heat continuously. So, starting from this point to this point, it can maintain the desired heat release rate. But if DTG plot is like this or if DTG plot is like this sharp curve, it will release entire energy at only center or maybe at this point depending on the particle density in such case it will always create some over temperature which may create some other consequences like tube failure, overheating or it may exceed the temperature which is required for the NOX formation. So, whatever we can learn or whatever we see from this that. from this section is that for efficient combustion we always we should use the design coal or we should always match their burning profile parameters as well as their desirable particle density and others typically this particle density we does not consider or do it doesn't take care when we select the coal or when we feed the coal to a particular boiler so Entire coal properties we have to use and see whether that coal properties is matching with the design and how we can match the design parameters. So that there is some less impact on changing the coal source. All such values, typically for which design coal has been, that particular plant has been designed for what type of coal.

This is typically mentioned in the power plant, that manual, which is made, which is supplied by the manufacturer. Each manufacturer, whenever they supply any of the boiler, typically they mention that this boiler can be used for 30% as coal or this amount of volatile matter, this GCV

coal. They mention all these parameters whenever they supply it. But in real time, as we are not getting those design coal, we ignore all these parameters. But we should consider all these parameters. Since similar or identical coal is not available, we should match the combustion profile—whether they align or not—along with the other characteristics of coal. This combustion parameter is a non-additive property. Now, what are additive properties and non-additive properties? Additive properties are those for which we can simply calculate a mathematical average. For example, if we say ash percentage—30% ash and 40% ash—we can average them as 35% ash. But non-additive means non-additive.

Although we blend two different coals, they will not exhibit average properties; instead, each coal will retain its own properties. These properties are called non-additive properties, such as grindability. One coal may be hard, and another may be soft, but when we grind the coal, each coal will be ground based on its hardness—not the average hardness. Thus, combustion properties are also non-additive properties. Individual coal will retain its own properties. There may be minor variations or changes. Since these are non-additive properties, we must always verify blended coal properties. We can predict them to some extent through mathematical modelling, but it is always preferable to verify with actual values. Similarly, we should measure the flue gas composition. We must check whether this flue gas contains carbon monoxide, hydrocarbons, or other components. If the flue gas contains carbon monoxide, it means there is unburned carbon present. This indicates an issue with the combustor. It is not receiving the desired amount of oxygen, or the coal particles are not getting sufficient residence time for combustion. So if CO is present and no oxygen is there, that means there is some problem with the oxygen supply or residence time. If both oxygen and CO are present, there are some severe problems in the combustor. So, if we conclude from this chapter or combustion characteristics chapter, what we can get is the information we obtain. Coal combustion characteristics vary widely based on the origin of coal, depending on hydrocarbon characteristics, mineral matter characteristics, their TGA, DTG curves—everything varies based on their origin and source. Burning profile analysis is most important, as it gives an indication about how a coal particle is getting burned and whether it is expected to match the design parameters or not. Both mineral matter and hydrocarbons play a major role here in terms of combustion characteristics, as well as in modifying the particle density, particle volume, and other factors. In general, proximate analysis, ultimate analysis, and GCV analysis give some preliminary indications about coal properties. So, if we want to utilize coal much more efficiently without having any major environmental impact, as well as without any unplanned failures, we should consider all the

parameters—not only these parameters. Typically, only these parameters—proximate analysis or GCV—are considered in thermal power plants, but they provide some basic information about the characteristics, not the final ones. We should always verify the complete combustion characteristics of coal—whether it matches the design or not, whether any other parameters could have an impact, which will affect the heat release rate as well as environmental issues. We should consider all these aspects, particularly the combustion characteristics, before selecting and feeding coal to a thermal power plant. This is particularly important when we feed coal in a thermal power plant with multiple sources where coal blending or coal mixing cannot be avoided.

Thank you.