Clean Coal Technology

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Hi, I am Prof. Barun Kumar Nandi, welcoming you to the NPTEL online certification course on Clean Coal Technology. In Module 6, we will discuss various methods used in industrial coal combustion utilities. In this module, we will discuss fuel bed combustion, pulverized combustion, and fluidized bed combustion. In Class 1 or Lecture 1, we discussed fuel bed combustion. In this lecture, I will discuss pulverized coal combustion.

Now, pulverized coal combustion, has been discussed in our previous classes many times. So, if we examine the details of pulverized coal combustion and its utilization in pulverized coal combustion. Most large installations, such as thermal power plants and cement plants, burn coal in pulverized form. To achieve consistency, their powder shape is almost at the level of talcum powder. They are burned in this particular size. Recently, it has been observed that pulverized coal firing is also used in some blast furnaces to reduce coke consumption, as coke is costly and not easily available.

So, if we observe what happens during pulverized coal combustion, initially, coal is pulverized. This coal is ground. First, coal is crushed and then further ground using a ball mill, impact mill, or rod mill, depending on the industry's requirements. These can be vertical or horizontal designs of impact mills or ball mills. This degree of fineness is typically very high, with about 85% of the coal particles passing through a 200-mesh sieve or, in terms of microns, being less than 75 microns. So, this is the level of fineness we need that all the coal should be grinded less than 75 micron size where most of the coal particle will that 85% of this coal particle will be less than 75 micron there can have some coal particle which is just above 75 micron but most of the particle should be less than 75 micron so we need a suitable grinder or mill which will reduce the size of this coal particles to this level of 75 micron or less and these fine coal particles are typically preheated air at about 100 degree or to 300 degree centigrade. So, whatever the waste heat available in thermal power plant that is heat is released to the through flue gas to the other that to the chimneys and to the ESP and others. So that flue gas from that flue gas significant amount of energy is recovered which is used to preheat the air now that preheated air is particularly used to transport these fine coal particles from this mill to the combustor that is We need a high velocity air which will have some amount of kinetic energy so that they can transport the fine coal particles of less than 75 micron to the combustor.

So, there is always a requirement of air. And if it is preheated air, then it will have much more energy efficiency compared to the if it is not heated. So, in such case, entire coal particle will be having atmospheric temperature and they will take some more amount of time to get ignited and burned. But if they are preheated, so in such case this coal particle will already be at higher temperature of 300 degree centigrade or 250 degrees centigrade and they can easily catch fire when they just enter to the combustor. So, purpose of this preheating of this air is also to make the coal dry, create some vacancy for removing all the moisture content from this coal so that whatever coal is entering in the combustor, they are just ready for ignition.

There will not have any delay in ignition, neither in terms of releasing moisture or not in terms of low temperature. So, due to this, Energy efficiency of the combustor is increased significantly as well as the overall energy efficiency of the plant is increased. As we can extract or we can collect some amount of the waste heat from the flue gas stream which is added to the preheated air. And that waste heat from the flue gas is typically used to preheat the coal and here as this coal is premixed with the primary air, so this primary air will be the fraction of total air needed for combustion which will be sufficient to blow or transport the coal mixer to the burner. So remaining amount of air required for the combustion, we can supply it as secondary air or tertiary air which is supplied at later stage. As the coal particles travel through the burner, they are heated by the radiation of the flame. So, in the pulverized coal combustion unit, already the combustor will be at much higher temperature.

So, like if we draw like in a combustor unit, so from this side any coal particles heated, so combustor will already be at much higher temperature, maybe 200 degrees centigrade. from the heat released by the previous coals or otherwise. So, this combustor will already be heated at much higher temperature. So, whenever these coal particles enter here, so they will get the heat from the radiation of the combustor and they will get or they will get the flame and immediately volatile materials from the coal are released and they started burning. And typically, this residence time for this pulverized coal combustion, this coal particle will be less than five seconds.

Like whenever they enter in this combustor, whenever they enter in this combustor from this point to fall it like this. They get typically time duration of about 5 seconds or less. So, they stay there for very shorter time of about 5 seconds or sometimes 4 seconds. So, all the coal particles have to get completely burned. They have to release all the energy during this short span of time. On the basis of firing method. Now, this coal combustion firing method can be of different designs. In some cases, they are in horizontal firing; in some cases, they can be in vertical firing; and in some cases, they can be in tangential firing. So, this firing method depends only on the design of the combustor or as per the requirement of the industry where they want to utilize this coal. or they want to utilize this heat available from the coal. And overall, coal particle size and density modify the performance of the combustor. Whether these coal particle sizes are bigger, as we have discussed previously, 85 percent will be less than 75 microns. So, in real-time, pulverizers typically produce particles less than 30 to 40 microns. They are in the range of 30 to 40 microns. Most of the coal particles are in the 30 to 40 micron range. Some of them may be in the 50 or 60 micron range, and very few particles will be above 75 microns. Now, why do we have to grind this coal, or why are these coal particles burned at such a smaller size? The purpose of burning these coal particles to such a fine size, compared to fuel bed combustion, as we discussed in the previous class, is that if the coal particles are ground to a very fine size like 30 to 40 microns or 50 microns, we can effectively reduce the impact of the ash layer over the coal particle. If we use bigger-sized coal particles, there will always be some ash generated, depending on the ash percentage of the coal. This ash layer prevents further combustion and reduces the rate of combustion. So, the purpose of grinding or burning them to a much smaller size is primarily to reduce ensure that the ash percentage of this coal does not create a problem in the combustion of the coal. This ash percentage of the coal may create other problems, but at least it ensures that all the coal particles get burned. So, if the ash percentage of the coal is on the higher side like if we use a 50% ash coal or if we use a 45% ash coal so they should be grinded to much finer size like 30 micron and if coal ash is around 10 to 15 to 20% even 75-micron size is okay. So, this coal particle size and the ash percentage of this coal is deeply correlated to ensure that all the coal particles get completely burned in the combustor. Higher is the percentage of ash, lower should be the fineness of this coal particle or lower should be the size of this coal particle. And we have to ensure that more than 85% to 90% of these coal particles are burned. below 75 microns.

This is one aspect. Second aspect is that if coal particles are of very fine size, all the coal particles will get burned immediately. So, if these coal particles get burned immediately within a short span of 4 to 5 seconds, in such case all the coal particles will release whatever the energy available in the combustor within a very short span of time. That means whatever the GCV or energy content coal has. So that entire energy amount of 6000 calorie or 5000 calorie per kg, if we are sending 1 kg of coal, then entire 1 kg of coal will get burned within 2 to 3 seconds or 4 seconds. So effectively we can release higher amount of energy and we can generate or we can achieve high temperature in the combustor. So, if we want to get much higher temperature like 1300 degree centigrade or 1400 degree centigrade, we have to burn coal at much smaller size or much finer size. If we burn coal at bigger size like 2 mm, 3 mm or 4 mm, we will not be able to maintain high temperature. So, in such case, maximum temperature achieved in the combustor will be limited to 1000 degrees or 900 degrees centigrade. To ensure that the combustor reaches very high temperatures like 1300 degrees, as required for most thermal power plants, or 1500 degrees, as required for cement plants to prepare cement, we need very high temperatures. To achieve this high temperature, we must burn a higher amount of fossil fuel within a short span of time. That means we must ensure that the kilocalorie heat release per minute of this unit is on the higher side. To achieve a higher kilocalorie-per-minute value, we should burn much more coal. For example, if we consider GCV (kilocalorie per kg), burning more coal quickly will increase the GCV. If we burn 10 kg of coal within a few seconds, we can achieve the corresponding GCV value within 10 to 15 seconds. In such cases, we can easily achieve much higher temperatures. This higher temperature is required in modern pulverized coal combustors. Coal combustion is used to produce steam, especially in large-capacity thermal power plants, such as those with 500 megawatts, 300 megawatts, or even 1000 megawatts. To produce 1000 megawatts of electricity from one unit, we must achieve much higher heat release from the coal. We cannot wait for one or two tons of coal to burn over several hours. To ensure this amount of coal burns within a short span of time, we must grind the coal and ensure all particles burn quickly. This is why coal particles are ground to a much finer size. The second aspect is preheating the coal or primary air.

The purpose of preheating is to heat the coal particles or air so that they enter the combustor at a much higher temperature, increasing thermal efficiency. For some coal types, 300 degrees centigrade is their ignition temperature. Some coal may ignite at 300 degrees centigrade or even lower. Typically, coal with higher volatile material, such as lignite or semi-bituminous coal, ignites at lower temperatures. Similarly, blending biomass with coal can also lower the ignition temperature. In such cases, we must be very careful with the preheating process. While preheating increases thermal efficiency, it can also cause ignition in the mill itself, which is a dangerous and hazardous condition. When preheating air to a specific temperature, we must ensure that neither coal nor any co-fired biomass reaches its ignition temperature in the mill. If coal ignites in the mill, it poses a significant risk. Or if they are being ground at the same time. They should not reach their ignition temperature. In such cases, we must use temperatures below 300 degrees centigrade. The preheating temperature may be 150 degrees centigrade, 170 degrees centigrade, or below 200 degrees centigrade, depending on monitoring requirements. The volatile material percentage in the coal or fuel mixture is another factor. If we preheat the coal, we must ensure the entire mixture is transported through the burner. And they must be carried by the primary air.

So, if the entire amount of coal is to be transported through the primary air. So, the velocity of the primary air should be on the higher side. Because it needs to be on the higher side so that all the coal particles are transported to the combustor. Now, if the velocity of this air is on the higher side, that means we have to use a compressor or similar mechanical equipment which will control or force this air to transport these particles to the combustor. So, in such cases, the efficiency of this pump or compressor should also be on the higher side, and that should also be monitored or adjusted depending on the particle density as well as the coal particle size. If the coal particle size is on the higher side or if their density is on the higher side, we have to change or modify the capacity of this pump which is used to generate or send the primary air to the combustor. So, this is the picture typically seen in the case of horizontal firing of coal. In the case of horizontal firing, typically, the coal mixture and primary air are kept here and sent to this boiler and furnace, and they will be released in this way. So, depending on the density of the coal particles, those with lower density will go to the lighter side, moving to the top, whereas heavier coal particles will reach the bottom.

So, in this combustor, in this entire zone of the combustor, all the coal particles will get burned. The required secondary air will be supplied and controlled through this valve depending on the combustion. So, the primary air will be sent through this combustor. So, whatever coal particles are staying there, these particles will be transported by this primary air to the combustor, and secondary air or tertiary air may need to be supplied depending on the requirement at other locations. So, the entire coal particle here will get burned within about 5 seconds. So, they will generate or they can create a very high temperature. In this horizontal furnace, if we see the vertical furnace here, the primary air and coal mixture are charged from the top, and they will get like a free falling. Along with the presence of primary air, after coming or entering here, they will travel this path. So here, some of the coal particles may get a higher amount of residence time depending on the particle size or combustion characteristics. Secondary air is provided from this side, and the additional requirement of tertiary air is supplied from this location. So here, to ensure that all the coal particles, because they are staying here for much more time, and there can be a condition where there is not proper mixing of coal particles and air. So, there can be a possibility of some unburned hydrocarbon. To ensure that, in this design, tertiary air is also sent or fed here.

At the bottom of this furnace, the coal particles will convert into ash. Now, ash—this temperature will be on the higher side in most pulverized coal combustion units; otherwise, we get ash in the stage of molten ash. So, if we exceed the temperature or ash fusion temperature of the coal, we will get this ash as molten ash. If we are within the range of the ash fusion temperature of the coal, we will get coal ash as solid particles. So, this is the diagram of how this coal is fired in a tangential firing. So, in this unit, from all four corners of a rectangular shape, from all four corners of the rectangular-shaped furnace, the coal particles are fired. So, all the coal will come, and primary air will be charged along with the coal. So, in this particular zone, we will be getting the fire bulb, or in this particular zone, the temperature of the coal combustion will be on the higher side. On the nearby side, we have to supply secondary air or tertiary air as per requirement. So, at present, most thermal power plants utilize this tangential firing in their units, as coal from four different corners is fed, and also, depending on the requirement.

There can be tangential firing from different heights as well. From one particular height, coal particles will be charged from four sides. There can be another side or another height with a gap of 1 to 5 meters, or 1.2 meters, 1.3 meters, depending on the design. So other coal particles also get charged. So that we can burn a very large amount of coal particles. We can even burn like three tons or four tons per hour of coal particles in this combustor. So that we can easily achieve much higher temperature, so we can get higher temperature as well as much higher heat release. The quantity of heat will also be on the higher side, as well as the temperature, which is required in bigger size thermal power plants to produce 1000 megawatt or 500-megawatt electricity in one unit. This is the total schematic of this combustor or boiler design. Typically, from this side, we send the pulverized coal and air. So, from four sides at the four different corners, we will be charging coal and can also charge at different heights. So, coal can be burned from different heights. So effectively, if it is on one side, it will be 4 into 1, like from 4 different points, we will be burning coal. If it is at 2 different locations, like one and two, we can have four into two equals to from eight corners or eight points we can burn coal. Similarly, if it is at the third point, we can get four into three, that means from 12 different locations we can charge pulverized coal to get it burnt so easily we can get much higher temperature around

1400 to 1500 degree centigrade which is required nowadays in super thermal power plants or ultra super thermal power plant. So, after that entire combustion gases or flue gases at much higher temperature they get contact with this boiler tubes. So, in this particular location different types of boiler tubes are placed according to the nomenclature of the boiler like they are either evaporator or super heater. So, they will be placed at this location and this flue gas will going to this zone. So, this is the zone typically known as the economizer where low temperature flue gas is used whether this is the zone where Water will get evaporated. So, that zone is typically called the evaporator. So, this particular zone is the economizer.

This is evaporator and this zone will be the superheater. So, whatever the flue gas releasing at 1200 or 1300 degree centigrade, they will make the steam superheated and they will send to the evaporator. turbine further if temperature is reduced they will be used to boil this water at 100 degree centigrade or 150 degree centigrade that's why this section is known as the evaporator and later low temperature flow gas that will come to this section which is known as the economizer which will be used to only heat the liquid water or only give the sensible heat of water to reach to the 100 degree centigrade And after that combustion gases will be going out through this section. And whatever the ash is produced that will be coming below or fall below as precipitates and we will get the combustion section fireball inside this zone inside at this particular zone we will get the combustion fireball as we have discussed in our combustion related chapters. So, these are the equipments typically or complete flow sheets whatever is used in the pulverized coal combustion units like this is the final unit where coal particle is gets burned. So, this is the part of the furnace where coal can be charged from different locations from different heights from all the four corners and at different heights. So, coal particle will be charged from here and from this location we can supply the secondary air. So, from this location we are supplying the secondary air to the combustor and this is the typically the mill or pulverizer which is used to grind or pulverize the coal. This pulverizer can also be of different design may be vertically, horizontally and other may be using some ball, may be using some rod or may be using other type of methodology to make the coal grinded or pulverized as per the requirement and this is the primary air fan, which is used to transport or blow the coal particles. From this pulverizer to this upper unit. So, primary air will be used typically to lift the coal particles from the pulverizer, and they will go further where again some more compressors or pulverized coal plus air—additional air—can be used here. If it is required, we can maintain the desired coal burning rate at this particular zone. So, whatever the coal burning rate is required, they are charged continuously from this pulverizer through the primary air. If we see the air circuit, like this is the normal air taken through the forced draft fan, this forced draft fan will take the air, and that air will be preheated. Which is coming from the flue gas.

So, whatever heat is getting released—that means, whatever flue gas is going there—that flue gas will be used to preheat this primary air. So, once this primary air is heated at this preheater, this hot air stream will be there. With this hot air stream, some part will be used to lift or transport the coal particles. So, if we see that this air can be divided into different parts. Some part of the air can be used to preheat the air further, which will be used to transport the coal particles.

Second air can also be used to send it directly as secondary air or, as per the requirement, as additional primary air at different points. So, overall, if we see, these pulverized coal combustion units need different equipment, add-on equipment like they also need a primary air fan, a dedicated pulverizer, and particularly if we see the pulverizer from this supply in any thermal power plant, it is in batch mode. Before that, there will be a very big bunker or coal storage. So, typically, coal is stored at this storage for coal burning here, which will have a capacity of 12 hours to 18 hours or maybe 24 hours, depending on the requirement. So, before that unit, it is the batch unit like coal can be crushed; they can be loaded in the storage in batches, maybe morning or evening slots, or as per the availability of coal which comes by the railway wagons. So, before this unit storage, the operations are typically in batch mode, and in the storage, coal is stored for about a minimum of 12 hours capacity and may go up to 24 hours capacity. That coal is continuously sent to the pulverizer where it will be ground by different mills, and all the fine coal particles will be transported through the primary air. Whatever coal particles are not good or have heavier density will go back as mill reject. We have already discussed these things in our previous chapter on combustion—how mill rejects are selected and how clean or good-quality coal is charged to the pulverizer. Overall, pulverized coal combustion is a very efficient process where we can easily achieve much higher temperatures.

In such cases, we can even get the temperature profile close to the maximum. Pulverization reduces coal to fine particles, making it act like a liquid fuel, allowing us to burn large amounts quickly. Pulverized coal behaves like a fine powder, burning almost like liquid fuel. As a result, we can have much better control over the temperature. If we use grate firing or bigger-sized coal, once we charge the coal, it will burn. We cannot remove these unburned coal particles.

Midway through the process. So, if we need to control the temperature in grate firing, we will not be able to do so. Once the coal is charged, it will burn. But in pulverization, since coal combustion takes very little time—4 to 5 seconds— we can easily control or modify the coal flow rate in the pulverizer by adjusting the primary air flow rate, primary air velocity, etc. So, we can have much better control over the temperature as we are using the very fine powder coal and almost this coal is acting like a liquid fuel. So, we have much better control. Second is we can easily achieve much higher temperature as the fine coal particles are burned here. And another point is that in many of the coal-fired thermal power plants, As the coal property variation is always there, that in every moment properties of coal get varied. And as per the requirement of grid electricity, sometimes plant has to modify its capacity or output electricity. Depending on the demand to the consumer side, every plant has to adjust its electricity production. Like morning time their load is less. maybe afternoon time load is more maybe for within some one or two minutes time or one or two hour time duration due to some particular occasion there can have increase in the load that means from 500 megawatt they may have to immediately reduce to 400 megawatt or 300 megawatts So, such load variations can be possible if we can modify the coal combustion rate.

So, such coal combustion rate can easily be modified, adjusted within the limits if we are using fine size coal particle or pulverized coal particle. If we are using bigger size coal particle as their combustion time is on the higher side, it will be difficult to control that heat release rate and combustion rate and accordingly the electricity output rate. So that's why this coal pulverization is the most preferred method in the thermal power plant nowadays. And in the second case, like if coal properties are not up to the mark, there can have some coal which is of higher GCV. Another coal can have some lower GCV. So, these coal properties variation is always there depending on the source and depending on the demand. So, in many cases, to modify the ignition characteristics as well as to modify the fireball temperature characteristics, always some amount of fuel oil that is in the liquid fuel. So, this liquid fuel is always charged along with this coal, pulverized coal maybe quantity is on one percent or two percent or point five percent or like this so this liquid fuel can easily get it adjusted if you are using in pulverized coal combustion but if you are using bigger size coal combustion this liquid will arrangement or controlling will be very much difficult. So as a result, in pulverization unit always some liquid fuel firing is also there to meet the additional electricity or additional heat demand to modify the combustion characteristics so in pulverization unit we can easily add both this liquid fuel and fine powder coal particles without affecting any of the performance of the combustor. So as a result, overall pulverized coal combustion is mostly used. Like at present days, more than 80% or 90% thermal power plant use the pulverized coal combustion as well as the cement plant, they also use the pulverized coal combustion.

And due to the same reason, in nowadays, if we see many of the blast furnace where coal is or coke is also used to supply heat as well as for the reduction of iron ore. So, in such case to reduce the coke consumption that means to get some amount of energy from the coal. So that we can reduce the consumption of coke. As the availability of coke is on the lower side as well as the price of coking coal is on the higher side. So nowadays many blasts furnace are getting modified and they are adding this pulverized coal injection or ECE in blast furnace to get or to utilize this advantage of pulverized coal combustion at higher temperature to reduce the consumption of coal and consumption of coke and make the plant much more profitable and economical.

Thank you.