Clean Coal Technology

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Week-06

Lecture-30

Hi, I am Professor Barun Kumar Nandi, welcoming you to the NPTEL online certification course on clean coal technology. We are in module 6, discussing various industrial coal combustion methods. In the previous class, I discussed in general, the advantages, disadvantages, and operating principles of fuel bed combustion, pulverized bed combustion, and fluidized bed combustion like AFBC, CFBC, and PFBC. So, in this lecture 5, I will discuss various aspects, their comparison, advantages, disadvantages in detail, and the suitability of different coal firing methods or combustion methods in thermal utilities.

So, if we start with the pulverized coal combustion methods, as we have discussed in earlier classes, if we see in the case of pulverized coal combustion, Typically, in the case of pulverized coal combustion, its major advantage is that it can be used with low excess air requirements. As coal particles are of very fine size, they are in the micron size range, below 75 microns. So, the mixing of air and coal particles is much better at that particular size, as these coal particles are almost in the range of talcum powder-like fineness. Coal combustion can be done with a lower quantity of excess air.

This excess air means 100% air is required for any type of combustion, irrespective of whether it is fuel bed, fluidized bed, or pulverized bed. But apart from this, in the case of pulverized combustion, it can work with 15 percent to 20 percent or maybe in some cases 10 percent excess air, but this excess amount requirement is higher if we see fuel bed combustion and others. So, in pulverized coal combustion, as it uses very fine-sized coal particles, better mixing of coal particles and air is achieved. We can use a lower quantity of excess air, particularly in the case of combustion, as it is the reaction between the solid and gaseous phases. So, in all such reactions, efficient mixing of solid and gas is very important to carry out this reaction.

So if mixing is very much uniform, reaction can go very easily with less unburned carbon and less amount of oxygen compared to the addition that actual theoretical amount of oxygen required this can be done but if mixing is not proper some coal particles can be there where no oxygen is reaching where in the other zone there can have excess oxygen like if we draw like a simple fuel bed combustion coal particles are present here. So, we must enter said oxygen here but if oxygen moves only in this path and travels, lives there. So maybe this zone, this zone there may not have any oxygen. So, whatever the oxygen is there, they may not reach at higher concentration to this particular zone.

That means there is possibility is that some of the zone may have less quantity of oxygen due to poor mixing of fuel particle and air. So, in case of pulverized coal combustion, this is much better or you can say this is superior in all these combustion methods. Second is that as we are using this air flow rate and coal particle mixer and these coal particles are not to be lifted. So, they only have to be transported to the reactor. In case of fluidized bed combustion, this air flow is used to fluidize the coal particle as the coal particle size is on the bigger side.

they are typically consuming large amount of power which is known as the auxiliary power consumption in any of the thermal power plant this auxiliary power consumption means the power required to run the thermal power plant and its different Like any thermal power plant can produce suppose 500 megawatt it is producing electricity. But out of these 500 megawatts maybe 10 megawatt or 15 megawatt is being consumed in the plant itself to operate the crusher, coal handling section, grinder etc. operating or running this plant, blower, ESP, cyclone separator etc. So, what about the different equipments are there. So, they also consume large amount of power. So as in this case we need lower quantity of fan power. So auxiliary power consumption also can be reduced further as this air particles are used they are mixed along with the coal particle. So, we can use any preheated air up to the temperature that is nearby the ignition temperature of coal. So, considering the ignition temperature of that coal particle we can increase that we can preheat the coal particle just below that temperature like if ignition temperature of the coal particle is 350 degrees centigrade we may preheat the coal up to 300 degrees centigrade or 250 degrees centigrade so that preheated air can be used and this particularly this preheated air is originated again from the exhaust flow gas. So, whatever the exhaust flow gas is there that means after combustion of coal this exhaust gases goes to the boiler tubes and others where heat is recovered from these exhaust gases. So, after that still some hot exhaust gas may be temperature of 300 degree or 350 degrees centigrade 400 degree centigrade they are released to the environment. So, from that gas, sufficient amount of heat can be recovered so if we recover that amount of heat, overall efficiency or thermal efficiency of the plant gets significantly improved. So as in this case we can use the preheated air and that preheated that preheat can be collected from the exhaust gas steam. Overall, it will have the higher side of boiler efficiency. So, overall thermal efficiency of the boiler will be on the higher side.

Similarly, in case of pulverized coal combustion, it can use different variations of coal. Like, mostly it is designed for the bituminous type of coal having significant amount of volatile material. But, along with this bituminous coal, we can blend some of the anthracite coal or some percentage of lignite coal. Those type of coal with varied ash percentage, varied volatile material percentage also can be burned here.

Even if the coal has a lower amount of volatile material, so required amount of fuel oil also can be added or typically added in pulverized unit to enable that coal gets burned. So even if we have large quantity of anthracite coal is available where the volatile material percentage may be on the lower side, using alternate fuel like maybe we can burn in the same reactor some amount of gaseous fuel or some amount of liquid fuel. So, this will enable us or the to help us to burn different type of fuel in the same combustor as this pulverized coal combustion is almost in the fine size, so they act like an almost like acts like a liquid fuel droplet. So, in this combustor, we can also burn nearby some of the gaseous fuel or liquid fuel depending on the heat requirement, depending on the temperature requirement of the boiler and other. So, in the pulverizer we can easily burn alternate fuel like gaseous fuel or liquid fuel and in case of pulverized coal combustion also, it can also respond very fast to the load changes.

And this is one of the major requirements of any thermal power plant at present, when all the thermal power plants are connected to the national grid. The national grid means all the thermal power plants are connected to one network. That network maintains the overall electricity demand of the country. So, if there is any increase or decrease in the electricity demand, the thermal power plant also has to either reduce or increase the burning of coal so that the electricity output can be adjusted. This ensures there is no electricity loss or fuel waste, such as electricity being produced without a consumer.

To avoid all these issues, the national grid always adjusts the electricity load. So, there is always a change in the load. That means, Certain hours of the day, like evening or afternoon hours on some days, may require a higher amount of electricity. In such cases, the coal-fired plant has to burn more coal. But if coal burning takes too much time to adjust to the electricity demand and coal burning rate, it becomes very difficult for the grid to maintain the desired power requirement. In pulverized coal combustion, the coal is burned as very fine-sized coal, and the coal feeding rate can be adjusted easily by modifying the mill capacity as well as the number of burners charging points or coal burning points in the pulverizer. Thus, they can respond much faster compared to fluidized bed combustors as well as fuel bed combustors. They can also release a large amount of energy in a small combustor. For example, we can burn 20, 32, or any number of coal feeding points as per design, even in a small combustor, if we reduce the volume of the combustor efficiently or effectively, we can increase the temperature of the combustor, so we can easily achieve higher or lower temperature depending on the requirement. If we follow or if we use the pulverized coal combustion, then from pulverized coal combustion by modifying the size of the combustor or by modifying the number of through which coal is being injected into the boiler, we can easily achieve higher steam temperature. And in this case also, it produces fly ash. This fly ash consists of the ash particles generated from the coal pulverizing unit after the burning of coal. These fly ash particles are of very fine size.

So, this ash can also be used in cement plants, for making refractory bricks, and other applications. So, at least some amount of solid waste can also be sold to the nearby market to recover some of the operating costs of the plant. So, if we can use this fly ash in different applications, the thermal power plant also gets some money back by selling this fly ash, improving its economic condition.

Further, if we look at the boiler, as these coal particles burn almost in a fine powder shape, the efficiency of such a boiler is very high. In terms of thermal efficiency, this boiler may reach up to 90 percent or nearby values. There is heat recovery, so waste heat is also being recovered and further used or recycled in the boiler. So, whatever heat is being released in the boiler that entire amount of heat will be used to produce steam. That means whatever energy or calorific value is available in the coal, that entire amount of energy can be utilized for the production of steam. So, as a result, this plant has much higher combustion efficiency.

Here, it mentions combustion efficiency, not the overall efficiency of the thermal power plant. Thermal power plant other units can have higher or lower efficiency, like their turbine or generator, as there can be some efficiency limitations. But at least on the boiler side, it is highly efficient. We can easily monitor or raise the steam temperature by increasing the coal flow rate. Combustion or pulverized coal combustion can also be readily adopted along with automatic control.

Nowadays, all thermal power plants want automatic control through software in their control rooms, and it can even be controlled remotely if connected to the network. So, the entire coal flow rate, coal pulverizing rate, and heat release rate, along with co-combustion or co-firing of any liquid fuel as auxiliary fuel consumption, can all be controlled in a well-adopted automatic control-based thermal power plant. Pulverized coal combustion wheels can be easily controlled using a modern control system, so these systems work successfully in combination with gaseous fuel and oil if required. A large amount of heat release is possible in this system compared to the stoker firing system. If we consider the stoker firing system or grate firing system, their overall heat release rate is on the lower side, as coal particles burn in bigger sizes and take a lot of time to completely burn.

So, we can achieve a large amount of heat release by using pulverized coal combustion. There are some disadvantages linked with pulverized coal combustion, such as added investment costs for coal preparation, particularly coal grinding, and maintaining the required coal fineness makes the overall plant somewhat complicated. That's why they need a modern, sophisticated process control system. Overall, their control system is a bit more complex compared to conventional fluidized bed combustors, and auxiliary power consumption in coal processing is higher due to the crushing and further grinding of coal and the use of fans. Since fan costs are involved, this cost is absent in stoker firing or grate firing, but it is present in the FBC system.

But here, as coal needs to be ground, so for the grinder, there is additional electricity consumption or energy consumption. Also, there is a requirement to remove the fly ash, as most of the coal particles generated will be very fine in size, maybe 10 microns or 5 microns or below that. So, most of these coal particles will report to the flue gas as fly ash. So, all this fly ash has to be removed or recovered from the system before it is released into the environment; otherwise, if we release all these fly ash particles into the environment, it will create extremely polluting conditions. So, this is the additional cost which is not required in normal coal firing, maybe to a lower value or to some extent in fluidized bed combustion, but fly ash capture is a major issue where the maximum amount of electricity is consumed.

If we see overall, more than 40% of the ash particles pass through the chimney. So here, the amount of bottom ash will be less, whereas the amount of fly ash will be much higher. So, they must be recovered and handled properly to avoid any type of environmental pollution. So, special efforts are required to precipitate most of this ash. So, whatever ash particles or fly ash particles are getting released from this plant, we need special efforts considering the particle size of ash, what type of equipment will be suitable, how to handle them, and how to remove the hot particles.

All this requires some special efforts. So, there will be additional costs for operating this flue gas handling equipment like ESP, cyclone air purification units, and if these coal particles are burning at much higher temperatures and if we are unable to control the amount of coal particles being fed, there can be temperatures that exceed the design. So, in such cases, there can be explosions in the system, like if the plant is designed to operate at 1400 degrees centigrade but suddenly, due to some malfunctioning of this equipment, more than or double the amount of coal particles are sent to the combustor, the coal particles will burn immediately, and the temperature may rise above 1400 degrees centigrade. In such cases, there can be explosions. These explosions can also occur even from the molten ash because, at higher temperatures, ash will melt, and this liquid ash may come out in any direction from the plant, depending on the operating principle or how we are handling that liquid ash in the plant.

Further we have to store some need some bunker and similar equipments similar arrangement has to made to store the powder coal or to store the smaller size coal particle. So, we have to keep some special attention in handling this powder coal particles which can also cause some fire hazard because if these coal particles already they are in preheated and if they exceed the ignition temperature. This coal particles may burn or ignite even during the storage, so they are need some special attention and higher protection as these fine coal particles are fire hazard to the plant if they are not properly handled Now, if we come to the fluidized bed combustion, what is their advantage? Mostly, we get their high efficiency, particularly for the burning high ash coal particles.

In pulverized coal combustion, we get high efficiency when we burn smaller size coal particles. But, if we consider the high ash coal particle, where ash percentage may be above 50% or above 60%, so in such case, with such poor combustion characteristics or inferior combustion characteristics whole particle. Even we can get very good thermal efficiency above 95% irrespective of ash content. So, in fluid as bed combustor, we can burn any type of coal irrespective of ash percentage.

So, most of the cases this fluidized bed combustor are used nearby the coal washeries to burn the high ash coal. So, from whatever the highest coal particles are there, they are very much efficiently burned with more than 95 percent efficiency in the fluidized bed combustor. So overall efficiency considering the auxiliary power consumptions and other they can reach even up to 84 percent which is significantly higher considering the high ash content or poor combustion characteristics of the coal. Similarly, there can have reduction in the boiler size that high heat transfer rate as we are maintaining the desired heat transfer rate by adding some bed materials and others. So, this bed material also improves the heat transfer rate to the nearby boiler tubes and others.

So, the overall heat transfer rate in this boiler is on the higher side. So, we can even reduce the boiler size and increase the overall efficiency of the plant. A further major advantage of this fluidized bed combustion is the fuel flexibility. This fluidized bed combustor can burn or be operated with any type of solid fuel—just any type. So, they can burn good-quality coal, they can burn inferior-quality coal, along with that, they can even burn municipal solid waste which has some good calorific value. Maybe agricultural residue, biomass, everything can be burned in the same combustor along with the coal. So, that is the major advantage of the fluidized bed combustor.

So, this advantage was not there in the case of the pulverized coal combustor. In the case of the pulverized coal combustor, we can only use coal. Not any other type of fuels or even high-ash coal like washery reject. Agro-waste can also be burned very efficiently in fluidized bed combustion. So, this can be fed either independently or in combination with coal in the same furnace. And particularly, if we see for coal, we can easily grind the coal and make it pulverized to around 75 microns or nearby. But it is not possible for all types of biomass and others.

Typically, most of the agro-waste cannot even be ground. They can be cut to a smaller size or they can be chopped. But they may not be able to produce 75 microns. So, those difficulties can be easily overcome or removed if we use the fluidized bed combustor, where we can burn them at a much bigger size. So, 2 mm, 3 mm, 4 mm, or even 10 mm size biomass particles can easily be fed to the fluidized bed combustor, and they can burn. So that's why their main advantage is their fuel flexibility. So, they can even burn any low-grade fuel like lignite coal, and in some cases, peat can also be burned along with the washery reject and tailings from the froth flotation units. So, they can even burn the fines like tailings released from the froth flotation unit. Another major advantage of this plant is that they can also capture sulfur dioxide and reduce NOx emissions. As we can add limestone or dolomite during combustion, those limestone or dolomites can capture or react with sulfur compounds to trap the sulfur emissions from the coal. So even in fluidized bed combustion, we can burn high-sulfur coal, meaning if the sulfur percentage exceeds the standard value of one mass percentage in ultimate analysis, like 1.5% sulfur in coal. Those types of coal can also be burned in a fluidized bed combustor. The only thing is that the consumption of limestone and other materials will vary depending on the amount of sulfur present, as in this fluidized bed combustor, we keep the temperature around 900 degrees Celsius or 850 degrees Celsius, so the possibility of NOx formation is very low. Typically, NOx formation reactions occur at higher temperatures, like 1400 to 1500 degrees Celsius. So those reactions can be easily avoided. As a result, fluidized bed combustors are almost free from any type of pollutant gases like NOx and Sox, as there is fluidization and some recirculation of air. Here we can easily use a lower quantity of excess air, and as a result, we can get a higher concentration of CO2 in the flue gas. Since there is no clinker formation, we can easily remove the ash particles. However, clinker formation is a major problem in pulverized coal combustion. If we compare pulverized combustion and fluidized bed combustion, there are no clinker formation issues with fluidized bed combustion, whereas clinker formation is a major issue in pulverized coal combustion due to the higher temperatures, around 1400 to 1500 degrees Celsius.

At that temperature, the ash fusion temperature of the coal may be reached. So, clinker formation is a major issue in pulverized coal combustion, whereas that issue can be easily avoided in fluidized bed combustors. NOx and SOx emissions are present in pulverized coal combustion, as there is no mechanism to trap sulfur during the combustion process. And NOx pollution may occur if the combustor temperature is too high. But these issues are not present in fluidized bed combustors.

So, if we simply compare this FBC and pulverized coal combustion. So, we can easily compare them based on the low-grade fuel or type of fuel we can burn in FBC and pulverized coal combustion units. We can compare them in terms of SOx and NOx emissions. We can compare them in terms of clinker formations and other factors, as well as in terms of fuel flexibility. These are the major four points where fluidized bed combustors are much more superior than the These are some of the disadvantages, such as its low-temperature limit, like temperatures limited to 900 degrees Celsius or 850 degrees Celsius. So, we cannot build a very large plant. Typically, fluidized bed combustion-based thermal power plants are of smaller capacity. Maybe 10 megawatts, 15 megawatts, or 20 megawatts or they can go up to maybe 30 to 40 megawatts. As their temperature is on the lower side, the steam temperature and steam quality parameters are also on the lower side. So, we cannot use fluidized bed combustion in a larger unit. Nowadays, as the overall electricity demand of the country—even in particular districts and villages—is increasing day by day.

So, we need some bigger size thermal power plants to maintain the desired electricity output. So, in such case, fluidized bed combustion-based power plants cannot be the future. In such case, only the pulverized coal combustion units only can be possible, whereas these fluidized bed combustion-based units only can be possible to utilize the poor or inferior grade coal. Similarly, it needs a lot of time or longer time for complete combustion. As we are burning coal at much bigger size, 2 mm to 10 mm size or even maybe 15 mm size depending on the FBC type of unit which you are using, whether it is PFBC or CFBC or internal circulating unit.

FBC. So overall the residence time of coal particle in a combustor is on the higher side. So, coal particle stays in the reactor for combustor for the longer time. That means feed coal rate. Rate of coal to be burned per unit minute like if you want to burn one ton of coal per minute. That is very difficult. Because that will take lot of time to burn the coal. So, residence time of coal is very long, longer time we cannot burn higher amount of coal. So, in such aspect pulverized coal combustion is much more superior and as this coal particle along with this sand particle limestone everything is their regular erosion and damage to the boiler tubes happens because these particles like sand particle or quartz particle or stone chips, whatever is used as a bed material. So, all these materials regularly, because they are in the solid phase, they damage or they erode the boiler tubes and whatever the other refractory material and other tubes are there. So, they need very frequent maintenance for when we utilize them in a fluidized bed combustor. So, if we see their advantage and disadvantage particularly for the pulverized coal combustion and fluidized bed combustion pulverized bed combustion or pulverized coal combustions are very much superior for high-capacity power plant where good quality coal can be burned and even we can get much bigger size coal particle much bigger size power plant output we can achieve higher temperature. So overall efficiency in terms of thermal efficiency as well as the plant efficiency in producing electricity. Overall efficiency will be on the higher side if we go for the pulverized coal combustion whereas the fluidized bed combustion, there will be some efficiency will be on the lower side but if we want to use different types of fuel like reject coal, tailing coal, low volatile material coal, any municipal solid waste, biomass. So, if we want to burn white variations of fuel particles or solid waste particles in a combustor, in such case fluidized bed combustor should be used, not the pulverized coal combustor. And if we see the environmental pollution, fluidized bed units cause less amount of environmental pollution compared to the pulverized coal combustion as SOX and NOX gases are trapped inside the fluidized bed combustion as well as the release of this quantity is very less as coal particles are burned at much bigger size. Most of the particles will for bottom mass for which there is no separate equipments are required but if most of the particles form fly ash particle they are need some separate arrangement or equipments to capture the fly ash particles now even if we see the advantage of the fuel bed combustion.

Fuel bed combustion is very much efficient if we want to burn coal at much more low temperature applications like 500 or 600 degrees centigrade. So, in such case fuel bed combustion can be used. So, as there is combustion rate is much slow. And they can also produce some of the unburned carbon in the ash. So, as their combustion rate is slow, so this type of combustion units can be operated for longer time at lower heat release rate. So here we need a smaller amount of heat but for a longer duration, like if you want to operate any foundry or forge factory that uses heat to process different types of metal to prepare different types of equipment. So, in such cases, the temperature requirement may be 600 or 700 degrees centigrade. But they need a continuous amount of heat. Even for domestic applications like cooking food and others, we need a smaller amount of heat, but that heat should be available for a longer time, like 5 kg of coal burned over a span of 12 hours. This coal can be burned at a much smaller rate, which will be very efficient for low-temperature applications. So, they are typically easy to operate. Even coal crushing is not required. We don't have to really crush the coal.

We can use even bigger-sized coal particles of 25 mm or even up to 50 mm. So, without crushing them to very small sizes like 2 mm or 10 mm, we can still burn that coal. It will take longer time for complete combustion. So, we can use the heat available for these units for a longer time. But if we see that their combustion is at a very slow rate and we are burning this coal in much bigger sizes, there is always some possibility of unburned carbon in the ash particles, which means Complete combustion of coal particles is very difficult. We can get only partial combustion, and in between, we have to remove the ash particles from the fuel bed so that the remaining amount of unburned carbon is exposed to the air and can be burned again. Typically, fuel bed combustion is used in low-temperature applications. From such applications, we can always get some unburned carbon particles in the ash, but they can be very efficiently used in different low-temperature applications, including domestic applications, whereas fluidized bed combustion and pulverized bed combustion are mostly used in high-temperature industrial applications like thermal power plants and production industries. So, they use FBC or pulverized coal combustion if they have readily available higher amounts of waste coal, like reject coal and other types of coal. They prefer fluidized bed combustion if they have access to good-quality coal; they go for pulverized bed combustion.

So overall, if we conclude about combustion, we find that secondary air is always required to avoid any type of fuel loss and to reduce unburned carbon in the flue gas. Pulverized coal combustion can replace liquid fuel, like where liquid fuel combustion is required. In such units, we can use pulverized coal combustion. FBC units can burn low-grade fuel waste rejects very efficiently. The capacity of FBC plants is lower compared to pulverized coal combustion units. So finally, we have to find suitable coal-firing methods depending on the coal properties. The coal size we want to burn and the amount of heat required. For industries like domestic applications or power requirements. So the final selection is based on the suitable size and coal properties. If we want to burn high-grade coal, pulverized coal combustion is used. If we want to burn inferior-quality coal, FBC is the process. And if we want to use low-grade fuel along with a very low heating rate, we use the fuel bed combustion.

Thank you.